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SURGICAL ANATOMY AND TECHNIQUES TO THE SPINE

Second Edition

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Surgical Anatomy & Techniques to the Spine

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SECOND EDITION

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To my wife Anslie, my daughters Elise and Rebecca, and Sarah.

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To my wife Seunglim, my daughters Rachel and Jai, and my whole family.

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To my wife Celeste; my children Alexander, Rachel, and Jacob; and my entire family.
Thank you for enriching my life, for teaching me, and for your love.

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To my father Daejo, my mother Insun, my wife Okran, and my son Justin.

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Preface

The fundamentals of spine surgery revolve around a thorough understanding of anatomy and surgical technique. With new instrumentation and minimally invasive techniques, spinal surgery has become complex in the twenty-first century. From occipital cervical fusions to sacroiliac fixation, the spine surgeon of today is confronted with an extensive array of surgical options. The rapid pace of technological change in this field has left many spine surgeons and colleagues struggling to keep up. The increasing variety of options for surgical treatments of spinal injury and disease renders the decision-making process regarding the use of any particular approach, procedure, or technology more and more difficult.

In addition to instrumentation, minimally invasive spinal techniques are becoming common. With smaller and smaller incisions, spine surgeons find themselves working with a smaller aperture and, subsequently, a limited view. Without exposure of the adjacent anatomic structures, these techniques can create a challenge. This challenge occurs not only with decompressions, but also with percutaneous instrumentation placement.

This instrumentation and these techniques are being used for an increasing patient base. Spinal instrumentation is used not only for trauma and degenerative disease, but also, with new techniques, increasingly in cases of tumor and infection.

In light of the myriad advancements, the topic of occipital cervical fusion is addressed, including cervical plating techniques along with atlantoaxial fixation devices. In addition, a review of fusions of the cervicothoracic and thoracolumbar regions is provided, as these transition zones have led to a new level of complexity. Last, longer fusion constructs have led to sacroiliac fixation.

Whether confronted with new instrumentation or minimally invasive techniques, the spine surgeon has to rely on the fundamentals of anatomy and technique. Thus, these essential items are reviewed to provide the spine surgeon with an armamentarium to approach increasingly complex issues facing medicine today.

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SECTION A

Craniovertebral Junction and Upper Cervical Spine

1 Surgical Anatomy and Biomechanics of the Craniovertebral Junction

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Overview

The anatomic relationship at the craniovertebral junction (CVJ) is quite complex. The *foramen magnum*, the *atlas*, and the *axis* together comprise the CVJ and provide the anatomic anchor that connects the cranium to the cervical spine below. The special bony configuration and articulation in this transitional zone are unique and have more built-in flexibility than any other region in the spine. The stability and complex movement of the CVJ region is dependent on highly intricate arrangements of ligamentous, membranous, and muscular structures. This chapter covers the developmental embryology of the CVJ, its anatomy, and the biomechanics unique to this region.

Embryology of the Craniovertebral Junction

NORMAL DEVELOPMENTAL EMBRYOLOGY OF THE CRANIOVERTEBRAL JUNCTION

The CVJ is a unique entity distinct in its form, function, and development from the remainder of the vertebral skeletal system. It comprises the occipital somites and the first three cervical somites (Fig. 1-1): the *occipital somites* are the first four somites; the first three *cervical somites* are numbered five through seven. Controversy is ongoing regarding the proper number of occipital somites in vertebrates, ranging from four to five according to various authors; for the purposes of our discussion, we will concede that the first four somites are included in this group. The first three occipital somites give rise to an axial perichordal sclerotome and a lateral sclerotome. The axial perichordal sclerotomes at these levels, however, do not undergo resegmentation and therefore never subdivide into loose cranial and dense caudal zones. Because of the absence of a dense zone, the intervertebral boundary zone (IBZ) fails to form, and they all eventually fuse into a single unit, which chondrifies to become the rostral basiocciput. The lateral sclerotomes of these occipital somites, like their vertebral counterparts, do in fact form dense and loose zones; the loose zones of the second and third sclerotomes ultimately develop into the upper and lower hypoglossal nerve roots and the corresponding arteries, and the dense zones form the bony hypoglossal canal.[1]

The fourth occipital somite differs from the first three in that it does show resegmentation. The caudal dense zone is incorporated into the cranial loose half of the first cervical somite to form the transitional sclerotome called the *proatlas*. The cranial half of the axial sclerotome of the proatlas combines with the other three axial occipital sclerotomes to form the basion of the skull base, and the most caudal portion of the first cervical axial sclerotome, likely derived from the first cervical somite, forms the foundation for the apical segment of the odontoid. Late in resegmentation, a boundary zone between this apical predecessor of the odontoid and the basiocciput allows this tissue to be incorporated into the odontoid. This unique formation of a physical separation between the basiocciput and the odontoid distinguishes the transitional zone from other vertebral levels. Typically, the IBZ that forms at the caudal end of the dense zone forms intervertebral disks. But at this level, this unique physical separation allows the skull to become completely independent from the vertebral column, thus differentiating it from the development at all other somitic or sclerotomal levels. Finally, the dense zones of the lateral sclerotomes of the proatlas ultimately form the two occipital condyles (OCs) and complete the rim of the foramen magnum (FM).[1]

The first three cervical somites also deserve their distinction from the remainder of the vertebral column. Resegmentation occurs in the typical fashion as the caudal half of somite five and the cranial half of somite six form the first cervical sclerotome; likewise, the caudal half of somite six and the cranial half of somite seven thus form the second cervical sclerotome. The formation of dense and loose zones in the axial perichordal sclerotome also progresses in the usual fashion to form the basal segment of the odontoid, from the axial sclerotome of the first cervical sclerotome and the body of the axis from the axial sclerotome of the second cervical sclerotome. At this point in development, however, the first two cervical sclerotomes do not form true intervertebral disks; the IBZ soon develops into the upper and lower dental synchondroses, which ultimately allows for the fusion of the apical to basal odontoid and the basal odontoid to the body of the axis, respectively.[1]

The development of the vertebral column occurs in three stages: *membranous*, *cartilaginous*, and *osseous*. The somite

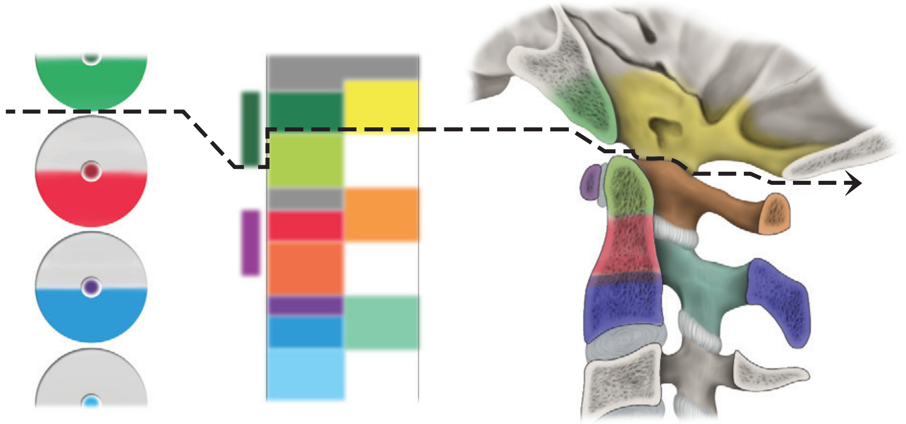


Figure 1-1 Correlation between the embryologic origin and final product in the craniovertebral junction. The dotted line is the severance line, which demarcates the final separation of the skull from the cervical spine.

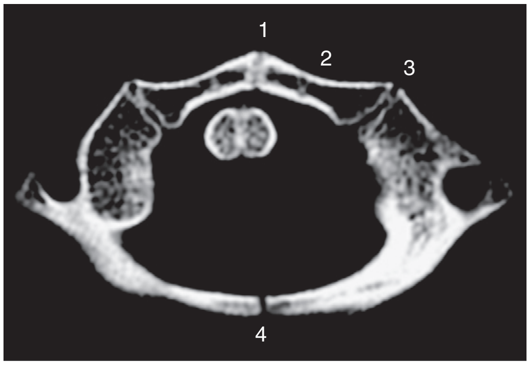


Figure 1-2 Centers of ossification of the atlas. This specimen has four synchondroses. *1,* Anterior midline synchondrosis; *2,* accessory synchondrosis; *3,* neurocentral synchondrosis; and *4,* posterior midline synchondrosis.

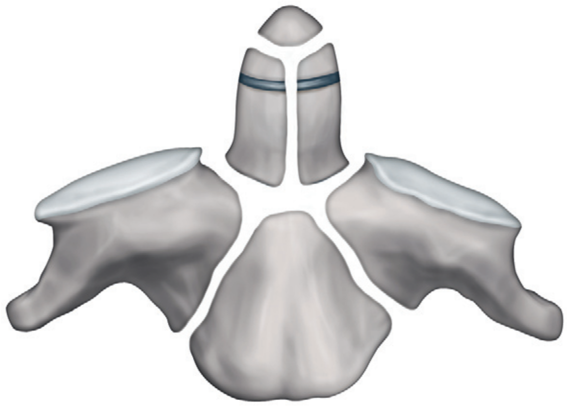


Figure 1-3 Six ossification centers of the axis.

formation and the sclerotome segmentation occur in the membranous stage in the third week of gestation. At the fourth week, chondrification centers appear on each side of the vertebral body, notochord, and on each half of the neural arch. As these centers form and join, they squeeze the notochord cells into the disk space, where they eventually become the nucleus pulposus. However, at the occipital bone level, the notochord cells regress and do not give rise to any structure.

At the seventh to eighth week of gestation, the ossification stage begins in the midthoracic region and progresses rostrally and caudally. This ossification process continues until early childhood.

DEVELOPMENTAL ANOMALIES OF THE CRANIOVERTEBRAL JUNCTION

The atlas has three centers of ossification (Fig. 1-2). At birth, the anterior arch consists mainly of cartilage. A separate center appears at the end of the first year and progressively joins the two lateral masses between the sixth and eighth years. Occasionally, only two centers of ossification are present, one on each half and the anterior arch, formed by forward extension of the two lateral masses.

The axis has six centers of ossification (Fig. 1-3). The upper and lower synchondroses separate the apical dental segment, the basal dental segment, and the body of the axis. These three components undergo chondrogenesis around 6 weeks of gestation but remain separated by the two synchondroses. The ossification of the synchondrosis occurs in three waves (Fig. 1-4). The first wave appears as a single ossification center within the axial body around 4 months of gestation. The second wave gives rise to two ossification centers on each side of the basal odontoid at 6 months of gestation; at birth these two centers begin to fuse, and thus begins the bony fusion of the dental process to the body of the axis, although this may not be completed even into the fifth or sixth year of life. Finally, the third wave of ossification occurs at 3 to 5 years of age, at which the tip of the odontoid undergoes bony fusion via the ossification of the upper synchondrosis; this may not be completed until adolescence. As one could presume, abnormalities in the various developmental phases of the CVJ can result in a variety of pathologic conditions, and in fact, embryology can be helpful in identifying some pathologic findings in the CVJ.[1,2]

Ossiculum terminale persistens is the term for an unfused apical dental segment, likely because of failure of the upper synchondrosis. There is little debate about this finding, and it is usually nonsyndromic. Less clear is the etiology of the more often seen *os odontoideum.* One theory speculates that os odontoideum is simply a nonunion of an odontoid fracture, whereas another proposes that it is in fact a developmental anomaly in which the basal odontoid fails to fuse

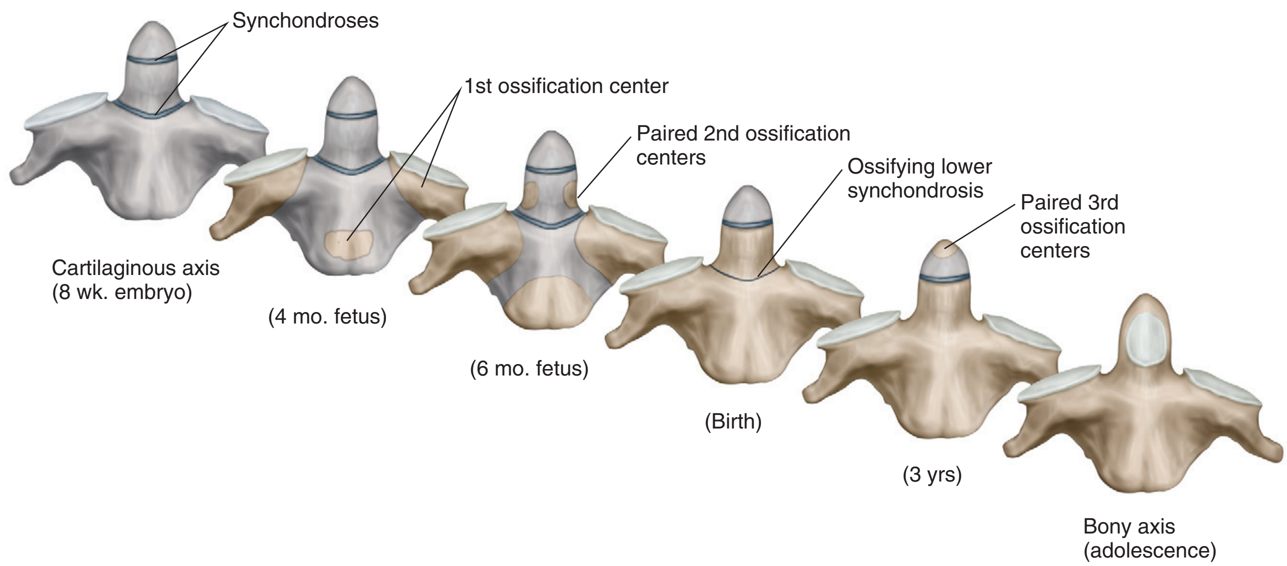


Figure 1-4 The three developmental phases of C2 and the three waves of ossification. The primordial structures for the odontoid components is assembled during the membranous phase. Upper and lower dental synchondroses are shown as dense lines. The first wave of ossification at the fourth fetal month consists of bilateral centers for the neural arches and a single center for the centrum. Second wave at the sixth fetal month consists of bilateral ossification centers for the basal dental segment. At birth, the basal dental centers should have integrated in the midline and should have begun to fuse to the centrum. The third wave of C2 ossification occurs from 3 to 5 years at the apical dental segment, which does not become fused to the basal odontoid until the sixth to ninth year and is fully formed during adolescence.

with the body of the axis. Another abnormality of resegmentation is the extremely rare *os avis,* in which the apical dental segment is attached to the basiocciput and not to the main dental process. The odontoid is thus shortened but clearly fused to the axis. Os avis is often associated with neurologic deterioration caused by a posterior dislocation of C1 on C2.[1]

Surgical Anatomy of the Craniovertebral Junction

BONY STRUCTURES OF THE CRANIOVERTEBRAL JUNCTION

Foramen Magnum and Occipital Condyle

The FM is the outlet for the transition of the cranium to the spinal column below. The FM is located in the occipital bone and is flanked anterolaterally by the OCs (Fig. 1-5). The most anterior midline point of the FM is the basion, and the most posterior point is the opisthion. Numerous morphometric anatomic studies have provided considerable understanding of the FM and surrounding areas to assist neurosurgeons with safe navigation through these complex and narrow surgical corridors.

The FM is slightly oval shaped with a sagittal diameter of 34.7 ± 2.5 mm (range, 29.5 to 43.5 mm).[3] The average transverse diameter of the FM is 27.9 mm (range, 23 to 32 mm).[4] The FM is found to be ovoid in 46% to 58% of specimens and is asymmetric 10% of the time.[4,5] Located anterolaterally from the FM are two OCs that articulate with the first cervical vertebra and provide the transition from the cranium above to the cervical spine below.

Occipital Condyle. The OC that articulates with the atlas is an oval bone mass located on the anterior half of the FM; it converges mesially toward the basion at 30 ± 7.5 degrees and delineates the lateral limits of the CVJ (Fig. 1-6; see also Fig. 1-5).[3] The OC protrudes into the FM in 57% of the skulls examined.[5] In articulating with the trapezoidal lateral mass of the atlas below, the condylar external surface is convex downward, facing outward and sloping cephalocaudal in both sagittal and coronal views.[6] The mean length of the OC is 23.6 ± 2.5 mm, mean width is 10.6 ± 1.4 mm, and mean height is 9.2 ± 1.4 mm.[3] The intercondylar distance is 29.4 mm (range, 26.2 to 37.0 mm).[6]

Although the OC is most commonly oval in shape, known as *type 1,* other possible shapes include kidney, S, figure-eight, triangle, ring, two-portioned, and deformed profiles.[3] These morphometric parameters have significant clinical implications because the shape of the condyle may influence the extent of the condylectomy during surgical approaches to this region. Among the various profiles, the triangle, kidney-shaped, and deformed condylar types may require more extensive condylar resection to adequately expose the ventral lesions. In addition, the OC varies in length, and it can be classified as *short* (condylar length <20 mm, 8.6%), *moderate* (23 ± 3 mm, 77.2%), or long (>26 mm, 14.1%).[3,5] In all these morphometric analyses, it is well established that no correlation exists between condylar length and head circumference or FM diameter (basion-opisthion distance).

Posterior to the condyle is the *condylar fossa,* a bony depression located behind the condyle that is often perforated to form the condylar canal (see Fig. 1-6), through which the condylar emissary vein connects the vertebral venous plexus with the sigmoid sinus. A more important canal for the surgeon to be aware of when performing the

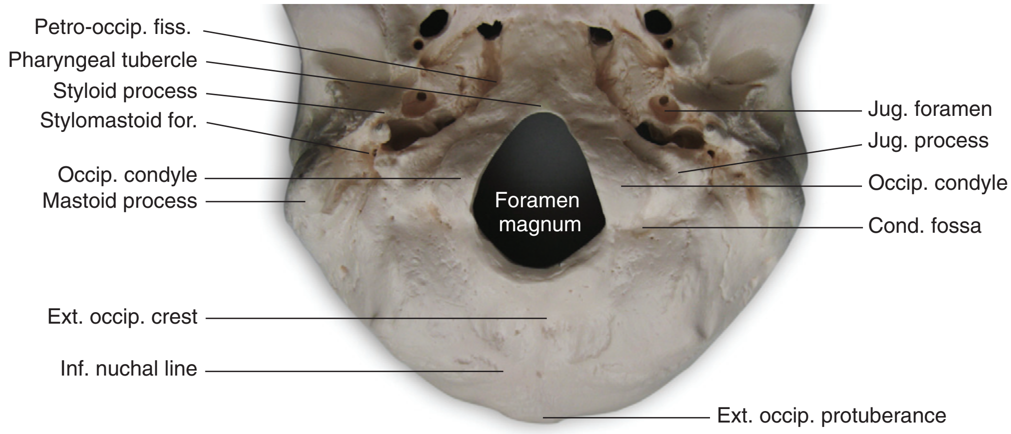


Figure 1-5 Foramen magnum (FM) anatomy with occipital condyles protruded into the FM.

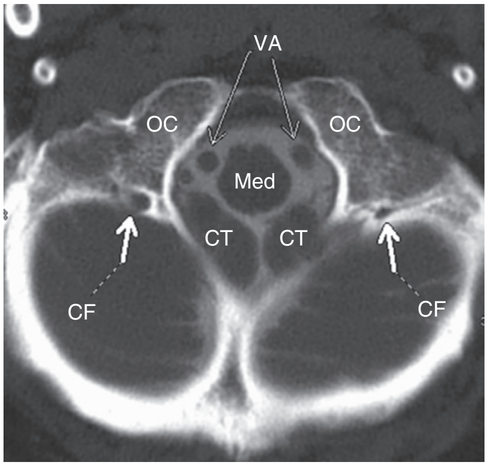


Figure 1-6 Axial computed tomography at the occipital condyle (OC). CT, cerebellar tonsil; Med, medulla; VA, vertebral arteries (*thin arrows*); CF, condylar foramen (*thick arrows*).

transcondylar approach is the hypoglossal canal (HC), which transmits the hypoglossal nerve anterolaterally, from intracranial to extracranial, at 45 degrees to the sagittal plane (Fig. 1-7, *A*). The average length of the HC is 12.6 mm (range, 11 to 15 mm).[4] The intracranial orifice of the HC is situated about 10 mm (range, 4.2 to 15.8 mm) superior and posterior to the anterior tip of the OC.[3] Most of the time, the intracranial origin of the HC is found in the middle third of the OC. The distance between the posterior margin of the OC and the intracranial HC orifice is critical because it indicates the maximum amount of condyle resectable without violating the HC. The average distance between the posterior OC and HC was found to be 12.2 mm[4] in one study, although other studies have shown that this distance can be as short as 7.9 mm (average, 9.8 mm; range, 7.5 to 12.2 mm).[5] This distance can be reliably measured with three-dimensional (3D) computed tomography (CT).[5]

The jugular foramen is located lateral and slightly superior to the anterior half of the condyles. It is bordered posteriorly by the jugular process and anteriorly by the jugular fossa. The jugular tubercle (JT) is situated anterosuperior to the OC and HC at the junction of the basilar and condylar portions of the occipital bone.[5] The mean anatomic length, width, and height of the JT were found to be 15.4, 9.6, and 7.7 mm, respectively. In a previous anatomic study, a "tall" JT (height >8.5 mm) was present in 23% of dry specimens, and a "flat" JT (height <3.5 mm) was found in 10%. The average distance from HC to JT was found to be 11.7 mm (range, 8 to 12 mm).[4]

According to Dowd and colleagues,[7] the surgical angle to the petroclival area via the suboccipital craniotomy is narrow and steep (88 degrees), which enables a very limited exposure of deep structures in this region. After resecting the OC up to the HC, exposure can be improved, and the surgical angle can be reduced to 47 degrees. Each millimeter of OC removal decreases the angle by 2.4 degrees. To visualize the contralateral JT, at least 17 mm of OC must be removed. Spektor and colleagues[8] have demonstrated that resecting the OC up to the HC increases the visualization only marginally, from 21% to 28%. The main obstruction that hinders visualization of the clivus is the JT, and resection of JT dramatically increases the exposure, up to 71% in the ipsilateral, contralateral, and rostral directions. Complete OC drilling did not increase exposure significantly but provided a greater degree of surgical freedom at the expense of stability.[4] In general, 25% condylar resection increased the lateral exposure by 3 mm and the angle of exposure by 10.7 degrees, whereas 50% condylar resection increased the exposure by 7 mm and the angle by 15.9 degrees.

The Atlas (C1)

According to Greek mythology, Zeus condemned the Titan warrior Atlas to carry the globe for losing a battle to the Olympians. Hence the first cervical vertebra, which holds the skull, bears his name and the significance associated with it.

The first vertebra, the *atlas,* is quite different from any other vertebra; it has a ring shape, without the corpus or spinous process. The atlas comprises two dense, cortical lateral masses connected circumferentially to a short anterior arch and a longer posterior arch (Fig. 1-8). The lateral mass provides a thick cortical-cancellous bone as an anchor for C1–C2 lateral mass screw procedures. The lateral mass is trapezoid in shape, wider laterally, and narrower toward the center (Fig. 1-9). The medial height of the lateral mass is

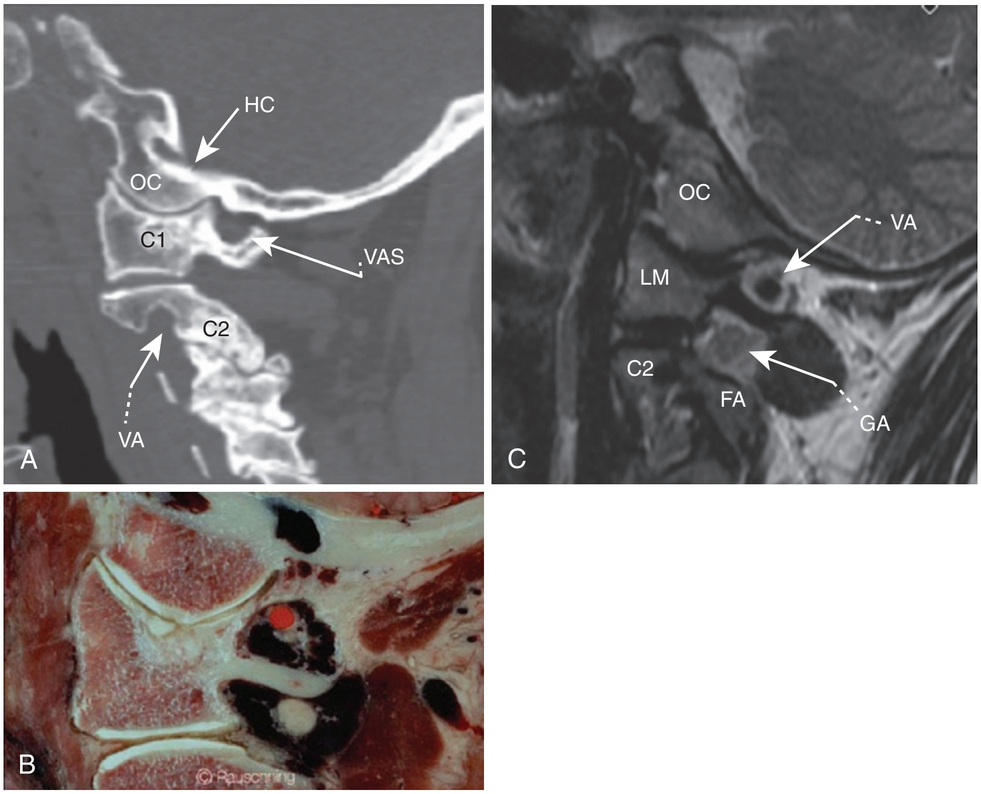


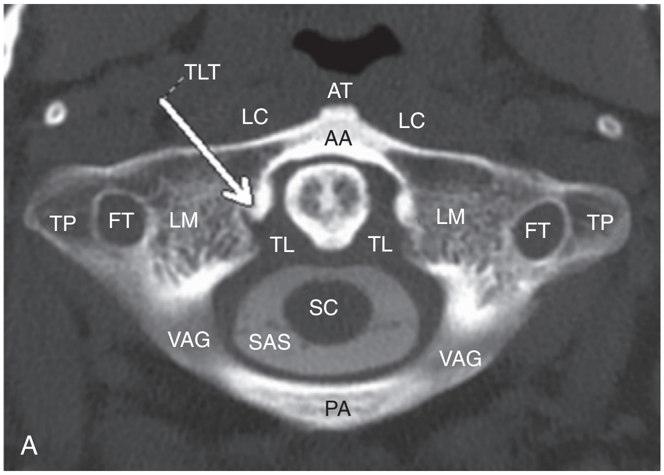
Figure 1-7 Parasagittal view of the craniovertebral junction (CVJ). **A,** Sagittal computed tomography (CT) of the CVJ. **B,** Cryosection of the CVJ. **C,** Sagittal magnetic resonance imaging (MRI). C2, axis vertebra; OC, occipital condyle; FA, facet of C2; GA, C2 ganglion (*thin arrow*); HC, hypoglossal canal; LM, lateral mass of C1; VA, vertebral artery; VAS, vertebral artery sulcus.

8.81 ± 1.46 mm, and the lateral height is 18.01 ± 2.33 mm.[9] The sagittal depth (anteroposterior [AP] diameter) of the lateral mass is 19.73 ± 1.71 mm. Both arches are convex outward, with each midline defined by a thickened tubercle. The shorter anterior arch is slightly taller and thinner than the posterior arch, which is not as tall but is thicker. The anterior arch height is 15.4 ± 3.2 mm, and its thickness is 6.4 ± 1.0 mm. The longer posterior arch height is 10.0 ± 1.8 mm, and its thickness is 8.0 ± 2.1 mm.[10] The atlas ring is slightly oval with an inner AP (sagittal) diameter of 31.7 ± 2.2 mm and a transverse diameter of 32.2 ± 2.3 mm.[10] The vertebral artery (VA) is nested in an oblong bony sulcus (the arcuate sulcus), etching from the edge of the lateral mass and extending over the top of the posterior arch (see Figs. 1-7 and 1-8). The length of the groove is 14.5 mm ± 2.1, which ends about 8 to 13 mm from the median tubercle of the posterior arch.[11] The length of the transverse course of the VA over the groove is 16.6 mm (13 to 19 mm).[12] The diameter of the VA in this area is 3.9 mm (range, 2.3 to 5.9 mm) with left VA greater than the right in 42.9% and equal in diameter in 21.4%.[12] It is recommended that the posterior arch of the atlas not be exposed more than 1 to 1.5 cm from the midline of the posterior arch.

The superior surface of each lateral mass is concave to allow the convex OC to fit snugly into this bowled facet surface. The inferior facet of the lateral mass is a fairly flat, round surface that angulates downward and faces mesially. On sagittal view, both the OC–C1 and C1–C2 facets slope slightly downward from front to back (see Fig. 1-7). On coronal view, from mesial to lateral, the trapezoid configuration of the lateral mass creates an upward sloping of the OC–C1 facets, with the occipital condylar surface facing outward and the C1 superior articular surface facing inward. To counterbalance, the C1–C2 facets slope downward, with the inferior articular surface of the C1 lateral mass facing inward (see Fig. 1-9).

Juxtaposed immediately behind the anterior arch is the odontoid process, protruding upward from the axis below. Passing behind the odontoid process is the thick transverse ligament, which is anchored to the small, bony tubercle on the mesial edge of each lateral mass (see Fig. 1-8). The transverse ligament is part of the cruciate ligament complex that stabilizes the C1–C2 complex to the occiput. Lateral to the lateral mass is the transverse process, which is prominent enough to be palpated digitally between the mandibular angle and the mastoid process (see Fig. 1-8). The transverse diameter of the entire atlas, from the tip of the transverse process to the tip of the other, is 78.6 ± 8.1 mm. Within the transverse process is the transverse foramen, which transmits the V2 segment of the vertebral artery.

With its dense cortical bone, the C1 lateral mass provides a secure anchor for placement of lateral mass screws. Insertion of lateral mass screws places the vertebral and carotid arteries, C2 nerve roots, and hypoglossal nerve at risk. Several studies have described the anatomy of C1 for safe placement of lateral mass screws. The mean depth of bicortical screw insertion is 19.3 ± 0.21 mm in the axial plane and 20.9 ± 0.19 mm in the sagittal plane. The mean sagittal entry angle for a lateral mass screw is upward 33.1 degrees ± 8.0 degrees on the right and 37.3 degrees ± 9.1



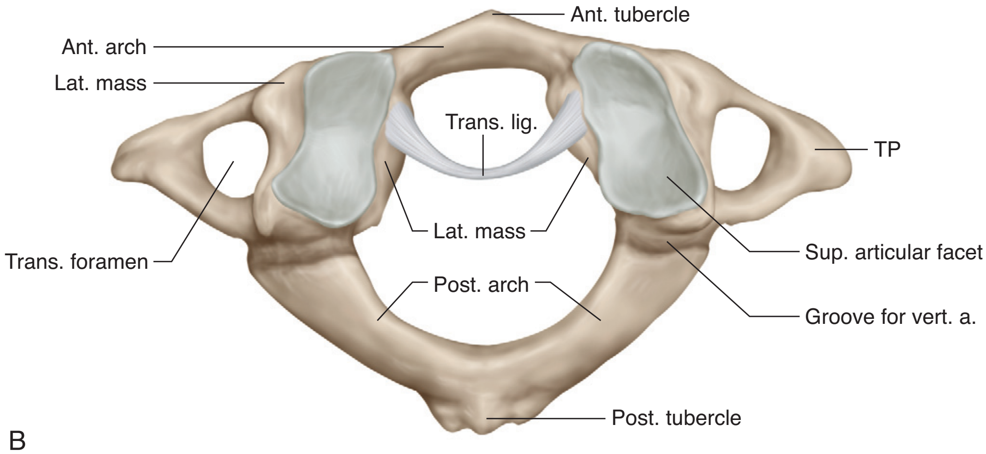


Figure 1-8 Axial CT of atlas (**A**) and dry specimen (**B**). AA, anterior arch of C1; AT, anterior tubercle; FT, foramen transversarium; LC, longus colli muscle; LM, lateral mass of C1; PA, posterior arch of C1; SAS, subarachnoid space; SC, spinal cord; TL, transverse ligament; TLT, transverse ligament tubercle (*arrow*); TP, transverse process; VAG, vertebral artery groove.

degrees on the left.[13-15] The axial angle for the bicortical lateral mass screw is slightly less, with 20.5 degrees angulation mesially from the posterior entry point. Based on these anatomic studies, it is recommended that the ideal entry point for a lateral mass screw is at the junction of the mesial edge of the posterior arch attaching to the lateral mass.[16] The average distance between the vertebral foramen and the screw pathway is 8.8 mm using this landmark. The safe screw angulation is 15 degrees upward and inward.[17]

Axis (C2)

The second cervical vertebra, the *axis*, also called *epistroeus*, was named for its configuration because it works as a pivot for the atlas that allows the head to rotate. The odontoid process projects upward from the body of C2 (Figs. 1-10 and 1-11). It is 1.0 to 1.5 cm long and 1 cm wide (9.8 ± 0.8 mm),[18] and it can incline posteriorly from 0 to 30 degrees relative to the body of C2.[19] On the ventral surface of the odontoid is an oval facet that articulates with the back side of the anterior arch of C1. The dorsal surface of the odontoid is a transverse groove, where the transverse ligament traverses from one side of the C1 ring to the other to stabilize the odontoid in its unique position. The odontoid is further stabilized by the apical ligament from its apex to the basion and the paired alar ligaments from the dorsal surface of the odontoid to the FM. The body of the axis is asymmetric and widest at the base, and it tapers to the tip of the odontoid (Fig. 1-12; see also Figs. 1-10 and 1-11). The C2 vertebral body height is 22.13 mm (range, 17.0 to 26.0 mm) from the inferior end plate to the base of the odontoid.[19] The vertebral body width is 19.2 ± 2.2 mm at its base and 15.9 ± 1.7 mm mid body.[20]

The odontoid and body are flanked by a pair of oval facets that extend from the body laterally onto the large pedicles and articulate with the inferior facets of the atlas (see Figs. 1-7 and 1-10); this articulation slopes downward on both coronal and sagittal views. Extending posteriorly from the superior facet is the pillar pedicle and the lamina of C2. The lamina of the axis is quite thick and can be used as a viable salvage in failed C2 pedicle fixation and in cases of high-riding anomalous vertebral arteries. The C2 laminar thickness is 5.75 ± 1.21 mm with a length of 24.8 ± 1.9 mm. The spinous process–laminar angle is 48.47 ± 5.37 degrees.[21]

The C2 pedicle is fairly solid and is large enough for screw placement (see Fig. 1-11). The C2 pedicle height is 8.7 mm (5.90 to 10.90 mm) not including the C2 body.[22] The mean

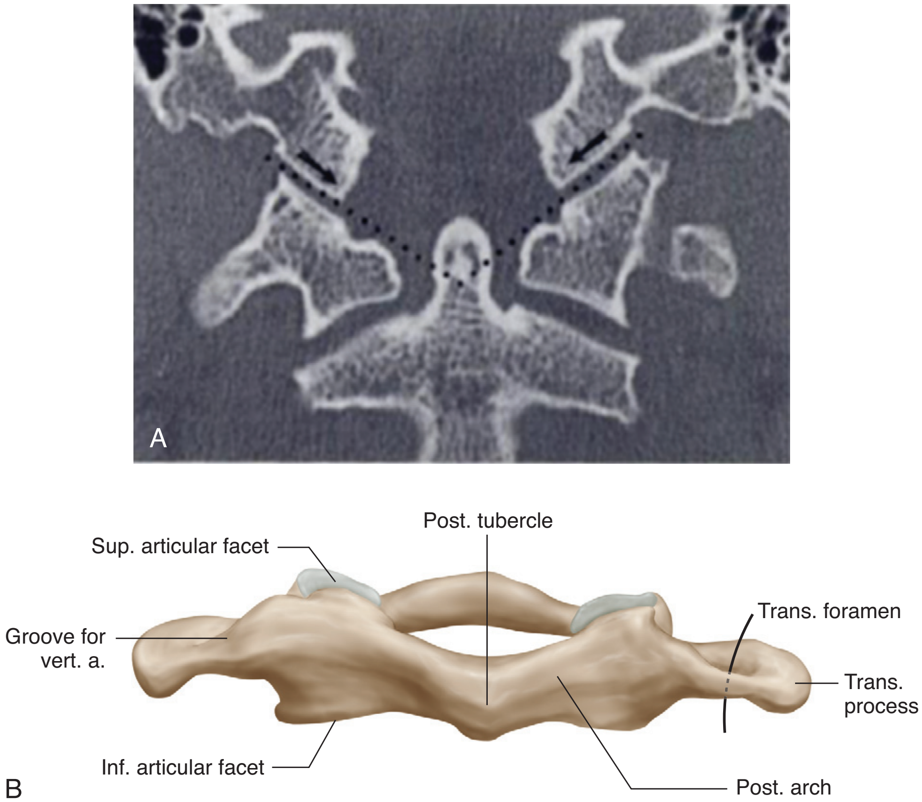


Figure 1-9 Coronal CT of the CVJ showing (**A**) the trapezoid configuration of the C1 lateral mass and (**B**) the angulation of the occipitoatlantoaxial joints.

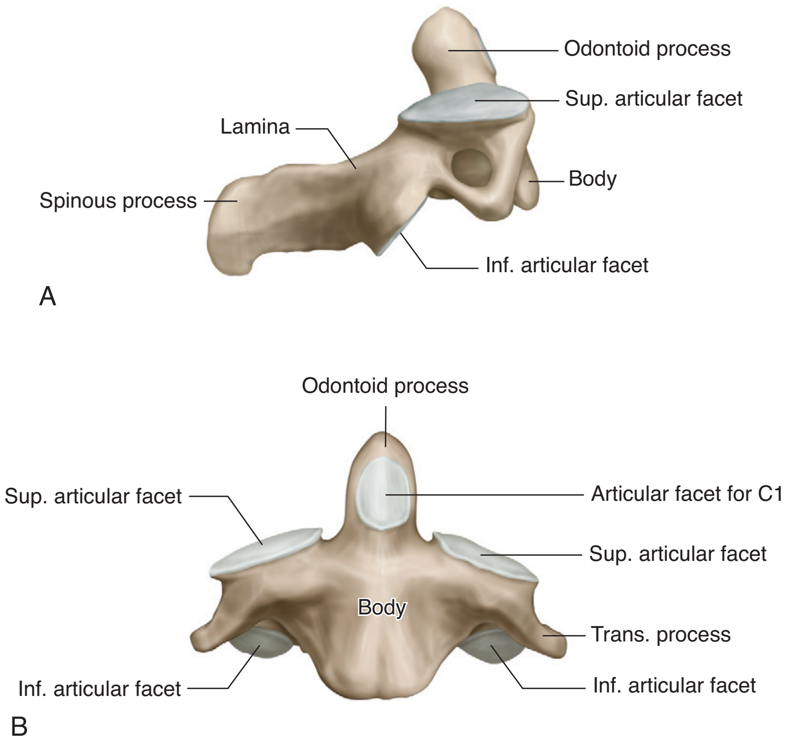


Figure 1-10 Axis vertebra. **A,** Lateral view. **B,** Anterior view.

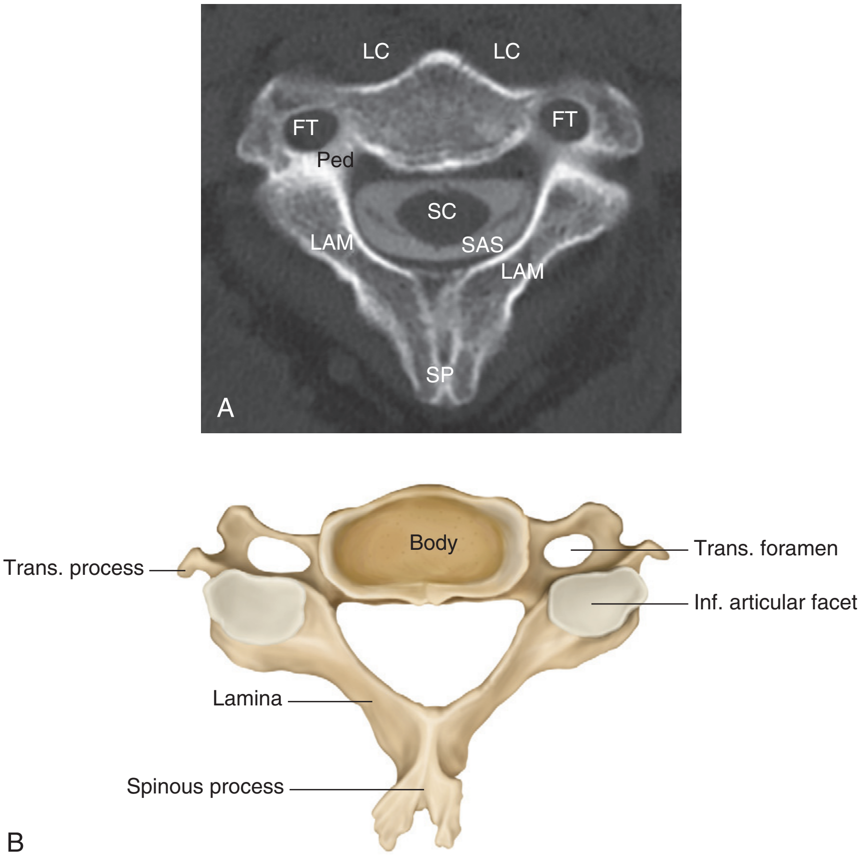


Figure 1-11 Axial CT of axis vertebra (**A**) and dry bone (**B**). LC, longus colli; FT, foramen transversarium; Ped, pedicle; SC, spinal cord; SAS, subarachnoid space; LAM, laminar of C2; SP, spinous process.

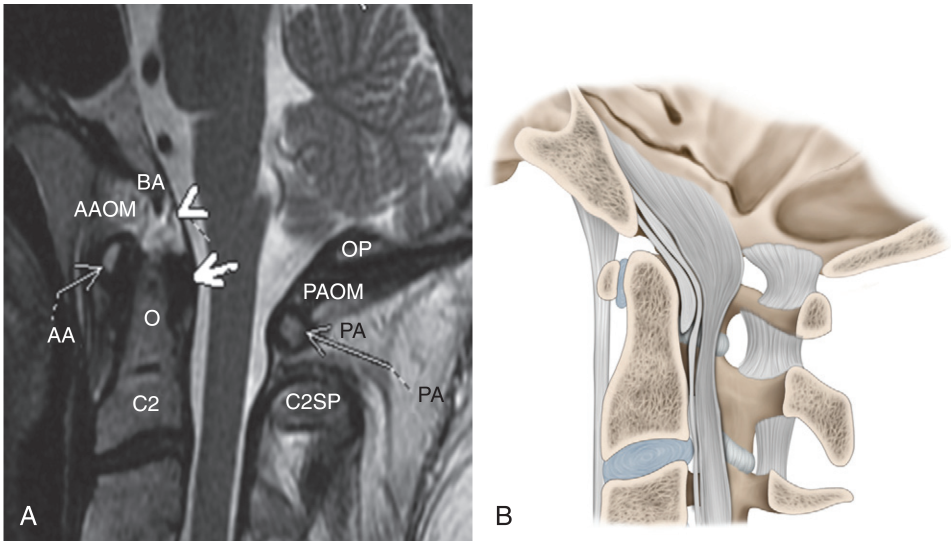


Figure 1-12 Sagittal view of CVJ, sagittal magnetic resonance imaging (**A**), and artist's rendition (**B**). The tectorial membrane (*arrowhead*) and transverse ligament (*thick arrow*) are shown. BA, basion; OP, opisthion; AAOM, anterior atlantooccipital membrane; PAOM, posterior atlantooccipital membrane; O, odontoid; C2SP, C2 spinous process; AA, anterior arch of C1 (*thin arrow*); PA, posterior arch of C1.

width of the C2 pedicle is 5.8 ± 1.2 mm with an overall pedicle transverse angle of 43.2 ± 3.9 degrees (32.8 to 53.2 degrees) for screw placement.[23] However, the anatomic median angle of the pedicle is only 10.37 degrees (6.00 to 20.00 degrees), and the angle of declination is 28.41 degrees (20.00 to 38.00 degrees).[22] The safe site of screw entry in the axis is the superior and mesial third of the posterior surface of the C2 pedicle. The vertebral artery foramen forms a deep groove in the undersurface of the C2 superior facets and occupies the entire undersurface of the superior facet 15% of the time. As such, the safe trajectory for a C2 pedicle screw is 40 degrees mesial and 20 degrees superior.[17]

The inferior articular facets are situated at the junction of the pedicle and lamina and face downward and forward as they articulate with the superior facets of C3 below. The transverse processes of the axis are small lateral projections that demarcate the lateral margin of the foramen transversarium, in which the vertebral artery courses upward before deviating mesially over the C1 superior sulcus.

LIGAMENTOUS AND MEMBRANOUS STRUCTURES OF THE CRANIOVERTEBRAL JUNCTION

The CVJ is a unique entity, not only in its embryologic origins as discussed above, but also in its anatomic elements and their interactions with each other. But despite all of its unique features, the CVJ remains at its core a combination of bone articulated with synovial joints, muscles, ligaments, and membranes. The bony structures that make up the CVJ include the occipital bone, atlas, and axis vertebrae with their associated tubercles and characteristic shapes that allow them to move and function as a single unit.

Destructive osteoarthropathies such as rheumatoid arthritis further illustrate the unique kinematics of the CVJ. As erosion of the bony elements of the spine progresses, attendant destruction of the insertion of the transverse ligament on the atlas follows suit, resulting in ligamentous laxity at the atlantoaxial joint. This can result in atlantoaxial dislocation or an upward translation of the odontoid, a process known as *basilar impression.*[17]

The ligamentous components of the CVJ can be classified into two types, extrinsic or intrinsic. The *extrinsic ligaments* include the fibroelastic membranes, which replace the anterior longitudinal ligament; the ligamentum flavum, which lies between the axis and atlas; and the ligamentum nuchae, which extends from the external occipital protuberance to the posterior aspects of the atlas and upper cervical spinous processes. The *intrinsic ligaments* are composed of the tectorial membrane (TM); the accessory atlantoaxial, cruciate, and odontoid ligaments; and the anterior atlantooccipital membranes. All of the ligaments that make up the intrinsic layer are located anterior to the dura and provide additional support to the bony structures that make up the CVJ (see Fig. 1-12).[2]

The special arrangements of the occipitoatlantoaxial ligaments are remarkable, and they allow for complex motion yet provide stability to the area. The articular capsules of the lateral atlantoaxial facets surround the articular surfaces and are strengthened by atlantoaxial ligaments. The capsules are reinforced by lateral fibers that pass in a rostral direction from the TM.

The odontoid-specific ligaments, especially the alar ligaments and transverse atlantal ligament, are most important for CVJ stability. Other odontoid-specific ligaments—such as the apical, atlantodental, and atlantoalar ligaments—perform accessory roles.

The cruciform ligament, as its name suggests, is composed of both vertical and transverse bands that form a cross behind the odontoid (Fig. 1-13; see also Fig. 1-12). The transverse band, also called the *transverse atlantal ligament,* is attached to a tubercle (see Fig. 1-8) on the medial side of the lateral masses of the atlas on either side, and it stretches across the ring of the atlas behind the odontoid. Longitudinal bands that extend in the rostrocaudal direction meet the transverse atlantal ligament in the midline to form the cross of the cruciform ligament. This vertical portion inserts on the upper surface of the clivus superiorly and to the posterior surface of the body of the axis inferiorly.[2] The transverse atlantal ligament is the strongest, thickest ligament of the CVJ (mean height/thickness 6 to 7 mm) and as such is the predominant stabilizer of the atlas.[24] Biomechanical studies have demonstrated that the transverse ligament is the primary defense against anterior subluxation of the atlas on the axis and that it is relatively inelastic, only allowing C1 to subluxate approximately 3 to 5 mm before rupturing. The authors of such studies[2,24,25] also concluded that the accessory ligaments of the atlantoaxial joints serve as secondary restrictions of the atlas to anterior shift.[16] By functioning as an anteroposterior stabilizer and holding the odontoid in its vertical position, the transverse ligament permits rotation to occur, while the alar ligaments prevent excessive rotation.[25] Disruption of these ligamentous structures destabilizes the CVJ.[8]

The paired alar ligaments (see Fig. 1-13) originate on the posterior surface of the upper third of the odontoid and extend laterally in two bands, the occipitoalar and

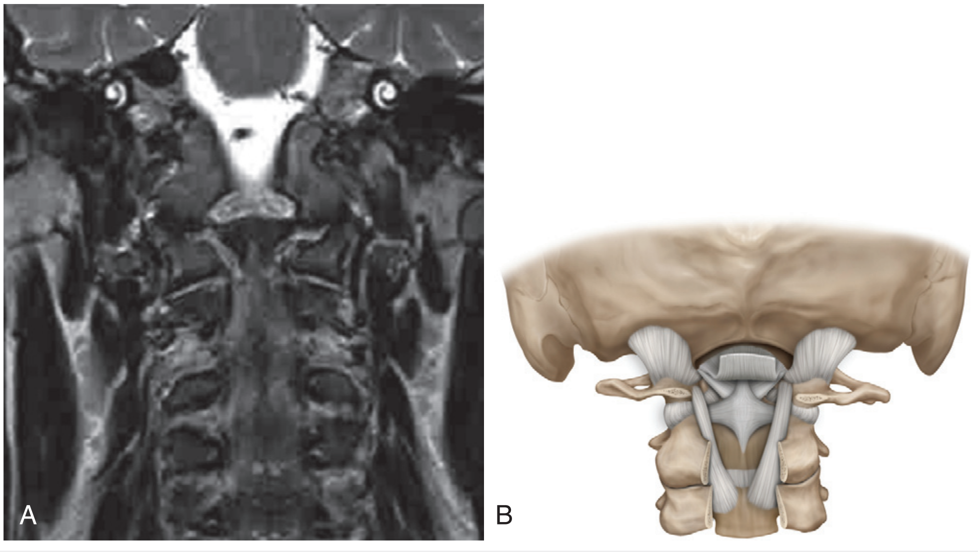


Figure 1-13 Cruciate, transverse, alar, and accessory ligaments. **A,** Coronal magnetic resonance imaging. **B,** Drawing.

atlantoalar bands, to insert on the occipital bone or the lateral masses of C1, respectively.[18] The fibers of the alar ligament are typically oriented in the horizontal direction, although this is wholly dependent on the position of the occipital bone. The alar ligaments play an important role in the stabilization of the head during movement, and they are the main restraint to axial rotation in the upper cervical spine.[2] Cadaveric dissections have demonstrated that transection of one or both alar ligaments subsequently causes an increase in flexion-extension, lateral bending, and most of all rotational movements between both the occipitoatlantal joint and the atlantoaxial joint. They are the only ligaments, except the transverse ligament, that are strong enough to stabilize the CVJ and prevent anterior displacement of the atlas. If the transverse ligament ruptures, the alar ligaments become responsible for preventing atlantal subluxation.[25] The alar ligament limits the axial rotation on the contralateral side to about 90 degrees. Damage to this ligament results in further axial rotation, which can result in compression or damage to the VA or to the spinal accessory nerves.

The TM (see Figs. 1-12 and 1-13) appears to be a cephalad extension of the posterior longitudinal ligament of the vertebral column. It is attached to the body of C2 caudally and to the basilar groove of the occipital bone cranially. The membrane is firmly adherent at its cranial and caudal regions to the respective bony insertions but appears to be free from the posterior aspect of the odontoid process. The function of the TM is still an issue of debate. Some authors have concluded from extensive cadaveric studies that it may serve a stabilizing role for the CVJ, much like the cruciate ligament. However, others have found that isolated transection of the TM, which in real life is an extremely rare event, failed to cause significant instability with increased flexion or rotational movements. It appears as though this cephalad extension of the posterior longitudinal ligament acts as a second line of defense in the prevention of ventral compression of the thecal sac and its neural contents by the anteriorly located odontoid process.[2]

The accessory atlantoaxial ligament, also known as the *Arnold ligament,* connects the lateral mass of the atlas to the body of the axis and extends cephalad to the occipital bone.[26] This ligament is about 5 mm thick and 30 mm long, and it connects the atlas to the axis and continues rostrally to the occipital bone. This accessory ligament seems to participate in rotational stability of the craniocervical junction.[2]

Another ligament that may be synergistic with the anterior atlantooccipital membrane is the *Barkow ligament* (BL), which was found in 92.3% of specimens. This is a 3.5 mm thick ligament that attaches to the mesial aspect of the OC anterior to the superior aspect of the odontoid and traverses anterior to the alar ligament.[27]

A more obscure ligament in the CVJ is the transverse occipital ligament, or *Lauth ligament*.[28] This is a thin transverse band that attaches to the OCs superior to the transverse portion of the cruciform ligament and posterosuperior to the alar ligament. Although this ligament was found in 10% to 77.8% of specimens,[28-30] the biomechanical significance of the Lauth ligament remained to be elucidated.

Finally, the apical ligament, also known as the *suspensory ligament* or *odontoid ligament,* extends from the tip of the odontoid process to the anterior border of the FM and lies between the anterior atlantooccipital membrane and the cruciform ligament (see Fig. 1-8). It is most often found in the midline and lies in the potential triangular space created by the paired alar ligaments. Some demographic studies have found that the absence of the apical ligament is a rare incident, whereas others have found it lacking in up to 20% of patients. As such, the ligament remains a vestigial remnant of an embryologic entity that offers little to no contribution in the stabilization of the CVJ.[2,31]

NEURORADIOLOGY OF THE CRANIOVERTEBRAL JUNCTION

Advances in imaging techniques, such as high-resolution magnetic resonance imaging (MRI) and multislice CT scans with multiplanar reconstruction capabilities, have significantly enhanced the visualization of CVJ anatomy with exquisite detail and have improved the diagnostic accuracy, assessment reliability, and treatment optimization of complex craniocervical junction pathology. However, most of the craniocervical morphometries were initially developed on the basis of Roentgen's radiography and are still proven to be quite reliable in discerning the relationship of adjacent anatomic structures.

Krakenes and colleagues[32] have demonstrated that anatomic details of various ligaments are best visualized using a high-resolution proton-density (PD)–weighted MRI sequence. Dullerud and colleagues[33] have also demonstrated that fat-suppressed PD sequences improved the resolution of ligamentous structures even further. Similarly, dynamic imaging of the CVJ demonstrate how arthritic processes in joints may have affected their stability, culminating with pressure on the medulla and upper spinal cord, which would not be visualized on neutral images. Thus MRI and CT scans in flexion-extension can be used to show cervicomedullary compression or joint instabilities in patients with degenerative disorders such as rheumatoid arthritis or osodontoideum.[34,35]

Skull Base and Atlantoaxial Morphometry

Numerous geometric indices have been described in CVJ morphometry. These well-established parameters were developed to provide quick and reliable diagnoses of CVJ abnormalities. Plain radiographs of the skull base with defined osseous landmarks have been used to draw various geometric lines and measurements. Cross-sectional CT or MRI scans are now being used for better delineation of soft tissue and osseous anatomy. Anatomic landmarks for morphometry include nasion, basion, opisthion, posterior margin of hard palate, tuberculum sellae, OCs, mastoid process, anterior/posterior arches of atlas, odontoid process, and posterior margin of axis. All the morphometric lines are drawn on lateral radiographs or midsagittal reconstructions of CT or MRI except for atlantoaxial joint axis angle, digastric and bimastoid lines, that can only be demonstrated on AP radiographs, or coronal reconstructions.

Indices for Skull Base and Craniocervical Junction on a Lateral (Sagittal) View (Table 1-1).

Welcher basal angle: This angle is formed by nasion-tuberculum and tuberculum-basion lines (Fig. 1-14).

Table 1-1 Indices for Skull Base and Craniocervical Junction on a Lateral/Sagittal View

Indices	Anatomic Location/Relationship	Remarks
Welcher basal angle	Angle between nasion-tuberculum and tuberculum-basion lines	>140° = Platybasia
Koenigsberg angle	Angle between nasion-dorsum sellae line and clival posterior surface tangent	Adults: >124° = Platybasia Children: >127° = Platybasia
Chamberlain line	Posterior margin of hard palate to opisthion	Tip of the odontoid should not be more than 5 mm above this line and anterior. Arch of atlas typically lies below this line.
McGregor line	Posterior margin of hard palate to inferior surface of basiocciput	Tip of the odontoid should not be more than 7 mm above. Anterior arch of atlas typically lies below this line.
McRae line	Basion to opisthion	Tip of the odontoid should not be above this line.
Wackenheim clivus baseline	Inferior extension of posterior surface of clivus tangent	The odontoid falls in front or tangent to it, and the clival baseline may intersect the posterior third of the odontoid.
Clivus canal angle	Angle between Wackenheim clivus baseline and posterior vertebral body line	Range: 150° maximum in flexion and 180° maximum in extension <150° anterior spinal cord compression
Cervicomedullary angle	Angles between tangents of upper spinal cord and medulla oblongata	Normal range: 136° to 158°
Redlund-Johnell criterion	Distance between McGregor line and midpoint of inferior end plate of axis	Normal: >34 mm in males and >29 mm in females
Ranawat criterion	Distance between the center of the pedicle of the axis and transverse axis of the atlas	Normal: >15 mm in males and >13 mm in females
Klaus height index	Perpendicular distance between tip of the odontoid and the internal occipital protuberance–tuberculum sellae line	<24 mm = Basilar invagination
Clark stations	Lines dividing lateral projection of odontoid/body of axis in three equal parts	Anterior arch of atlas should lie in upper third of odontoid/body of axis.
Kulkarni-Goel index; vertical atlantoaxial index (VAAI)	Three parallel lines: Inferior end plate of axis Tangential to inferior border of anterior arch of atlas Tangential to tip of the odontoid VAAI: Ratio of distance between first two lines and first and third lines	Normal: >0.8 Mild: 0.61-0.70 Moderate: 0.41-0.60 Severe: <0.40

Obtuseness more than 140 degrees is suggestive of platybasia. Using the center of the pituitary fossa, similar angles have been described by McGregor and Poppel.[36,37] Koenigsberg and colleagues[37a] have recently described similar angles formed by a line extending across the anterior cranial fossa to the tip to the dorsum sellae with a second connecting line drawn along the posterior margin of the clivus. Angles more than 124 degrees in children and more than 127 degrees in adults are suggestive of platybasia.[38]

Chamberlain and McGregor lines: A *Chamberlain line* is drawn from the posterior end of the hard palate to the most posterior margin of the FM, at the opisthion (see Fig. 1-14). Because the opisthion is not always visible, a modification was made by McGregor to draw a line, from the posterior margin of the hard palate to the lowest part of the basisquamous occiput, now called the *McGregor line* (see Fig. 1-14). In normal morphology, the tip of the odontoid process should be not more than 5 mm above the Chamberlain line and 7 mm above the McGregor line. The anterior arch of the atlas lies below both these lines.

McRae line: The McRae line joins the basion and opisthion. The tip of the odontoid process normally lies below this line (see Fig. 1-14).

Wackenheim clivus baseline: This line is otherwise known as the *basilar line.* It is the inferior extension of line drawn along dorsum of the clivus (Fig. 1-15). This line should be tangential to or should intersect the posterior one third of the odontoid process. In posterior craniocervical dislocation, the line will fall too far posterior to the odontoid process. In cases of anterior cervical dislocation, the line will intersect the base of the odontoid.[33]

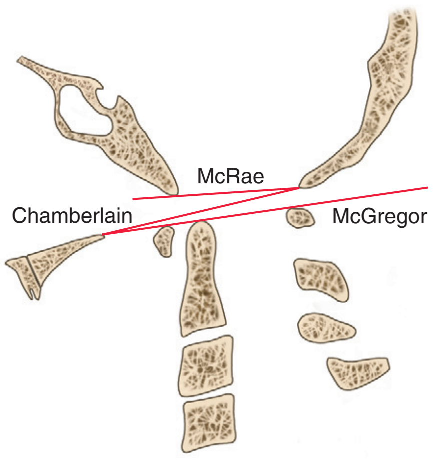


Figure 1-14 Demonstration of skull base morphometry lines.

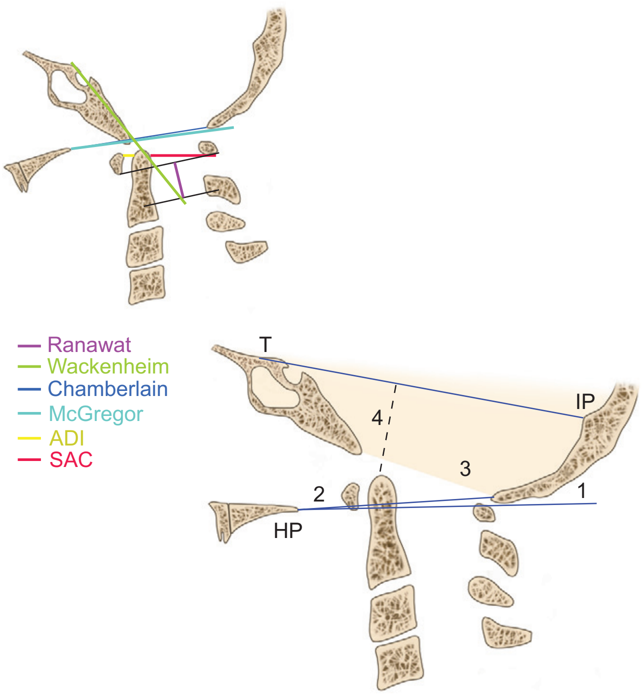


Figure 1-15 Demonstration of atlantoaxial indices.

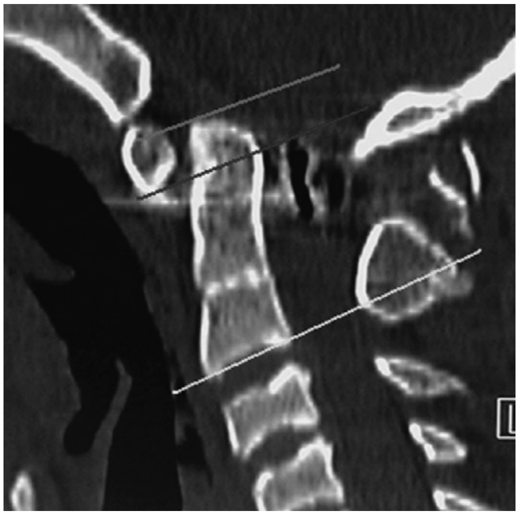


Figure 1-16 Three parallel lines drawn for measurement of Kulkarni-Goel index.

Clivus canal angle: This angle is formed by the Wackenheim clivus canal line and the posterior vertebral body line (see Fig. 1-14). The normal range varies from 150 degrees in flexion to 180 degrees in extension. Angles less than 150 degrees may be seen in anterior spinal cord compression.
Cervicomedullary angle: This angle is formed by tangential lines of the upper cervical spinal cord and medulla as described by Bundschuh and colleagues.[39] The normal range varies from 136 to 158 degrees, and angles less than 135 degrees have been correlated with cervical myelopathy and C2 nerve root pain with radiologic evidence of brainstem compression.
Redlund-Johnell criterion: This criterion uses the distance between the McGregor line and the midpoint of the inferior end plate of the C2 body. A distance less than 34 mm in males and 29 mm in females is suggestive of basilar invagination.
Ranawat criterion: The Ranawat criterion is based on the distance between the center of the pedicle of axis and transverse axis of the atlas as measured in a lateral cervical radiograph. A distance less than 15 mm in males and 13 mm in females is suggestive of basilar invagination.
Clark stations: Two lines are drawn on a lateral projection of the odontoid process, dividing it into three equal parts (or stations) from superior to inferior on the sagittal plane (see Fig. 1-15). Diagnosis of basilar invagination is made if the anterior arch of the atlas is in the caudal two parts.
Klaus height index: This is the perpendicular distance between the tip of the odontoid process and the line joining the internal occipital protuberance and tuberculum sellae (see Fig. 1-15). Clear visibility of tentorium, as in MRI as compared with lateral skull radiograph, improves the accuracy of detecting basilar invagination. A measured index less than 24 mm is suggestive of basilar invagination.

Kulkarni and Goel's vertical atlantoaxial index (VAAI; Fig. 1-16): As demonstrated by Kulkarni and Goel, this index measures the vertical relationship of the atlas and axis.[40] Three parallel lines are drawn: 1) at the low end plate of the axis, 2) tangential to the lower edge of the anterior arch of the atlas, and 3) tangential to the upper end of the odontoid process, parallel to the first two lines. The ratio of the distance between the first two lines and the first and third lines is the VAAI. A normal result for the VAAI is greater than 0.8; the basilar invagination is considered *mild* if the VAAI is 0.61 to 0.70, *moderate* at 0.41 to 0.60, and *severe* if it is less than 0.40.

Indices for Skull Base and Craniocervical Junction on an Anteroposterior (Coronal) View (Table 1-2).
Atlantooccipital joint axis angle (Schmidt angle): On the AP radiograph or coronal CT or MRI, angles formed by intersections of tangential lines of atlantoaxial joints are called *Schmidt angles.* If the OCs are symmetric, the arms of this angle usually intersect at the center of the odontoid process, usually between 124 and 127 degrees. In OC hypoplasia, this angle becomes more obtuse.
Fischgold-Metzger line: This line is drawn between the tips of the mastoid process in an open-mouth AP radiograph. The tip of the odontoid process lies below this line.
Reiw and colleagues[41] concluded that no radiographic criteria were sensitive enough for diagnosing basilar invagination by their own merit in rheumatoid arthritis patients. However, a combination of Clark's station, the Redlund-Johnell criterion, and the Ranawat criterion on a lateral radiograph were proved to be 94% sensitive with 91% negative predictive value for diagnosing basilar invagination in prompting further advanced imaging.

Indices for Atlantoaxial Instability (Table 1-3)**.** All the indices are assessed on a lateral radiograph or sagittal reconstruction.
Anterior atlantodental interval (AADI): This is the shortest distance between the posterior surface of the anterior arch of the atlas and the anterior surface of the odontoid (Fig.

Table 1-2 Indices for Skull Base and Craniocervical Junction on an Anteroposterior/Coronal View

Indices	Anatomic Location/ Relationship	Remarks
Atlantooccipital joint axis angle	Angles between axes of atlantoaxial joints	Joint lines intersect normally at the center of the odontoid Normal = 124°-127°
Fischgold-Metzger line	Line joining tips of mastoids	Tip of the odontoid should lie below

Table 1-3 Indices for Atlantoaxial Instability

Indices	Anatomic Location/ Relationship	Remarks
Anterior atlantodental interval (AADI)	Distance between anterior atlas arch and the odontoid	Adults: <3 mm Children: <5 mm
Posterior atlantodental interval (PADI)	Distance between posterior atlas arch and the odontoid	<14 mm with or without neurologic deficits or < 18 mm with neurologic deficits = atlantoaxial instability
Harris measurements Basion-axial interval (BAI)	Perpendicular distance between basion and posterior spinal axial line	Normal BAI and BDI is <12 mm
Basion-dental interval (BDI)	Distance between basion and tip of the odontoid	
Powers ratio	Ratio of two lines Distance between basion and posterior atlas arch Distance between opisthion and anterior atlas arch	Ratio >1 = anterior atlantoaxial dislocation

1-15). Normal parameters are less than 3 mm in adults and 5 mm in children.

Posterior atlantodental interval (PADI): This is the shortest distance between the posterior surface of the odontoid and the anterior surface of the posterior arch of the atlas (see Fig. 1-15). Adult measurements less than 14 mm of this index with or without neurologic deficits and less than 18 mm with deficits are suggestive of atlantoaxial instability.

Harris measurements: Also known as *Harris's rule of 12* (see Fig. 1-15), this involves two indices—the *basion-dental interval* (BDI) is the distance between the basion and the tip of the odontoid process and is also known as the *Wholey odontoid basion index;* the *basion-axial interval* (BAI) is the distance between the basion and the tangent of the posterior border of the axis. Measurements less than 12 mm in both BDI and BAI are suggestive of stable CVJ articulation.

Powers ratio: This is calculated from the ratio of two measurements: the distance between the basion and midpoint of the anterior surface of the posterior arch of the atlas (BC) and that between the opisthion and midpoint of the posterior surface of the anterior arch of the atlas (OA; see Fig. 1-15). Anterior atlantooccipital dislocation is indicated by a BC/OA ratio greater than 1.

Table 1-4 Normal Range of Motion of Craniovertebral Junction

	Flexion	Extension	Axial Rotation	Lateral Bending
C0–C1	21°	3.5°	7.2°	5.5°
C1–C2	12.5°	13.1°	47°	6.7°

Data from Dickman CA, Lekovic GP: Biomechanical considerations for stabilization of the craniovertebral junction. *Clin Neurosurg* 53:205–213, 2005.

Biomechanics of the Craniovertebral Junction

The CVJ is the most mobile region of the cervical spine, and it functions as a transition from the skull to the spine that is uniquely adapted for stability and motion. The unique bony configuration of the atlas and the axis vertebrae—as well as the articulations between the skull, the atlas, and the axis vertebrae—allow for a variety of complex movements at the CVJ.[42]

The mechanical properties of the occipitoatlantal (Occ–C1) motion segment are largely determined by bony elements,[43] whereas those of the atlantoaxial (C1–C2) segment are largely determined by ligamentous elements.[44,45]

OCC–C1 COMPLEX

The OCs are relatively rounded structures that articulate with the cup-shaped upper surfaces of the C1 lateral masses to form ball-and-socket joints that allow moderate sagittal deflections (i.e., flexion–extension) but severely limit the degree of axial rotation or lateral bending.[44]

The primary movement at C0–C1 is flexion and extension, often termed *capital flexion-extension*. In the normal state, 21 degrees of flexion and 3.5 degrees of extension occur at C0–C1 (Table 1-4). This is the largest contribution to flexion and extension from any single motion segment in the cervical spine. Flexion is limited by impingement of the tip of the odontoid on the FM, and extension is limited by the TM.

As could be predicted from the anatomy of the joint, lateral bending and axial rotation are much more restricted at 5.5 and 7.2 degrees, respectively. Although the idea of axial rotation in this joint had long been rejected, more recent investigations have shown axial rotation in both in vitro and in vivo studies.[43,46,47]

Lateral bending averages 3.4 to 5.5 degrees per side. This movement is resisted by the Occ–C1 articulation and the alar ligaments. Axial rotation is 2.4 to 7.2 degrees per side and is also limited by the Occ–C1 articulation and the alar ligaments.[48]

Lateral bending and coronal and sagittal translation are significantly restricted under normal conditions. These motions are limited by the Occ–C1 articulation and possibly by the TM and the apical ligament.[49]

ATLANTOAXIAL COMPLEX

The atlantoaxial (C1–C2) joint consists of four joint spaces: the two atlantoaxial lateral joints; the atlantoaxial median joint, between the anterior arch of the atlas and the odontoid axis; and a joint between the posterior surface of the odontoid and the transverse ligament. The lateral atlantoaxial joint has a large synovial fold. In contrast to that of the altantooccipital joint, this joint capsule is loose, allowing a great deal of motion. The vertical odontoid of the axis (C2) acts as a pivot, about which the atlas (C1) rotates.[50]

Moreover, the articular surfaces of C1 and C2 are both convex, allowing a much greater degree of freedom at C1–C2 for axial rotation around the odontoid and also allowing lateral bending and flexion–extension.[51] Mean rotational movement is 23.3 to 38.9 degrees per side. As the head rotates in the transverse plane, the axis of motion is in the odontoid process.

Anatomic studies have shown that stretching and kinking of the contralateral vertebral artery occurs between 30 and 35 degrees of atlantoaxial rotation.[52] When rotation exceeds 40 degrees, an interlocking of the facets occurs between the atlas and the axis vertebrae. In fact, the vertebral artery loop between the atlas and axis allows the artery to remain undamaged by normal movement in this plane; the length of the artery between the atlas and occiput would not be sufficient if the same degree of motion were to occur there.[45]

Axial rotation at C1–C2 is negatively coupled to rotation at Occ–C1; in effect, axial rotation at C1–C2 induces axial rotation of a lesser magnitude, and in the opposite direction, at C0–C1.[44,45]

Flexion–extension ranges from 10.1 to 22.4 degrees total at C1–C2. Flexion is limited by the transverse ligament, whereas extension is limited by the TM and the C1–C2 articulation. In flexion and extension, the instantaneous axis of rotation is located midway between the tip and base of the odontoid near its dorsal cortex.[46,47]

Lateral bending is limited by the alar ligaments to an average of 6.7 degrees. Lateral translation, distraction, and compression at C1–C2 are minimal in nonpathologic states. The atlantoaxial joint is responsible for about 47 degrees of rotation at the neck. Studies on both cadavers and finite-element models have demonstrated the range of motion in axial rotation to be up to 8 degrees for the occipitoatlantal joint compared with up to 40 degrees for the atlantoaxial joint,[53] and axial rotation up to 45 degrees in each direction has been observed at the atlantoaxial joint in children.[54] By comparison, flexion and extension are nearly equal at the two joints, with a total average movement of 27.1 degrees in flexion and 24.9 degrees in extension for the complex encompassing the occiput, atlas, and axis.

This degree of inflammatory pathology and its predilection for the atlantoaxial joint, as opposed to the atlantooccipital joint—or, for that matter, the subaxial cervical spine—demonstrates the underlying instability of the joint and its reliance on ligamentous support for proper function.[45]

Furthermore, data from a validated 3D model of the Occ–C1–C2 complex with application to rheumatoid arthritis also indicated that a mechanical component, in addition to enzymatic degradation, may be associated with the osseous resorption observed in rheumatoid arthritis. Specifically, erosion of the odontoid base may involve Wolff's law and various considerations regarding loading forces over the bone. Changes through the lateral aspects of the atlas suggest that this same mechanism may be partially responsible for the erosive changes seen during progressive rheumatoid arthritis. Finally, the anterior and posterior atlantodental interval values indicate that complete destruction of the transverse ligament coupled with alar and/or capsular ligament compromise is requisite if advanced levels of atlantoaxial subluxation are present.[47]

Conclusions

The complex anatomy and intricate relationships among its various components make the CVJ unique and pose a significant challenge for surgeons trying to gain access to deeply seated lesions in this area. A thorough understanding of the anatomy of the CVJ is paramount for achieving successful surgical outcomes. Numerous morphometric and anatomic studies of this region provide a wealth of knowledge in regard to normal measurements, indices, and parameters that are essential in preoperative planning and intraoperative guidance during surgical approaches to such a unique and challenging region.

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2 Transoral Approach to the Craniocervical Junction and Upper Cervical Spine

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Overview

Pathology of the craniocervical junction remains technically difficult to access, but because of advancements in instruments, the operating microscope, endoscopic techniques, and materials to repair skull base defects, these lesions have become more accessible, and it has become safer to provide treatment. Ventral pathology located anterior to the spinal cord and cervicomedullary junction is the most difficult to access. Historically, pathology in this location was often treated by a posterior or posterolateral decompression followed by a fusion if needed. This indirectly addressed the compressive component on the spinal cord or cervicomedullary junction, whereas it only minimally addressed the pathology itself, if this was addressed at all. The transoral approach and its variations were developed specifically as ventral or anterior approaches to the cervical spine and craniocervical junction.

Anterior approaches were first developed to reach pathology anterior to the spinal cord and then were extended to access pathology anterior or ventral to the lower brainstem and cervicomedullary junction. A truly anterior approach to this region offers the advantage of the shortest and most direct route and a straight-on view of the pathology without manipulation of the spinal cord or brainstem. The transoral approach was first described in 1909, when Kanaval used it to extract a bullet that had been lodged between the foramen magnum and the anterior arch of C1. The approach was later popularized by Scoville and Sherman[1] in the 1950s for platybasia repair and by Fang and Ong[2] in the 1960s for infectious etiology. Complications were common and included vertebral artery injuries, cerebrospinal fluid (CSF) leaks, and meningitis. The transoral approach did not gain popularity until the 1980s and early 1990s, after refinements in technique by Menezes and Crockard[3,4] showed that the approach could be done safely with less morbidity than previous attempts.

Approaches to the craniocervical junction are divided into anterior and posterior approaches. *Anterior approaches* include the transoral approach and its variations and transfacial approaches. *Anterolateral approaches* include the high cervical retropharyngeal and posterior approaches, which include the standard midline posterior approach and the far-lateral approach and its variations (these are all described in separate chapters). The transoral approach provides the most direct access to midline ventral pathology but is limited in its lateral access. The transoral approach has a few variations that add rostral or caudal exposure to the standard approach.[3-10] To better classify these approaches, the classic or standard transoral approach has been described with and without palatal splitting. The classic transoral approach is performed with sparing of the soft palate only where it is elevated; this commonly allows access from the anterior foramen magnum to the C2–C3 disk space. To gain more rostral access than that allowed by the standard transoral approach, the soft palate alone or the combination of the soft and hard palate can be split; this is termed the *transpalatal approach*, which will provide access to the lower third of the clivus. If further rostral or caudal exposure is needed than is available from the standard transoral or transpalatal approaches, extended transoral approaches may be used. Rostral exposure is provided by the addition of the transmaxillary or “open-door” maxillotomy procedure; this provides access to the sphenoethmoid recesses, the entire clivus, and to areas as caudal as the C2–C3 disk space. This approach was designed for severe basilar invagination to allow for clival resection. Further caudal access can be gained by the addition of a transmandibular splitting (labiomandibular) approach with or without a transglottic or tongue-splitting variation (labioglossomandibular). This will provide caudal access to the C3 and C4 vertebral bodies in most patients.

Anatomy

The anatomy of the craniocervical junction and upper cervical spine involves a complex arrangement of bony, vascular, and ligamentous anatomy. Through its paired occipital condyles, the clivus articulates with the superior articular facets of the atlas (C1). The occipital condyles are located lateral to the anterior half of the foramen magnum. This atlantooccipital joint provides about 50% of the head and neck flexion and extension. The atlas articulates through its inferior articular facets with the superior articular facets of the axis (C2). The atlantoaxial joint provides the majority of the rotation of the head, up to about 45 degrees in either direction. The anatomy of both C1 and C2 are dramatically different than the rest of the subaxial cervical spine. The important functional movements allowed by the anatomy of the craniocervical junction are held tightly together by a complex ligamentous network.

C1 is a unique bone of the cervical spine because it lacks a vertebral body and spinous process and takes the shape of a ring (Fig. 2-1). At the lateral aspects of the ring are the two lateral masses that form the superior and inferior articular processes. The superior articular processes articulate

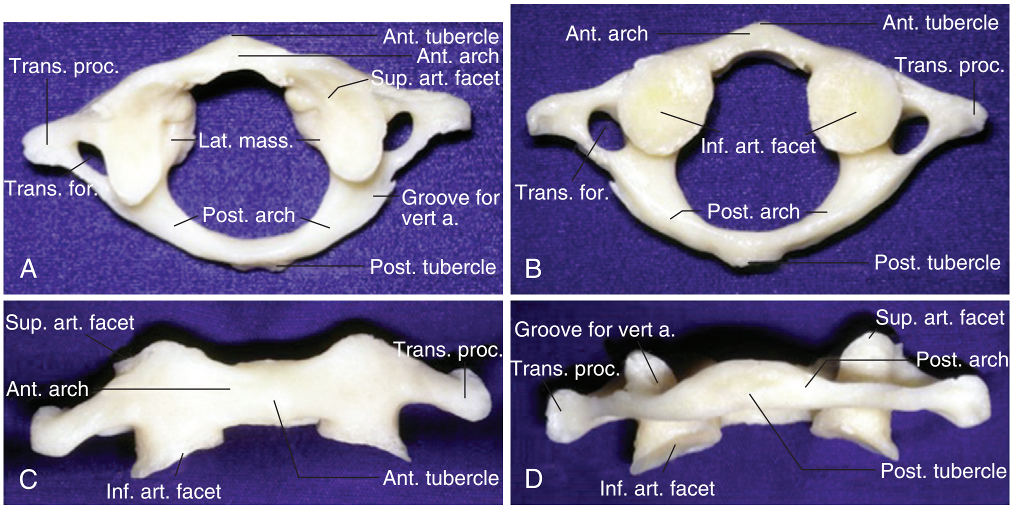

Figure 2-1 The atlas (C1). **A,** Superior view. **B,** Inferior view. **C,** Anterior view. **D,** Posterior view. Important anatomic landmarks of the atlas are shown, specifically the anterior atlantal tubercle in the ventral midline. The atlas lacks a spinous process and vertebral body. Note the location of the transverse foramen carrying the paired vertebral arteries. The atlas will rotate with the head on the axis and may therefore alter midline anatomic structures if the head is turned when the patient is positioned.

with the occipital condyles of the clivus, and the inferior articular processes articulate with the superior articular processes of C2. The lateral masses each support a transverse process, which contains the transverse foramen that carries the vertebral artery from the transverse foramen of C2 inferiorly. The C1 ring is formed by an anterior arch and a posterior arch; these are separated by the lateral masses; the posterior arch has an indentation just behind the lateral masses called the *sulcus arteriosis.* As the vertebral artery enters the C1 transverse foramen, it takes a slightly posterior course along the sulcus arteriosis of the posterior arch before turning medially then anteriorly and superiorly to enter the dura.

C2 is also a unique bone of the cervical spine. Although it appears more like the rest of the cervical spine than the atlas, because it contains a vertebral body and spinous process, the axis is identifiable by its rostrally pointing peglike projection from the vertebral body, called the *odontoid process* (Fig. 2-2). It also has lateral masses that contain the superior and inferior articular processes, which articulate with the atlas and C3, respectively; the superior articular processes are located more anteriorly than the inferior articular processes. Transverse foramina carry the vertebral arteries and span laterally off each of the lateral masses. The odontoid process has multiple impressions that show where the supporting ligaments attach or traverse.

The odontoid process is secured to the C1 ring and clivus by a series of ligaments that provide most of the strength of the atlantooccipital and atlantoaxial structures. The atlas and axis are held together by the anterior longitudinal ligament (ALL) and the posterior longitudinal ligament (PLL), the synovial joints of the articular processes, and the cruciform ligament. The cruciform ligament has a transverse portion, called the *transverse atlantal ligament,* and two vertical portions. The anterior arch of the C1 ring articulates posteriorly with the odontoid process of C2, and the transverse atlantal ligament holds the odontoid process against the anterior ring of C1. The transverse ligament attaches to small tubercles on each of the medial aspects of the C1 lateral masses, spanning from one lateral mass to the other while wrapping around the posterior surface of the odontoid process at its base with the vertebral body. The vertical portions of the cruciform ligament form from the transverse ligament as it crosses the odontoid; one travels superiorly, the other inferiorly (Fig. 2-3).

Four structures attach the axis to the occipital bone: the tectorial membrane, apical ligament, and paired alar ligaments. The *tectorial membrane* is the cranial extension of the PLL; it is continuous with the PLL inferiorly from the posterior body of C2 and extends rostrally behind the odontoid process to attach at the inside of the foramen magnum at its anterior margin. The *apical ligame*nt is a single, midline structure that spans from the superiormost apex of the odontoid process to the anterior margin of the foramen magnum. The *alar ligaments* are paired bands that attach at either side or the tip of the odontoid and span superolaterally to insert onto the medial surface of each occipital condyle (Fig. 2-4).

Midline anatomic structures are extremely important to identify when using any anterior approach, such as a transoral approach. In the most rostral exposure, the posterior nasal septum will attach at the sphenoid face in the midline at the vomer. The pharyngeal tubercle on the lower clivus is where the superior pharyngeal constrictor muscles attach (Fig. 2-5, *C*). In the middle of the anterior arch of C1 is the anterior atlantal tubercle, where the ALL attaches (see Fig. 2-1).

This midline anterior approach is limited laterally by important anatomic structures. The vertebral arteries at the level of the C1 transverse foramen lie about 14 to 15 mm on either side of the anterior atlantal tubercle.[9] At the base of the sphenoid sinus laterally, the soft tissue of the nasopharynx and oropharynx is densely adherent to the clivus and occipital bone at the petrooccipital fissure. Anteriorly at the fissure lies the foramen lacerum, where the petrous carotid artery is covered by soft tissue only, placing it at risk. Within the fissure intracranially is the inferior

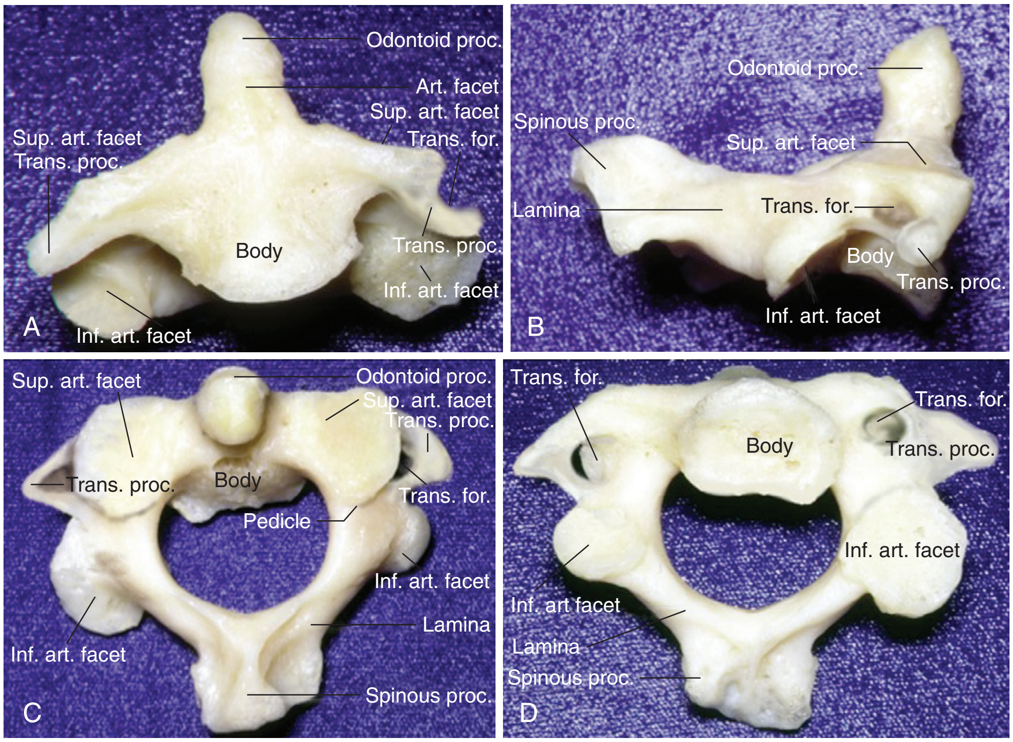

Figure 2-2 The axis (C2). **A,** Anterior view. **B,** Lateral view. **C,** Superior view. **D,** Inferior view. The axis is easily identifiable by its peglike process—the odontoid process, or dens—which articulates with the anterior arch of the atlas. The axis is attached by multiple ligaments, giving it stability in the anterior-posterior plane. Fracture of the odontoid or damage of the ligaments in this location can cause anterior or posterior subluxation and instability. Lateral rotation of the head occurs between the atlas and the axis around the odontoid process. Note that the transverse foramina have a superolateral to inferomedial trajectory, which places the vertebral arteries closer together at the C2–C3 disk space than the C1–C2 interspace.

Figure 2-3 Posterior view of the foramen magnum with a superficial to deep dissection, showing the atlantooccipital and atlantoaxial ligaments. **A,** Superficial posterior view of the foramen magnum with the tectorial membrane lying over the deeper ligamentous complex. Note the close proximity of the rootlets of cranial nerve (CN) XII to the foramen magnum. **B,** Deeper dissection after removing the tectorial membrane, exposing both the vertical and horizontal portions of the cruciform ligament and the alar ligaments. The horizontal portion, or transverse ligament, attaches to both medial edges of the C1 lateral masses; the vertical portion attaches to the anterior lip of the foramen magnum; and the alar ligament attaches to each occipital condyle. **C,** The vertical portion of the cruciform ligament has been folded downward to expose the apical ligament deeply attached to the foramen magnum.

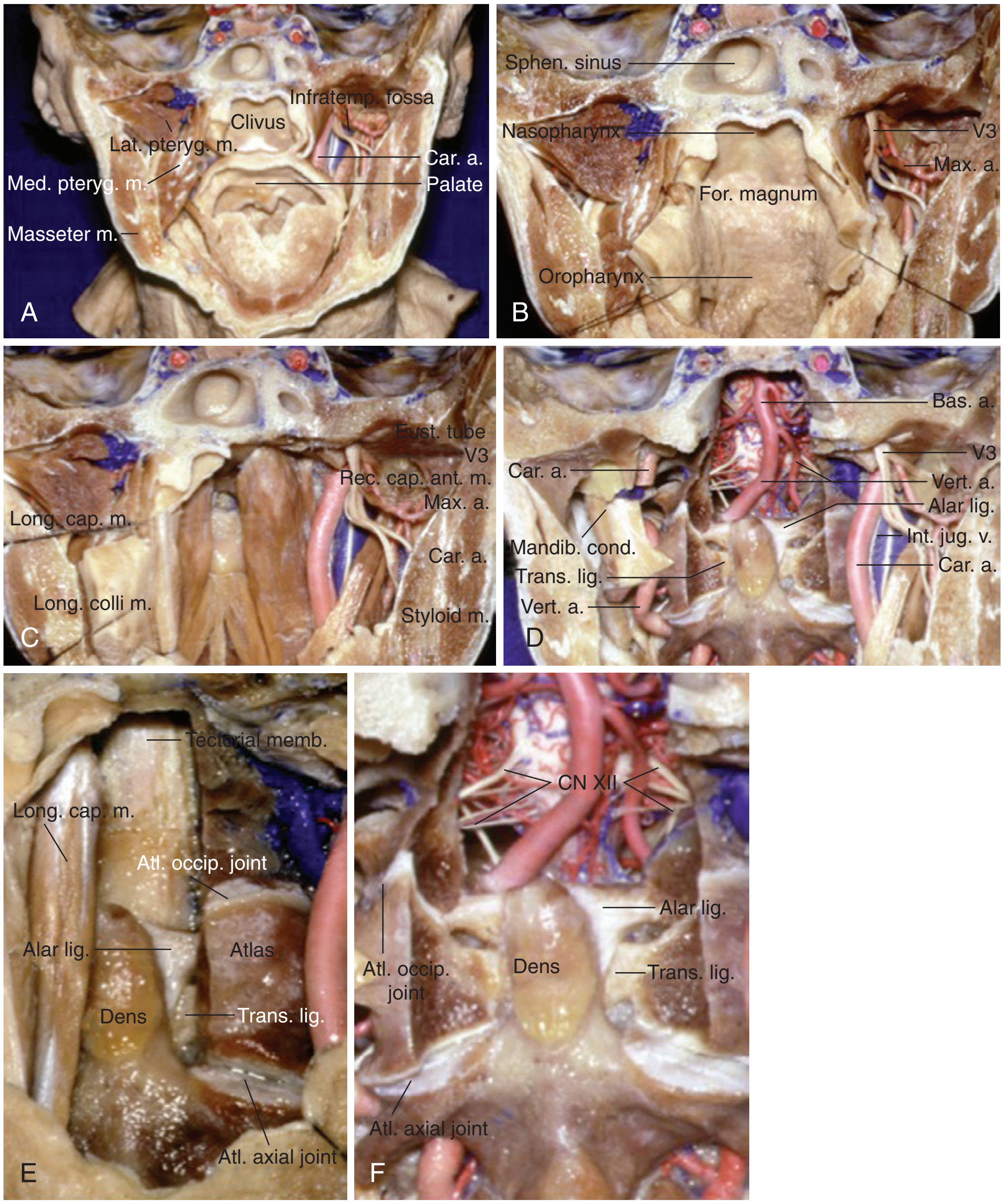

Figure 2-4 Anterior cross-section and stepwise dissection of the anatomy of the oropharynx, clivus, foramen magnum, atlas, and axis. **A,** Coronal cut looking into the nasopharynx; shown are the clivus and the oropharynx, with its soft palate and uvula. Note the proximity of the carotid artery, internal jugular vein, and cranial nerves (CN) IX, X, and XI. **B,** Close-up view: splitting of the soft palate and retraction laterally, revealing the clivus and foramen magnum covered by the posterior pharyngeal mucosa and musculature. **C,** The mucosa has been opened and reflected laterally to expose the longus capitis muscle attached to the clivus and the longus colli muscle attached to the anterior atlantal tubercle. Again note the location of the proximity of the carotid artery and how an ectatic artery may appear in the operative field. **D,** The anterior arch of C1 and the clivus have been removed to expose the odontoid process and the transverse and alar ligaments. **E,** Before **C** and **D,** a close-up view after removal of the anterior arch of C1 and the lower clivus, revealing the odontoid process and tectorial membrane, respectively. The atlantooccipital and atlantoaxial joints can be seen. **F,** Enlarged view of **D** shows the transverse and alar ligaments. Note the vertebral arteries are closer to each other at the C2–C3 space than at the C1–C2 space.

petrosal sinus; it travels posterolaterally toward the jugular foramen, which lies posterior and rostral to the occipital condyles and carries the jugular vein and cranial nerves IX, X, and XI. Slightly anterior and medial to the jugular foramen lies the carotid canal, where the carotid artery enters the petrous bone. The hypoglossal nerve exits the hypoglossal canals slightly rostral to the occipital condyles and joins cranial nerves IX, X, and XI as they exit the jugular foramen in the neck. Staying between the jugular tubercles provides a safe entry into the lower clivus extradurally or intradurally and avoids these important structures. The average distance between the occipital condyles is about 22 to 25 mm. A computed tomographic angiography (CTA) scan to evaluate the bony anatomy in reference to the carotid and vertebral arteries can help with preoperative planning, to evaluate for ectatic carotid arteries that may travel more medially, or to evaluate for vertebral artery dominance.

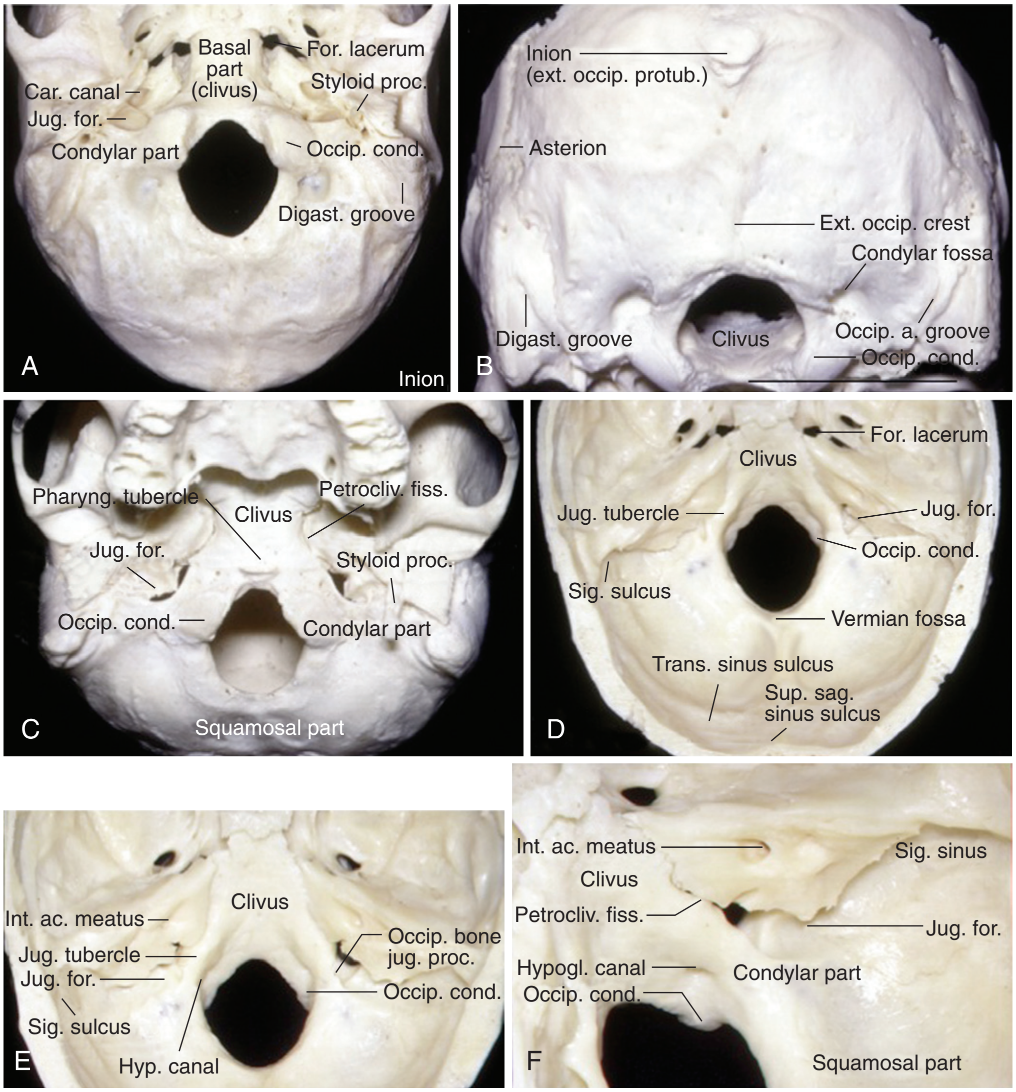

Figure 2-5 Occipital bone, foramen magnum, and important anatomic landmarks. **A,** Inferior view. **B,** Posteroinferior view. **C,** Anteroinferior view. **D,** Superior view. **E,** Posterosuperior view. **F,** Oblique posterosuperior view.

Ventral Pathology of the Craniocervical Junction

- Rheumatoid arthritis with odontoid pannus formation
- Basilar invagination in rheumatoid arthritis
- Congenital basilar invagination or platybasia
- Odontoid fractures with nonunion and os odontoideum
- Primary neoplasms such as chordoma, chondrosarcoma, plasmacytoma
- Secondary neoplasms such as nasopharyngeal tumors, metastases
- Foramen magnum or high cervical meningiomas
- Ventral epidural abscesses

Indications

This chapter will focus on the standard or classic transoral procedure and the transpalatal and transmandibular variations. Each addition to the transoral approach provides a more extensive anatomic exposure (Fig. 2-6).

The major indication for the transoral approach is that of midline, irreducible ventral pathology of the cervicomedullary junction causing neural compression. Although originally indicated only for extradural lesions, this approach has been used with or without the assistance of endoscopy to access intradural lesions as well, as our ability to repair the skull base and prevent CSF leakage has improved. This approach has also been used for débridement and diagnosis of infectious causes of ventral compression, such as tuberculosis and epidural abscess.

Relative Contraindications

Most contraindications are due to the inability to access the surgical corridor. Patients who cannot open their mouths to provide a space greater than 25 mm between the lower and upper teeth generally should either undergo a posterior

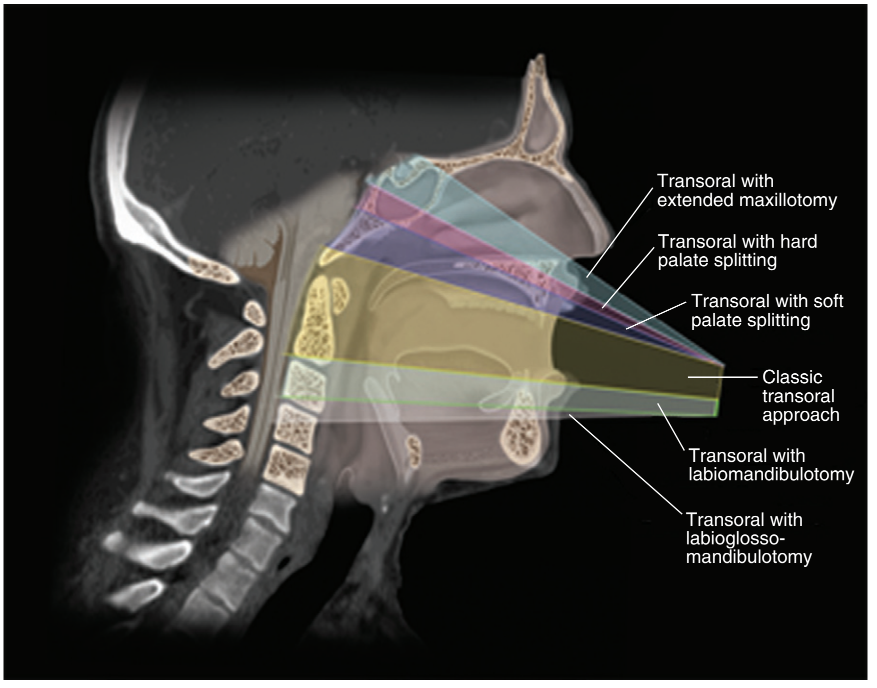

Figure 2-6 Lateral midsagittal artist's rendering of the anatomic regions accessible by the classic transoral approach with its variations. In yellow is the exposure obtained by the classic transoral approach with elevation or splitting of the soft palate. The blue region is the exposure gained by hard palate splitting or extended maxillotomy. The green region is the exposure gained by adding a labioglossomandibulotomy.

approach or a transmaxillary or transmandibular extension to the transoral approach; these must be added to provide a wide enough surgical corridor. A chin-on-chest deformity poses two problems with this exposure: the patient's mouth may not be able to open adequately, and the chest may hinder use of instruments; this limits the full range of mobility of the surgeon. Lesions that extend more than 15 mm laterally from midline are difficult to access because of the limitations of the occipital condyles and vertebral arteries extracranially and cranial nerves VI and XII intracranially. Intracranial pathology was once a contraindication, but with better instruments and better ability to repair dural defects of the skull base, this is a relative contraindication. Active oral infection is a contraindication to this procedure, unless your goal is to access a ventral epidural abscess for diagnosis and drainage.

The major advantage of this approach is the direct access to the ventral cervicomedullary junction without retraction of any neural structures or major vascular structures. The major disadvantage is having to operate in the contaminated space of the oral cavity. Lesions that extend far from midline may be difficult to access because of the limitations of the exposure. Unintended durotomy places the patient at risk for CSF leakage and meningitis. In addition, many transoral approaches will destabilize the spine and require posterior stabilization techniques.

Surgical Technique

PREPARATION AND POSITIONING

Nasotracheal intubation is preferred, because this allows an optimal view into the oropharynx. This can be performed in awake patients via a fiberoptic scope to minimize hyperextension of the neck. A nasogastric tube is also placed, because patients will not be able to take anything by mouth for at least a few days. For patients with lower cranial nerve dysfunction or those for whom an extended transoral approach is planned, a preoperative tracheostomy is in order, and a percutaneous endoscopic gastrostomy (PEG) tube should be placed before surgery.

The patient is placed in the supine position, and the head is fixed neutrally into a three-point Mayfield head holder; it is important to keep the patient's head in line with the body to prevent movement of C1 onto C2, which can alter midline anatomic landmarks and possibly place the vertebral arteries in the operative field. The bed can always be turned toward the surgeon to allow a comfortable operating position; in addition, neuronavigation may be helpful in identifying bony landmarks. If resection of intradural pathology is intended, a lumbar drain may be placed preoperatively, and drainage may be carried out for 3 to 5 days postoperatively. Prophylactic antibiotics should be given that cover gram-positive, gram-negative, and anaerobic bacteria. The oral cavity may be irrigated with an antiseptic solution such as chlorhexidine or Betadine. Some authors recommend the use of 1% hydrocortisone cream on the lips, tongue, and mouth to decrease postoperative swelling.[3]

SURGICAL PROCEDURE

The patient's mouth is opened as wide as possible. The lower the mandible can be positioned, the more the clivus can be exposed (Fig. 2-7). Specially designed self-retaining retractors are used for the transoral approach; these include an oral retractor, a retractor to depress the tongue, and retractors to reflect the soft tissue and endotracheal tube. A tongue blade is used to depress the tongue and mandible caudally, and a retractor is placed at the upper alveolar margin to provide traction in the rostral direction. A right-angle retractor is used to reflect the endotracheal tube and nasogastric tube laterally in the oropharynx. After

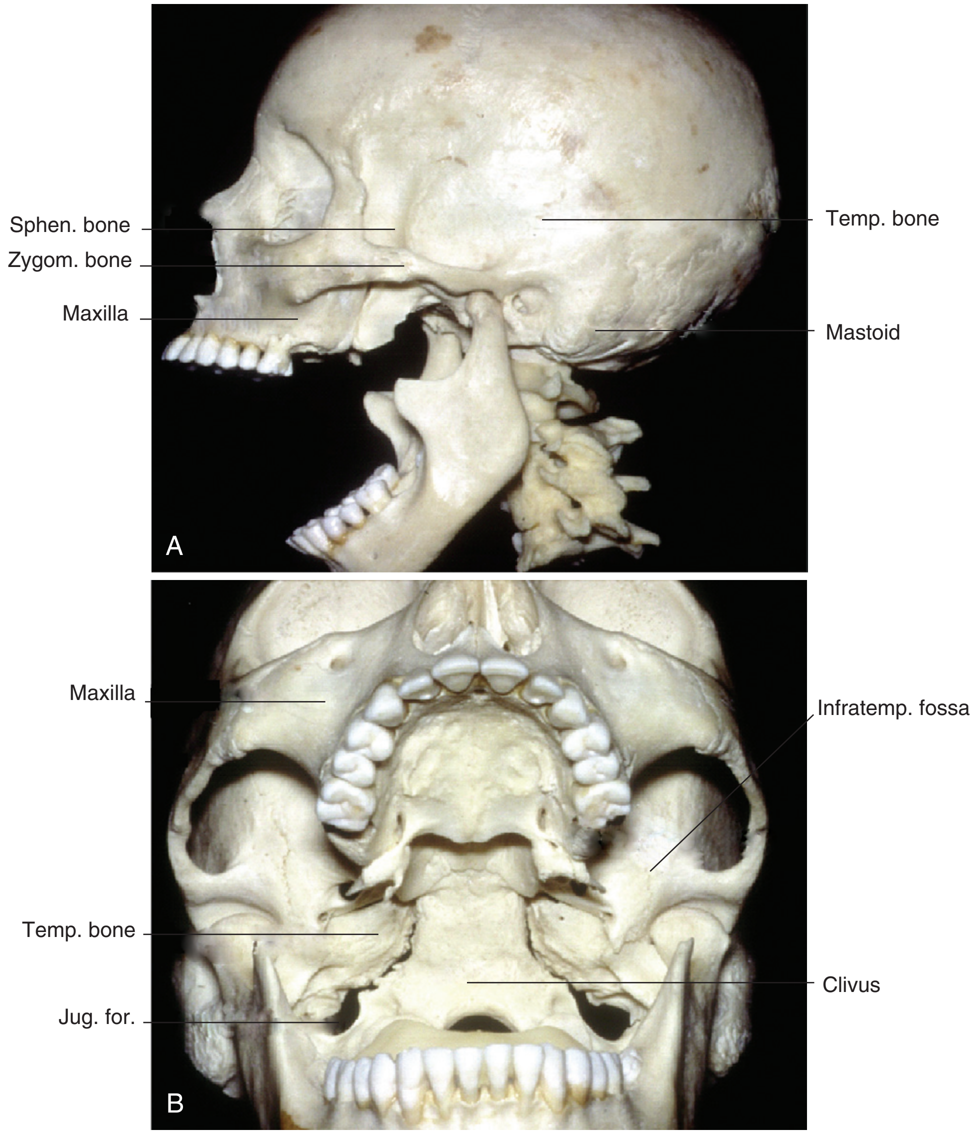

Figure 2-7 **A,** Lateral view of the skull with the mandible lowered, which allows exposure of the clivus from below the palate. **B,** Anterior view through the open mouth reveals how well the clivus can be visualized from below when no soft tissue, such as the soft palate, inhibits the view.

depression of the tongue with the retractor, it should be verified that the tongue is not compressed between the teeth and the retractor, because this can cause severe postoperative swelling. It is recommended that the retractor be released frequently during the case if possible to minimize swelling.

Once the retractors have been set, you will have a view of the posterior oropharynx, soft palate, and uvula. A standard transoral approach with palatal sparing will provide a view from the anterior foramen magnum to the C2–C3 disk space. Elevating the soft palate and uvula may be possible without splitting them by placing sutures or vessel loops through the nose and out the mouth, with gentle upward traction elevating the soft palate, or using a curved retractor blade to retract them rostrally. If further rostral exposure is needed, the soft or hard palate may need to be split (Fig. 2-8).

If the lesion involves the lower third of the clivus, a palatal-splitting approach should be added. A transoral approach with palatal splitting will provide access from the lower third of the clivus to the C2–C3 disk space. Local anesthetic with epinephrine is injected into the posterior pharyngeal wall. Elevation of the soft palate and uvula is accomplished as described above if sparing is intended. If splitting of the soft palate is required, an incision is made in the midline rostrally and is carried down caudally in a paramedian fashion around one side of the uvula (Fig. 2-9). Complications related to soft palate splitting include velopharyngeal insufficiency and dysphagia. If it is determined that even more rostral exposure is required, the incision is carried further along the hard palate in the midline, and the mucoperiosteal flaps are elevated laterally. The posterior hard palate can be resected or removed and replaced with miniplates at the end of the procedure. If hard palate removal is necessary, care should be taken to preserve the mucosa on the superior surface of the hard palate, which can be retracted but should not be opened.

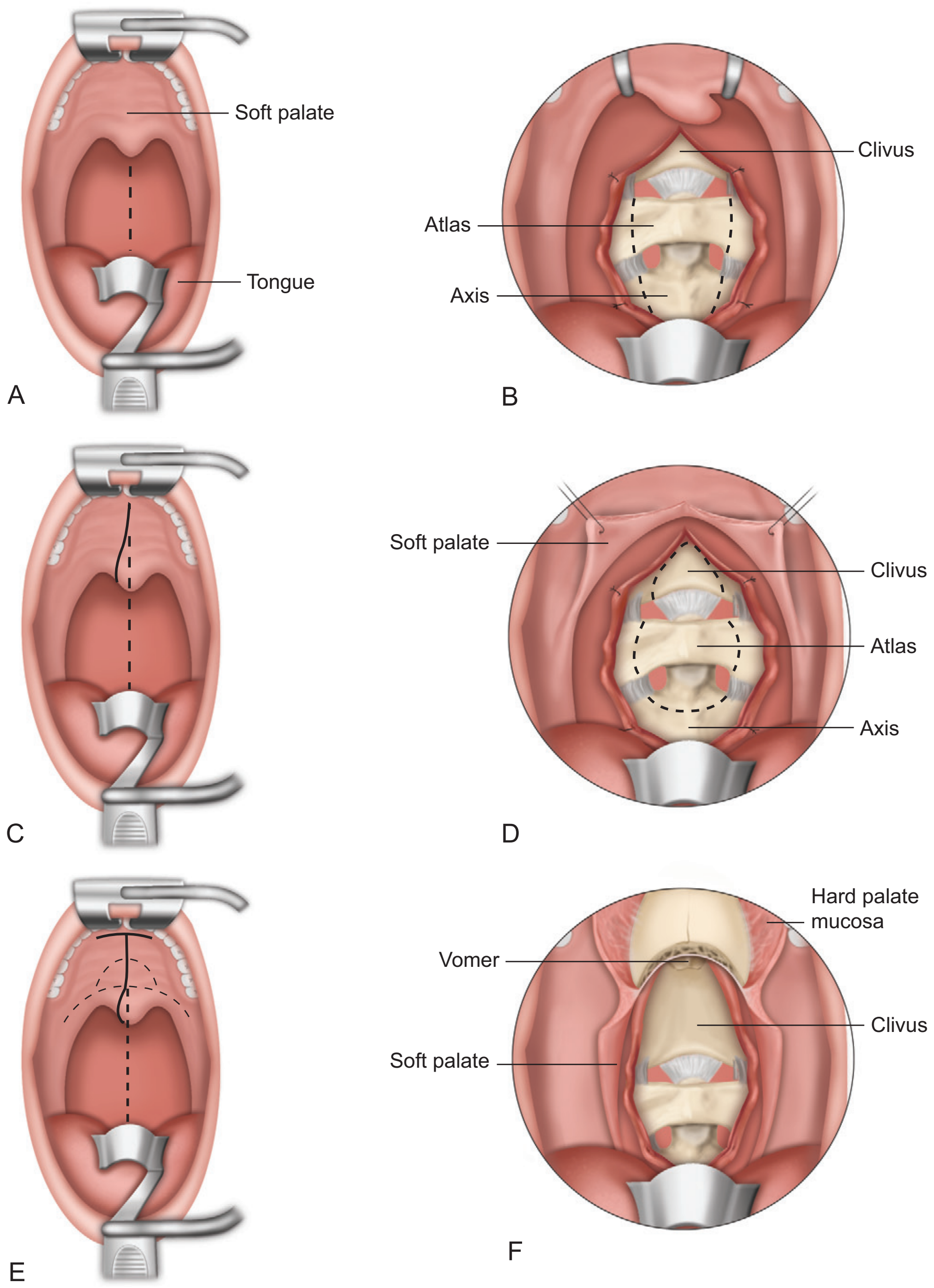

Figure 2-8 Transoral approach and variations. **A,** Classic transoral approach with palatal sparing. Catheters inserted into the nose and brought behind the soft palate and out through the mouth can elevate the soft palate and prevent splitting. Dashed lines show the midline posterior pharyngeal wall incision. **B,** Exposure in the classic transoral approach of the lower lip of the clivus, atlas, and axis after reflection of the mucosa and the muscles of the pharynx. **C,** Transoral approach with soft palate splitting. The solid line represents the incision in the soft palate; the dashed line represents the incision in the posterior pharyngeal wall. **D,** Exposure in the transoral approach with soft palate splitting after reflection of the soft palate and mucosa and muscles of the pharynx with a view of the lower third of the clivus, atlas, and axis. **E,** Transoral approach with soft and hard palate splitting. Solid line represents the soft palate incision carried into the inferior hard palate. Oblique lines represent hard palate to be removed. The dashed line represents the incision in the posterior pharyngeal wall. **F,** Exposure in the transoral approach with soft and hard palate splitting reveals the clivus up to the vomer, the atlas, and axis.

A vertical incision is made through the posterior pharyngeal wall in the midline with a scalpel centered over the atlantal tubercle of C1. Monopolar cautery is used to continue the incision deeper through the longus capitis and longus colli muscles to the clivus, C1 arch, and C2 body (see Fig. 2-9). The muscles and mucosa are dissected in a subperiosteal fashion and are reflected laterally as a single unit to maintain a strong, thick layer for closure in case of a CSF leak. The midline incision is carried as far rostrally and caudally as needed for the pathology under the given limits of the exposure.

If a transoral odontoidectomy is planned (Fig. 2-10), curettes and sharp dissection should be used to expose the anterior rim of the foramen magnum, the C1 arch, and the body and odontoid process of C2. If the anatomy of this region is distorted congenitally or by tumor, neuronavigation can be extremely helpful in verifying these important landmarks. A high-speed drill is used to remove the inferior half of the anterior C1 arch, which will provide access to the odontoid process. If possible the superior portion of the C1 arch should be left intact to provide structural support to the occipitocervical and atlantoaxial system. A high-speed drill with a cutting burr is used to reduce the odontoid process internally, leaving the cortical surface of bone intact. Curettes and rongeurs are then used to free up the odontoid remnant from the alar and apical ligaments. A small diamond burr or a 1- or 2-mm Kerrison rongeur can be used to release the base of the odontoid. A small pituitary rongeur can be used to grab the remaining cortical remnant of the odontoid and remove it by pulling in a ventral and caudal direction. If soft tissue remains, as in the case of rheumatoid pannus, or if tumor is present, it is important to take extra time to define a plane between the lesion and the thin ventral dura of this region to prevent durotomy and risk of a CSF leak. In cases of severe basilar invagination with a vertically translocated odontoid, the entire anterior arch of C1 must be removed, and sometimes the anterior lip of the foramen magnum must be excised as well. Many transoral procedures destabilize the cervical spine and require posterior stabilization techniques. Care must be taken to maintain inline spinal alignment.

At the completion of the procedure, the wound is copiously irrigated with antibiotic solution. Meticulous attention should be paid to the closure to prevent CSF leakage, hematoma formation, or infection. If the dura was opened, the defect needs to be closed. Clival dura and dura of the cervical spine are very thin, and primary closure with sutures is almost impossible. There are many ways to close these skull base–type defects, which are beyond the scope of this chapter, but a fat graft or dermal-fat graft with a synthetic glue-type sealant are commonly used. A vascularized nasal septal flap off of the sphenopalatine artery may

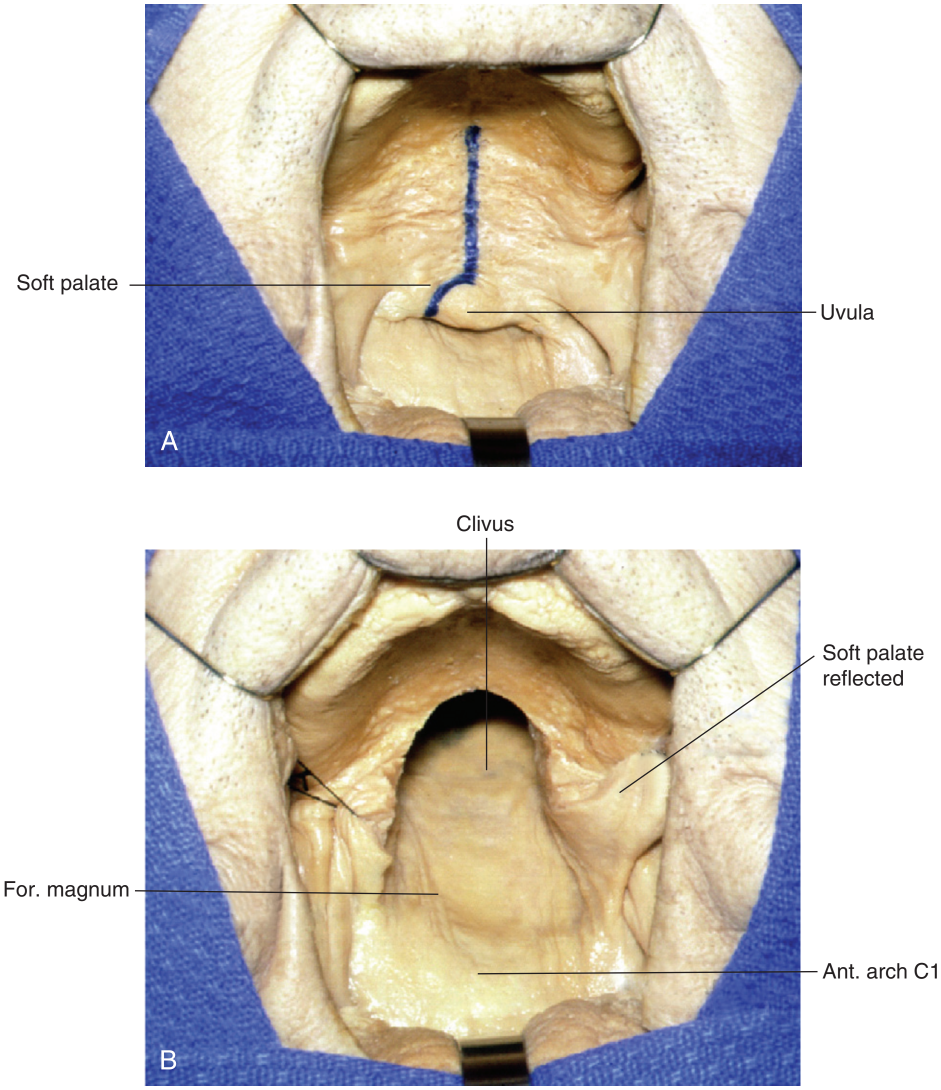

Figure 2-9 Cadaveric dissection using the transoral approach with soft palate splitting. **A,** Cadaveric dissection with a view into the oropharynx. The solid line represents the soft palate incision in a soft palate–splitting procedure. Note that not much of the clivus is visible. **B,** The same dissection after sutures were placed into the soft palate and reflected laterally, exposing the mucosa of the lower clivus.

Continued

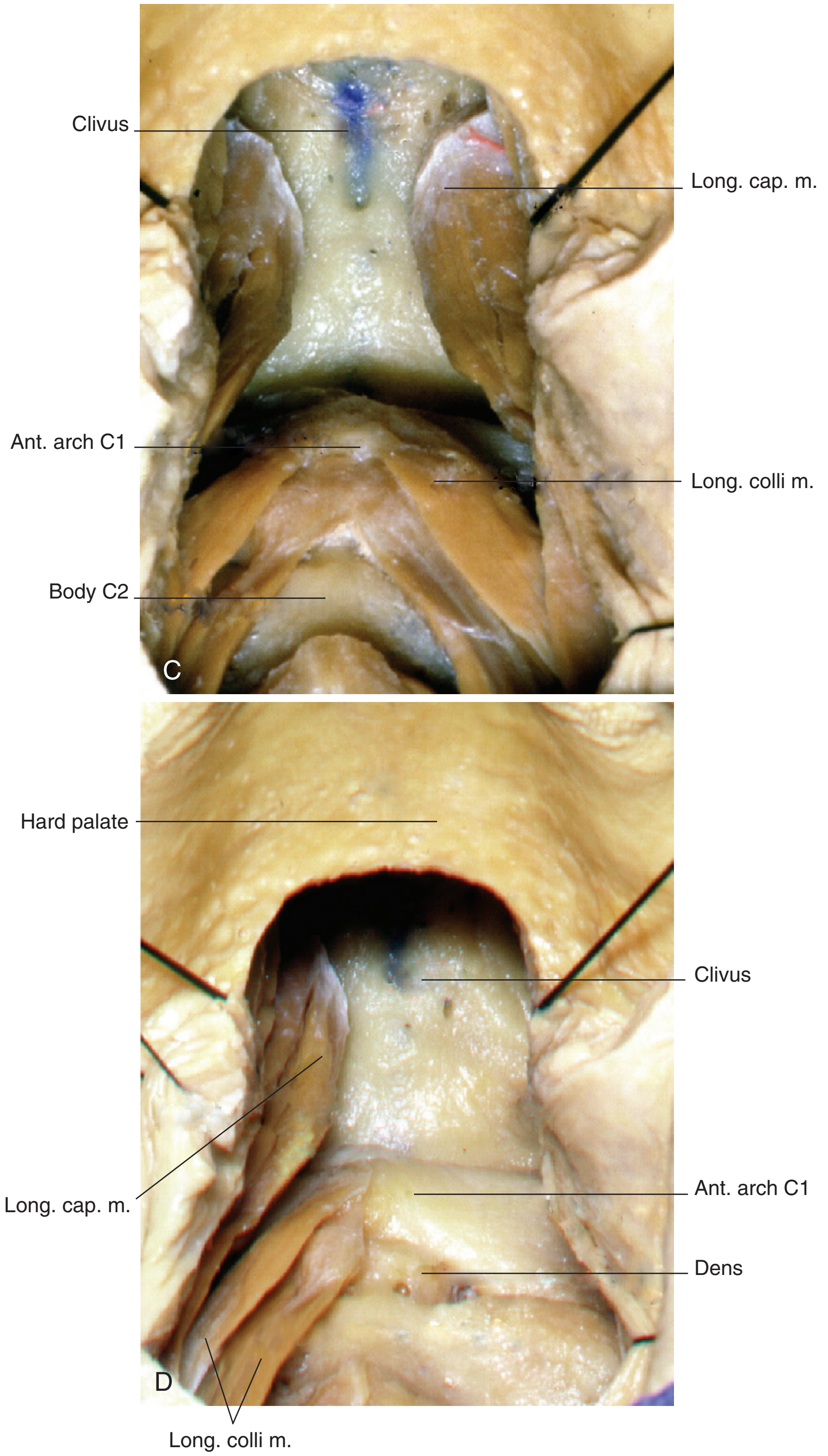

Figure 2-9, cont'd C, The pharyngeal mucosa has been opened in the midline, the longus capitis and longus colli muscles have been exposed, and the anterior atlantal tubercle can be seen. **D,** The longus capitis and longus colli muscles on the left have been reflected, and the anterior arch of C1 and the dens can now be seen.

be used for the lower clivus, but it may not reach the upper cervical spine easily. A pharyngeal mucosal flap may be taken from the lateral pharyngeal wall and rotated into cover defects of the upper cervical spine and lower clivus. The pharyngeal incision is then reapproximated with interrupted or running absorbable sutures as a single layer to ensure a watertight seal, and the mucosa and muscle of the soft palate are closed with interrupted or running absorbable sutures. If the posterior hard palate was removed, it is reattached with miniplates. The hard palate mucosal incision is also closed with interrupted or running absorbable sutures.

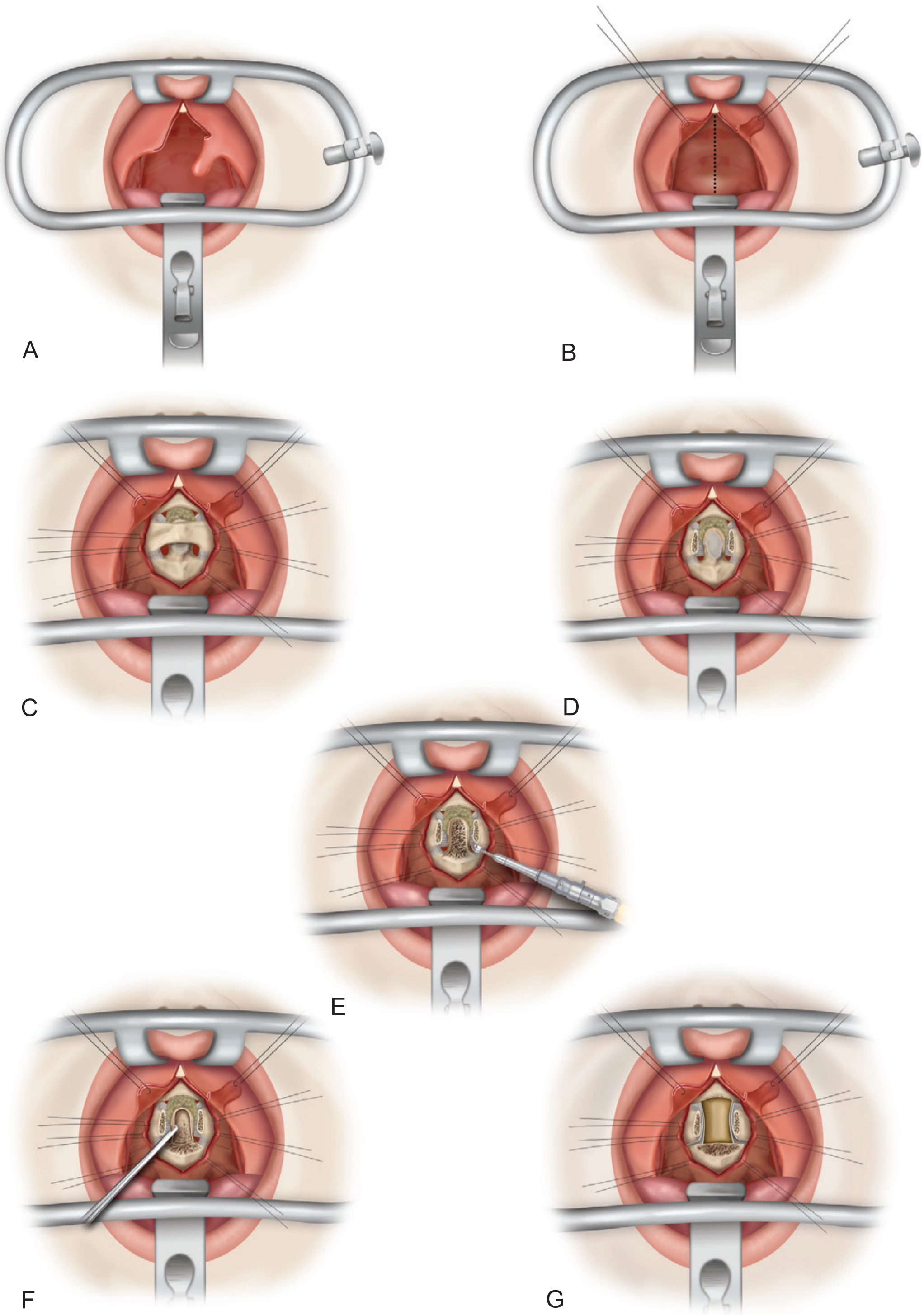

Figure 2-10 Transoral odontoidectomy. **A,** Oral retractors placed with depression of the tongue. Soft palate incision can be seen. **B,** Elevation of the soft palate with sutures. Posterior pharyngeal wall incision has been marked. **C,** Posterior pharyngeal wall opened and deflected laterally and subperiosteally, exposing the anterior lip of the foramen magnum, C1 tubercle, and body of C2. **D,** Anterior arch of C1 has been removed, exposing odontoid process. **E,** The central portion of the odontoid process has been cored out with a drill, leaving a shell of cortical bone posteriorly. **F,** Kerrison rongeurs used to remove the remnant of the odontoid process. **G,** After odontoidectomy, the ventral spinal cord can be accessed.

If the pathology of interest extends from the clivus or C1 and C2 region down to the C3 or C4 body, a mandible-splitting procedure is necessary to access this area (Fig. 2-11).[9,10] As described above, a preoperative tracheostomy and PEG tube are required. The labial incision begins in the midline at the lower lip and extends inferiorly using a strictly midline or zigzag incision across the chin to end at the midline at the level of the hyoid bone. The oral mucosal incision begins in the midline and extends to the frenulum inside the mouth at the base of the tongue at the mandibular

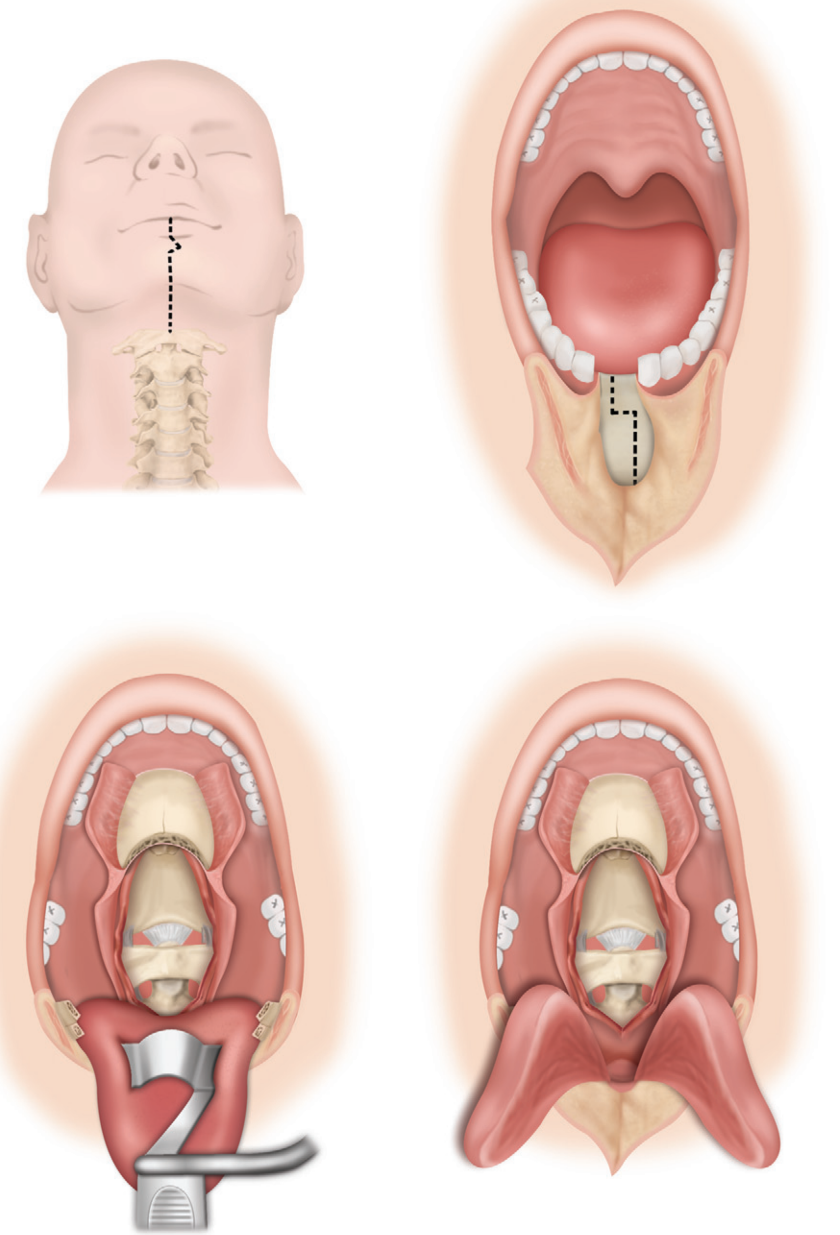

Figure 2-11 Transoral approach with labiomandibulotomy and labioglossomandibulotomy. **A,** Dashed line represents soft-tissue incision for labiomandibulotomy approach. **B,** Enlarged view after soft-tissue incision. Dashed line represents site for mandibulotomy. An incisor tooth can be removed (shown here), but it can typically be done between the teeth without removing any. **C,** The mandibulotomy has been performed, the halves have been reflected laterally, and the tongue is retracted caudally. Incision has been carried out through the soft and hard palate, exposing the lower clivus to the top of the C3 body. **D,** A portion of the hard palate has been removed, and the tongue and floor of the mouth have been split in the midline to expose the midclivus to the C3 body.

origin of the genioglossus and geniohyoid muscles. The mandible periosteum is dissected laterally about 1 cm in either direction, a space sufficient for the placement of miniplates. The miniplates are then shaped to the normal anatomy, and holes are drilled prior to splitting the mandible to ensure good alignment and minimize dental malocclusion postoperatively. The osteotomy is performed with a reciprocating saw focused between the central incisors. The lingual frenulum, geniohyoid, and genioglossus may be incised in the midline, sparing tongue splitting to provide a better exposure. Each portion of the mandible is retracted laterally. The tongue may now be retracted caudally, without the splitting exposing the upper C3 body. If access to the C3–C4 disk space or C4 body is necessary, a median glossotomy is performed. The tongue is split in the midline using monopolar cautery; this can be extended posteriorly and caudally to the anterior margin of the epiglottis. Each half of the tongue is displaced laterally with retractors.

If more rostral access is required than the lower third of the clivus, a maxillary-splitting or open-door maxillotomy can be performed. A maxillotomy will expose the upper clivus down to the upper C3 body.

Topical steroids may again be applied to the tongue, lips, and mouth to reduce postoperative swelling. The nasogastric tube is left in place, and after verification of its location by radiograph, tube feedings may be started. The endotracheal tube should be left in place for about 24 to 48 hours to allow airway swelling to decrease. To prevent wound breakdown, clear liquids should not be started for about 5 to 10 days, and the diet is advanced as tolerated.

Great advances have been made in the field of endoscopic skull base surgery, allowing for minimal soft-tissue dissection and minimal incisions. A vast amount of the anterior skull base can be accessed via the endoscopic endonasal route. More recently the endoscope has been used for transoral procedures, such as odontoidectomy or resection of ventral compressive pathology.[11] The benefit of endoscopic procedures for this approach is that they may limit the need for palate- and mandibular-splitting procedures, which account for the major morbidity of the classic transoral approaches and their variations. Because of the decreased bacterial flora in the nasal cavity compared with the oral cavity, a transnasal endoscopic approach may also be acceptable in patients whose pathology may be accessed by this route. This technique will likely become more widely used as instruments become more available and training in endoscopic surgery becomes more common.

Conclusion

The transoral approach is useful for ventral midline pathology, and it is preferred for extradural midline ventral pathology; but with improved techniques for repairing the skull base, intradural pathology can also be accessed. The transoral approach and its variations provide midline access from the upper clivus to the upper C4 body.

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3 Transmaxillary and Transmandibular Approaches to the Clivus and Upper Cervical Spine

COLIN C. BUCHANAN and ISAAC YANG

Overview

The clivus, craniovertebral junction (CVJ), and ventral upper cervical spine are relatively inaccessible, and surgical approaches to these structures are intimidating; however, a wide range of pathologic lesions can affect this region. Because of the capaciousness of the cervicomedullary cisterns, lesions often encompass a large mass of compressive tissue before they produce neurologic symptoms. Lesions may also affect the vertebrobasilar arterial circulation and cerebrospinal fluid (CSF) circulation, adding to the complexity of the presenting symptomatology.

Whereas the clinical significance of abnormalities at the CVJ has been recognized since the early studies of basilar invagination by Chamberlain in 1939, the treatment of such abnormalities consisted almost exclusively of posterior decompression, until Menezes introduced the transoral approach for ventral decompression in 1977.[1] This traditional transoral approach is well suited to access medial extradural lesions of the CVJ. Several modifications have been described that enhance the transoral exposure to allow access to lesions that extend to the upper lateral clivus or upper cervical spine; these include transmaxillary and transmandibular approaches.

These "extended transoral approaches" require knowledge of skull base anatomy and a multidisciplinary team to achieve entry and a good cosmetic reconstruction. The selection of the best approach is determined by factors such as location and nature of the lesion as well as individual patient anatomic variations.[2] Generally, transmaxillary approaches expand the exposure rostrally to the sphenoid sinus and upper lateral clivus; transmandibular approaches expand the exposure caudally to C4–C5. In this chapter, we will discuss the various transmaxillary and transmandibular techniques as expanding maneuvers to the transoral approach.

Anatomy Review

BONY AND LIGAMENTOUS ANATOMY

The CVJ consists of the foramen magnum, atlas, and axis. The occipital bone surrounds the foramen magnum, and it can be divided into a squamosal part located posteriorly, a basal part located anteriorly, and paired condylar parts located laterally. The clivus, which includes the basal part, is a plate of bone that extends forward and upward at a 45-degree angle. It joins the sphenoid bone at the spheno-occipital synchondrosis. Along the superior surface, the clivus is separated from the petrous temporal bone laterally by the petroclival fissure. At the inferior surface is the pharyngeal tubercle, which gives attachment to the fibrous pharyngeal raphe. The oval-shaped occipital condyles articulate with the atlas. Above the condyle is the hypoglossal canal, and along the medial surface is the tubercle that forms the point of attachment for the alar ligament.

The occipital bone and the atlas are joined by the atlantooccipital joints and by the anterior and posterior atlanto-occipital membranes, attached superiorly to the anterior edge of the foramen magnum, inferiorly to the edge of the anterior arch of the atlas, and laterally to the atlantooccipital joint capsule. The atlas, C1, forms a ring composed of two lateral masses connected by an anterior and posterior arch. At the midline along the anterior arch is the anterior tubercle. Along the medial surface of each lateral mass is a small tubercle for the attachment of the transverse ligament. The transverse process extends laterally from the lateral mass. Between the transverse process and the lateral mass is the transverse foramen, which contains the vertebral artery.

The atlas (C1) and axis (C2) articulate at four synovial joints: two median joints on the front and back of the dens and two lateral joints between the articular facets. These two vertebrae are joined by the cruciform ligament, the anterior and posterior longitudinal ligaments, and the joint capsules between the opposing articular facets. The cruciform ligament has transverse and vertical parts. The transverse part, or transverse ligament, is a thick band that arches across the ring of the atlas behind the dens. As it crosses the dens, ligamentous bands are directed upward to the clivus and downward to the body of the axis.

The axis (C2) is distinguished by the odontoid process (dens), which projects upward from the body. The dens and body are flanked by the facets, which join the pedicles of C2 posteriorly and articulate with the inferior facets of the atlas. The transverse processes are small and transmit the vertebral artery in a superolateral direction to allow for lateral deviation as the artery ascends from C2 to C1. Four fibrous bands connect the axis to the occipital bone: the tectorial membrane, the paired alar ligaments, and the apical ligament. The tectorial membrane is a rostral extension of the posterior longitudinal ligament, which attaches to the upper surface of the occipital bone in front of the foramen magnum. The alar ligaments arise from the upper part of the dens and attach to the medial surface of the occipital condyles. The apical ligament extends from the tip of the dens to the anterior margin of the foramen magnum.

MUSCULAR ANATOMY

The sternocleidomastoid muscle divides the neck into an anterior and posterior triangle. Within the anterior triangle, the platysma is outermost and extends from the face to the pectoralis and deltoid fascia. Deep to the platysma are the suprahyoid and infrahyoid muscles. The anterior vertebral muscles insert on the clivus; this group of muscles includes the longus colli, longus capitis, rectus capitis anterior, and rectus capitis lateralis. These muscles are embedded in the cervical fascia, which can be divided into superficial and deep layers: the superficial fascia invests the platysma, and the carotid sheath is a condensation of the deep fascia that invests the common and internal carotid arteries, jugular vein, and vagus nerve.

RELEVANT NEUROVASCULAR ANATOMY

The blood supply to the craniocervical complex is via the vertebral arteries that form an arcade around the dens and the external carotid artery's occipital branches. Anterior surgical approaches to this region may encounter other branches from the external carotid in association with major nerves. The inferior alveolar nerve, a branch of the mandibular division of the trigeminal nerve, supplies sensation to the jaw and mandibular teeth. This nerve runs with the inferior alveolar artery, a branch of the internal maxillary artery. The nerve exits the mandible anterolaterally at the mental foramen.

The lingual nerve also arises from the mandibular branch of the trigeminal nerve and courses together with the lingual artery, a branch of the external carotid artery, and the lingual vein, which drains into internal jugular vein. The lingual nerve courses anteriorly along the lateral aspect of the hyoglossus and genioglossus muscles of the tongue. Distally it dives into the anterior tongue base. The chorda tympani nerve, a branch of the facial nerve, joins the lingual nerve and runs in its sheath. The hypoglossal nerve supplies all muscles of the tongue except the palatoglossus and descends from the medulla and exits the skull via the hypoglossal canal. From the hypoglossal canal, located just above the occipital condyle, the nerve passes between the internal jugular vein and the internal and external carotid arteries. It then turns anteriorly to enter the tongue and, like the lingual nerve, courses along the lateral aspect of the genioglossus.

Indications and Contraindications

The basic expanding maneuvers to the transoral approach to access the clivus and upper cervical spine are outlined below (Fig. 3-1):

1. Transmaxillary approach
   - Unilateral Le Fort I osteotomy with palatal split
   - Bilateral Le Fort I osteotomies with downfracture of the maxilla (*drop-down maxillotomy*)
   - Bilateral Le Fort I osteotomies with palatal split
2. Transmandibular approach
   - Mandibulotomy
   - Mandibulotomy with midline glossotomy
   - Mandibular swing-transcervical approach
3. Combined transmaxillary and transmandibular approach

Like the transoral approach, these extended approaches are primarily utilized for ventral access to extradural lesions of the CVJ (Fig. 3-2). Whereas the transoral approach is capable of addressing midline pathology, expanding maneuvers allow for better access to the lateral clivus. They also increase the exposure to include the sella, upper and lateral clivus, and upper cervical spine to C4–C5. Generally, transmaxillary approaches are used to extend the upper limits, and transmandibular approaches are used to extend the lower limits. However, jaw-splitting approaches also extend rostral access by allowing surgeons to drop their hands more inferiorly. In addition to allowing ventral access to the lesion, the ideal approach should take into consideration the particular pathologic entity. More aggressive tumors, such as chordomas and chondrosarcomas, benefit from en bloc resections that require more extensive exposure to access the entire lesion. Benign tumors (e.g., schwannomas and neurofibromas), as well as degenerative processes, are amenable to piecemeal resection via more restricted approaches, thereby minimizing the associated morbidity.

The selection of the best approach is facilitated by careful preoperative assessment, physical examination that includes measurement of mouth opening, dynamic cervical spine x-rays in flexion and extension, magnetic resonance imaging (MRI), and thin-slice computed tomography (CT) with three-dimensional (3D) reconstruction. Anatomic considerations that favor an extended approach over the standard transoral approach include macroglossia, inability to open the jaw greater than 25 mm, platybasia, and severe basilar invagination.[3] In the latter two, greater rostral exposure is required, because these anatomic anomalies significantly elevate the CVJ. A preoperative dental evaluation should be obtained in the majority of cases for planning osteotomies and to ensure no tooth root abnormalities or dental hardware is present that may impede exposure.

Bilateral Le Fort I maxillotomy with downfracture of the maxilla is suitable for lesions of the upper and middle third of the clivus, for removing lesions that extend beyond the lateral boundaries of the clivus, and for profound basilar invagination associated with abnormalities that inhibit the standard transoral route. It should be used for lesions that are primarily extradural, such as chordomas or bone tumors/metastases, but it is contraindicated for lesions with more dural involvement, because a watertight closure is difficult. For lesions such as larger clival chordomas, calcified lesions, and pathology with significant brainstem compression, a unilateral or bilateral maxillotomy with palatal split should be used; a vascularized temporoparietal myofascial flap can be mobilized to provide coverage for a larger

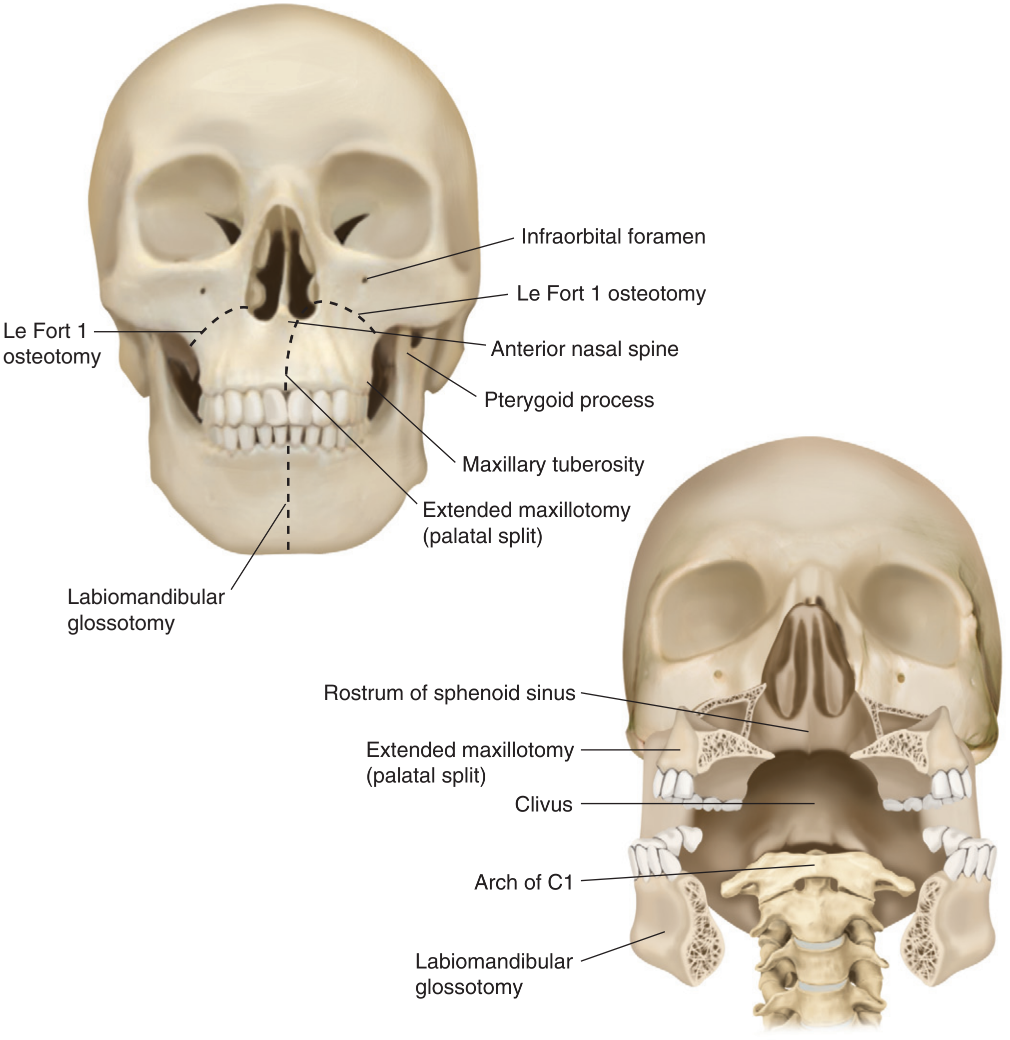

Figure 3-1 Expanding maneuvers to the transoral approach.

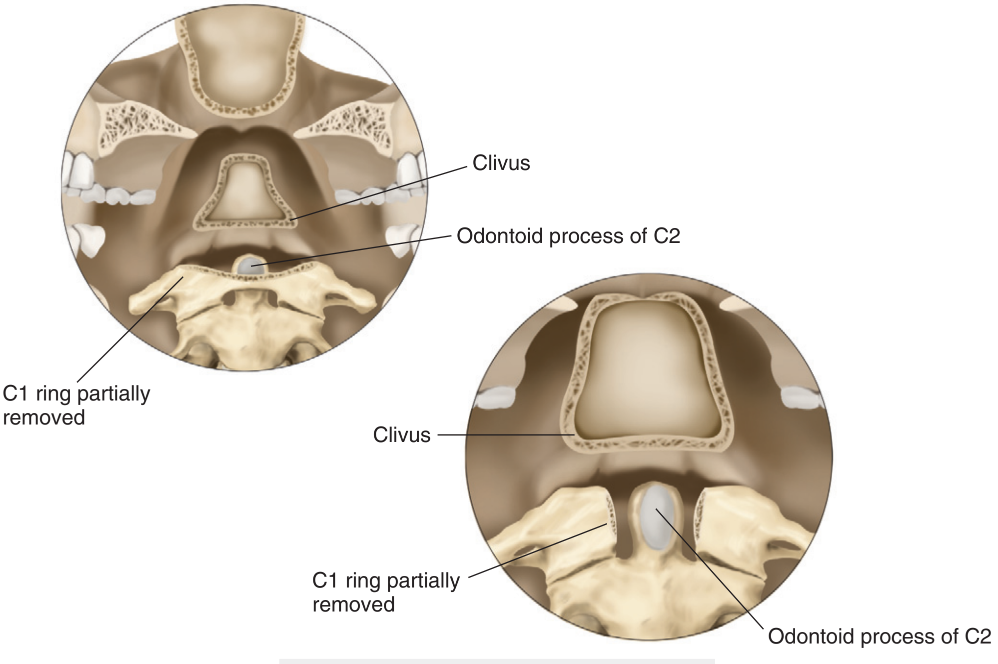

Figure 3-2 Ventral craniovertebral junction.

dural defect.[4] Some authors advocate using the unilateral Le Fort I maxillotomy, because it often provides adequate exposure while minimizing morbidity and allowing for a vascularized temporopartietal fascial flap.[5] Moreover, this approach may be converted to a bilateral approach if exposure is inadequate.

The transmandibular approaches can expose the inferior third of the clivus down to C4–C5. Mandibulotomy and glossotomy successively increase the angles of exposure in the axial plane (Fig. 3-3).[2] Additionally, the transmandibular approaches significantly decrease the working depth of the operative field and allow for more extensive brainstem decompression; this is particularly helpful in the resection of chordomas and chondrosarcomas. When more lateral exposure is required, the mandibular swing-transcervical approach can be used. This approach is superior in the treatment of large, lateral tumors and also when considering anterior reconstruction in simultaneous cervical fusion.

Combination transmaxillary and transmandibular approaches have been described and may be useful in the resection of chordomas of the CVJ.[6,7] For these combined techniques, bilateral Le Fort I osteotomies with palatal split and mandibulotomy with glossotomy are used. In this manner, both halves of the maxilla and mandible are displaced laterally to provide extended access to the midline CVJ.

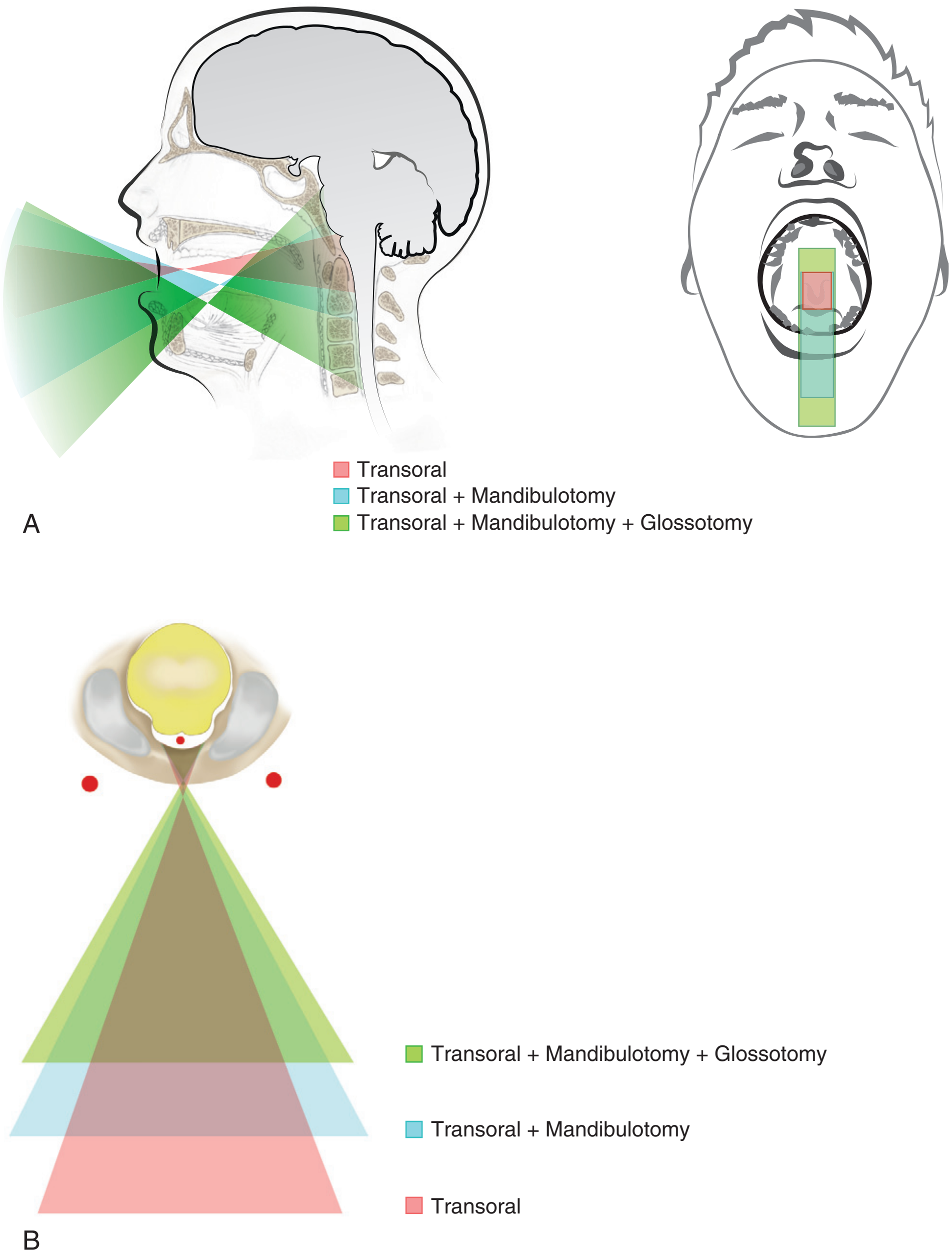

Figure 3-3 **A,** Comparison of the sagittal exposure achieved by the transoral approach, transoral approach plus mandibulotomy, and transoral approach plus mandibulotomy and glossotomy. **B,** Increase in axial exposure and decrease in operative distance achieved by transoral, transoral plus mandibulotomy, and transoral plus mandibulotomy with glossotomy approaches.

Operative Technique

UNILATERAL LE FORT I OSTEOTOMY WITH PALATAL SPLIT

A tracheostomy is placed to allow maximal space within the oral cavity. As in the transoral approach, the patient is positioned supine with the neck in slight extension. The neck, jaw, face, and oropharynx are prepped, and the gingival mucosa is infiltrated with local anesthetic. A mucogingival incision is made under the lip from the ipsilateral canine to the contralateral molar. Facial degloving is performed subperiosteally by elevating the mucosa and muscles from the maxilla, until the infraorbital nerve is identified. The piriform aperture is exposed, and the nasal mucosa is elevated along the lateral wall to just below the inferior turbinate and in midline along the septum. A midline mucosal incision is then made along the oral surface of the hard palate, from the space between the front incisors to the soft palate.

To minimize postoperative malocclusion, titanium miniplates are shaped and fitted along the maxilla; screw holes are predilled before osteotomy. A unilateral Le Fort I osteotomy is made just above the roots of the teeth with the oscillating bone saw. Placement of the transoral retractor helps to protect the tongue, while the oscillating saw is used to split the hard palate in the midline, starting between the front incisors, proceeding around the anterior nasal spine, and extending posteriorly along the vomer. The hemimaxilla is separated from the pterygoid plate with a chisel and is displaced inferolaterally.

At this point, the posterior pharyngeal wall and longus colli muscles are incised along the clivus down to the foramen magnum. If needed, removal of the posterior nasal septum allows for wide visualization of the sphenoid sinus and upper clivus. After the decompression, the pharyngeal wall is reapproximated and closed with interrupted absorbable suture. If a watertight dural closure is not possible, a vascularized temporoparietal fascial sling should be performed. The temporalis fascia is passed over the zygoma, tunneled behind the masseter, positioned over the defect in the clivus, and is then sutured to the pharyngeal wall. The mobilized maxilla is replaced and plated with use of the predrilled holes. All mucosal incisions are closed with interrupted absorbable suture, the nares are packed to reset the septum to the midline, and enteral nutrition is initiated postoperatively to allow the nasal and oral mucosa to heal.

BILATERAL LE FORT I OSTEOTOMIES WITH DOWNFRACTURE OF THE MAXILLA

An oral endotracheal tube can be used to establish the airway. A bilateral mucogingival incision is made, followed by facial degloving. The piriform aperture is exposed, and the nasal mucosa is elevated bilaterally to the level of the inferior turbinate. Again, titanium miniplates are fitted on the maxilla with predrilled screw holes. A horizontal osteotomy is made bilaterally from the piriform aperture through the maxilla laterally using the oscillating bone saw. Osteotomes are used to separate the pterygoid plates and nasal spine from the maxilla. The maxilla is then downfractured into the oral cavity using finger pressure, and the inferior turbinates are fractured and removed with rongeurs. The transoral retractor is then inserted with a palatal plate attachment and the tongue retractor to hold the downfractured maxilla in place. The pharyngeal dissection, decompression, and closure are performed as described above. The limitations of this approach are that the inferiorly displaced maxilla can obscure the lower operative field. Also, a temporoparietal fascial sling cannot be performed with this approach.

BILATERAL LE FORT I OSTEOTOMIES WITH PALATAL SPLIT

Although in many cases a unilateral approach will suffice, bilateral maxillary osteotomies with palatal split are occasionally necessary (Fig. 3-4). It is possible to convert a unilateral approach to a bilateral approach simply by repeating the steps on the contralateral side. Whereas this approach provides the greatest exposure of the transmaxillary techniques, it is also associated with a greater rate of oropalatal morbidity and dental malocclusion.

MANDIBULOTOMY

Like the transmaxillary palatal split approach, a tracheostomy tube is placed preoperatively to secure the airway. The patient is placed supine, and the jaw, oropharynx, and upper neck are prepped. The vermillion border of the lower lip is sharply scored to cosmetically realign the incision upon closure. A midline incision is made from the lower lip through the gingival mucosa to the mandible and inferiorly to the hyoid. The mandible is exposed in a subperiosteal fashion, from medial to lateral, until the mental foramen is visualized. Titanium miniplates are prebent, and the screw holes in the mandible are created in such a fashion as to ensure accurate realignment of the jaw. A stair-step mandibulotomy between the central incisors is created with the oscillating saw; it is not necessary to remove an incisor. A midline incision is then made beneath the tongue to divide the mucosa between the orifices of the Wharton ducts.

At this point, the two halves of the mandible are split and retracted laterally, and the tongue is depressed into the relaxed oral floor. Pharyngeal dissection and exposure of the clivus, C1, and C2 are performed as above. After decompression is complete, closure of the pharyngeal wall is performed with interrupted absorbable suture. The mandible is reapproximated and plated with the previously fitted miniplates and screws to facilitate closure of the floor of the mouth. The alveolar margin is repaired with absorbable suture, followed by closure of the lip, which is performed in a four-layer fashion with absorbable suture at the mucosal layer, muscularis layer, deep dermal layer, and at the skin of the lip; great care must be taken to exactly reapproximate the scored vermillion border. Postoperatively, enteral nutrition is initiated.

MANDIBULOTOMY WITH MIDLINE GLOSSOTOMY

Mandibuloglossotomy extends the exposure by dividing the tongue in the midline (Fig. 3-5). The tongue is incised in the midline raphae from the tip to the circumvallate papillae, a relatively avascular plane. Monopolar cautery is used to divide the intrinsic muscles of the tongue, preserving the

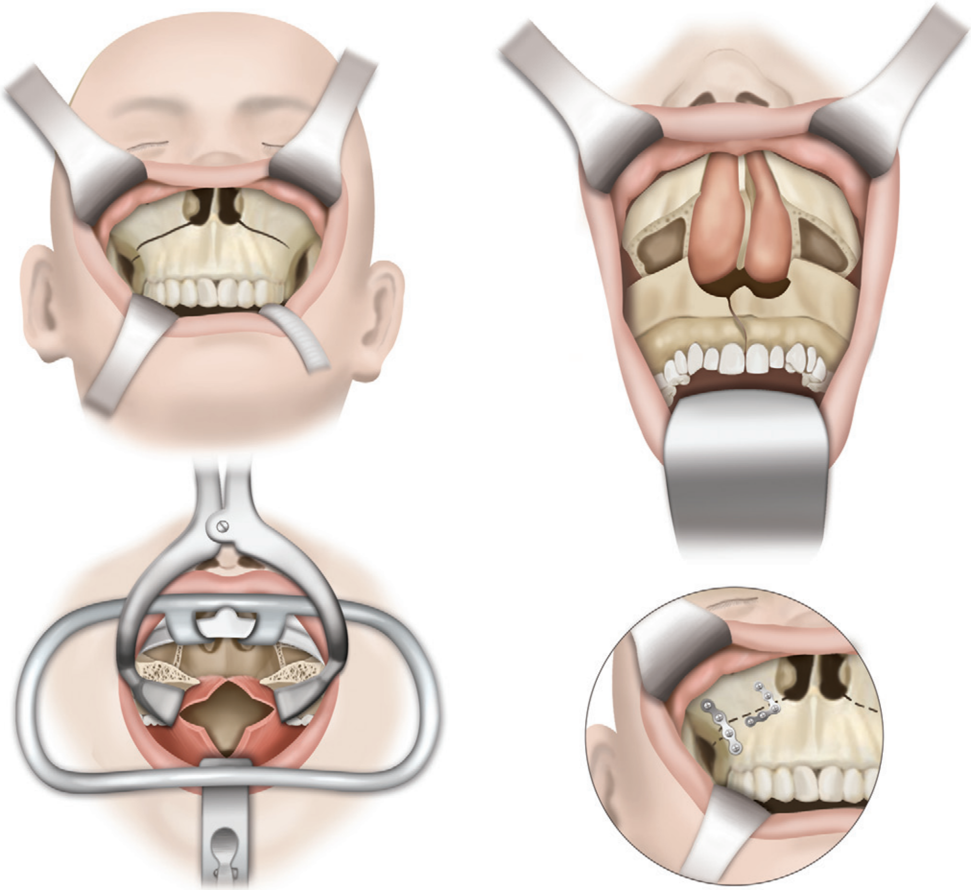

Figure 3-4 Bilateral Le Fort I maxillotomies with palatal split.

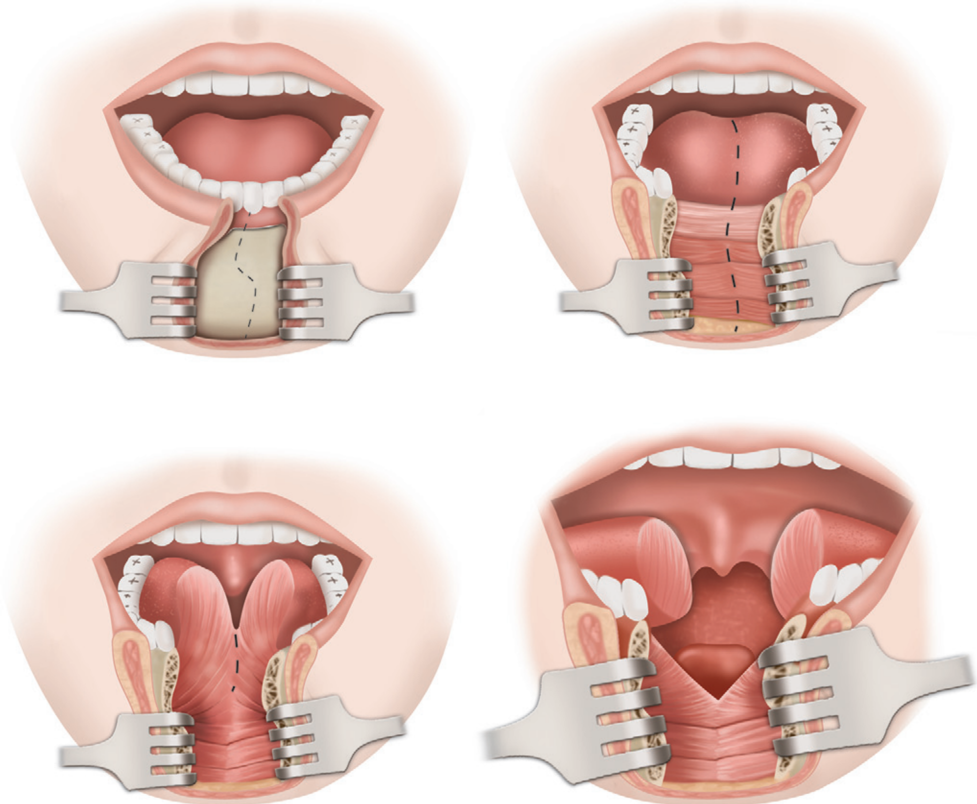

Figure 3-5 Mandibulotomy with midline glossotomy.

innervation and vascular supply to each half. The entire floor of the mouth is then incised and divided in midline, and retractors are placed to separate the two halves of the tongue and mandible laterally. After the pharyngeal wall is incised in midline, the bony resection is again extended to the limits of the exposed clivus (middle to inferior) and upper cervical spine (C3–C4). Closure is performed as described above for mandibulotomy. The intrinsic muscles of the tongue are closed with interrupted absorbable suture, and the dorsum of the tongue is closed separately with absorbable suture, as is the underside of the tongue. The mandible is reapproximated, and the floor of the mouth is sutured as described above.

MANDIBULAR SWING-TRANSCERVICAL

Tracheostomy is performed preoperatively. The patient is positioned supine with the neck in slight extension. After the sterile prep has been performed and drapes are applied, an incision is made starting at the lower lip midline and extending inferiorly to the level of the hyoid. The incision continues in a curvilinear fashion 4 to 5 cm below the mandible, curving above the mastoid tip. The subcutaneous tissue and platysma muscle are divided with monopolar cautery. Limited subplatysmal dissection is performed inferiorly and superiorly to create subplatysmal flaps, and the subplatysmal dissection is continued superiorly to identify the lower inferior border of the submandibular gland. Dissection is carried below and deep to the gland. Keeping the skin incision sufficiently low is important to avoid injury to the gland, and it will also help to preserve the marginal mandibular nerve.

Next, the hyoid bone is palpated, and muscles inserted on it are identified. The digastric tendon is also identified. This muscle is released, together with the stylohyoid, from the hyoid attachment, and both are reflected superiorly with the submandibular gland, being careful to avoid injury to the hypoglossal nerve as it exits from the carotid sheath, passing deep to the digastric tendon and superficial to the internal and external carotids. The sternocleidomastoid muscle is retracted posterolaterally to initiate exposure of the major neurovascular structures. Toward the skull base, the internal and external carotid arteries, internal jugular vein, and cranial nerves X, XI, and XII will pass deep to the posterior belly of the digastric tendon.

The mandible is split in a similar fashion as described above. Following subperiosteal dissection and prefitting the miniplates on the mandible, an oscillating saw is used to create a stair-step mandibulotomy between the central incisors. The tongue is grasped with a towel clamp and is retracted contralaterally. An incision is made on the floor of the mouth, extending between the Wharton ducts and then posteriorly to the anterior tonsillar pillar. The lingual nerve is preserved, but postganglionic fibers to the submandibular and sublingual glands are transected. The ipsilateral Wharton duct is divided, and as the hemimandible is retracted laterally, the tongue and opposite hemimandible are retracted contralaterally to allow division of the mylohyoid. The oropharynx and upper cervical space should now communicate. Branches of the external carotid artery distal to the superior thyroid artery and branches of the internal jugular vein are ligated and divided as needed.

Access to the lateral compartment of the extracranial skull base requires no further dissection at this point. However, if the area to be exposed is in the medial compartment, pharyngotomy as described above is required. Division of the soft palate, eustachian tube, and palatini muscles can facilitate the superior exposure, but these increase morbidity.

An alternative to pharyngotomy is the retropharyngeal approach, in which a laterally based pharyngeal flap allows separation of the surgical field from the aerodigestive tract upon repair. In this variation of the approach, the incision extending along the floor of the mouth to the anterior tonsillar pillar splits to form a Y-shape. The upper limb extends to the soft palate and continues on to the hard palate about 8 to 10 mm medial to the gingival margin; it then passes anteriorly along the alveolar ridge to the contralateral hard palate.

Next, a hemipalatal flap (soft palate plus mucoperiosteum of the hard palate) is elevated after sacrifice of the ipsilateral greater palatine artery and nerve. The lower limb extends into the hypopharynx, passing lateral to the tonsil. The incision should continue to just past the orifice of the eustachian tube laterally. The eustachian tube and the tensor veli palatini and levator veli palatini muscles are divided. Blunt dissection is then used to separate the superior and middle constrictors of the pharyngeal flap from the longus capitis and longus colli muscles. The nasopharynx is detached from the skull base. If visualization of the sphenoid sinus is required, the exposed hard palate base can be removed.

Closure of the retropharyngeal dissection begins by reattaching the superior constrictor muscle to the skull base. The hemipalatal flap is reapproximated to the maxillary gingiva; a palatal splint can be used to buttress the repair. The mylohyoid, digastric, and stylohyoid muscles are reapproximated with absorbable suture. The mandible is brought together and secured with the prefitted miniplates. The oral mucosa is closed as previously described, and the platysma, deep dermis, and skin are closed in separate layers. The lower lip is repaired with the previously described four-layer closure.

Complications

The extended transoral approaches require understanding of the oral and pharyngeal anatomy and demand technical skills typically used by otolaryngologists. To ensure a cosmetic result and minimize complications, it is essential to have a well-prepared multidisciplinary team that includes a neurosurgeon, plastic surgeon, otolaryngologist, and neuroanesthesiologist.

Regardless, the addition of each subsequently more extended approach increases the morbidity significantly. As described above, most procedures require preoperative tracheostomy and percutaneous endoscopic gastrostomy (PEG) tubes. Postoperative complications include:

- Dental malocclusion
- Nerve injury (hypoglossal, lingual, vagal, and accessory)
- Swallowing and speech difficulties
- Mandibular pseudarthrosis

- Mandibular osteonecrosis, especially with postoperative radiotherapy
- Serous otitis media and conductive hearing loss from sectioning of the eustachian tube
- Postoperative meningitis as a result of direct extension from the mouth
- Retropharyngeal abscess
- Orocervical fistula

The approach selected should be tailored to the specific level and needs relative to the pathology at hand. In general, the risks of such extended transoral approaches are balanced by the high morbidity of pathologic conditions at the CVJ.

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4 High Cervical Retropharyngeal Approach to the Craniocervical Junction

SUNGSAM JUNG

Overview

Retropharyngeal approaches to the upper cervical spine are anterior approaches directed through the fascial planes of the neck. The main advantage of anterior approaches is the direct route to the lesion, avoiding the potential need to work around or manipulate neural structures. The transcervical approach can provide access to the C2 body and odontoid process, the anterior arch of C1, and the lower clivus. The major targets of these approaches are anterior or anterolateral lesions of the craniovertebral junction (CVJ), such as anterior midline extradural tumor of the first, second, and third cervical vertebrae or hangman's fracture. The retropharyngeal approach is an option to reach high cervical targets or those of the CVJ, and it can obviate the need to open the oropharynx and avoids potential risks associated with the transoral approach.

Because full occlusion of the teeth is essential for optimum exposure of this approach, nasotracheal intubation or tracheostomy is recommended, and no other access is given between the teeth. Retropharyngeal approaches require dissection of fascial planes in the submandibular and carotid triangle rostral to the hyoid bone and adjacent to the superior pharyngeal constrictor muscle, ultimately accessing the space between the upper cervical vertebral bodies and the prevertebral fascia.

Two types of retropharyngeal approaches are well established: one route is medial to the carotid sheath, the other is lateral to it. The former is the *medial retropharyngeal approach,* and it may cause complications that include injury to the glossopharyngeal, hypoglossal, and superior laryngeal nerves, but it holds the advantages of a more anterior approach angle. The latter is a *lateral retropharyngeal approach,* and it has the advantage of a low incidence of nerve palsy and fewer anatomic structures for dissection; the disadvantage is a slightly lateral approach.

Medial Retropharyngeal Approach (Anterior Retropharyngeal Approach)

The patient is positioned with the head slightly extended to raise the mandible up and away from the surgeon's line of view, and the head is rotated 30 degrees contralateral to the surgical approach. The four methods of skin incisions are 1) transverse, 2) oblique vertical, 3) hockey stick, and 4) T-shaped. A submandibular transverse skin incision is enough for exposure of the atlas and axis, but for the additional exposure of any cervical level below C2, a vertical skin incision should be added with a transverse T-shaped skin incision. Regardless of the kind of incision, the important point is wide dissection of the cervical fascia planes. A transverse incision is made from the midline of the neck to the mastoid tip with one finger width (~2 cm) below the mandible's lower margin. A vertical skin incision is extended inferiorly as far as necessary for better exposure and to avoid stretch injury to the surrounding structures.

The side of approach is decided by the laterality of the lesion and the surgeon's preference. If lower cranial nerve impairment is already present, the approach should be performed from the side of impairment.

After the skin incision, a wide subcutaneous flap should be prepared on each side of the incision superficial to the platysma muscle. The medial edge of the platysma muscle is grasped in the midline. Vertical incision of the platysma is made from the mental symphysis to the superior notch of the thyroid cartilage, and the platysma muscle is undermined and freed; the platysma can then be transected across its fibers parallel to the direction of the primary incision for the full length of the exposure (Fig. 4-1).

The fascial plane between the pharynx and the prevertebral muscles is reached through an exposure directed along the anterior border of the sternocleidomastoid muscle (SCM) and between the carotid sheath laterally and the esophagus and trachea medially. By performing the initial exposure inferiorly, the approach can be considered an extension of the familiar anterior cervical approach. To expose the CVJ, additional superior exposure is needed. Structures that may be divided from below to above to increase the exposure include the ascending pharyngeal and superior thyroid arteries, external laryngeal nerve, ansa hypoglossi, internal laryngeal nerve, lingual artery, stylohyoid muscle, anterior belly of the digastric muscle, stylohyoid ligament, and the stylopharyngeus and styloglossus muscles.

The superficial cervical fascia and platysma muscle are mobilized superiorly, and subsequently the submandibular gland and facial artery and vein are visualized (Fig. 4-2). At that time, the marginal mandibular branch of the facial nerve is identified with the aid of a nerve stimulator; inadvertent injury to this nerve will result in drooping at the

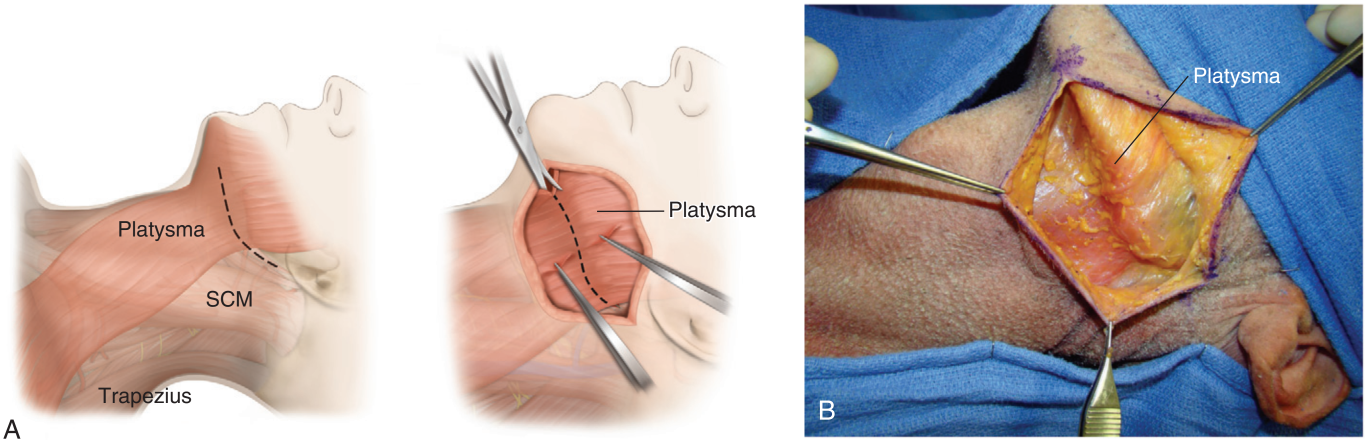

Figure 4-1 Transverse or T-shaped skin incision is used in a medial retropharyngeal approach. The patient is positioned with the head slightly extended and rotated 30 degrees contralateral to the surgical approach. The transverse incision is made 2 cm inferior and parallel to the lower margin of the mandible. After skin incision with broad dissection of subcutaneous tissue, careful incision of platysma muscle is made along the skin incision for the full length of the exposure. SCM, sternocleidomastoid muscle.

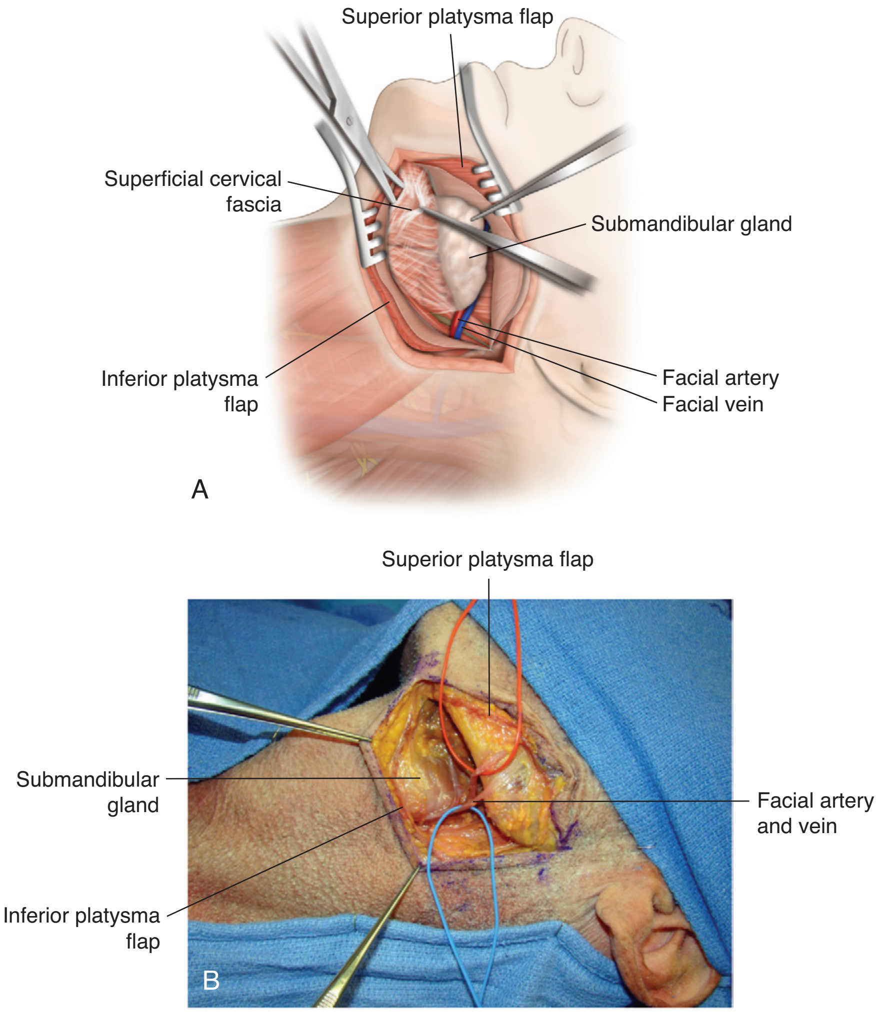

Figure 4-2 The superficial cervical fascia and platysma muscle are mobilized, and the submandibular gland and facial artery and vein are apparent. The marginal mandibular branch of the facial nerve is found, usually running anteriorly below the angle of the mandible; it lies in the upper part of the submandibular gland in the subplatysmal plane of the superficial cervical fascia.

corner of the mouth as a result of orbicularis muscle paresis. This nerve usually runs anteriorly below the angle of the mandible and lies in the upper part of the submandibular gland in the subplatysmal plane of the superficial cervical fascia. The superficial fascia should be incised below this nerve and lifted over the submandibular gland, keeping the dissection deep and inferior to the submandibular gland as the exposure is extended and retracted superiorly to reduce the risk of injury to the marginal mandibular branch of the facial nerve.

For more comfortable retraction of the submandibular gland, the facial vein is transected, and the facial artery is dissected until fully retracted. The facial artery runs posterior to the submandibular gland, and the facial vein is medial to it in the mandibular notch.

Following retraction of the submandibular gland, the next fascial plane, including the digastric muscle, is exposed and transected. The digastric muscle and tendon, fascial sling, and stylohyoid muscle are then exposed (Fig. 4-3). The digastric tendon is attached to the hyoid bone by the fascial sling, which is transected; the digastric muscle and stylohyoid muscle are retracted superiorly, and the next fascial plane is exposed.

The hypoglossal nerve runs deep and inferior to the anterior belly of the digastric muscle. The hypoglossal nerve exits the skull in close proximity to the vagus nerve and courses between the internal carotid artery and internal jugular vein, becoming superficial at the angle of the mandible. After its point of identification over the arteries, it passes deep to the tendon of the digastric muscle for distribution to the muscles of the tongue. The hypoglossal nerve is gently dissected and completely mobilized from the base of the skull to the anterior border of the hypoglossal muscle and is then retracted superiorly with the digastric muscle (Fig. 4-4).

Dividing the digastric and stylohyoid muscles allows mobilization of the hyoid bone and the hypopharynx medially. Incision of a thin fascia overlying the hyoid bone is made, and the retropharyngeal space is developed between the carotid sheath laterally and the larynx and pharynx medially with finger dissection, similar to the Smith-Robinson method (Fig. 4-5). Medial retraction is performed along the greater horn of the hyoid bone and the superior pharyngeal constrictor muscle.

The superior laryngeal nerve is running deep and medial to the carotid artery along the middle pharyngeal constrictor muscle, below the hyoid bone and superior pharyngeal constrictor muscle. The superior laryngeal nerve is vulnerable to stretch injury that may render the voice weak and result in a high-pitched phonation deficit; it may also cause difficulty swallowing because of altered laryngeal sensation. During the retropharyngeal space opening, care must

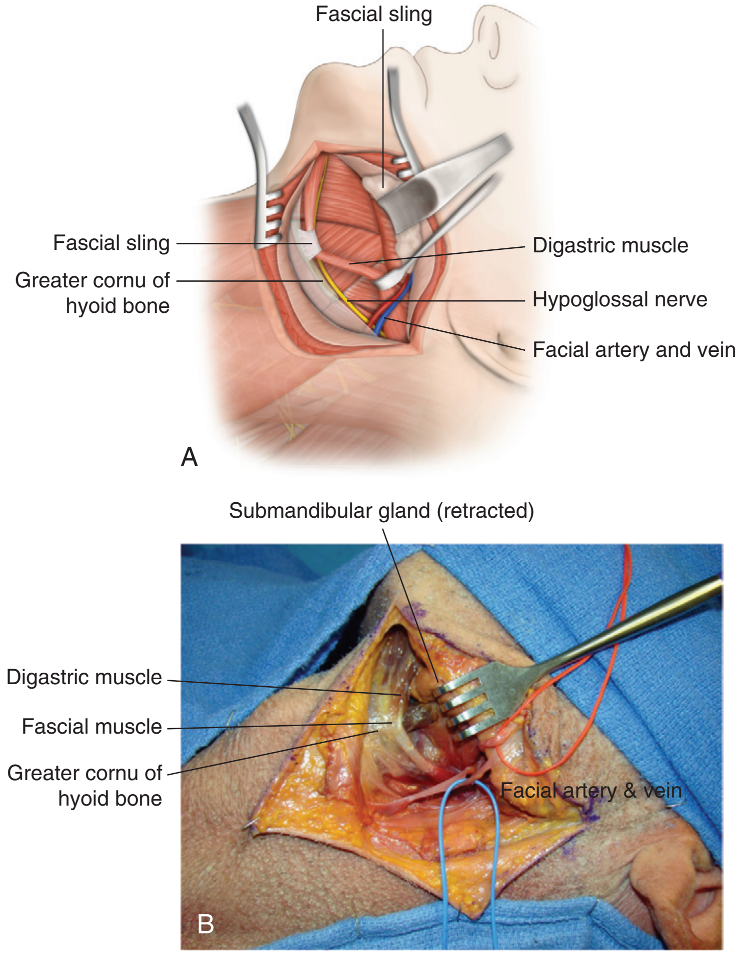

Figure 4-3 After the retraction of the submandibular gland, the next fascial plane, including the digastric muscle, is exposed and transected. The digastric muscle, digastric tendon, fascial sling, and stylohyoid muscle are exposed.

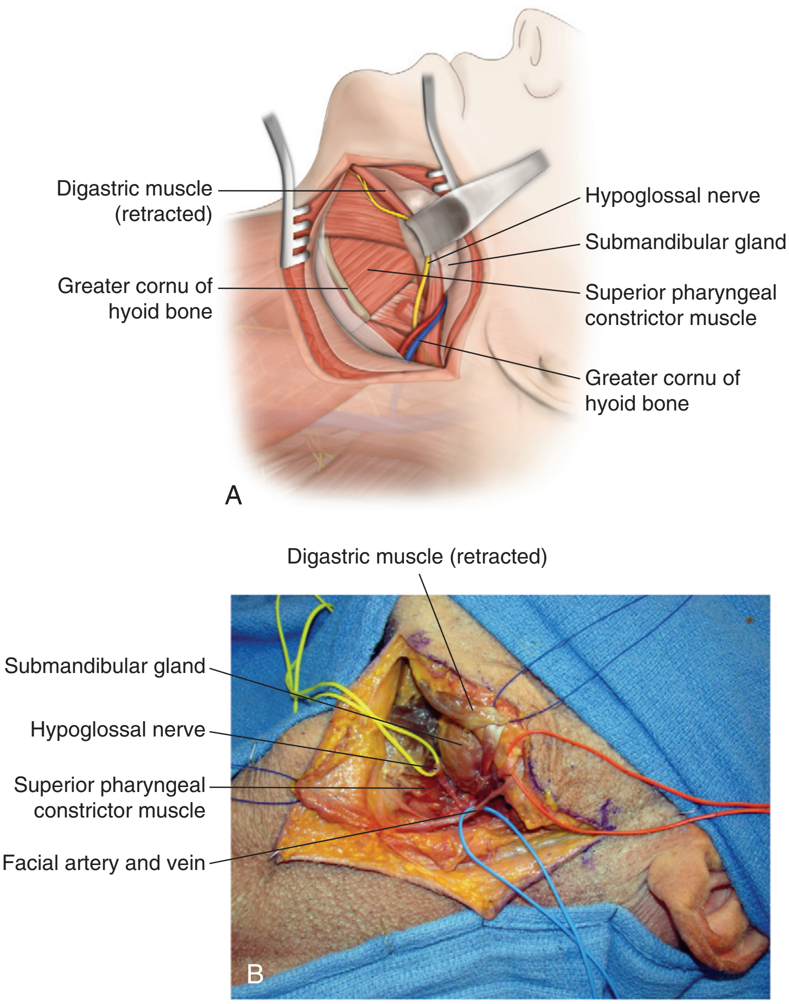

Figure 4-4 The digastric muscle and stylohyoid muscle are retracted toward the mandible, and the next fascial layer is shown. The hypoglossal nerve is deep, slightly inferior, and parallel to the digastric tendon. The hypoglossal nerve is gently dissected and completely mobilized and is then retracted superiorly with digastric muscle.

be taken not to injure the nerve, because it must be identified and mobilized from its origin near the nodose ganglion to the thyrohyoid membrane, its entrance to the larynx. Wide dissection of the fascial planes will help reduce the risk of nerve injury. If the deep cervical fascia is opened vertically in the lateral exposure to gain access to C4 or lower cervical levels, the superior laryngeal nerve must be identified and preserved.

Sometimes ligating the branches of the carotid artery and internal jugular vein is needed for more lateral mobilization of carotid sheath and more extensive exposure. These branches are, in ascending order, the superior thyroid artery and vein, the lingual artery and vein, the ascending pharyngeal artery and vein, and the facial vein.

Although rarely necessary, the hypoglossal and glossopharyngeal nerves may be divided if required for additional exposure. The tagged ends may be reapproximated at the conclusion of the procedure. Deviation laterally may damage the internal jugular vein, internal carotid artery, eustachian tube, and the ninth through the twelfth cranial nerves.

Once the retropharyngeal space is opened, orientation to the midline must be ensured by inspection of the bilateral longus colli muscles and palpation of the midline "keel" of C2. The tubercle on the anterior arch of C1 shifts toward the side of rotation of the patient's head. The longus colli muscle converges at the midline at the upper cervical level; therefore it should be dissected from the anterolateral surface of C2 and C3 to the pharyngeal tubercle of the basiocciput, including the anterior arch and lateral mass (Fig. 4-6).

The anterior rim of the foramen magnum is palpated just above the anterior arch of C1. The pharyngeal tubercle is the most rostral landmark and limit to this approach; the anterior arch of the atlas and the odontoid process and a 2-cm width of clivus extending from the foramen magnum to the sphenooccipital synchondrosis may be removed. If necessary, the dura may be opened to provide access to the vertebrobasilar junction and anterior cervicomedullary junction. The ability to approach ventral intradural lesions represents a key advantage of this approach over the transoral approach, in which dural entry carries a high risk of meningitis and cerebrospinal fluid fistula. Because the local anatomy may be markedly distorted by tumors, infection, or trauma, biplanar radiographs will ensure proper orientation, and intravenous contrast can help to define the dangerous zone in radiographs. By approaching medial to the carotid sheath, a more direct anterior view of the pathology and the plate or screw fixation will be gained.

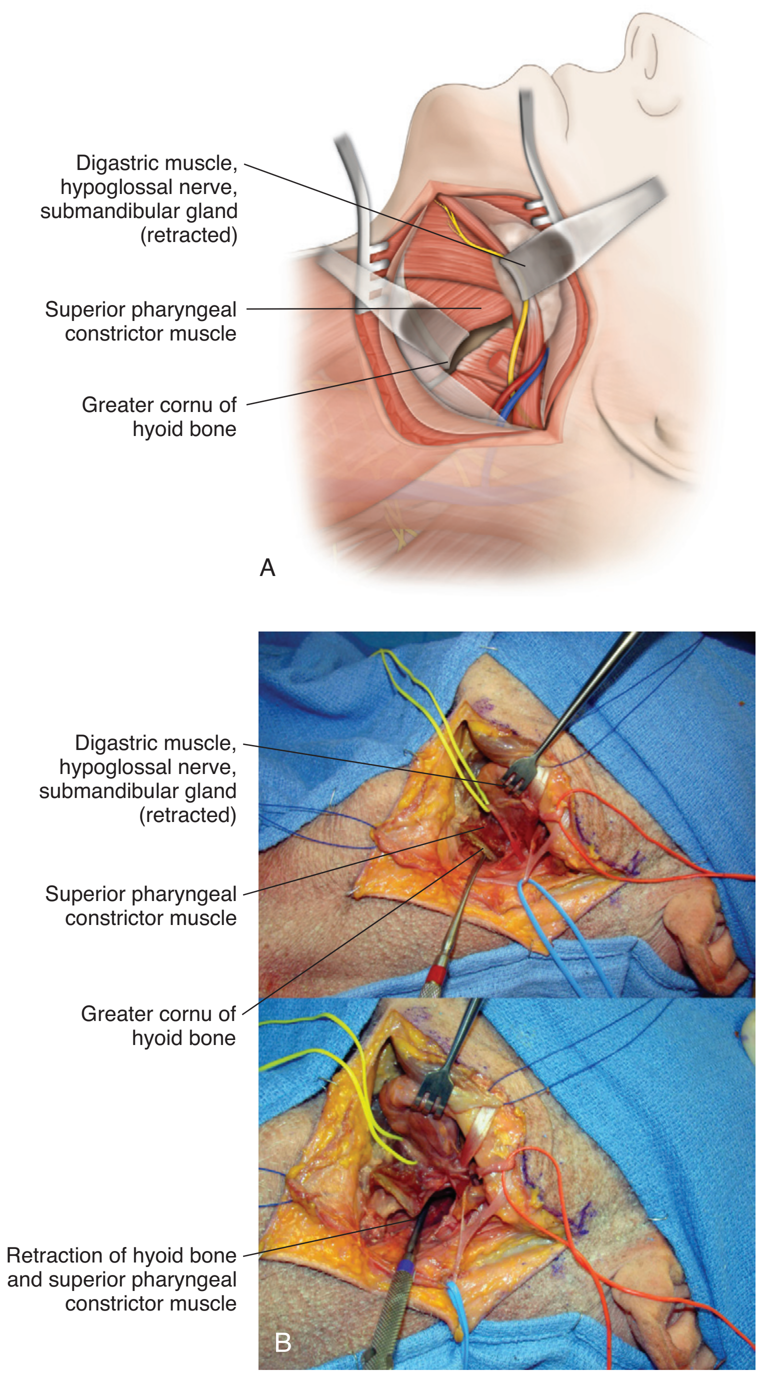

Figure 4-5 After the hypoglossal nerve is retracted superiorly, fascia overlying the hyoid bone is incised along the course laterally to the carotid sheath; the carotid artery is retracted laterally to open the retropharyngeal space. The retropharyngeal space is developed between the carotid sheath laterally and the larynx–pharynx medially.

Closure begins by reapproximation of the digastric tendon. Suction drainage is placed in the retropharyngeal space, and closure is done in layers: first, the superficial layer of deep cervical fascia along the anterior border of the SCM, then the platysma, and finally the skin.

Lateral Retropharyngeal Approach

This approach is medial to the SCM and lateral to the carotid sheath. In the supine position, the neck is extended and rotated to the opposite side about 30 degrees, and the earlobe is reflected and sutured to the skin for better exposure.

A hockey stick–shaped incision is begun transversely, curving across the mastoid process, and is carried out distally along the anterior border of the SCM. The subcutaneous and platysma muscles are divided along the line of the skin incision (Fig. 4-7).

The greater auricular nerve is identified in the subcutaneous tissue and is dissected in both directions for mobilization. It may be retracted, or it can be resected, although resection results in a small but acceptable sensory deficit (Fig. 4-8).

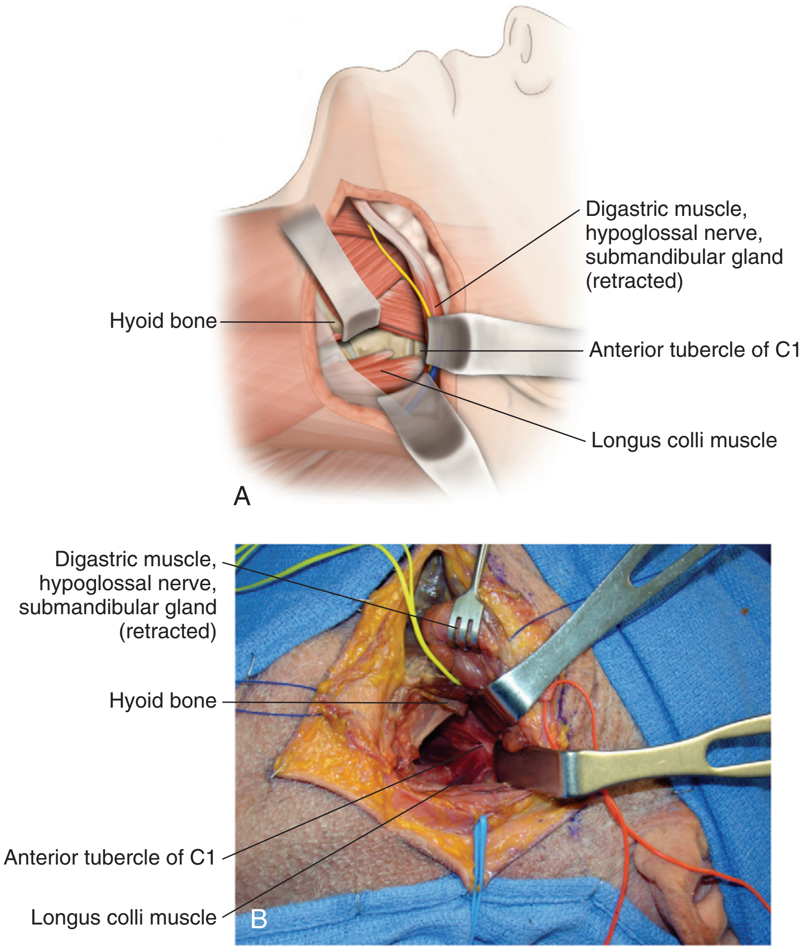

Figure 4-6 The greater horn of the hyoid bone and the superior pharyngeal constrictor muscle are retracted medially, and the carotid artery is retracted laterally. The retropharyngeal space is developed between them, and the fat pad in the space confirms the location. The precervical fascia and longus colli muscle are seen in this space. The midline is identified with bilateral longus colli muscles and anterior tubercle of C1. Longus colli muscle converges at the midline, upper cervical level, so it should be elevated by sharp dissection from the anterolateral surface of C2 and C3.

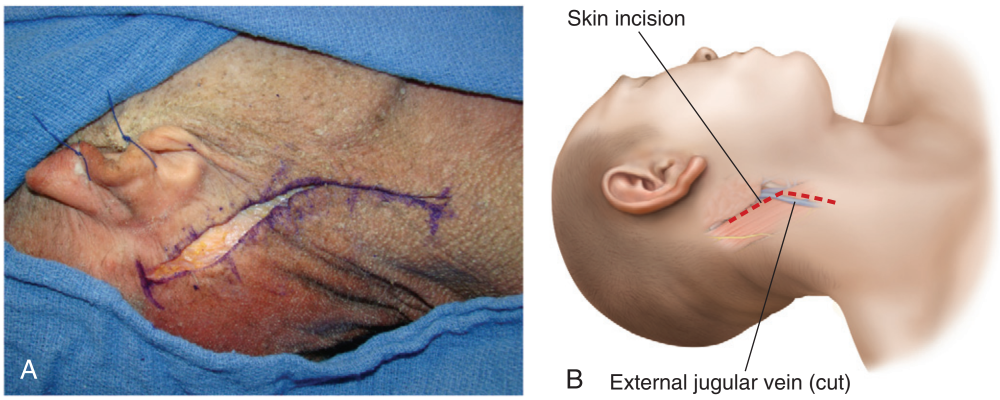

Figure 4-7 Skin incision for lateral retropharyngeal approach. The patient is placed supine with head extended and turned away. A hockey stick–shaped incision is made transversely over the proximal sternocleidomastoid muscle then distally along the anterior border of this muscle, posteriorly curving across the mastoid process.

The external jugular vein is seen overlying the SCM, and it can be ligated if necessary. For better exposure, the SCM is detached from the mastoid process or is partially divided perpendicular to its anterior border. This is not always necessary in cases of limited exposure or in thin patients with small muscles. The posterior portion of the parotid gland is on the anterior border of the SCM and should be protected. The SCM is partially divided in its tendinous portion in a direction perpendicular to its anterior border. Sufficient tendon tissue should be left for easy repair of the muscle.

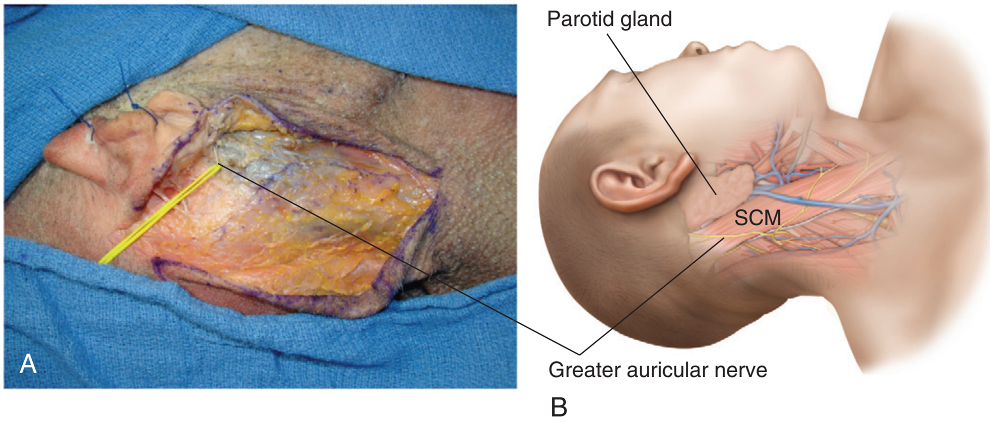

Figure 4-8 Following the skin incision, the greater auricular nerve is identified in the subcutaneous tissue and is dissected in both directions for mobilization, or it may be resected.

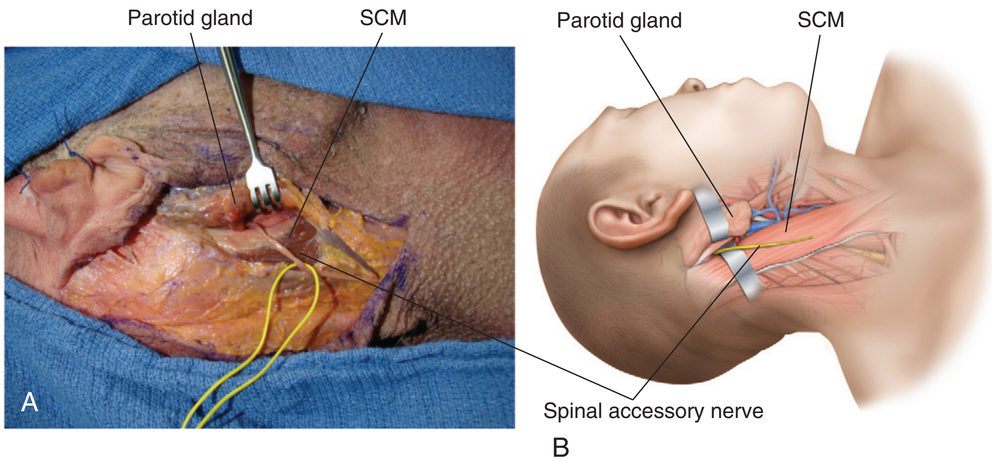

Figure 4-9 After division of the sternocleidomastoid muscle (SCM) and parotid gland, the spinal accessory nerve is identified running down and entering the SCM about 3 cm below the mastoid process.

After division of the SCM, the common carotid artery, internal jugular vein, and multiple lymph nodes are seen. The spinal accessory nerve is identified running down and entering the SCM about 3 cm below the mastoid process (Fig. 4-9).

The nerve is retracted medially with the contents of the carotid sheath for surgery with only C1–C2 area exposure. For a more extensive approach distally, the nerve is dissected from the jugular vein, retracted to the lateral and posterior part, and is subsequently everted at the SCM. The transverse process of C1 is easily palpated, because it extends more prominently than other cervical vertebrae (Fig. 4-10).

Several lymph nodes in this area can be resected. Continuous dissection is then carried out medially, between the anterior border of the transverse process and the posterior border of the carotid sheath, thus avoiding vertebral artery injury. By extending the blunt dissection of the areolar plane, the prevertebral fascia and muscles can be divided, and the retropharyngeal space is opened (Fig. 4-11).

To expose the appropriate vertebral bodies, it is necessary to strip off or remove the anterior cervical muscles. These are the longus colli and longus capitis muscles that cover the lateral articulations of C1 and C2 (Fig. 4-12).

The lateral mass and anterior arch of the C1–C2 complex can be easily identified by detecting the prominent, transversely oriented C1 arch and the vertical midline ridge of C2. Care must be taken not to injure the facial nerve by superior retraction, and the upper limit of the exposure is the posterior belly of the digastric muscle. A fiberoptic headlight and malleable retractor are helpful for proper illumination and exposure of the surgical field. By levering the distal tip of the retractor on the contralateral transverse process, the frontal view of the C1–C2 complex can be obtained.

After managing the pathology, the SCM is sewn, and only the platysma and skin layers are approximated. However, the prevertebral fascia and muscles may also be sutured to prevent cerebrospinal fluid leakage. Postoperative immobilization with a halo vest or brace is recommended depending on the pathology. Because of the risk of retropharyngeal edema, intubation or tracheostomy is left in place until postoperative swelling has subsided and is deemed satisfactory, and swallowing function is assessed.

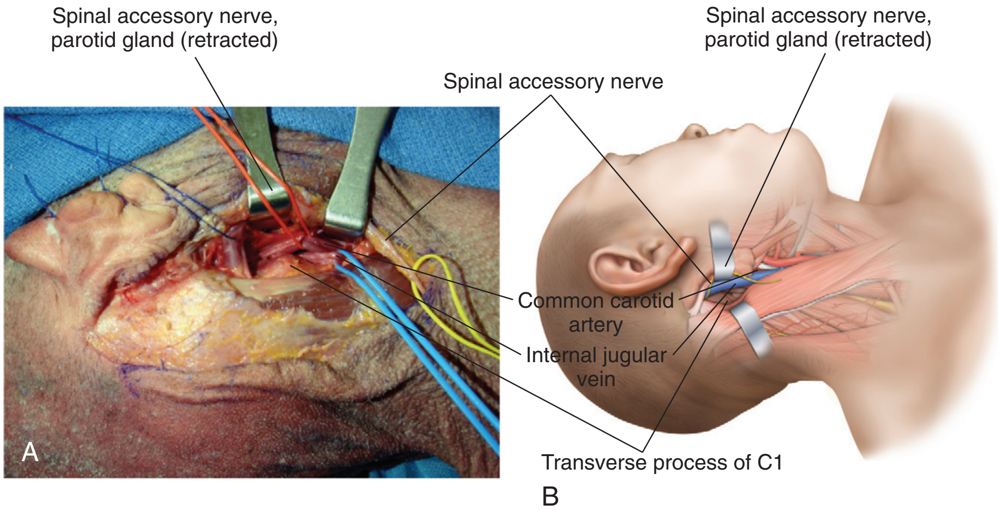

Figure 4-10 After gentle retraction of the parotid gland and the spinal accessory nerve medially, the transverse process of C1 is exposed. Common carotid artery, internal jugular vein, and multiple lymph nodes are also seen.

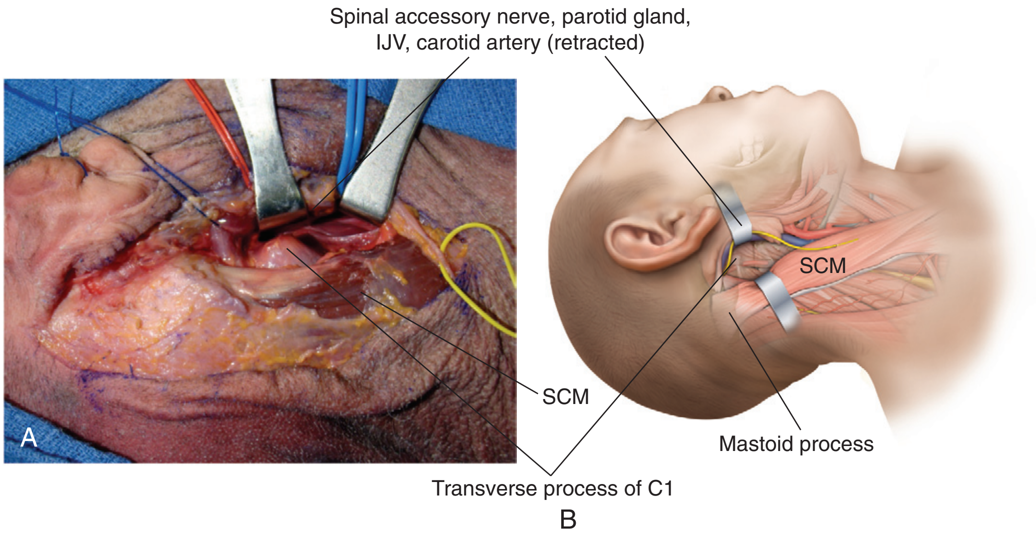

Figure 4-11 Retraction of the parotid gland, spinal accessory nerve, carotid artery, and internal jugular vein (IJV). The transverse process of C1 is clearly visualized. SCM, sternocleidomastoid muscle.

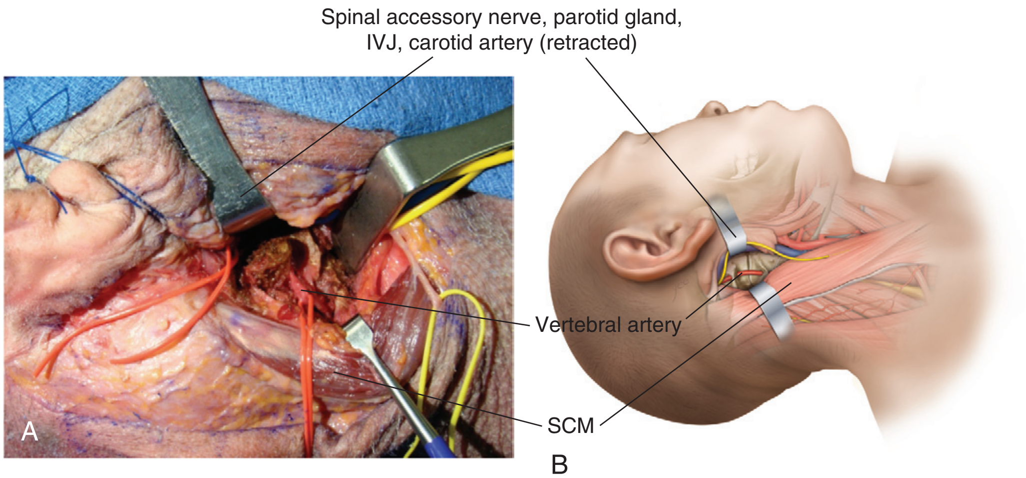

Figure 4-12 The retropharyngeal space can be reached by dissecting between the internal jugular vein (IJV) and longus capitis muscle. This space can be extended in the areolar plane by blunt or sharp dissection. To expose the bony surface, it is necessary to elevate off the longus colli and longus capitis muscle from the transverse process of C1–C2 from a lateral to medial direction. SCM, sternocleidomastoid muscle.

Summary

The high cervical retropharyngeal approach is an option for management of anterior lesions of the upper cervical spine or CVJ. It does not entail opening of the oropharyngeal mucosa, and potential associated risks of the transoral approach can be avoided. As a result, it is better suited to treat transdural or intradural lesions. The infection rate is very low, and bone grafting can be successfully accomplished. To minimize the surgical complications, thorough knowledge of the anatomy in this area is mandatory.

5 Approaches to the Craniocervical Junction: Posterior and Lateral Approaches

KYLE M. FARGEN, MATTHEW M. KIMBALL, ALBERT L. RHOTON JR, and DANIEL J. HOH

Overview

The indications for a posterior or far-lateral approach to the craniocervical junction (CCJ) are diverse and include craniocervical instability, neoplasm, trauma, and degenerative changes. This includes pathologies such as rheumatoid arthritis, Chiari malformation, odontoid fracture, tumors (bony, intradural, and extradural), upper cervical facet dislocation, ligamentous incompetence, and intravertebral disk degeneration. In many instances, posterior approaches to the CCJ are favored over anterior approaches given surgeon familiarity and ease.

The primary operative fixation methods used during CCJ approaches include occipitocervical (O–C) fusion, atlantoaxial wiring, atlantoaxial screw fixation, and interlaminar clamp fixation.

Posterior Approaches

ANATOMY

The CCJ is a complex interface of joints and ligaments through which the head achieves substantial mobility upon the neck while the lower brainstem and spinal cord are safeguarded. To accomplish these two functions, the CCJ harbors several structures that are unique to this region of the spine. These include two uniquely shaped bones, the atlas (C1) and axis (C2), and a complex ligamentous network.

The atlas is a ring-shaped bone composed of two lateral masses and an anterior and posterior arch. It lacks a body, and in its absence articulates with the peglike superior process of C2, the *odontoid*, or *dens.* The superior and inferior articulating processes, which articulate with the occipital condyles and superior facets of C2, respectively, are located within the lateral masses. The transverse processes extend laterally from the lateral masses and are fenestrated by the transverse foramen, through which the vertebral artery courses. This artery ascends through the transverse foramen, then it turns medially and slightly posteriorly around the posterior arch of C1 in its sulcus, and then turns anteriorly to enter the dura. Both the anterior and posterior arches of C1 form a platform through which ligaments attach to the bones above and below. Just medial to the lateral masses are two small tubercles that serve as attachment sites for the transverse atlantal ligament; this ligament drapes across the posterior aspect of the odontoid process of C2, allowing for rotation of C1 around the odontoid.

The odontoid process of the axis (dens) sits just behind the anterior arch of C1 and is held in position by the transverse atlantal ligament. It serves as an attachment for several important ligaments that course from C2 to the skull base. The pedicles are broad and are covered by the superior articulating processes; the transverse processes are diminutive and are pierced by the transverse foramen and the vertebral arteries that course through these canals. The laminae are strong and, in contrast to the atlas, join in the midline as the prominent spinous process, a useful landmark when navigating the upper cervical spine through a posterior approach.

The ligamentous complex surrounding the upper cervical spine is important in providing stability while at the same time allowing for rotation and flexion–extension (Fig. 5-1). The anterior longitudinal ligament extends from the skull base to S1 and is adherent to the anterior vertebral bodies. The superior segment, which courses from C1 to the anterior basion, is called the *anterior atlantooccipital membrane.* The posterior longitudinal ligament extends from C1 to S1 along the posterior vertebral bodies of the spine. A continuation of this ligament superiorly, known as the *tectorial membrane,* extends from the posterior aspect of the anterior arch of C1 to the posterior basion.

The transverse ligament of C1 extends from the tubercles of C1 and divides its vertebral foramen into an *anterior compartment,* composed of the dens process of C2, and a *posterior compartment,* through which the spinal cord courses. Two cruciate ligaments arise from the midline of the transverse ligament immediately posterior to the dens: the *superior cruciate ligament* extends superiorly to the posterior basion; the *inferior cruciate ligament* extends inferiorly to the body of the axis. The *apical ligament* is a single ligament that extends from the tip of the dens to the basion. Finally, the paired *alar ligaments* course from the lateral dens superiorly to the lateral margin of the foramen magnum. Together these ligaments are responsible for maintaining stability of the CCJ while allowing the flexibility of this complex in

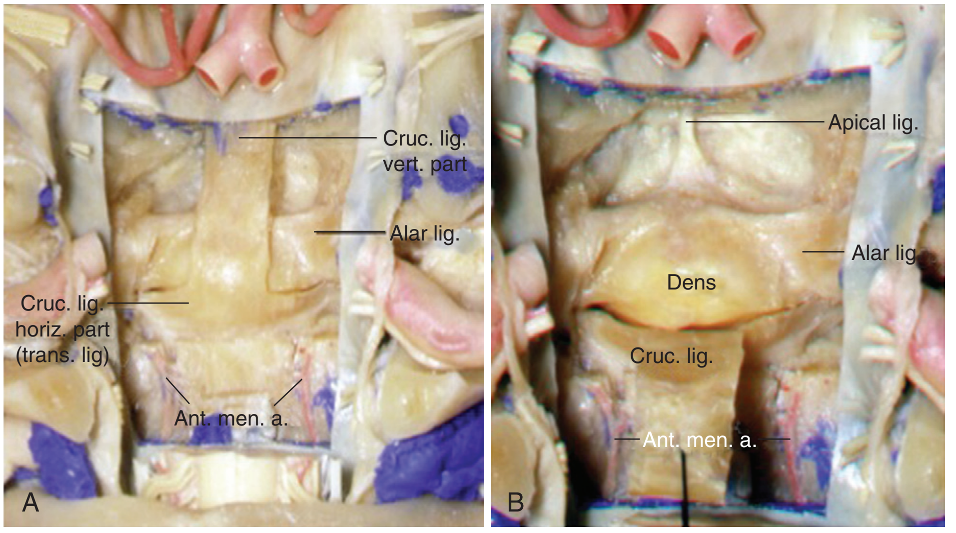

Figure 5-1 **A,** The brainstem and vertebral arteries have been sectioned to display the ligaments traversing posteriorly on the C2 vertebral body and dens. The tectorial membrane has been removed to reveal the alar ligaments and the vertical and horizontal cruciate ligaments. **B,** After removal of the vertical cruciate ligament, the apical ligament is seen traveling superiorly from the odontoid to the margin of the foramen magnum.

rotatory and flexion-extension movements. Specifically, the joint between the occipital condyles and the superior articulating processes of C1 offers approximately 50% of the total *flexion-extension* movement of the head, and the articulation of the dens on C1 offers approximately 50% of the total *rotation* movement of the head. As such, the complex ligamentous relationships, unique bony structures, and inherent mechanical properties of the CCJ result in an elegant yet complicated anatomic setting to effectively navigate surgically. Furthermore, because of the important mechanical relationships of the CCJ, stability must be accounted for at all times.

Posterior approaches to the cervical spine traverse a series of symmetric muscles that may be categorized into groups based on their depth (Fig. 5-2). The most superficial layer is the trapezius muscle, followed by a middle layer composed of the lesser rhomboid muscle. Finally, the deepest layer is composed of the intrinsic muscles of the neck and includes the splenius capitus, splenius cervicis, semispinalis capitis, semispinalis cervicis, rotator muscles, and the multifidus muscles. The short nuchal muscles are located more laterally and consist of the rectus capitis major and minor and the superior and inferior oblique capitis muscles (Fig 5-3). These muscles form the suboccipital triangle and are useful in locating the vertebral artery, which courses through its center.

POSITIONING

Stabilization of the head in a neutral position is of utmost importance during posterior approaches. A Mayfield pinion head holder is placed after intubation, and the patient is rotated to the prone position. The majority of posterior approaches are performed with the patient prone, usually with a Wilson frame under the chest. The head may be elevated relative to the body to enhance venous drainage and minimize blood loss. The sitting position is an additional option for posterior stabilization procedures; however, this position has become less popular given the inherent risk of air embolism. Lateral decubitus or three-quarter prone positions may also be used depending on individual patient anatomy and surgeon preference. It is also not uncommon for patients undergoing posterior craniocervical fixation to be maintained in preoperative traction to obtain reduction before their procedure.

Before securing the patient's head in position for surgery, it may be necessary to make adjustments to the patient's position to optimize preoperative alignment. In cases where the CCJ is unstable, fiberoptic intubation may be necessary to ensure that the head is not passively extended during placement of the endotracheal tube. Finally, the need for monitoring of somatosensory and motor-evoked potentials should be determined before surgery. In patients at risk for spinal cord compromise during surgery, monitoring of these potentials may be helpful in providing feedback to the surgeon during intraoperative maneuvers.

SURGICAL TECHNIQUE

Prior to prepping the patient, the incision is planned, and the involved skin is shaved with trimmers. In most cases, the incision extends from just above the external occipital protuberance to the lower cervical vertebrae, depending on individual patient factors and treatment goals. The dermis and subcutaneous tissues are injected with a local anesthetic mixed with epinephrine to enact vasoconstriction and minimize skin bleeding. The patient is prepped widely, and sterile drapes are placed. The fluoroscopic device may be draped in the field at this time.

Next, the skin is incised from roughly two fingerbreadths above the external occipital protuberance caudally to the desired level, and monopolar cautery is used to divide the subcutaneous tissue and obtain hemostasis. Self-retaining retractors are placed to gently retract and facilitate cautery dissection. The nuchal ligament is then identified on the cranial aspect of the incision. A midline avascular plane bisects the nuchal ligament and the cervical musculature; by staying within this plane, bleeding is minimized during

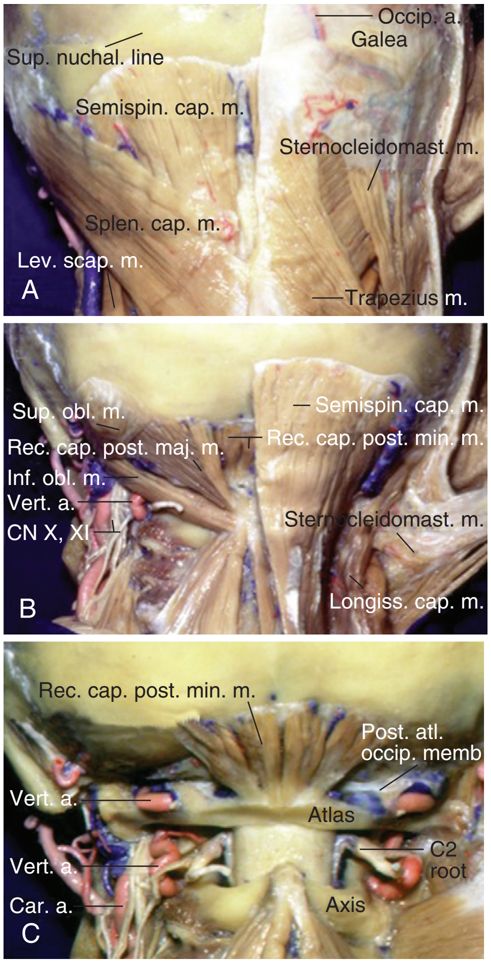

Figure 5-2 Posterior view of the muscles overlying the CCJ. **A,** The trapezius (most superficial) and sternocleidomastoid muscles have been removed on the left and preserved on the right. Underlying the trapezius muscle are the semispinalis capitis and splenius capitis. **B,** After removal of these muscles, the suboccipital triangle is seen containing the vertebral artery (*left*). The triangle is composed of the superior oblique muscle, which runs from the occipital bone to the transverse process of C1; the inferior oblique muscle, which travels from the transverse process of C1 to the spinous process of C2; and finally the rectus capitis posterior major, which arises from the C2 spinous process and courses superiorly to the occipital bone near the superior nuchal line. CN, cranial nerves; Longiss. cap. m., longissimus capitis muscle. **C,** The muscles of the suboccipital triangle have been removed bilaterally to reveal the bony arches of C1 and C2 and the vertebral arteries and C2 nerve roots. The vertebral artery travels superiorly and laterally from the transverse process of C2 to the transverse process of C1 and then turns medially to course on the posterior arch of C1 before entering the dura.

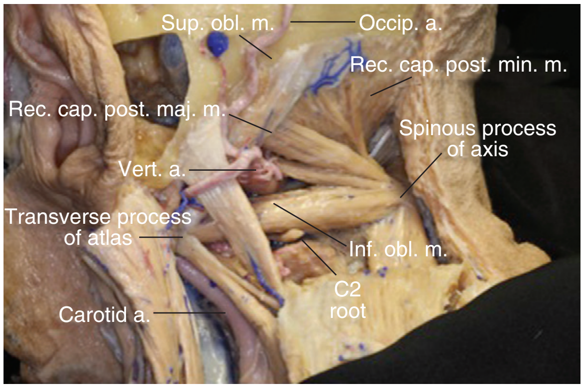

Figure 5-3 Oblique view of the left CCJ. The trapezius, splenius capitis, and semispinalis capitis muscles have been reflected downward to expose the vertebral artery in the suboccipital triangle. The superior and inferior oblique muscles can be seen attached to the C1 transverse process laterally. Note the proximity of the carotid artery to the C1 transverse process.

muscle division. The occiput is easily exposed using cautery, and the ligamentous attachments of the bone are swept laterally while retraction is performed with a Cobb or periosteal elevator. Venous bleeding from emissary veins is frequently encountered along the occiput and may easily be stopped by using bone wax. The foramen magnum is identified and demarcated using curettes.

The spinous processes of the cervical vertebrae are palpated, and dissection is continued until the tips of the processes are exposed. The divided muscle layers are retracted using larger self-retaining retractors. Next, the spinous process of C2 is identified, and dissection of the deeper muscle layers from the bone is performed. Subperiosteal dissection of the prominent ligamentous attachments may be performed initially using monopolar cautery or a scalpel, but it is best performed later using blunt dissection with a Cobb or periosteal elevator. During this maneuver, the tip of the instrument is placed on the spinous process, and then the flat end, facing downward, is pulled in a medial to lateral direction. This maneuver is continued caudally along the spinous process of the additional cervical vertebrae with the vertebral facet joints serving as the lateral boundary.

Next, the small muscles on C1 and C2 are then dissected from the bone, most commonly with a rasp, with the zygapophyseal joints serving as a lateral boundary. This dissection amounts to approximately 1.5 cm from the midline from C1 to the most caudal level. Further lateral dissection along C1 or C2 may result in inadvertent injury to the vertebral plexus surrounding the vertebral artery or to the second cervical ganglion and nerve. In general, lateral exposure is best performed with blunt dissection using a rasp or bipolar cautery to prevent inadvertent injury to the venous plexus or the vertebral artery. Care should be taken during blunt dissection to keep the instrument directly on bone to avoid arterial injury, because the vertebral artery courses medially in its sulcus on C1. Venous bleeding from the vertebral plexus is usually easily controlled with bipolar cautery or Gelfoam and cotton pledgets. The second cervical ganglion may be identified laterally near the sulcus of the vertebral artery, and it should be spared.

At this point, the spinous processes, laminae, and occiput have been exposed. If cervical fusion is to be performed, the spinous processes and interspinous ligaments may be removed using rongeurs. Curettes are used to expose the yellow ligament between adjacent vertebral arches and the posterior atlantooccipital membrane between the occiput and C1. At this point, exposure of the dura, occipital bony removal, laminectomy, or fixation maneuvers may be performed based on the goals of surgery. Broad fascial attachments usually connect the foramen magnum periosteum to the dura, and these should be respected during dissection. Furthermore, a midline dural sinus, or venous lake, is found in this position that should be respected and cauterized, if needed.

After the goals of the surgery have been met, closure is obtained by achieving hemostasis during slow removal of the retractors. A surgical drain may be left in place based on operator preference. Reapproximation of the cervical musculature is performed through numerous fascial sutures. The skin is then closed, and the patient is removed from pins.

Lateral Approaches

INDICATIONS

Lateral approaches to the upper cervical spine and CCJ are not commonly performed but have utility in addressing intradural lesions ventrolateral to the upper spinal cord or cervicomedullary junction. Furthermore, lesions of the vertebral artery near the foramen transversarium of C1 or its vertical course caudally may be accessed by a lateral approach. Lesions that lie in a ventral or dorsal position to the spinal cord are usually accessed more easily from either an anterior or posterior approach. This approach has the benefit of low risk of cerebrospinal fluid leak given the multiple layers closed over the dural incision. Complications associated with this approach include injury to the spinal accessory nerve or to the vertebral artery. The accessory nerve is usually at greatest risk from suboptimal retractor placement.

POSITIONING

It is important to consider the position of the mandible when positioning the patient, because it may need to be displaced anteriorly to allow adequate exposure. Therefore, the airway is usually secured with nasotracheal intubation, allowing the mouth to be fully closed, so that the angle of the mandible does not obstruct the exposure of the spine. Additionally, the mandible may be pulled forward using adhesive tape, and the ear may be reflected forward. After intubation, the patient is placed in Mayfield pins, and any necessary sensory or motor potential monitoring is configured. The patient is placed in the true lateral position with the neck extended; gently directing the chin toward the floor may offer additional degrees of exposure.

SURGICAL TECHNIQUE

After prepping and draping the patient, local anesthetic with epinephrine is injected into the subcutaneous tissues. The skin incision is made along the anterior margin of the sternocleidomastoid (SCM) muscle from roughly the level of the cricoid cartilage to the mastoid, depending on the exposure necessary. The platysma muscle is split, and the deep cervical fascia is divided using blunt dissection and scissors. The SCM is then dissected so that it may be seen coursing from its insertion on the mastoid caudally to the inferior aspect of the incision. Next, the SCM and splenius capitis are divided from their bony attachments, leaving enough tissue so that reapproximation is possible at the termination of the procedure, and these are then mobilized inferiorly. At this point, the spinal accessory nerve should be visible roughly 4 cm inferior to the mastoid along the posterior aspect of the SCM belly. The nerve enters and supplies the muscle belly at this location.

Next, the deep cervical fascia is incised. The incision begins at roughly the C1 transverse process, which is usually about 1 cm below the mastoid, and it continues on a trajectory that is parallel to the course of the accessory nerve. After the initial rostral opening, the levator scapulae and splenius capitis muscle attachments to the C1 transverse process are identified. Lying just beneath these muscle bellies is the vertebral artery, and care must be taken to avoid injury to this vessel during dissection.

At this point, the muscles are divided at the C1 transverse process, and the vertebral artery is exposed. Once this critical structure has been identified, the muscle bellies are then divided inferiorly to expose the transverse process of C2 and the posterolateral arch of C1, near the dorsal root ganglion of the second cervical nerve, and the lamina of C2. The muscles should be removed posteriorly to the midline to aid with exposure. A curette is used to strip the remaining muscle attachments to the C2 lamina and the inferior margin of C1; the vertebral artery may be avoided by keeping the curette in a subperiosteal position along the inferior arch of C1. A drill is then used to remove the lamina of C2 and the posterolateral arch of C1. The facet joints should be spared, as should a portion of lamina adjoining the foramen transversarium. If needed, the dura is then opened using a curved incision from an anterosuperior position to an anteroinferior position, with a curve concave to the operator. The dural opening is aided by the relatively sparse epidural fat in this location. Tumors ventral to the spinal cord are best removed in a piecemeal fashion to avoid any unnecessary spinal cord manipulation.

When the goals of the procedure have been achieved, the dural incision is closed with suture, and the muscle bellies are reapproximated. The subcutaneous tissue is closed with suture, the skin is closed in a manner based on operator preference, and the patient is removed from pins. A cervical collar may be helpful in reducing postoperative pain associated with the mastoid and C1 muscle dissection.

Lateral Retropharyngeal Approach

INDICATIONS

The lateral retropharyngeal approach allows for visualization of both the right and the left C1–C2 joints through a lateral window that courses posterior to the pharyngeal complex. This approach provides a view of the odontoid process and anterior vertebral bodies. Most commonly, this exposure is used for obtaining biopsies of lesions in the anterior upper cervical spine. Furthermore, caudal extension of the exposure allows for fusion of the upper cervical vertebrae through T1.

POSITIONING

The patient is placed supine and is intubated using nasotracheal intubation of the contralateral nare. The head is usually placed in a halo–ring or Mayfield pinions. The neck is then extended, and the head is rotated to the contralateral side. The mandible and ear are then pulled forward, using tape and suture, respectively, to maximize the operative exposure.

SURGICAL TECHNIQUE

Skin incision is made horizontally across the mastoid and is then carried caudally and anteriorly downward across the anterior border of the SCM; the incision will resemble a hockey stick. Once again, superficial tissues are divided until the SCM is exposed. The greater auricular nerve is identified rostrally, and the accessory nerve is identified caudally, approximately 4 cm below the mastoid. The accessory nerve bisects the incision and will be a nuisance unless it is retracted from the field. If the surgeon will need exposure of the cervical vertebrae from C1 down to the lower cervical spine, the nerve should be traced rostrally to near the jugular foramen. The nerve may then be separated from the nearby jugular vein and may be retracted posteriorly with the SCM. Should only upper cervical exposure be necessary (C1 or C2), the nerve can be retracted anteriorly with the carotid sheath.

Next, the transverse processes of C1 and C2 are identified, similar to the previously presented lateral exposure. The fibrous attachments to these processes are dissected anteriorly to expose the retropharyngeal space. Using blunt subperiosteal dissection, the retropharyngeal fascia and pharyngeal muscles are swept anteriorly off the anterior vertebral bodies. If more lateral exposure is required, the anterior cervical muscles may similarly be stripped from the lateral articulations of C1 or C2. This approach allows for exposure of the odontoid process, the lateral masses of C1–C2, the anterior arch of C1, and the C1–C2 joints. Therefore C1–C2 fusion is possible via this approach with decortication of the bony articulations. Transarticular C1–C2 screws may be placed unilaterally under fluoroscopic guidance; bilateral transarticular screws necessitate bilateral exposures. If exposure of the CCJ is required, removal of the lateral portion of C1 and the ipsilateral occipital condyle is necessary. More expansive craniocervical exposures may combine the lateral retropharyngeal approach with a suboccipital craniotomy.

Far-Lateral Approach

INDICATIONS

A far-lateral approach is used to access the foramen magnum and resect lesions situated laterally or anterolaterally to the cervicomedullary junction. The traditional approach exposes the foramen magnum and occipital condyle; various derivations may then be used to access more ventral or superior locations that include the transcondylar, paracondylar, and supracondylar variants. The basic transcondylar approach consists of exposure of the occipital bone and foramen magnum with suboccipital craniotomy, exposure and removal of the posterior arch of C1, exposure of the vertebral artery, and resection of the posterior occipital condyle to allow for a ventrolateral exposure of the cervicomedullary junction (Fig. 5-4).

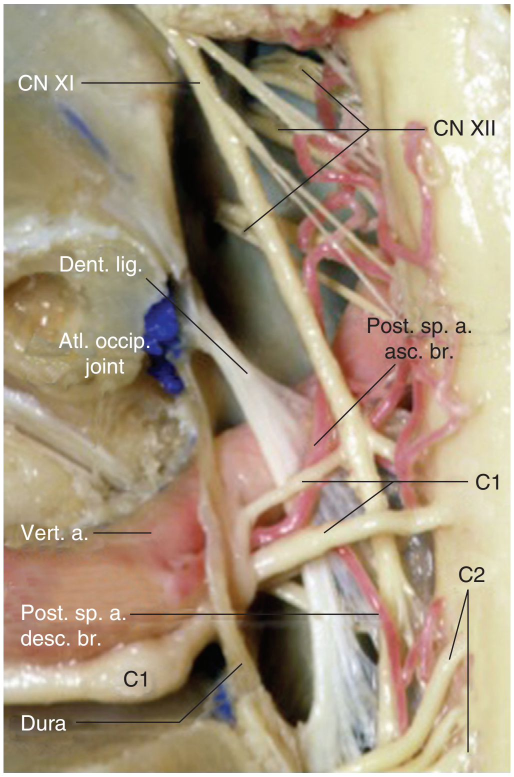

Figure 5-4 **A,** Posterior view of the left half of the CCJ after craniectomy and removal of the C1 vertebrae. The vertebral artery is seen passing below the atlantooccipital joint, piercing the dura (with the C1 nerve), and heading anterosuperiorly in front of cranial nerve (CN) XI and the dentate ligament. The cervical portion of CN XI ascends toward the jugular foramen, and the hypoglossal nerve courses behind the vertebral artery and enters the hypoglossal canal with the occipital condyle.

POSITIONING

Orotracheal intubation is performed, and the patient is placed in a Mayfield head holder. Neurologic monitoring may be used, including bilateral somatosensory-evoked potentials (SSEPs), bilateral brainstem auditory-evoked potentials, and cranial nerves X through XII. The patient is then placed in lateral decubitus position with the head in a neutral position.

SURGICAL TECHNIQUE

An inverted horseshoe or occasionally a hockey stick or C-shaped incision is made, with the two vertical components running in the midline and just medial to the ear. The horizontal component of the inverted horseshoe courses at the level of the upper pinna. The vertical components extend to approximately 5 cm below the external occipital protuberance (midline) and 5 cm below the mastoid (laterally), respectively. The subcutaneous tissues are dissected off the underlying SCM and splenius capitis muscles laterally and the trapezius medially. The skin flap is then retracted inferiorly.

Next, the occipital bone is dissected by sweeping the overlying musculature laterally with a periosteal elevator. The multiple muscles inserting on the mastoid are detached from the mastoid in a single layer. Those muscles in the posterior cervical triangle are dissected individually from their bony attachments and are reflected inferiorly. Underlying these muscle groups is the deep muscular layer that forms the suboccipital triangle. Recall that the horizontal segment of the vertebral artery and the C1 nerve root lie within the suboccipital triangle. This triangle is formed by the rectus capitis (major and minor) muscles medially, the superior oblique muscle superiorly, and the inferior oblique muscle inferiorly. The superior and inferior oblique muscles form the apex of the triangle, where these two muscles insert on the transverse process of C1.

Once the suboccipital triangle has been identified, and the transverse process of C1 has been visualized, the vertebral artery and its surrounding venous plexus can be identified (Fig. 5-5). Usually, mobilization of the vertebral artery is not needed; dissection to identify its course is frequently all that is necessary. However, if mobilization of the vertebral artery is necessary, the artery should be freed from its close relationship with the joint capsule between the occiput and C1. Should complete mobilization of the vertebral artery be necessary, resection of the C1 and C2 transverse processes and the C1 nerve root may be performed to allow inferior mobilization of the artery.

At this point, the vertebral artery has been exposed, as have the posterior arch of C1, the occipital bone, and the foramen magnum. A craniectomy is then performed with the extent of bone removal dependent on the degree of cranial exposure needed (Fig. 5-6). For large tumors that involve the posterior fossa, this may require removal to the sigmoid and transverse sinuses. The asterion (junction of sigmoid and transverse sinuses) and the external occipital protuberance (~1 cm below the torcula) are important landmarks to aid in bony removal.

Next, the posterior arch of C1 is removed, and the foramen magnum is exposed fully (Fig. 5-7). This is usually performed initially with a high-speed drill, with curettes and rongeurs used as needed. With the vertebral artery exposed below the occipital condyle, the posteroinferomedial margin of the condyle may then be drilled to increase anterolateral exposure. Removal of condyle is limited superiorly by the hypoglossal canal and above that by the jugular foramen and bulb. If the removal of the entire condyle is necessary, such as with invasive tumors of the condyle, occipitocervical fusion is required.

For intradural lesions, usually only about a third of the condyle must be drilled for adequate exposure. Usually, the dura is opened just medial to the sigmoid sinus, and the dural opening is extended caudally to the junction of the vertebral artery with the dura. At this point, the incision is carried around the vertebral artery, such that it has been totally freed from the surrounding dura to enable mobilization. Once the surgical objectives have been attained, closure proceeds in standard fashion.

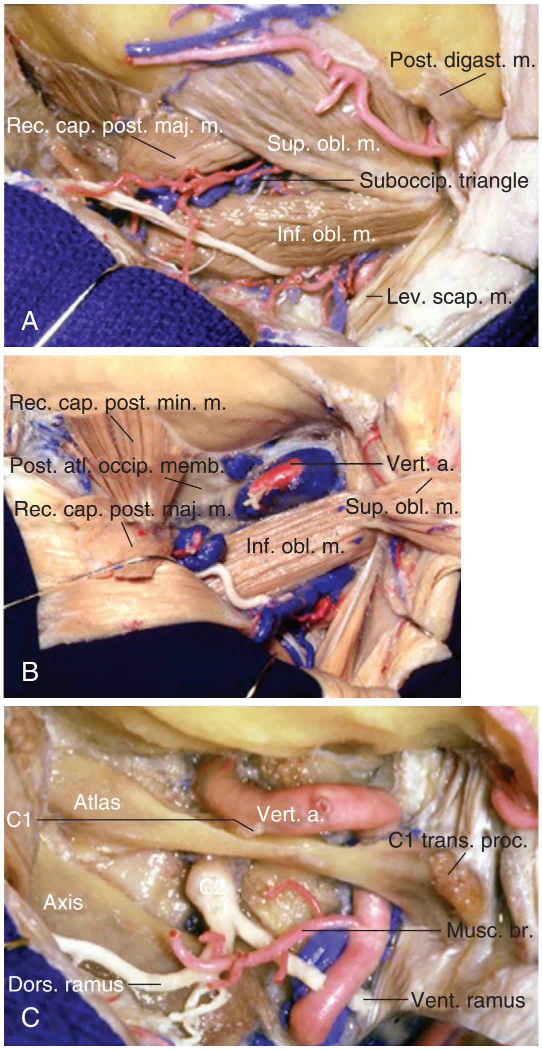

Figure 5-5 **A,** The right suboccipital triangle is exposed. **B,** With removal of the overlying muscles, the vertebral artery and its venous plexus are clearly visualized. Note the location of the C1 and C2 nerve roots. **C,** The venous plexus around the vertebral artery has been removed. The artery passes behind the atlantooccipital joint in the sulcus arteriosus before penetrating the dura.

Conclusions

The posterior approach to the CCJ is the most common means of obtaining dorsal decompression and in performing occipitocervical fusion. Most surgeons are familiar with this approach, and it carries a low risk of complications.

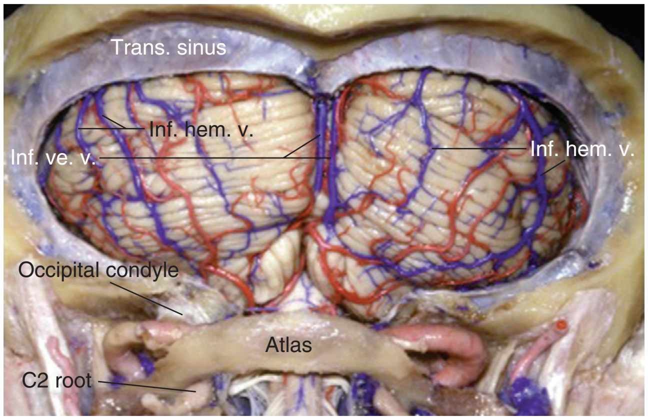

Figure 5-6 Posterior view of the CCJ demonstrates the relationships between the occipital condyles, C1 posterior arch, and vertebral arteries. A suboccipital craniectomy has been performed, which demonstrates the sigmoid and transverse sinuses.

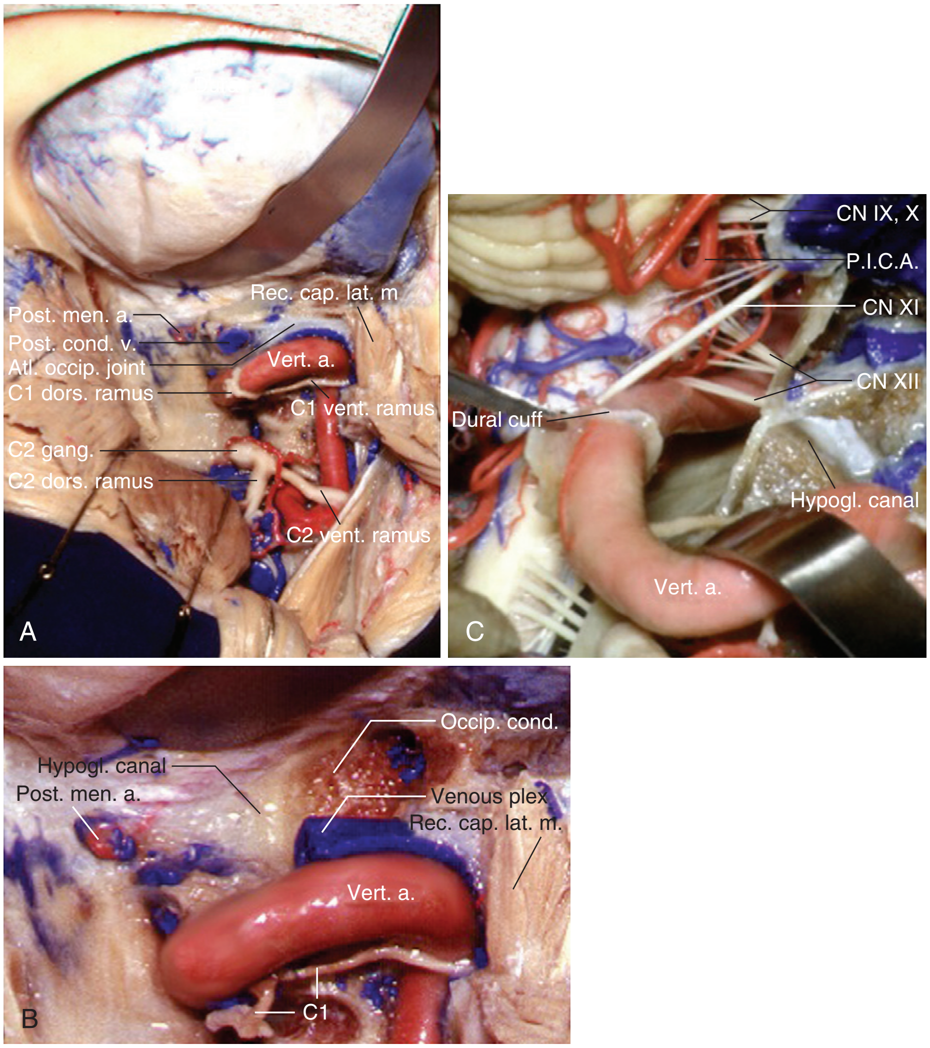

Figure 5-7 **A,** Exposure of the right suboccipital dura, condyle, and vertebral artery has been performed after suboccipital craniectomy and removal of the posterior arches of C1 and C2. **B,** The occipital condyle has been drilled (transcondylar approach) to the cortical bone lying immediately over the hypoglossal canal. This can usually be detected by the change from cancellous bone to cortical bone while drilling the condyle. **C,** After opening the dura, the lower cranial nerves are seen (note the dural cuff on the vertebral artery, demonstrating the normal location of the dura). The hypoglossal nerve is shown traveling inferolaterally to the hypoglossal canal.

Lateral and far-lateral approaches are best suited for lesions that are intradural and ventral or ventrolateral to the spinal cord near C1 and C2. The exposure is straightforward, with a true lateral view, and these approaches allow for identification and mobilization of the vertebral artery and spinal accessory nerve. Similarly, the risk of complication is low, and the bone removal usually does not result in a need for spinal fusion. If necessary, all of these approaches allow for fusion. Furthermore, each of these approaches offers the benefits of exposures that do not traverse contaminated spaces, such as may occur during anterior approaches to the CCJ.

6 Posterior and Far-Lateral Approaches to the Craniovertebral Junction: Lateral Transcondylar Approach

ANUBHAV G. AMIN, SHAAN M. RAZA, and MICHAEL LIM

Overview

A variety of surgical approaches have been developed for lesions located at the craniovertebral junction (CVJ). Access to the CVJ can be achieved via anterior, anterolateral, lateral, posterolateral, and posterior approaches depending on the location of the lesion.

The transoral-transpalatopharyngeal approach is most frequently used for anterior midline CVJ lesions because the lower clivus, C1, and C2 will be accessible.[1] Palatal or mandibular splitting may be utilized to achieve further rostral or caudal exposure. One significant disadvantage of the transoral route is its limited lateral visualization. Improved rostral-caudal and lateral visualization can be achieved with the use of angled endoscopes. Despite the use of endoscopes, the transoral approach is typically associated with several complications, including airway and swallowing difficulties, palatal dysfunction, and pharyngeal complications related to the posterior pharyngeal incision.[2] Most of these complications can be avoided with an endoscopic transnasal approach, because the incision will be more rostral, thus avoiding soft palate and pharyngeal complications. If a lesion extends laterally or caudally, the high anterior cervical retropharyngeal approach may be preferable. Another advantage of the high anterior cervical approach is that anterior cervical fixation and fusion can be performed simultaneously from this approach, thus avoiding supplementary posterior fusion.[3]

The far-lateral transcondylar approach (LTA) was first described by Heros.[4] The LTA consists of 1) muscle dissection along the posterolateral CVJ, 2) suboccipital craniectomy or craniotomy with 3) partial removal of the occipital condyle, and 4) partial removal of the posterior arch of the atlas. The LTA is particularly suited to access lesions located in the lower third of the clivus, anterolateral foramen magnum, and anterolateral to the CVJ. The LTA provides a wide lateral exposure to the brainstem while minimizing risk of vascular injury and provides good access to both intradural and extradural lesions, better development of the lesion-brainstem interface, and good reconstruction options for the cranial base.[5] The LTA provides significant advantages over alternative approaches to the anterior aspect of the CVJ. Unlike anterior transoral approaches, no contamination with oral flora occurs with the LTA. In comparison with traditional posterior approaches, the LTA provides better visualization of the vertebral arteries, its branches, and the lateral extent of the lesion with minimal retraction of the brainstem and cerebellum. However, there is a greater risk of lower cranial nerve (CN) deficits, increased incidence of aspiration pneumonia, and more difficulty with dural closure.

Anatomy Review

The CVJ consists of the lower clivus, foramen magnum, and C1–C2 with lateral borders extending to the jugular foramina, hypoglossal canals, and the occipital condyles.[5]

MUSCLE LAYERS

Three layers of muscles must be resected to gain the relevant exposure. The most superficial level consists of the sternocleidomastoid (SCM) and trapezius muscles. The middle muscle layer consists of the splenius capitis, longissimus capitis, splenius cervicis, and the semispinalis capitis. The muscles of the deepest layer make up the suboccipital triangle: the rectus capitis is the superior and medial border, the superior oblique is the superior and lateral border, and the inferior oblique is the inferior and lateral border (Fig. 6-1, *D*). The floor of the suboccipital triangle is made up of the posterior arch of the atlas and the posterior atlantooccipital membrane.

BONY ANATOMY

The occipital condyles are situated along the anterolateral border of the foramen magnum and project downward (see Fig. 6-1, *A*). The longest axis of the condyles is in the anterior-posterior direction with an average length of 21 mm; the articular surfaces are ovoid and articulate inferolaterally with the C1 superior facets, which face superomedially.[6,7] The hypoglossal canal is located directly above the

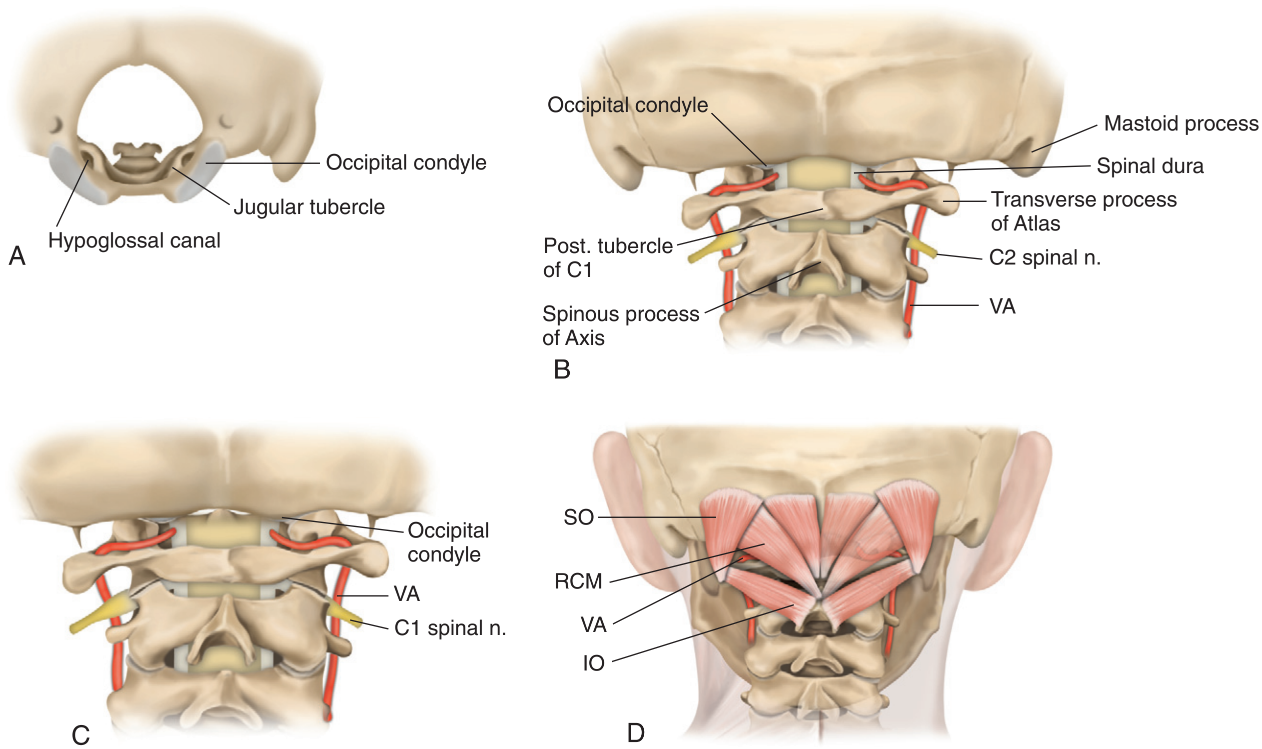

Figure 6-1 Relevant anatomy. **A,** The relationship of the occipital condyle to the hypoglossal canal and jugular tubercle. **B** and **C,** The path of the vertebral artery (VA) in relation to the bony anatomy. **D,** The suboccipital triangle formed by the superior oblique (SO), inferior oblique (IO), and rectus capitis muscle (RCM) is shown in relation to the VA.

middle of the occipital condyle, facing anterolaterally at a 45-degree angle from the midsagittal plane. The intracranial opening of the hypoglossal canal is approximately 5 mm above the junction of the posterior and middle third of the occipital condyle and 5 mm below the jugular tubercle. The extracranial opening of the hypoglossal canal is approximately 5 mm above the junction of the anterior and middle third of the condyle and medial to the jugular foramen.

The transverse process of C1 is an important landmark, because it projects farther laterally than other transverse processes and is the attachment point for several muscles that will be dissected in this exposure. The anterior portion attaches to the rectus capitis. The posterior portion of the superior surface attaches to the superior oblique muscle, and the inferior and lateral surfaces attach to the inferior oblique, levator scapulae, splenius cervicis, and scalenus medius muscles.

VERTEBRAL ARTERY

The LTA provides excellent exposure to the vertebral artery as it courses from C2 superiorly to the foramen magnum. The vertebral artery ascends laterally between the transverse foramen of C2 to C1 (see Fig. 6-1, *B* and *C*). The vertebral artery then makes a sharp medial turn as it advances along the upper surface of the posterior arch of the atlas, passing the C1 nerve root and surrounded by the vertebral venous plexus. The vertebral artery then bends anteromedially as it enters the dural layer just adjacent to the occipital condyle.

Several muscular arterial branches arise from the vertebral artery during its course from the C2 transverse foramen to the foramen magnum. The posterior meningeal artery branches from the posterior surface of the vertebral artery, typically before it penetrates the dura in the region of the foramen magnum, but it may also have an intradural origin.[7]

The C1 transverse process is a significant landmark, because the internal jugular vein and the eleventh CN lie anterior to it, and the vertebral artery can be followed coursing through the transverse foramen when the transverse process is removed. The C2 nerve root is an important landmark, where it traverses over the vertebral artery. The ventral rami of the C1 and C2 nerve roots pass behind the vertebral artery.

CRANIAL NERVES

After entering the dura, the lower CNs can be seen coursing from the brainstem to their exiting foramina. The transcondylar exposure will allow the dura to be reflected further laterally, thus providing a larger viewing angle. The rootlets of CNs IX to XI arise just posterolateral to the olive, and they exit via the jugular foramen and descend behind the internal carotid artery. Of note, CN XI has two distinct components, with cranial rootlets arising from the medulla that join lower rootlets arising from the spine at the level of the foramen magnum. CN XI will be the first CN encountered through this approach. The rootlets of CN XII arise from the medulla and pass anterior to the vertebral artery and exit via the hypoglossal canal.

Indications

INTRAMEDULLARY

- Hemangioblastomas
- Cavernous malformations

EXTRAMEDULLARY, INTRADURAL

- Meningiomas
- Hemangiopericytomas
- Schwannomas
- Paragangliomas
- Dermoid/epidermoids
- Vertebrobasilar aneurysms

EXTRADURAL

- Chordomas
- Metastases
- Epidural abscesses
- Rheumatoid pannus
- Bony compression

Relative Contraindications

- Limited life expectancy
- Severe medical comorbidities that would prevent major surgery
- Lesions primarily located midline

Preoperative Imaging

MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging (MRI) provides excellent detail of the soft-tissue component of the lesion. It reveals the relationship of the lesion to the brainstem, clival dura, and adjacent CNs and shows whether it extends into the retropharyngeal and parapharyngeal spaces. MRI will also allow assessment of the size of both vertebral arteries relative to each other and assessment of their relationship to the lesion.

COMPUTED TOMOGRAPHY

Computed tomography (CT) will allow for good visualization of the lesion and of the bones involved in the approach. Bony erosion extending to the occipital condyles can be seen with some chordomas. CT can also be used to assess for CVJ instability (atlanto-dens interval, basilar invagination, etc.).

VERTEBRAL ANGIOGRAM

Angiography is useful for identifying major blood vessels for detailed surgical planning. It can be used to assess the patency of the contralateral vertebral artery, possible extradural origin of the posterior inferior cerebellar artery (seen in 5% to 20% of cases),[8] presence of patent posterior communicating arteries in case of a vertebral artery injury, and presence of a patent contralateral transverse sinus–sigmoid sinus and jugular bulb in case the ipsilateral system is exposed and sacrificed.

A vertebral artery balloon occlusion test or preoperative takedown can be considered for tumors when an en bloc resection will be attempted (C2 chordomas).

Operative Technique

EQUIPMENT

Intraoperative neurophysiologic monitoring should be used for real-time assessment of neurologic deficits that may occur during surgery. Somatosensory evoked potential (SSEP) monitoring has been shown to have a high positive predictive value during surgery for cranial-based tumors but may not detect all postoperative deficits.[9] Brainstem auditory evoked potentials can be used to ensure the integrity of the auditory nervous system during skull base surgery without interfering with the actual surgical procedure.[10] Lower CN monitoring—especially of the glossopharyngeal, vagus, and hypoglossal nerves—is feasible in skull base surgery and should be used to prevent injury and maintain adequate pharyngeal function and swallowing.[11,12]

PATIENT POSITIONING

The patient is placed in the lateral decubitus position (Fig. 6-2, *A*) with the head secured within a Mayfield clamp. The head is positioned such that the cervical spine is flexed in the anteroposterior plane, with the head rotated 45 degrees to the contralateral side, so that the mastoid process is the

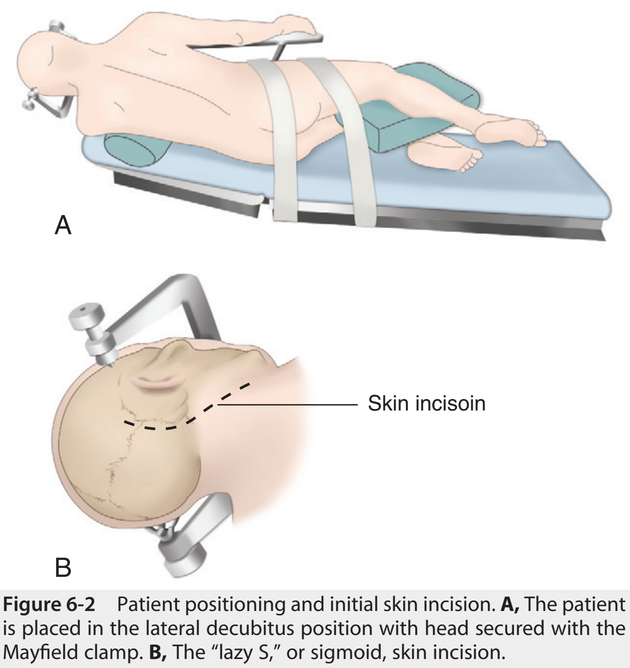

Figure 6-2 Patient positioning and initial skin incision. **A,** The patient is placed in the lateral decubitus position with head secured with the Mayfield clamp. **B,** The "lazy S," or sigmoid, skin incision.

highest point in the operative field and with lateral cervical flexion toward the opposite shoulder to distract the occipital –C1 joint space. The ipsilateral shoulder is retracted to preclude obstruction of the surgical view. The dependent arm is protected in foam padding and is positioned below the operating table, attached to the Mayfield clamp.

INCISION

Three types of skin incision can be used. A 1- to 2-cm linear paramedian incision starting from the superior nuchal line and medial to the mastoid process can be used for its ease in opening and closing.[13] However, this incision requires extensive retraction and creates a deep surgical field, thus making it difficult to remove the C1 posterior arch and the C2 lamina. Alternatively, an inverted hockey stick incision can be made that starts at the mastoid process, proceeds medially along the superior nuchal line, and projects inferiorly at the midline. This extended incision allows a wide C1–C2 laminectomy, if needed. The third type is the sigmoid or "lazy S" incision (see Fig. 6-2, *B*). This skin incision begins 1 to 2 cm dorsal to the mastoid at the level of the superior portion of the pinna and extends inferiorly in an "S" shape along the SCM to C3–C4.

MUSCLE

The scalp, galea, pericranium, and fascia are incised and retracted to reveal the SCM and trapezius muscles. These muscles are divided, the SCM is retracted laterally along with the scalp, and the trapezius is retracted medially. Anterolateral to the SCM lies the internal jugular vein. Deeper, the splenius capitis and longissimus capitis are detached from their insertions at the occiput, and the splenius cervicis is detached from its insertion on the C1 transverse process. These middle layer muscles are retracted posteriorly. The vertebral artery lies deep to the splenius cervicis within the transverse processes of C1 and C2. The deep muscles—obliquus capitis superior, obliquus capitis inferior, and rectus capitis major—form the suboccipital triangle. The vertebral artery lies within fibrofatty tissue in the suboccipital triangle as it traverses medially across the atlas and ascends superiorly into the foramen magnum. The obliquus capitis superior is resected, and the obliquus capitis inferior is detached from its insertion on the C1 transverse process and is retracted posteriorly. C1–C2 laminae and vertebral artery are exposed. The posterior atlantooccipital ligament is adherent to the dura mater and is incised to expose the dura.

BONE EXPOSURE

A burr hole is drilled near the transverse sinus–sigmoid sinus junction, which can be marked with neuronavigation. A craniectomy or craniotomy is created: the anterior border extends to the sigmoid sinus, the posterior border extends to the midline, and the inferior border extends to the foramen magnum (Fig. 6-3, *A*). Lastly, a C1 hemilaminectomy is performed. During removal of the C1 posterior arch, the vertebral artery is dissected and protected. If necessary, the vertebral artery can be further mobilized by removing the bony roof of the foramen transversarium.

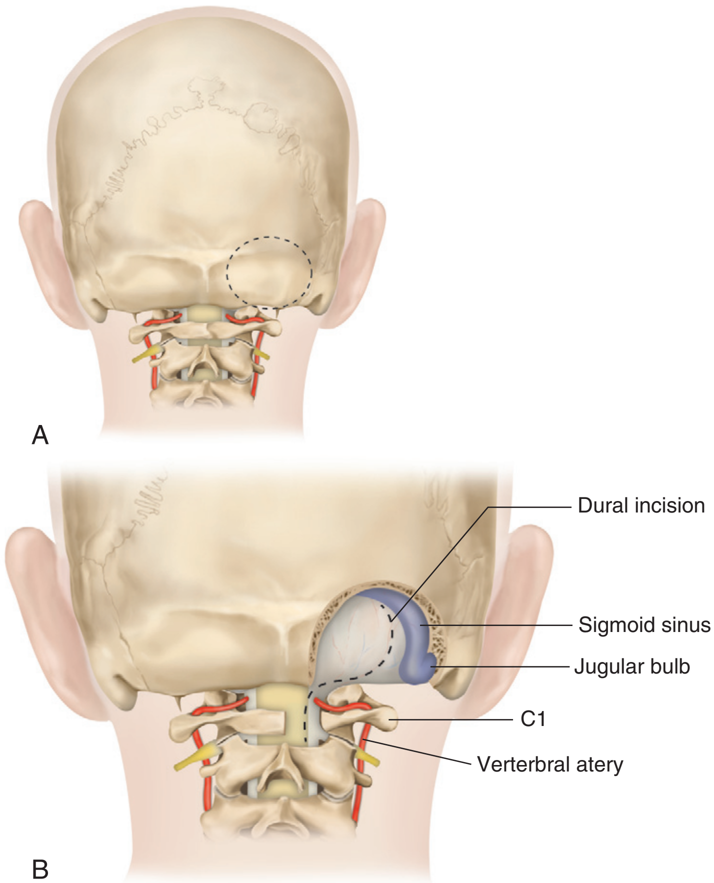

Figure 6-3 Bone exposure and dural incision. **A,** The location of the suboccipital craniectomy is outlined. **B,** Suboccipital craniectomy with a C1 hemilaminectomy has been performed, revealing the path of the dural incision.

To maximize exposure to the anterior side of the brainstem, the atlantooccipital joint is exposed by dissecting the synovial capsule, and the posterior one third of the occipital condyle and the jugular tubercle are reduced. CN XII typically lies anterior and superior to the occipital condyle; thus removal of the posterior portion of the occipital condyle poses minimal risk. The condylar emissary vein is located superior to the atlantooccipital joint and is packed to prevent profuse bleeding; this typically marks the extent of the necessary condylar drilling. The thinned bone is dissected from the dura. Typically no more than one third of the occipital condyle is reduced; however, if the lesion involves the occipital condyle, the entire condyle may need to be reduced, and stabilization will be necessary.

For lesions with inferior extension, hemilaminectomies down to the appropriate spinal level can be performed to provide appropriate exposure. Furthermore, for lesions with ventral extension inferiorly around the spinal cord, ipsilateral facetectomies can be performed to provide additional ventral exposure.

INTRADURAL EXPOSURE

The dura is incised just posterior to the sigmoid sinus, and the incision extends inferiorly to C1–C2, staying medial to the vertebral artery (see Fig. 6-3, *B*). If needed, a second circular dural incision around the vertebral artery can be made to retract the dural leaflet without compromising vertebral artery flow. The dural layer is then secured anteriorly and laterally with multiple tack-up sutures. The arachnoid layer is incised, revealing the vertebral artery, posterior inferior cerebellar artery, anterior inferior cerebellar artery, lateral medulla, and the sixth through twelfth CNs (Fig. 6-4). Resection of the lesion is achieved with standard microsurgical techniques depending on the lesion.

CLOSURE

The dura is closed with a running suture, either Prolene or Surgilon, to achieve a watertight seal. If needed, pericranium can be used as a dural graft, or dural substitutes and sealants can be used to bolster the dural incision. When a craniotomy has been performed, the flap is secured with standard titanium plates. The muscular layers are subsequently reapproximated and sutured in place in a meticulous fashion to prevent formation of a postoperative cerebrospinal fluid fistula.

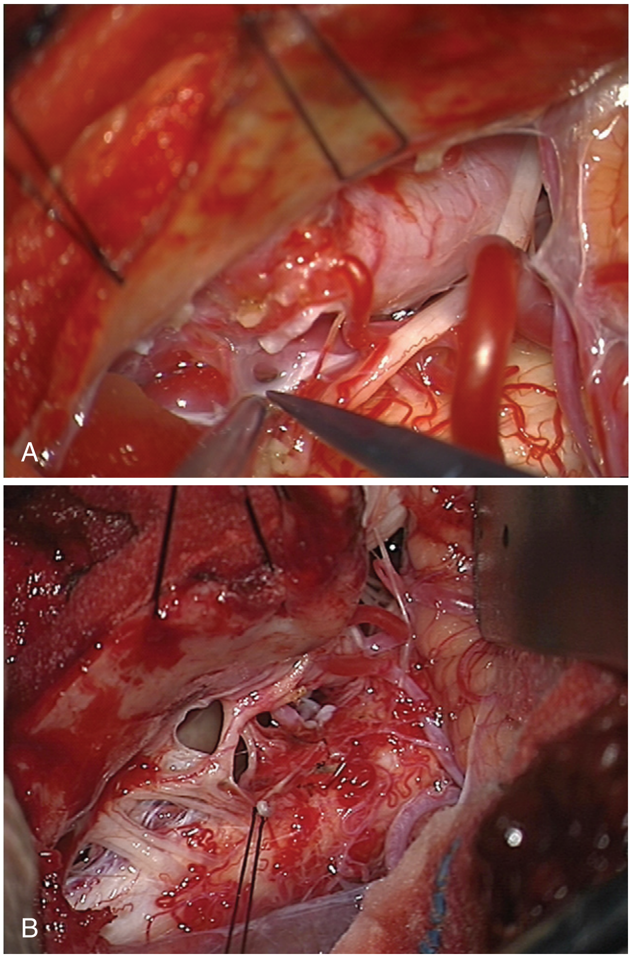

Figure 6-4 **A,** Dural arteriovenous (AV) fistulas exposed via the far-lateral transcondylar approach. **B,** Dural AV fistulas exposed via the far-lateral transcondylar approach.

Postoperative Care

The patient is monitored in an intensive care unit. If a lumbar drain is used, it is typically removed 3 days after surgery. Prophylactic antibiotics are continued for three doses postoperatively.

Complications

NEUROLOGIC

The lower CNs are well visualized via the LTA. It is critical to follow the course of each CN within the operative field to minimize postoperative deficits. The nerves are identified early, at either the exit from the brainstem or at the appropriate foramina, to protect them during the tumor dissection. The use of intraoperative monitoring, including for lower CNs with brain auditory-evoked responses and a Vim tube, helps to guide intraoperative decision making and brain manipulation to minimize the chances of postoperative deficits. Depending on the degree of CN manipulation, patients can be left intubated postoperatively until their lower CNs can be accurately assessed before extubation.

VASCULAR

Adequate exposure will minimize the risk of vertebral artery injury. Inadvertent intraoperative injury can be managed with primary repair (with 10-0 nylon sutures) or trapping of the injured segment. Before trapping a lacerated segment, assess the location of the posterior inferior cerebellar artery origin, and determine whether it backfills from the contralateral vertebral artery.

When drilling for bony exposure, the sigmoid sinus and jugular bulb are at risk for injury. A thin layer of bone can be left on the venous sinus to minimize risk of injury. To further minimize the risk of venous sequelae, the patency of the contralateral transverse sinus–sigmoid sinus system should be assessed before skeletonizing venous structures in the operative field.

CLOSURE AND LEAKS

A watertight seal is needed when suturing the dura to avoid a cerebrospinal fluid leak. A lumbar drain is used in the presence of communicating hydrocephalus.

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7 Endoscopic Approaches to the Craniovertebral Junction

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Overview

Surgical access to the craniovertebral junction (CVJ) is challenging because of its deep, anatomically protected location and the diverse pathology involved in this region. Examples of lesions that involve the CVJ include rheumatoid pannus, lower clival chordomas and chondrosarcomas, congenital skull base malformations and basilar invagination, metastatic disease, and even intradural pathology such as meningiomas and vascular malformations. The most direct approach to the anterior CVJ is by the ventral transoral route.[1,2] Initially described by Fang and Ong[3] in 1962 and refined by Menezes,[4,5] Crockard[6] and Hadley,[7] this approach is the preferred workhorse for pathology in this location; however, it has several limitations. Specifically, the microscopic transoral route creates a deep and narrow working channel that can produce inadequate visualization of the pathologic process and surgical bed. To improve visualization and access, additional approaches to the craniocervical junction include transfacial and high-cervical retropharyngeal approaches. In addition, lateral and posterior approaches to the CVJ have been described, but we focus our discussion on ventral approaches in this chapter.

Based on the significant morbidity associated with the more traditional microsurgical approaches, surgeons have pioneered less-invasive techniques to approach the CVJ. Although the operative microscope provides direct illumination of the operative field, illumination and visualization are restricted to a narrow cone of direct light. In contrast, endoscopes can provide direct illumination with a wider, panoramic field of view. Fortunately, endoscopes have become commonplace in hospitals and operating rooms across the world, and the technology is easily available in almost any operating room. Endoscopic illumination is at the end of a long glass rod, allowing light to penetrate deeper and closer to the target. Modern endoscopes can also capture a large field of view up to about 80 degrees, giving the surgeon a panoramic perspective.

The familiar drawback of the endoscope is its ability to give only a two-dimensional (2D) image, which can be somewhat overcome with movement of the scope and manual palpation to provide secondary depth perception clues. In addition, resolution of an endoscope coupled to a camera is only as good as the camera and screen (e.g., 1080 light pairs), whereas a microscope allows for direct visualization using the human retina, which has dramatically more resolving power than even the best high-definition video. Nevertheless, rapid improvements in video technology and the introduction of three-dimensional (3D) endoscopes have continued to provide advancements in the field.[8,9] Endoscopes can be used free-hand, or they can be placed in a holding system to allow the surgeon and assistant full use of both hands during the procedure. Endoscopes come in a wide variety of angles but typically only a zero-degree, 30-degree upviewing, and 30-degree downviewing endoscope are needed for neurosurgery, because greater-angle scopes may provide adequate visualization without the corresponding ability to perform the manual dissection.

Given the improvements in endoscopic access to the ventral skull base and ventral CVJ, this chapter will review three endoscopic approaches: 1) endoscopic endonasal; 2) endoscopic transoral, including transoral robotic surgery (TORS); and 3) endoscopic transcervical. All use endoscopy to aid in visualization of the CVJ, and all attempt to avoid the morbidity usually associated with the more "open" approaches discussed above.

Surgical Anatomy

Because the ventral transoral route is the standard approach to the CVJ, we only briefly review the anatomy here with a focus on endoscopic nuances.

ENDOSCOPIC ENDONASAL APPROACH

- This approach allows access to the skull base superiorly but is limited to the upper C2 inferiorly (Fig. 7-1).
- When entering the nasal cavity, the turbinates must be lateralized, and the nasal septum must be resected, followed by a sphenoidectomy.
- By removing the posterior nasal septum, space is made for four instruments to pass through both nares.
- The floor of the sella, the carotid protuberances, and the upper clivus can be visualized after removal of the posterior sphenoid sinus wall using a zero-degree endoscope; a 30-degree endoscope can be used to visualize more superiorly or inferiorly as necessary.
- A midline incision in the posterior pharyngeal mucosa should be kept above the Passavant ridge to avoid subsequent swallowing difficulty. The mucosa can be retracted out of the way of surgical dissection with use of long, thin, vocal cord retractors that can be placed either endonasally or transorally to allow the surgeon to continue to use the endonasal access for surgical instruments.

Figure 7-1 The limits of surgical access for transnasal and transoral endoscopic surgery.

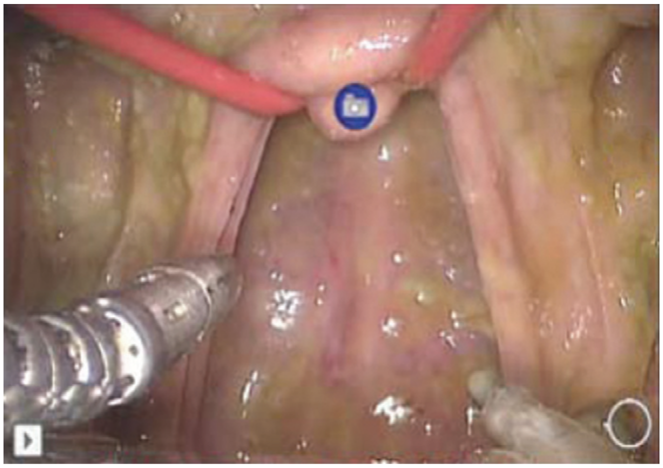

Figure 7-2 Zero-degree endoscopic view of the uvula and soft palate being retracted superiorly.

ENDOSCOPIC TRANSORAL APPROACH

- The transoral approach is typically limited by mouth opening and by the concern for disarticulation of the temporomandibular joint (TMJ) with excessive mouth opening. In addition, the hard palate remains a physical barrier for superior access along the lower clivus. Both mouth opening and restricted view secondary to the hard palate are less of an issue with use of an endoscope, which can provide illumination and visualization that is more panoramic and not necessarily limited to line of sight.[10]
- The soft palate can obscure the view, but it can be retracted and elevated using red rubber catheters taken out through the nose and the mouth (Fig. 7-2).
- Splitting of the soft palate for better superior or inferior visualization is rarely needed with angled endoscopes; if necessary, it can be performed by carrying an incision from the posterior soft palate anteriorly through the uvula to the hard palate, securing both flaps laterally (Fig. 7-3).
- The anterior arch of the atlas can be visualized through the soft tissues of the pharyngeal mucosa and can be palpated with soft pressure (see Fig. 7-3).
- A midline incision in the posterior pharyngeal mucosa can be carried down to the bone at C1 and extended inferiorly as an incision in the midline, a relatively avascular plane (Fig. 7-4).

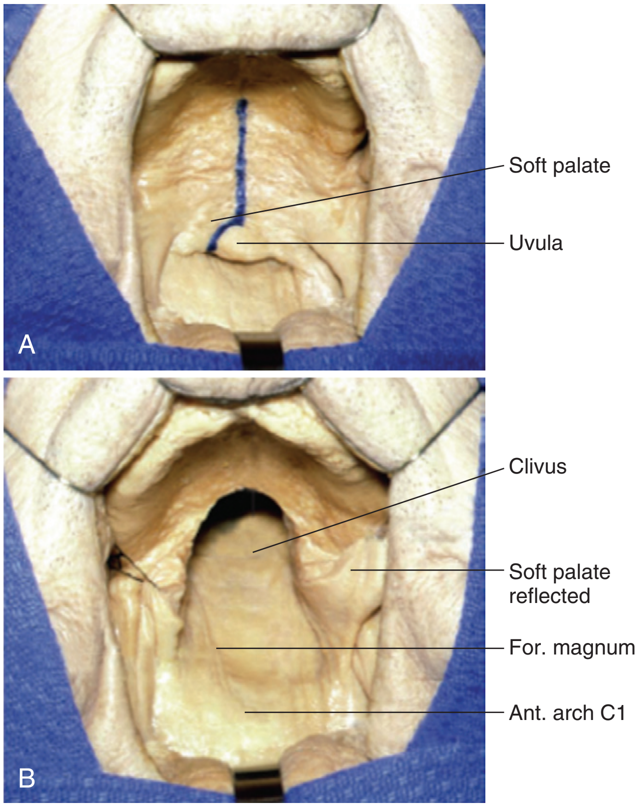

Figure 7-3 Splitting of the soft palate by carrying an incision from the posterior soft palate anteriorly through the uvula and reflecting the divided tissue laterally.

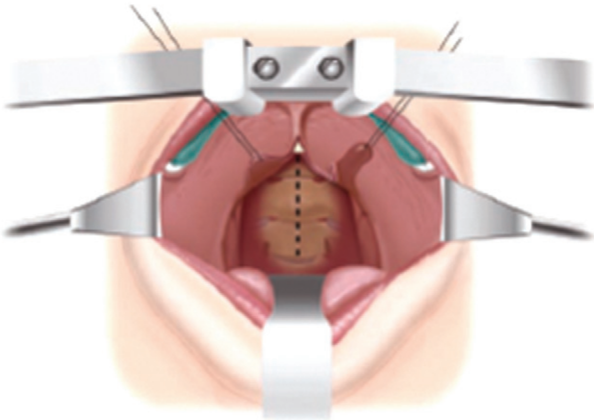

Figure 7-4 A midline incision is made in the posterior pharyngeal mucosa.

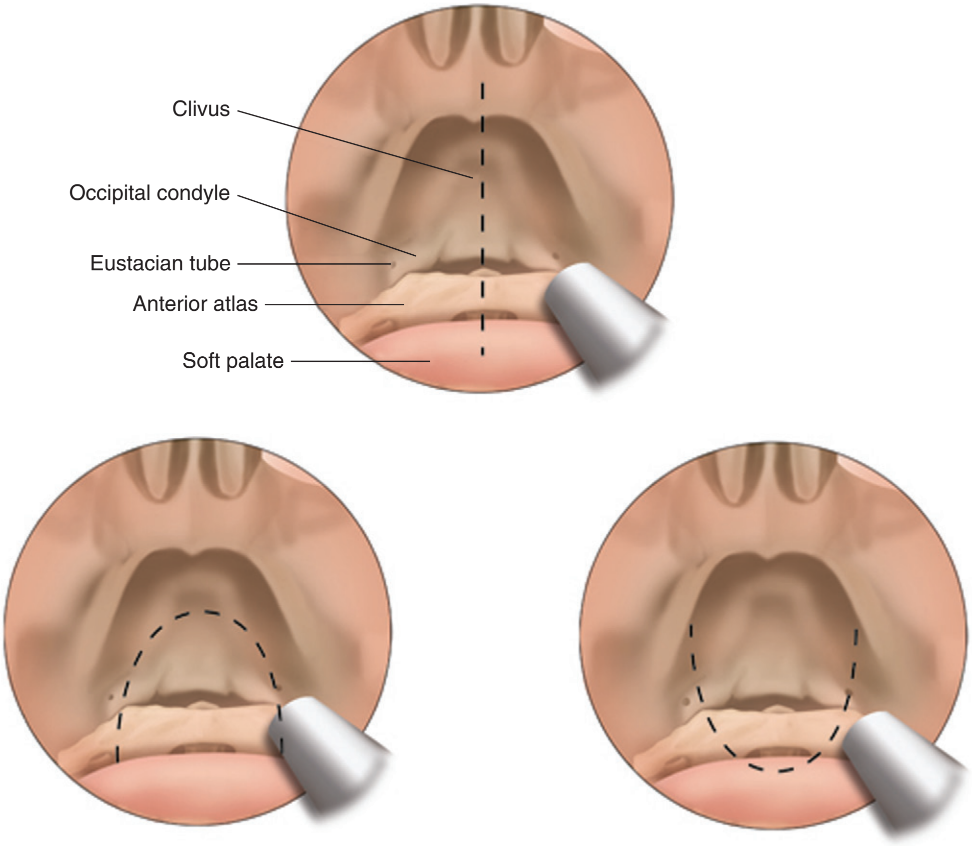

Figure 7-5 Endoscopic view of the landmarks used in the endoscopic transoral approach, including the eustachian tubes, anterior atlas, and soft palate. A U-shaped incision can be made in the posterior pharyngeal wall but must be limited to the superficial muscular layers to avoid injury to the pharyngeal plexus of the vagus nerve.

- A U-shaped incision, preferred by some surgeons, may be made, but it must be limited to the mucosal layers only, because the deeper muscular layers contain the pharyngeal plexus of the vagus nerve (Fig. 7-5).
- The surgeon must be aware of the possibility of aberrant vertebral arteries, although these usually lie at least 1 cm from the midline (Fig. 7-6).
- The eustachian tubes are an excellent landmark, although their position may be altered as a result of the pathologic process; they represent the lateral extent of the subperiosteal dissection at the level of C2, because they are relatively fixed in the skull (see Fig. 7-5).
- The endoscopic transoral approach allows access to the lower one third of the clivus and inferiorly to the C2–C3 disk space (see Fig. 7-1).

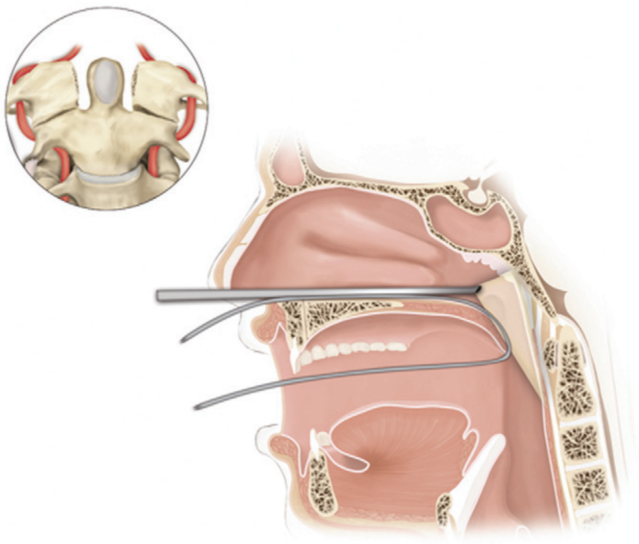

Figure 7-6 Bony anatomy and vertebral artery course encountered during a ventral approach to the craniovertebral junction. The vertebral arteries lie laterally but may be aberrantly medial in some cases.

ENDOSCOPIC TRANSCERVICAL APPROACH

- The endoscopic transcervical approach permits access to the anterior tubercle of C1 superiorly and the lower cervical spine inferiorly. This approach theoretically has no lower limit, because a wide transverse cervical incision can expose the cervical spine to the cervicothoracic junction.[11]
- Anatomy via this approach is well known to spine surgeons; it mirrors the anatomy encountered when performing an anterior approach to the lower cervical spine. Careful attention to the location of the digastric muscle

and hypoglossal nerve will help to minimize traction injury to that nerve.

- A tubular retractor system helps to minimize overly aggressive retraction, and the use of a 30-degree endoscope positioned at the superior portion of the tubular retractor can look "down" on the anatomy, providing the familiar perspective of a head-on view of the ventral cervical spine.[11]
- Visualized anatomy in this approach is limited to the surface anatomy that can be visualized through the tubular retractor. If there is a need to see an area greater than that provided by the tubular retractor, the retractor must be repositioned along with the endoscope. This may make it difficult to see anatomic relationships to neighboring structures.

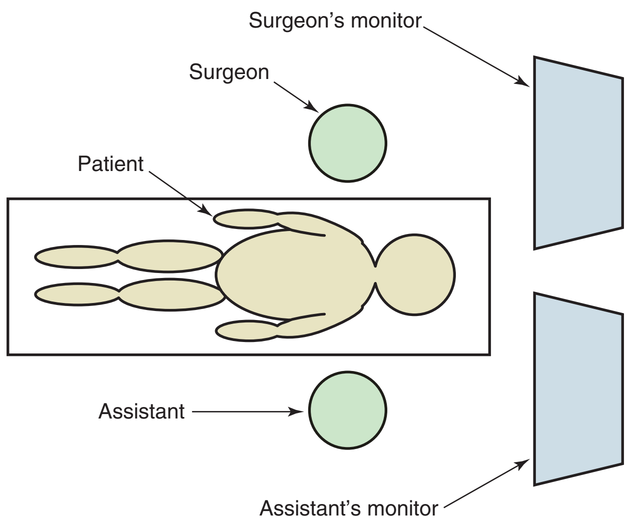

Figure 7-7 Room setup for endoscopic endonasal or endoscopic transoral surgical procedures. The positions of the primary operating surgeon, assistant, and endoscopic monitor displays are shown.

Operative Techniques

ENDOSCOPIC ENDONASAL APPROACH

Rationale

Transnasal endoscopic surgery has become the workhorse of minimally invasive approaches to the ventral anterior skull base and is primarily used to tackle tumors in the anterior skull base and the sellar/suprasellar region. Endoscopic transclival surgery is technically feasible, and approaches through the endonasal route to the CVJ are possible, including both extradural and intradural pathology. It is best used for tumors of the lower clivus that secondarily involve the CVJ.

Preparation and Positioning

When approaching the CVJ via the endonasal route, it is important to take into account that this approach is not capable of providing access to the lower portion of the body of C2 (see Fig. 7-1).[10] If a large dural opening is planned for intradural pathology, such as a foramen magnum meningioma, closure techniques must be addressed prior to surgery. A lumbar drainage device may be placed for cerebrospinal fluid (CSF) diversion and may be used as an aid to dural closure and healing, although our group has gradually moved away from this as a routine adjunct for dural closure. In addition, proper consideration of vascularized closure with mucosal flaps must be made in conjunction with a rhinology or head and neck ENT colleague.[12]

The patient is positioned supine on the operating table. If imaging guidance is to be used, the preferred system may be set up at this time, which may require rigid skull fixation. A surgeon and assistant stand on either side of the patient at the level of the patient's shoulders; viewing monitors are situated at the head of the bed (Fig. 7-7). The patient is given a broad-spectrum antibiotic; the nares are not usually prepped with any specific topical antibiotic. The nasal mucosa is subjected to cocaine or cottonoids soaked in Afrin, and major mucosal feeding vessels and mucosa are injected with a vasoconstrictor, such as lidocaine, to reduce bleeding and mucosal bulk.

Surgical Procedure

In endoscopic endonasal cases, we prefer to work in collaboration with an otolaryngologist, especially if vascularized nasoseptal flaps are needed to assist with closure. We generally do not use an endoscope holder and instead prefer the active movement and attention provided by an engaged otolaryngologist as a surgical assistant. A zero-degree endoscope is used for the initial portions of the case and may be supplemented with a 30-degree endoscope, looking down over the hard palate to the CVJ. Under endoscopic visualization after vasoconstrictor injection, the middle and superior turbinates are gently lateralized to reveal the sphenoid os. A nasal septoplasty is then performed to reveal the sphenoid sinus and nasopharynx. This approach allows four instruments to be used, two in each nostril.

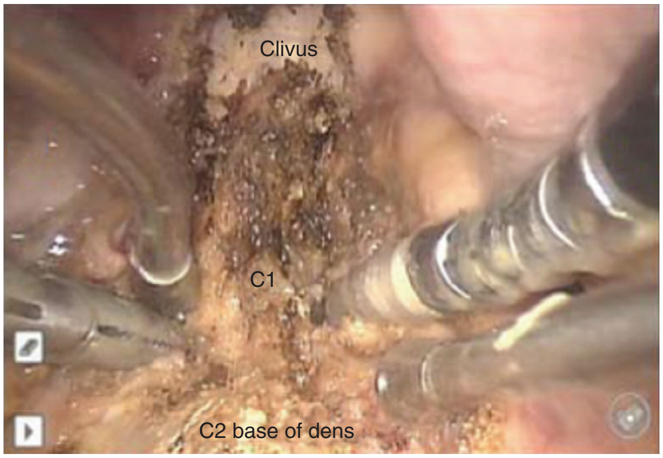

Figure 7-8 Endoscopic view of the cadaveric CVJ after removal of the soft tissues and anterior longitudinal ligament.

The sphenoid face and prow are then resected to reveal the superior one third of the clivus. If the inferior clivus is to be reached at midline, a linear incision in the posterior pharyngeal mucosa is made, and the mucosa is retracted with vocal cord laryngeal retractors that can be placed either transnasally or transorally. This reveals the bone of the clivus (Fig. 7-8), which can be drilled. When drilling the clivus, brisk venous bleeding is typically encountered that

Figure 7-9 Endoscopic view of opening of the dura in a cadaver following bony removal. Endoshears are used to carry the incision inferiorly and superiorly as necessary.

can be controlled with hemostatic agents and gentle pressure and packing. Following removal of the clival bone, the dura becomes apparent, and typically the pulsation of the basilar artery is encountered. The medial occipital condyles can be used as lateral borders of drilling. If the pathology extends laterally, the hypoglossal canal usually serves as the limit of the lateral dissection.[13] Drilling can continue inferiorly to the atlantoaxial complex as the pathology dictates. If intradural pathology is to be reached, the dura can be opened in the midline (Fig. 7-9), and tack-up sutures can be placed in the dural edges and taken out through the mouth and hung or tacked to the lateral pharyngeal mucosa. Following intradural work, the dura can be closed in a variety of methods, including the use of intradural and extradural fat, fascia lata patches, and nasal septal flaps. Fibrin glue can also be used to assist with closure.

ENDOSCOPIC TRANSORAL ROBOTIC SURGERY

Rationale

Endoscopic transoral surgery improves visualization of the standard transoral approach and minimizes the need to perform mandibulotomy, Le Fort fracture extensions, or maxillary antrostomies in an effort to improve access via the standard transoral approach. The difficulty of the standard transoral approach for odontoidectomy and access to the CVJ lies in the depth of critical structures and corresponding difficulty in obtaining adequate visualization to safely carry out dissection; in addition, the narrowness of the working channel limits the freedom with which a surgeon can manipulate instruments. The transoral route has been expanded to include intradural pathologies such as meningiomas and intradural extensions of chordomas and chondrosarcomas. A major limitation of tackling intradural pathology, however, is the limited ability to achieve a watertight dural closure.

An extension of the endoscopic transoral approach is offered by the da Vinci Surgical System (Intuitive Surgical, Sunnyvale, CA). TORS is a new development pioneered at the University of Pennsylvania for head and neck cancers.[14] In this approach, a dual-channel endoscope provides stereoscopic visualization, and the telerobotic arms provide distal dexterity within the confines of the natural opening of the mouth. TORS using the da Vinci robot overcomes the problem of visualization through superb illumination and 3D depth perception, even several centimeters deep to the posterior oropharyngeal mucosa. This is achieved without elaborate measures taken to improve visualization, such as splitting the mandible or incising the soft palate, which creates significant postoperative pain and is a source of morbidity. Using the robot also aids operation on intradural pathology, because the robotic arms can manipulate sutures in the small space to repair dural defects. The da Vinci's major limitation, however, is the lack of bone-cutting instruments, such as rongeurs or drills; thus endoscopic transoral robotic procedures using the da Vinci robot often include a substantial portion of the bone work being performed by the bedside assistant, rather than the surgeon, at the console.

Preparation and Positioning

Before surgery, communication and collaboration with anesthesia colleagues is important. Correct choice and proper placement of the endotracheal tube (ETT) is a must. Ideally, an armored ETT is placed in the midline that exits inferiorly toward the patient's feet. All intravascular access lines also exit toward the feet so as to not interfere with imaging or movement of the surgeon or robot during the procedure. Use of intraoperative monitoring, including somatosensory evoked potentials and motor evoked potentials, can also be useful to prevent positioning the patient's neck in such a way that will compromise the spinal canal.

The patient is positioned supine with the neck slightly extended as permitted by the patient's specific pathology. The patient's head is fixed in either a Mayfield head holder or halo–vest, depending on the stability of the patient's spine. Lateral fluoroscopy may be brought in at this time to aid in visualization and localization of the bony anatomy both preoperatively and intraoperatively; this can be moved to the foot of the bed when not in use. For TORS, the robot is positioned at the head of the bed, cranial to the patient's head, to optimize the use of its three robotic arms (Fig. 7-10). The binocular endoscope arm is brought in on the midline, and the two articulating arms enter laterally without compression of the buccal skin folds (Fig. 7-11). The procedure is begun with a 12-mm zero-degree endoscope with the option of using a 30-degree endoscope for looking inferiorly or superiorly. A Maryland articulated dissector is placed in the left endoscope arm, and a monopolar spatula-type electrocauterizer is placed in the right. For endoscopic procedures, surgeons position themselves at both sides of the head of the patient for optimal ergonomics and visualization, with the endoscopic display monitor at the head of the bed (see Fig. 7-10). Standard endoscopic instruments are used.

Surgical Procedure

Several retractor options are available for mouth opening, such as a Dingman retractor or a Crowe-Davis retractor (Storz; Figs. 7-12 and 7-13). The oral opening should be no more than 4 cm, and care should be taken to avoid overdistraction, especially in patients suffering from trismus or TMJ

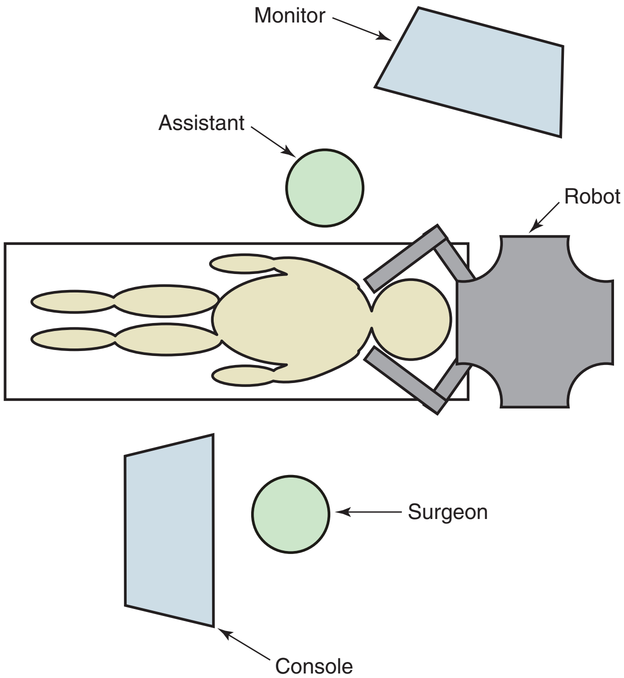

Figure 7-10 The room setup for TORS. The position of the operating surgeon at the robotic console and the assistant at the bedside are shown.

Figure 7-11 The robotic arms are introduced transorally and are angled cephalad toward the nasopharynx and cranial base.

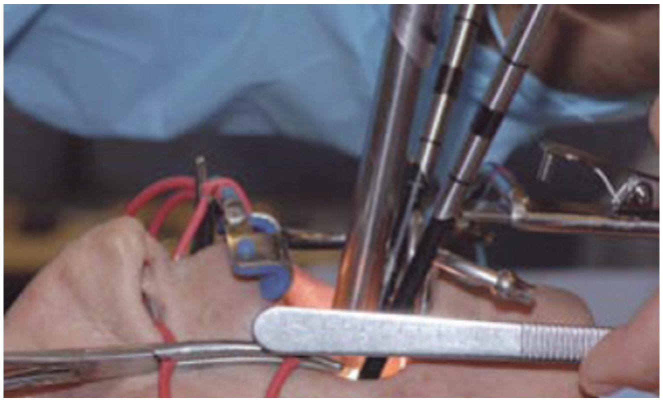

Figure 7-12 The camera and arms are all inserted through the mouth, which is held open by a transoral Crowe-Davis retractor. Red rubber catheters are used to retract the soft palate. The maximum diameter of the interincisal opening was restricted to 4 cm.

disease. Two red rubber catheters can then be placed through the nose and brought out laterally through the mouth for uvular and soft palate retraction (see Fig. 7-2). Alternatively, a stitch can be placed in the uvula and carried out through the nose for retraction. Teeth guards should be used to protect the patient's dentition, and it is important to ensure that the tongue is not compressed against the teeth by either the retractor or the ETT.

The mucosal dissection is begun by the primary operating surgeon, typically an assisting otolaryngologist, at the robot console station; a midline incision is made in the pharyngeal mucosa with the assistant providing suction with a standard Frazier-tip sucker. The assistant is positioned to the right of the patient and can view exactly what the primary surgeon is viewing via an adjacent monitor. The assistant in this position can also monitor for contact between the robot arms and the structures of the oral cavity to avoid inadvertent injury. The anterior ring of C1, the vertebral body of C2, and intervertebral spaces are identified, as are the eustachian tubes, which must be carefully avoided.

Dissection proceeds quickly; the articulated Maryland dissector can maintain tension on the mucosa, and the electrocautery can dissect through layers down to the ring of C1 and then inferiorly to the body of C2, with the location confirmed on fluoroscopy (see Fig. 7-13). The anterior longitudinal ligament is then taken down in the same fashion to expose the anterior atlantooccipital membrane superiorly, the arch of C1, and the dens and body of C2 (see Fig. 7-8). The dissection is controlled at the console by the operating surgeon with only minimal assistance from the bedside surgeon. The soft tissue may be retracted using retracting sutures if necessary.

At this point, the soft-tissue dissection is complete; the primary operating surgeon is now the neurosurgeon, who must be at the bedside to carry out bone work, because currently no drill attachment exists for the da Vinci robot. The endoscope is left in, and the procedure becomes a classic endoscopically assisted procedure with a surgeon still stationed at the robotic console to assist in bone and ligament removal under the better 3D optics visualized at the console. The C1 arch is removed with the drill by creating two troughs no more than 16 mm in maximum width; that is, the width of the medial border of the C1 lateral mass.[15] Once the C1 arch has been resected, the apical ligament is identified. A top-down drilling approach is used, as advocated by Haid.[16] Using a Kerrison punch and curettes, the neurosurgeon can accomplish final removal of the residual bone of the dens and the apical and alar ligaments (Fig. 7-14). With the benefits of the 3D view available with the binocular endoscope, the operating surgeon can perform the corrections in the placement and direction of the dissection.

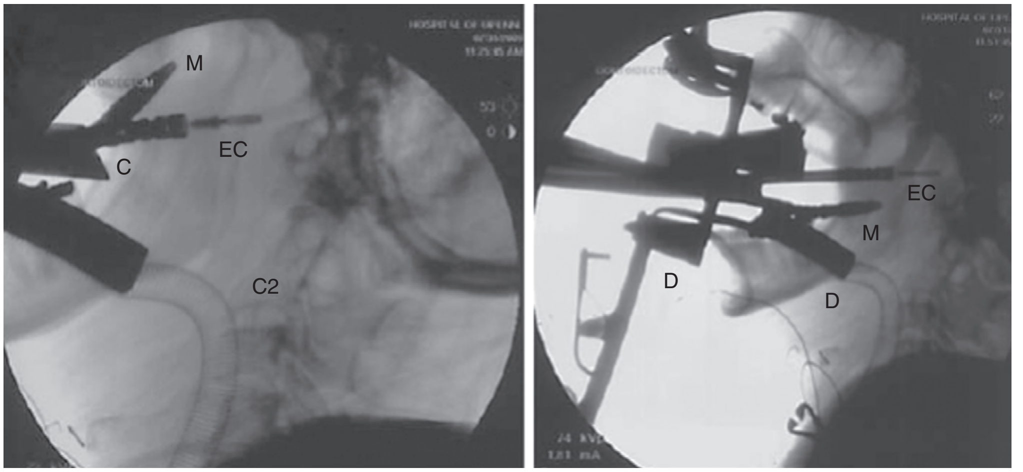

Figure 7-13 Lateral intraoperative radiograph during transoral robotic surgery. C, Transoral Crockard retractor; C2, C2 vertebral body; D, Dingman retractor; EC, 5 mm Endowrist monopolar electrocautery arm; M, 5-mm Endowrist Maryland dissector robotic da Vinci arm.

Figure 7-14 Removal of the odontoid tip after drilling in a cadaver.

Figure 7-15 Endoscopic view of robotic arms being used to close the dura in a cadaver; this is done primarily with sutures.

If decompression is the sole goal of the surgery, once adequate bony decompression is performed in the above manner, the robot arms may be brought back in for tremor-free closure of the posterior mucosa by the otolaryngologist. Using two articulated needle drivers, the seated surgeon closes the muscle and mucosa with the robotic arms. A single-layer suture with 3-0 Vicryl is performed, and all suture ties can be made by the operating surgeon at the console, using the articulated hands of the robot. The upper sutures may require the 30-degree endoscope, whereas the middle of the incision can usually be closed with the zero-degree instrument.

If an intradural pathology is to be treated, the surgery may continue, with the robotic arms once again moving back into place if TORS is to be performed. The neurosurgeon now sits at the robotic console, although this is done only with institutional review board approval under study protocol, because this is not currently a U.S. Food and Drug Administration (FDA)–approved procedure for neurosurgeons. The surgeon at the console can open the dura in a linear fashion using a number 11 blade, and the incision is carried inferiorly and superiorly with the endoshears (see Fig. 7-9). Alternatively, the dura is opened under endoscopic visualization in the same manner. Dural tack-up sutures can be placed and fixed to the mucosa, or they can be hung outside the mouth on clamps. The surgeon can then proceed to open the arachnoid. Intradural work can then be performed, depending on the pathology.

When the intradural work has been completed, the method of dural closure used will depend on the approach. If using a robot, the dura may be sutured closed using the articulated robot arms and interrupted 4-0 suture (Fig. 7-15) and U-clip nitinol suture (Medtronic, Minneapolis, MN). Depending on how comfortable the surgeon feels with how watertight the closure is, a dural patch and fibrin glue may be added. If a purely endoscopic approach is used, a mucosal flap or dural patch with fibrin glue or both may be used. The mucosa is then closed using interrupted suture.

TRANSCERVICAL ENDOSCOPIC APPROACH

Rationale

A third endoscopic approach that has recently been pioneered by Wolinsky and colleagues[11] is the transcervical endoscopic approach. Although this surgical approach has been performed without the use of an endoscope, illumination requires significant retraction and results in consequent morbidity. The use of the endoscope limits the degree of morbidity associated with retraction. As compared with the endonasal or transoral approach, the transcervical approach avoids violating nasopharyngeal or oropharyngeal mucosa and is thus sterile. Violation of the oral mucosa of the oropharynx leads to increased chances of infection and poor wound healing of the posterior pharyngeal wall.[11] Additionally, a transoral pharyngeal incision often requires extended intubation, possible tracheostomy, and extended use of tube feeding while the posterior oropharyngeal mucosa heals. The endonasal route avoids this problem at the expense of instrument length. The transcervical approach similarly limits the need for tracheostomy and tube feeding, and it uses a very familiar approach to spine surgeons, the Smith-Robinson anterior cervical approach. The cephalad extension of the exposure, however, is not as versatile as the transoral or endonasal approach; the inferior clivus is its extreme cephalad exposure.

Preparation and Positioning

Positioning for this procedure is very similar to positioning for an anterior cervical diskectomy (ACD). However, nasotracheal intubation with a flexible armored ETT is used rather than orotracheal intubation. The patient is positioned supine on a flat Jackson table with a shoulder roll for gentle neck extension, and the head is fixed to the table in a halo–ring. The approach is made from the right side for a right-handed surgeon and from the left for a left-handed surgeon. Imaging guidance can also be used per the surgeon's preferred system, because the head is fixed in place. Retractor and endoscopic arms are fixed to the table contralateral to the surgeon, as are the monitors. The neck is prepped and draped in the usual fashion for an ACD.

Surgical Procedure

The usual Smith-Robinson approach to the anterior cervical spine is used via an incision at about the C4–C5 level. The esophagus and trachea are swept medially, and the carotid sheath is swept laterally. The spine exposure is continued rostrally to the anterior tubercle of C1. A custom-made, beveled, tubular retractor is then placed flush against the spine, and the longus colli muscles are dissected. Using a 30-degree endoscope in an angle similar to the tubular retractor, the odontoidectomy is performed with a drill in a top-down fashion to avoid a free-floating odontoid tip. Following this, the spine is unstable, and great care is required for further transport or positioning of the patient if posterior stabilization is required. Because this is a relatively new method of reaching the CVJ, the reader is encouraged to refer to the 2007 work of Wolinsky and colleagues[11] for more information and illustrations of this technique.

Complications

Contraindications to TORS and endscopic transoral surgery are similar to those of classic transoral surgery and include dental or periodontal infections and lesions reducible from a posterior approach that need simple posterior decompression and fusion. Prior to endoscopic-assisted visualization via the transoral route, an inability to open the mouth at least 25 mm was a relative contraindication, and more morbid approaches had to be attempted. Now with robotics, endoscopes, and a combined endonasal/transoral approach, this is no longer a consideration.

Pathologies for which the ventral approach to the CVJ may be used can create spinal instability, and the approach itself may further add to this instability. Careful consideration of this point must be taken into account during patient positioning and postoperatively, until posterior fixation is achieved. Halo–vest application preoperatively may overcome this hazard with removal of the anterior portion of the vest intraoperatively and replacement of the anterior portion before transport or any patient movement.

Dural breech is a classic complication that can be very difficult to control, because watertight closure in this area can be difficult to achieve, especially using endoscopic approaches. Endonasal surgeons have vast experience in this area and have developed several techniques to combat this that include fat packing and vascularized flaps. Via the transoral route, dural breech can present a significant challenge, but using the articulated robot arms can allow the surgeon to suture dural defects closed with tremor-free precision. In any transoral approach, dural patching and the use of fibrin glue may still be necessary, along with lumbar drainage.

Airway compromise is another factor to be considered during any transoral approach, and it is recommended that the patient remain intubated postoperatively until oral edema decreases, and the patient can pass an ETT cuff leak test prior to extubation. Extubation should be performed in a monitored setting with easy access to an otolaryngologist and an emergency airway cart. This complication is less of an issue in the transcervical endoscopic approach, however, and patients typically have minimal airway or swallowing compromise postoperatively.[11]

When choosing the route to approach the CVJ, some factors must be considered that can aid in this decision. The first is the actual location and extent of the pathology. Endoscopic transoral approaches can usually be used to gain access from the lower clivus to about the C2–C3 disk space, whereas endonasal approaches can usually be used to gain access only to areas as inferior as the C2 body, but they have the benefit of being able to access the entire clivus and more superior structures (see Fig. 7-1). A transcervical approach can be used to approach the midcervical spine, and it can reach to about the lower clivus, but it is limited to some degree by patient body habitus.

Imaging can help guide the limits of exposure on a patient-by-patient basis, and guidelines have been published to aid in this decision making.[10] Of course, surgeon preference and experience will also play a role in this decision. Additionally, these approaches can be combined to provide better access to the pathologic lesion, should it not be amenable to a single approach (Fig. 7-16).

Pathologies of the CVJ often can create instability in this area, and this must be accounted for at all times. Surgery on the junction can then create further instability, or it may even lead to instability if it is not already present. These cases may require posterior decompression or stabilization, and this factor must not be ignored postoperatively. Spinal reconstruction is a vital component in the decision-making

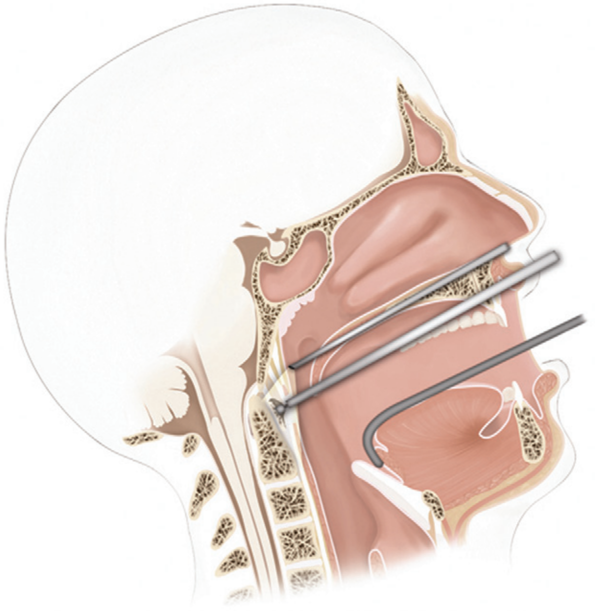

Figure 7-16 A combined approach with an endoscope in the nasal cavity and operating instruments transorally.

process before entering the operating room. Additionally, posterior lesions that may be better suited for a posterior approach or some lesions that simply require stabilization following reduction are contraindicated for anterior endoscopic surgery. Other contraindications include pharyngeal infection or anomalous anatomy where vital structures lie ventral to the pathology.

Discussion

Endoscopic and TORS approaches to the CVJ are technically feasible and allow the surgeon to treat a wider array of pathologies than with a classic microscopic transoral approach, and endoscopic and TORS approaches allow for less morbidity. Additionally, depending on the area of pathology, the surgeon can use a combined transoral/endonasal approach or the newly developed transcervical endoscopic approach as well. As more surgeons adopt these approaches, more tools will be developed for this specific operation; the tools currently used for this approach are somewhat lacking in design specificity, but they remain adequate for this procedure.

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8 Surgical Approaches to Craniovertebral Junction Congenital Malformations, Chiari Malformations, and Cranial Settling (Invagination)

AKASH J. PATEL, STEVEN W. HWANG, and ANDREW JEA

Surgical Anatomy of the Craniocervical Junction

The craniocervical junction extends from the occipital bone to the second cervical vertebra. Understanding the surgical anatomy of the bony structures of the lower clivus to C2, associated articular processes and ligaments, muscular attachments, and relationships to the vertebral artery and lower cranial nerves is crucial for managing diseases in this region. The musculature of the neck is an important part of the surgical anatomy in this area. Many important muscles attach to this bony structure, including the superior and inferior obliques, levator scapulae, and rectus capitis muscles (Fig. 8-1, *A*). The longus capitis muscle attaches to the lower clivus, and the rectus capitis muscle attaches anterior to the ventral surface of the occipital condyle.[1]

The occipital bone is divided into a *squamosal segment,* a *basal segment,* and paired *occipital condyles.* The basal portion of the occipital bone lies anterior to the foramen magnum and is joined to the sphenoid bone by the clivus, which arises at a 45-degree angle. The occipital condyles, located lateral to the anterior half of the foramen magnum, articulate with the atlas in a cup-and-ball mechanism. The C1 transverse process projects anteriorly and laterally (see Fig. 8-1, *B*).

Several ligaments are encountered at the craniocervical junction traversing from ventral to dorsal. The anterior longitudinal ligament covers the dens anteriorly. Posterior to the dens is the cruciate ligament, which is made of the transverse ligament and associated superior and inferior longitudinal bands. The cruciate ligament is followed by the tectorial membrane (the rostral extension of the posterior longitudinal ligament) and then the dura (see Fig. 8-1, *C*).[2]

Cranial nerves IX and X arise from the lateral aspect of the medulla, and cranial nerve XI arises from the medulla and upper cervical spinal cord and travels upward dorsal to the dentate ligament. These nerves exit the skull base through the jugular foramen, medial to the jugular bulb. Anterior and superior to the occipital condyle is the hypoglossal canal, which transmits the hypoglossal nerve (cranial nerve XII).[1]

The vertebral artery enters the transverse foramen of C2 and ascends through the C1 transverse process. Surrounded by a rich venous plexus, much like the C2 nerve root, it wraps around the superior aspect of the C1 lamina in the sulcus arteriosus by crossing medially behind the articular capsule of the atlantooccipital joint to penetrate the dura. This segment of the vertebral artery above C1 runs in the anatomic suboccipital triangle, which is bordered by three muscles: the *obliquus capitis superior* extends from the occipital bone to the C1 transverse process; the *obliquus capitis inferior* extends from the C1 transverse process to the C2 spinous process; and the *rectus capitis posterior major* extends from the C2 transverse process to the occipital bone.[1]

Basilar invagination is the term for a developmental anomaly of the craniovertebral junction (CVJ) in which the odontoid prolapses into the foramen magnum.[3,4] It is the prototypic disease process that may be associated with other bony and central nervous system (CNS) abnormalities at the CVJ, such as Chiari malformation, and it necessitates surgical intervention; therefore this pathology and its management will be the focus of this chapter. Reported etiologies of basilar invagination include basiocciput (clivus), occipital condyle, or atlas hypoplasia; incomplete ring of C1 with spread of the lateral masses; achondroplasia; and atlantooccipital assimilation.[3-7] Between 25% and 35% of patients with basilar invagination also have associated CNS abnormalities, including Chiari malformation, syringomyelia, syringobulbia, and hydrocephalus.[8]

Basilar Invagination

The literature inaccurately uses the terms *basilar invagination, basilar impression, cranial settling,* and *platybasia* synonymously[8]; however, *basilar impression* refers to the acquired form of basilar invagination, the result of softening of the bone at the base of the skull in cases of Paget disease, osteomalacia, tumor, infection, hyperparathyroidism, osteogenesis imperfecta, Hurler syndrome, and rickets.[5] *Cranial settling,* a form of basilar impression, is a term reserved for cases of rheumatoid arthritis,[9] whereas *platybasia* is a flattening of the skull base that presents in combination with basilar invagination or in isolation.

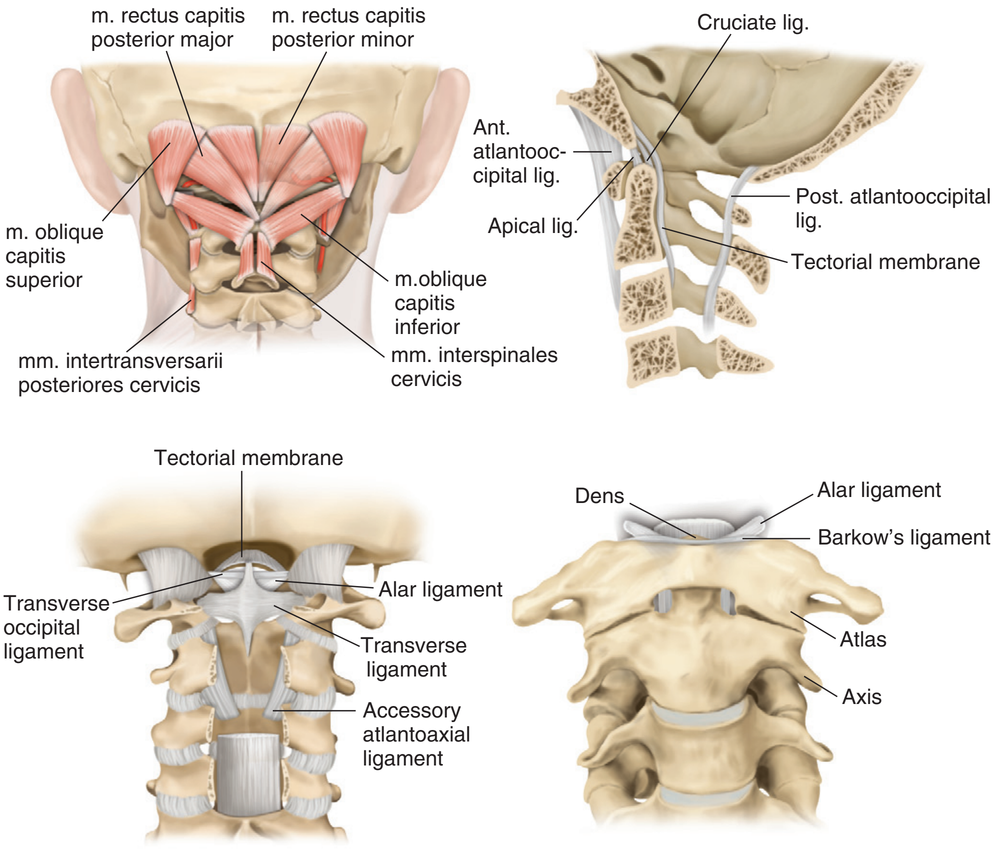

Figure 8-1 Bony and soft tissue anatomy of the craniocervical junction.

INDICATIONS FOR SURGICAL TREATMENT

Basilar invagination can result in progressive and profound neurologic deficits and death if left untreated. The majority of patients come to medical attention with some degree of neurologic disturbance[10-17]; this is an absolute indication for surgical treatment. Surgery may also be performed prophylactically to prevent development of potentially irreversible neurologic deficits. Finally, a subset of patients may be neurologically intact with mild basilar invagination, which may be followed clinically and radiographically for progression.[8]

Before surgical treatment, patients with basilar invagination may undergo a trial of cervical traction in an attempt to reduce the odontoid. As a general rule, basilar invagination that is not reducible is treated with anterior decompression followed by posterior occipitocervical fusion.[18,19]

ANTERIOR SURGICAL APPROACHES

Transoral-Transpalatopharyngeal Approach

The transoral-transpalatopharyngeal approach can be used to access the anterior CVJ. The lower clivus, atlas, and axis readily come into view via this approach (Fig. 8-2). When combined with palatal or mandibular splitting procedures, additional rostral and caudal exposure may be attained.[19-24]

The operative procedure consists of positioning the patient supine with fiberoptic orotracheal intubation. A

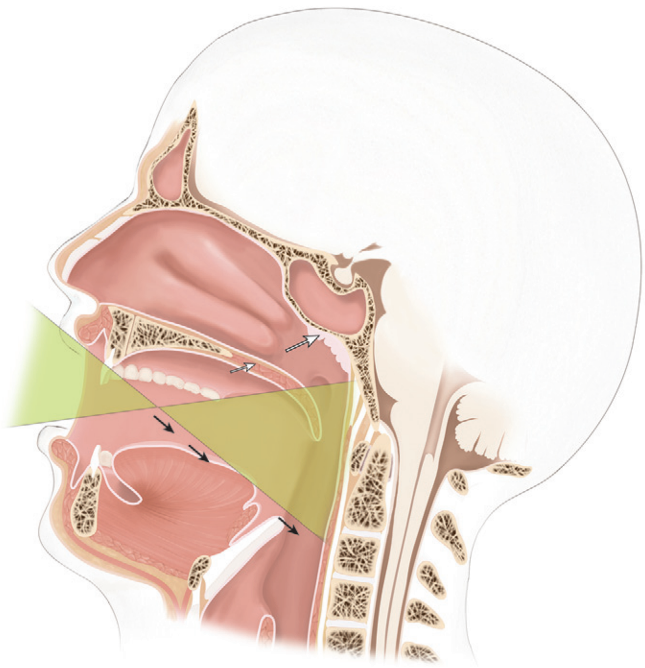

Figure 8-2 Exposure from a standard transoral approach from inferior clivus to middle to lower C2 body.

throat pack is placed, and the oropharynx is prepped with 10% povidone-iodine and hydrogen peroxide.[8] Prophylactic antibiotics are given to the patient, usually a third- or fourth-generation cephalosporin. The oral cavity and pharynx are exposed with the help of a Dingman or Crockard oral retractor (Fig. 8-3). Retracting the soft palate superiorly with a suture and transnasal rubber catheter can enhance exposure. Additional exposure may be obtained by incising the soft palate in the midline, starting on one side of the base of the uvula and retracting laterally.[2]

A midline incision is made into the posterior pharynx extending from the rostral clivus to the C2–C3 disk space, exposing the prevertebral fascia and longus colli muscles. The posterior pharyngeal wall is dissected laterally, exposing the clivus, anterior arch of C1, and odontoid. Subperiosteal dissection of the anterior longitudinal ligament is then done with electrocautery up to a width of 3 cm to avoid injury to the eustachian tubes, vertebral arteries, and hypoglossal nerve laterally.[2]

The C1 anterior arch is drilled out, and the inferior clivus is removed using a high-speed air-powered drill and Kerrison rongeurs. The dural attachment at the inferior edge of the clivus is dissected carefully at this point to avoid hemorrhage at the circular sinus (basilar plexus) and a cerebrospinal fluid (CSF) leak. The ligamentous attachments to the odontoid, the alar and apical ligaments, are similarly dissected carefully and sharply, and the odontoid is drilled and hollowed out. The cortical shell is then dissected from the surrounding ligaments, rostral to caudal. Caudal resection of the odontoid may create a mobile rostral fragment that compresses the cervicomedullary junction. When the odontoid is completely removed, the cruciate ligament and tectorial membrane are incised to expose the dura.[2]

The wound is closed in layers, including longus colli and longus capitis muscles, posterior pharyngeal muscles, and posterior pharyngeal mucosa. Posterior procedures for both decompression and stabilization may need to be performed.[8] These procedures may be performed during the same anesthetic setting, or they may be staged for another day. If the posterior approach is staged, the patient may need to be placed in a halo vest until definitive stabilization can be performed via an occipitocervical fusion.

A nasogastric tube is left in place for postoperative parenteral nutrition, and endotracheal intubation is maintained until oral and airway edema improves.[8] Consideration should be given to performing the procedure with intraoperative neurophysiologic monitoring.

Advantages and Disadvantages of the Anterior Approaches

The entrance to the oral cavity between the upper and lower incisors must be at least 2.5 to 3.0 cm to have adequate loupe or microscope visualization and to introduce instruments in a transoral approach. This opening may not be possible in elderly patients with rheumatoid arthritis or in patients with mandibular disorders. These patients may require a median glossotomy, circumglossal approach, or mandibular splitting procedure to access the oral cavity.[2]

Complications associated with the transoral approach include velopharyngeal incompetence, hypernasal speech and nasal reflux, dental injury, edema or tongue necrosis, upper airway obstruction from retropharyngeal edema, posterior pharyngeal wound dehiscence, dysphagia, odynophagia, pharyngeal cellulitis, meningitis, and temporomandibular joint syndrome.[19,20,23,25-32]

POSTERIOR APPROACHES

In cases of basilar invagination, posterior procedures may be performed for foramen magnum and posterior cervical decompression and for occipitocervical stabilization. Numerous methods of obtaining occipitocervical stabilization have been well described,[33] including the use of methylmethacrylate,[34] onlay bone graft with wires,[35] contoured rods with wires,[36] and metal plates with wires or screws.[37-39]

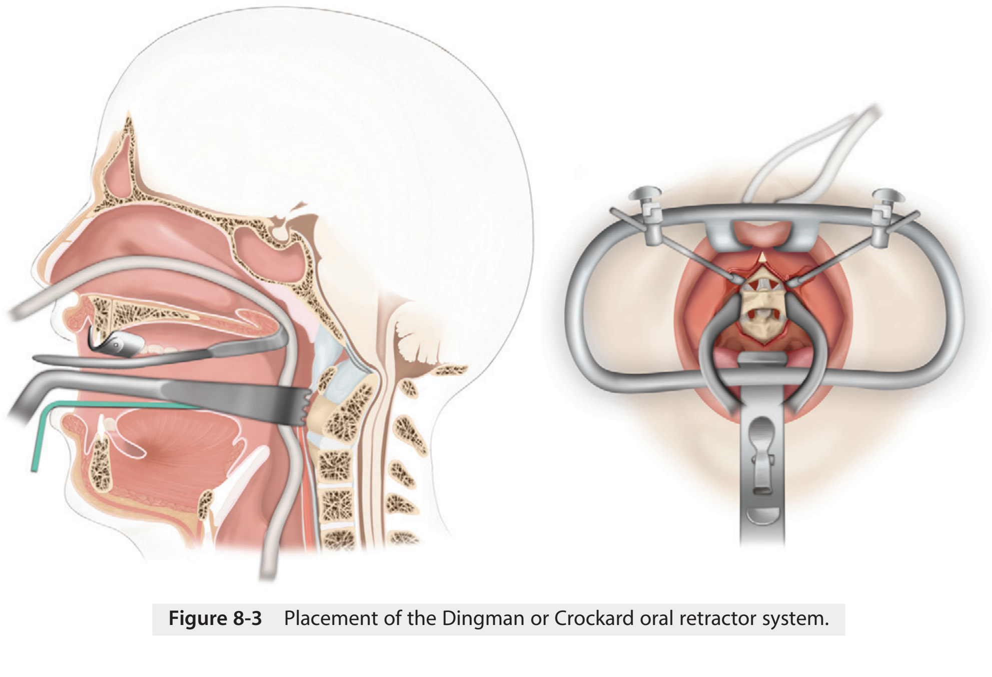

Figure 8-3 Placement of the Dingman or Crockard oral retractor system.

Internal fixation is advised to guarantee postoperative stability and to enhance the rate of arthrodesis.[39,40] Occipitocervical constructs should extend at least down to C2.

Occipital Screw Technique

Prior to drilling, anatomic landmarks are identified. Four bony landmarks on the outer occipital cortex should be visible: 1) the posterior rim of the foramen magnum, 2) the superior nuchal line, 3) the inferior nuchal line, and 4) the external occipital protuberance (Fig. 8-4). Safe placement of occipital instrumentation is between the inferior and superior nuchal line. Using the stop-drill or stepwise drill technique, occipital screws 4.0 to 4.5 mm in diameter may be placed in a bicortical fashion in 2-mm increments. Drill and screw trajectories should be angled medially toward the thick midline keel, and left and right occipital screws are staggered to avoid intersection of screw paths.

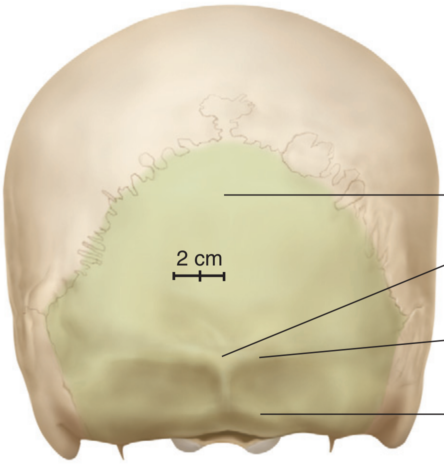

Figure 8-4 Bony landmarks of the occipital skull.

C1 Lateral Mass Screw Technique

The posterior arch of C1 is identified and followed laterally to visualize the lateral masses. Notably, there is a step-off between the medial aspect of the C1 lamina and the medial surface of the C1 lateral mass; this anatomic feature is different in adults whose medial C1 lamina is flush with the medial C1 lateral mass. Subperiosteal dissection of the C2 nerve roots and associated venous plexi from the junction between the posterior arch of C1 and lateral masses is performed to minimize bleeding. Alternatively, the C2 nerve roots and venous plexi can be coagulated with bipolar electrocautery and divided with little clinical significance. After palpating the medial and lateral surfaces of the lateral mass, a pilot hole may be drilled in the center of the lateral mass, usually no more than 2 to 3 mm from the medial surface. The rest of the placement of the C1 lateral mass screws proceeds using the technique described by Harms and Melcher,[40a] using either 3.5- or 4.0-mm diameter polyaxial screws (Fig. 8-5). The drill and the screw trajectory are angled medially 0 to 5 degrees and aimed at the superior half of the anterior arch of C1 on fluoroscopy. Bicortical purchase is usually achieved about 4 mm from the anterior cortex of the anterior arch.

C1–C2 Transarticular Screw Technique

A midline incision is made to expose the posterior elements from C1 to C3 with particular attention paid to the C2–C3 facet joints. The superior and medial aspects of the C2 pars are exposed, but there is no reason to expose the lateral aspect of the C2 pars; in fact, this may be a dangerous maneuver because of the proximity of the vertebral artery. The roof of the C2 pedicle is followed to the C1–C2 facet joint.

The C2 entry point may be identified by first locating the medial edge of the C2–C3 facet joint (Fig. 8-6). The C2 entry

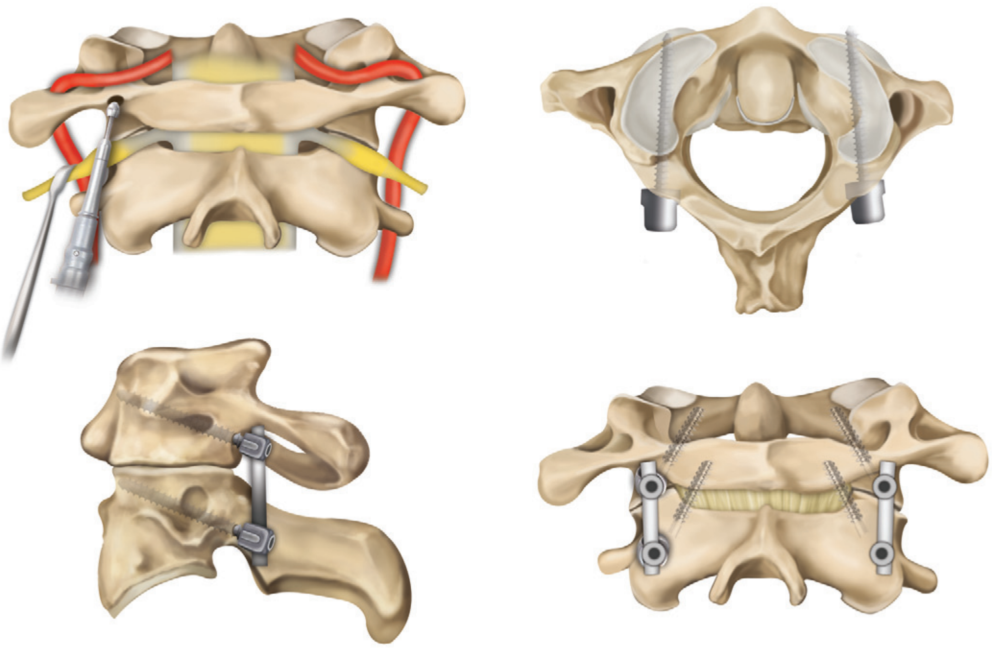

Figure 8-5 Placement of bilateral C1 lateral mass screws and C2 pars/pedicle screws in the Harms construct.

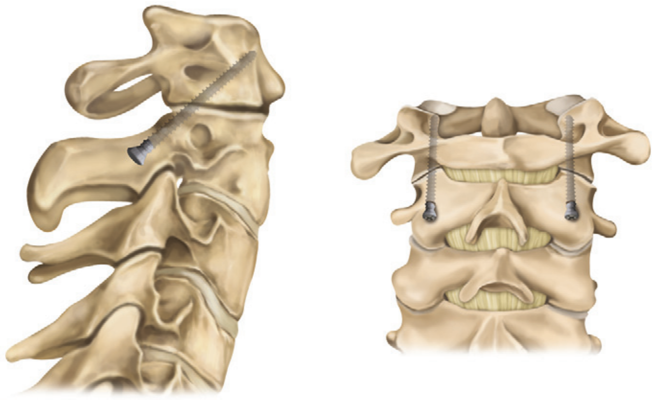

Figure 8-6 Placement of C1–C2 transarticular screws using the Magerl technique.

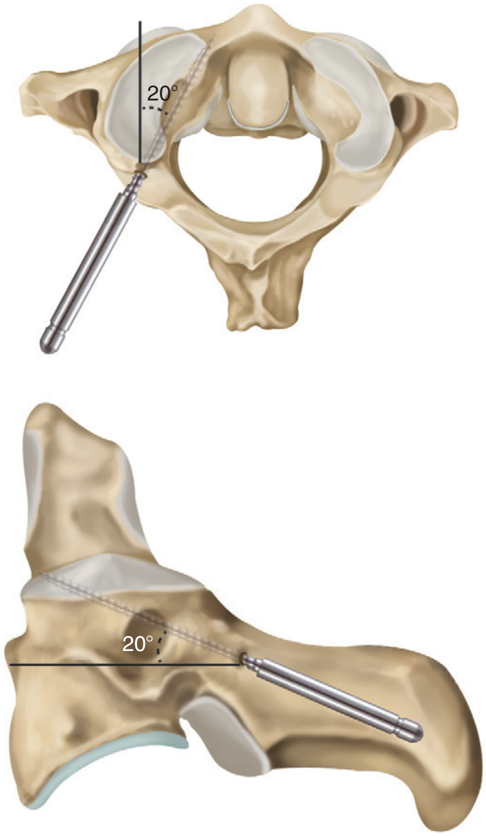

Figure 8-7 Technique of placing a C2 pars/pedicle screw.

site is just lateral and rostral to this point and may be estimated by visualizing the course of the medial pars (approximately 3 mm up and 3 mm out). Either through a stab incision lateral to the T1 spinous process or through an extended incision, the drill or K-wire is typically directed medially 15 degrees, with the superior angle visualized by fluoroscopy. The drill or K-wire is directed down the C2 pedicle and across the C1–C2 joint and is aimed at the anterior tubercle of C1. The tip of the drill or K-wire is advanced to a point 4 mm short of the anterior C1 tubercle to attain purchase of the anterior cortex of C1.

After tapping, a fully threaded 3.5- or 4.0-mm diameter cortical screw is used. The necessary screw length can be measured directly from the drill or the K-wire, but screws are typically 34 to 44 mm in length. The technique is repeated on the contralateral side.

C2 Pars/Pedicle Screw Technique

The entry point of a C2 pars/pedicle screw is similar to that for the C1–C2 transarticular screw. The medial, superior, and roof portions of the C2 pars/pedicle should be exposed, dividing the C2 nerve root and venous plexus if necessary. The medial trajectory of the C2 pars/pedicle screw parallels the medial border of the C2 pars/pedicle, and the superior trajectory is guided by fluoroscopy, aiming for the anterior tubercle of C1; however, the C2 pars/pedicle screw stops short of the C1–C2 joint (Fig. 8-7). Screw length is typically half of the screw length for a C1–C2 transarticular screw, measuring 16 to 22 mm in length.

Translaminar Screw Technique

A high-speed drill is used to open a small “entry” cortical window at the junction of the spinous process and lamina, close to the rostral margin of the lamina. Similarly, a high-speed drill is used to open a small “exit” cortical window at the junction of the facet and lamina, close to the rostral margin of the lamina. Using a hand drill as described by Wright,[40b] the contralateral lamina is carefully drilled along its length, with the drill visually aligned along the angle of the exposed contralateral laminar surface, aiming for the exit point. The drill tip should then be observed at the exit window; this confirms that the drill did not violate the inner cortex of the lamina, allows for bicortical screw purchase, and ensures an accurate measure of the appropriate screw length. Typically, a screw 20 to 30 mm in length and 3.5 or 4.0 mm in diameter could be placed.

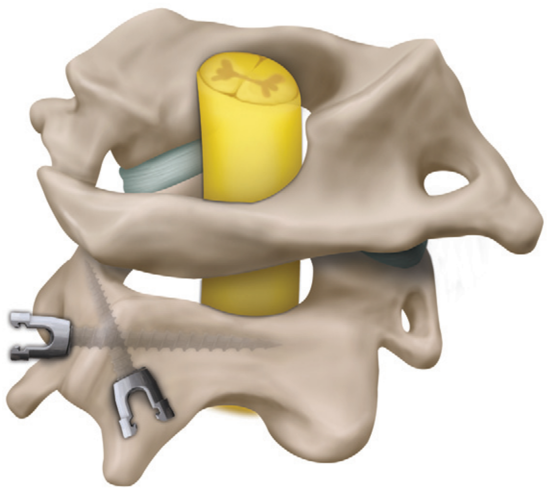

Figure 8-8 Placement of bilateral, crossing C2 translaminar screws.

A small cortical entry window is then made at the junction of the spinous process and lamina, close to the caudal aspect of the lamina on the opposite side. The above technique is then repeated for this crossing translaminar screw (Fig. 8-8).

Fluoroscopy is not used during this technique. It neither guides screw trajectory nor confirms screw placement, because it is difficult to interpret where the screw is in relation to the spinal canal on anteroposterior (AP) and lateral views.

C3–C7 Lateral Mass Screw Technique

The entire lateral mass of the subaxial cervical spine is exposed from its medial junction with the lamina to the lateral step-off. The entry point is identified approximately 1 mm inferior and 1 mm medial to the center of the two-dimensional (2D) "square" posterior surface of the lateral mass. The drill and the screw trajectory are directed superiorly and laterally, about 20 degrees up and out, to avoid the nerve root and vertebral artery, respectively, aiming for the superolateral "deep" corner of the three-dimensional (3D) "cube" of the lateral mass in the mind's eye of the surgeon. Unicortical purchase is safe, but bicortical purchase may afford a biomechanical advantage. Fluoroscopy may be used but is unnecessary. Men usually tolerate 12 to 16 mm by 3.5 mm screws, and women tolerate 10 to 14 mm by 3.5 mm screws.

Advantages and Disadvantages of the Posterior Approaches

Most of the limitations of occipitocervical fixation systems reside in the cranial part of the construct.[41,42] The occiput does not easily accommodate instrumentation,[42-44] and the slope of the occipital bone and the angle it makes with the cervical spine impose unique geometric constraints. These limitations may lead to poor occipital screw purchase, screw loosening, pullout, breakage, and difficulties with screw insertion,[45] culminating in catastrophic hardware failure.

Although bicortical screw placement may result in superior holding strength secondary to greater cortical purchase,[46,47] caution is needed to avoid overpenetration and potential neurologic compromise.[48] Bicortical occipital screw insertion risks dural laceration, CSF leakage, dural venous sinus injury or thrombosis,[49] and subdural or epidural hematoma formation. CSF leakage and sinus bleeding can be stopped with placement of the occipital screws; if a screw cannot be placed, bone wax may be used to plug the drill hole in the bone.

Bleeding from the venous plexus around the C2 nerve root can be substantial as dissection down to the junction of the C1 lamina and lateral mass is carried out. This blood loss can be life threatening to small children who have low blood volume, and it may lead to unwanted blood transfusions. Bipolar coagulation of the venous plexus and division of the C2 nerve root may obviate much of this venous hemorrhaging while improving exposure, without any significant neurologic sequelae.

C1–C2 transarticular screw placement is technically demanding because of the close proximity of the vertebral artery to the screw path. Vertebral artery injury has been reported to occur in 2% to 8% of patients in several large series.[46,47,50] C1 lateral mass screws and C2 pars/pedicle screws may have a lower incidence of arterial injury,[48] but these screws still place the vertebral artery and spinal cord at risk.[49,51]

Abumi and colleagues[52,53] reported clinical results of pedicle screw fixation for reconstruction of traumatic and nontraumatic lesions of the middle and lower cervical spine. However, the procedure has been criticized because of the potentially high risk to neurovascular structures, except at the C2 level.[54-56] Lateral mass screws may have a safer track record, but these screws also still place the vertebral artery and spinal cord—in addition to the exiting nerve roots, facet joints, and dura—at risk.

ENDOSCOPIC APPROACHES

Recently, endoscopic approaches have been described to reduce the morbidity associated with anterior decompression of the craniocervical junction. Husain and colleagues[57] described an endoscopic transoral approach, Wolinsky and colleagues[58] reported an endoscopic transcervical approach, and Kassam and colleagues[59] first described an endoscopic endonasal approach for resection of the odontoid.

Endoscopic Endonasal Approach

The endoscopic endonasal approach can provide access to the odontoid process, particularly in cases of basilar invagination (Fig. 8-9). After endotracheal intubation, the patient is placed in rigid head fixation in a neutral position; frameless stereotactic image guidance may also be useful. In addition, intraoperative neurophysiologic monitoring may be a helpful adjunct to surgery, even during positioning. Preparation and cleansing of the nares is done with 10% povidone-iodine and hydrogen peroxide, and the patient is given antibiotic prophylaxis, usually a third- or fourth-generation cephalosporin.

A zero-degree endoscope is used via a bilateral approach with the endoscopic and suction irrigator in the right nare and a dissecting instrument or drill in the left nare. The middle turbinate is removed in the right nare; the sphenoid ostium is opened; and wide, bilateral sphenoidotomies are performed. Then, the left nare is accessed, and its middle turbinate is displaced laterally but not resected; rather the

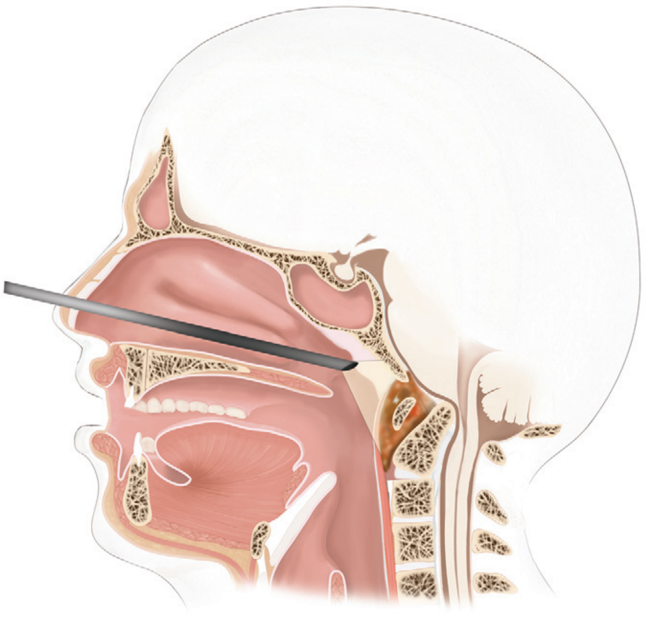

Figure 8-9 Exposure from an endoscopic endonasal approach from tip of clivus to C1 anterior arch.

posterior attachment of the nasal septum holding it to the rostrum is detached.[59]

Next, an inferiorly based U-shaped flap in the nasopharyngeal mucosa is prepared with Bovie electrocautery from the sphenoidotomy to the level of the soft palate, and this flap is elevated and reflected caudally to the level of the soft palate. The basipharyngeal fascia is then elevated from the sphenoid floor and ventral clivus at the inferior edge of the sphenoidotomy, and the sphenoid floor is drilled with a 3-mm diamond "matchstick" drill bit until it is flush with the clival recess.[59]

The midline fascia over the paraspinal muscles, attaching to the ring of C1 and extending to the foramen magnum, is then incised along the avascular median raphe using Bovie electrocautery. The longus capitis and longus colli muscles are reflected laterally, and the ring of C1 is exposed.[59]

Once an adequate portion of the ring of C1 is removed—with a high-speed, air-powered drill; standard Kerrison rongeurs; and sharp, straight, and angled curettes—disrupted abnormal ligaments and other soft tissue may be seen and removed. Visualization of the tip of the dens may become disrupted as it courses through the foramen magnum. In this case, the ventral rim of the foramen magnum and lower clivus must be removed to see the odontoid peg in its entirety. Removal of the odontoid process may then proceed as described previously in the transoral-transpharyngeal approach. Resection begins at the tip and proceeds caudally toward its base; the odontoid is cored out with the 3-mm diamond matchstick drill bit, and the remaining cortex is removed using an eggshell technique with sharp curettes. The remaining atlantoaxial membrane may be resected to guarantee complete decompression of the cervicomedullary junction.[59]

The nasopharyngeal tissues are not reapproximated, and the surgical defect is covered with fibrin glue. Silastic nasal septal splints are inserted to minimize the risk of postoperative synechiae.[59]

Advantages and Disadvantages of Endoscopic Approaches

The endonasal approach to the CVJ offers some advantages to the traditional open transoral approach that include improved lateral visualization, decreased airway and swallowing morbidity, preservation of palatal function, decreased postoperative pain, and reduced need for tracheostomy.[59] The posterior pharynx musculature and mucosa are spared, leading to fewer pharyngeal complications.[2]

The transcervical endoscopic approach allows for access to the odontoid process via a trajectory similar to odontoid screw placement; this offers cosmetic advantages. Of the few cases that have been reported, patients have had less morbidity and have not required placement of feeding tubes or tracheostomy, as can be the case for the traditional transoral route. However, whether endoscopic approaches actually translate into reduced morbidity and improve outcomes remains to be determined.

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9 Surgical Approaches to the Craniovertebral Junction in Rheumatoid Arthritis

DANIEL AGHION and ADETOKUNBO OYELESE

Overview

Pathologic processes that may involve the craniovertebral junction (CVJ) include rheumatoid arthritis (RA), infection, trauma, tumor, Down syndrome and other congenital anomalies, osteoarthritis, osteogenesis imperfecta, achondroplasia, and iatrogenic instability.

RA is a chronic, progressive, systemic inflammatory disease that peaks in the fourth through sixth decades and leads to inflammation of the synovial joints and surrounding tissue, usually in a symmetric fashion. The cervical spine and CVJ are the most affected parts of the spinal column; synovial and facet involvement is present in up to 90% of RA patients (Fig. 9-1). Cervical spine disease manifests as facet inflammation, synovitis, loss of cartilage, ligamentous laxity, and bony erosion; all lead to cervical instability.

The etiology of RA is unknown but has been associated with the class II human leukocyte antigen, HLA-DR4. Spinal instability is the direct result of rheumatoid bone, cartilage, and ligament destruction. This causes synovial inflammation and instability by atlantoaxial subluxation (AAS) as a result of transverse ligament failure and granulation formation between the C1–C2 lateral masses; this causes anteroposterior (AP) and rotatory subluxation or fixation (Fig. 9-2). Cranial settling or basilar invagination is also frequently seen because of bony erosion of the occipital condyles and lateral masses that causes vertical penetration of the odontoid process into the foramen magnum. As a result, this instability causes the dens to move superiorly and posteriorly, compressing the brainstem (Fig. 9-3). Additionally, C1–C2 instability from synovitis causes fibroblasts to proliferate, and granulation tissue forms a periodontoid pannus, which can become large enough to compress the cervicomedullary junction (Fig. 9-4).

Diagnosis and Evaluation

The goals of surgical treatment should be to treat pathology at the CVJ, including instability and neurologic compromise. The most common symptom in RA patients with cervical spine disease is pain in the upper cervical area with radiation to the mastoid or cranial regions. C2 nerve root compression from AAS may cause radicular pain and numbness in the distribution of the greater occipital nerve. Limb paresthesias, hand clumsiness, urinary incontinence or retention, diplopia, vertigo, head tilt, basilar migraine, nystagmus (usually downbeat and lateral gaze), tinnitus, and involuntary leg spasms may also be present. Neurologic compromise typically results in pain, myelopathy, or lower cranial nerve deficits. Meticulous physical exam is necessary to detect hyperreflexia, spasticity, and pathologic reflexes; early diagnosis is crucial. The symptomatology, extent of involvement, and radiographic findings must be considered before conservative or surgical intervention is proposed. Once cervical myelopathy has been established, the natural history without surgical intervention is grave, and mortality is high. Up to half of the patients with cord compression will die within a year if left untreated. Goals of surgery must be discussed with the patient and family.

Atlantoaxial instability is easily demonstrated on plain film radiography; therefore initial radiographic evaluation begins with plain, multiview radiographs to establish landmarks and lateral-bending, open-mouth, oblique, flexion, and extension films. Subluxation, odontoid erosion, cranial settling, and C1–C2 instability can all be reliably detected with x-rays, which are then supplemented with thin-section multiplanar computed tomography (CT), magnetic resonance imaging (MRI) or MR angiography (MRA), and CT myelograms as needed (Figs. 9-5 and 9-6).

ATLANTOAXIAL SUBLUXATION

This is the most common type of cervical subluxation and accounts for up to 65% of subluxation in RA patients. Anterior subluxation makes up the majority of these cases, whereas lateral and posterior subluxation may occur less frequently. AAS is caused by erosive synovitis in the occipital–cervical (O–C1) and C1–C2 joints and in the odontoid process and by laxity in the transverse ligament. For stability the C1–C2 complex depends on the transverse and alar ligaments and, to a lesser degree, the apical ligaments. Anterior AAS may result in compression of the

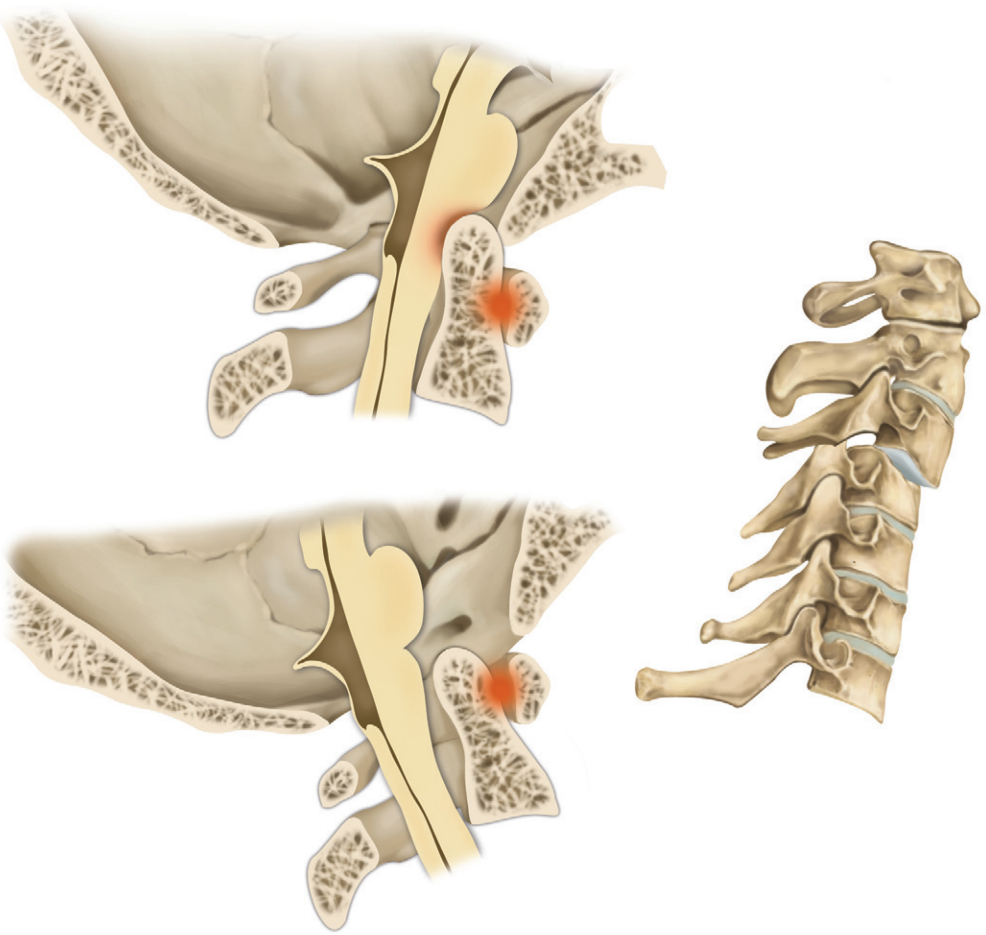

Figure 9-1 The cervical spine and craniovertebral junction are the most affected parts of the spinal column in rheumatoid arthritis. Facet inflammation, synovitis, loss of cartilage, ligamentous laxity, and bony erosion can all lead to cervical instability and basilar invagination, as shown.

cervical cord, especially during flexion, as C1 slides forward onto C2 (Fig. 9-7).

Cervicomedullary compression, as well as vertebral artery occlusion, may produce the clinical manifestation of AAS (Figs. 9-8 and 9-9). Pain is the most frequent complaint, usually in the upper neck, radiating to the occiput or the vertex, and it is increased with flexion and rotation. On plain films, the anterior and posterior atlantodental interval should be measured to determine the amount of subluxation. The upper limit of normal is 3 mm in adults and 4 mm in children.

The most common procedure for stabilization of AAS is a posterior arthrodesis, which can be accomplished by several techniques, such as posterior screw fixation (Fig. 9-10). Given the inherent instability of the rheumatoid process, however, close follow-up must ensue to investigate whether cranial settling of the C1–C2 mass occurs postoperatively (Fig. 9-11).

ATLANTOAXIAL ROTATORY SUBLUXATION

Up to 20% of RA patients may have atlantoaxial rotary subluxation (AARS). The pathologic process for rotatory subluxation is the same as in AAS, allowing for rotation at the O–C1–C2 joints (Fig. 9-12). This may result in significant pain and ultimately in fixed torticollis (Figs. 9-13 and 9-14). Cervical and occipital pain are the most common clinical symptoms, and C2 dermatomal hyperalgesia may also be present. The diagnosis is confirmed radiographically: more than 2 mm of subluxation of the C1 lateral masses onto C2 has been established as the definition. Asymmetry of the lateral masses on open-mouth plain film radiographs is also suggestive of rotation.

If rotation is not fixed, low-weight halo–ring traction over a period of 3 to 10 days may be placed to correct the deformity, and then an O–C2 fusion may be performed for definitive reduction. To prevent cranial settling, patients may also be kept in a halo–vest orthosis for 10 to 12 weeks postoperatively.

Indications and Relative Contraindications

The decision to intervene surgically is complex. A clear understanding of the patient's overall health, symptoms, and neurologic findings on exam is crucial. Indications for surgery include 1) impending or established neurologic injury to the spinal cord or brainstem; 2) reduction, stabilization, and/or decompression of the instability; 3) AAS; 4)

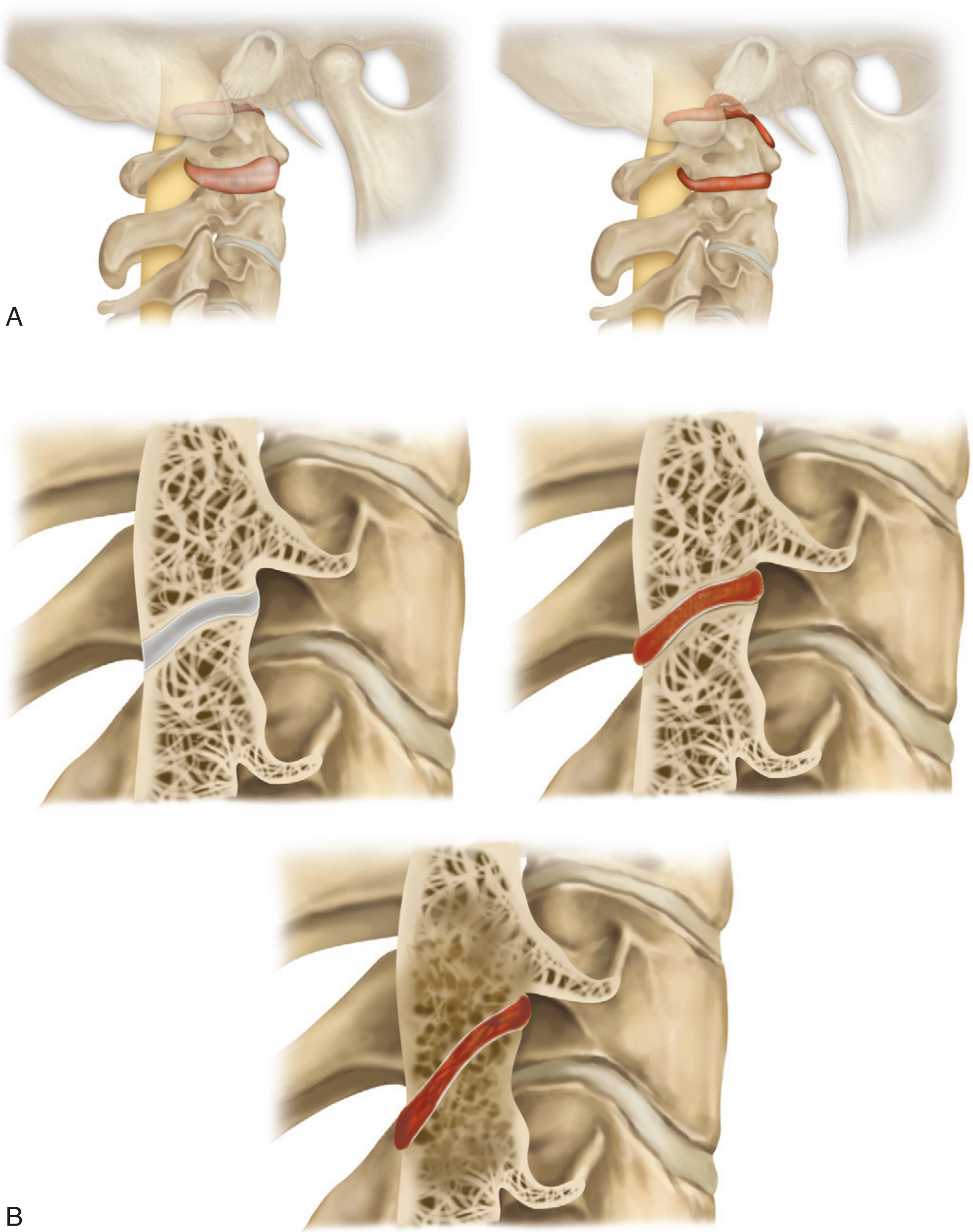

Figure 9-2 Cervical spine disease manifests as facet inflammation, synovitis, loss of cartilage, ligamentous laxity, and bony erosion in addition to the ligamentous destruction seen here. These cause synovial inflammation and instability.

correction of a deformity in AARS; 5) fixed CVJ kyphosis; and 6) alleviation of intractable pain. No clear guidelines exist for operative intervention in patients with asymptomatic C1–C2 instability, and each case should be individually assessed.

Relative contraindications include severe osteopenia, because this may be difficult to stabilize postoperatively and may require halo traction; severe myelopathy or paralysis, when neurology may be irreversible; and when the patient is nonambulatory or is unlikely to regain ambulatory status (Ranawat III B). Far-lateral pathologies should be addressed by a different approach; this is covered in other chapters.

Surgical Approach

Multiple surgical approaches to the CVJ exist. In modern times, better knowledge of the biomechanics and the wide use of new instrumentation devices and endoscopy allow us to access the CVJ through multiple routes. Historically, several factors have been discussed that influence the treatment of CVJ abnormalities. These include 1) the reducibility of the lesion; that is, whether anatomic alignment must be restored to alleviate compression; 2) the direction and the mechanics of the compression; 3) the etiology of the compression and associated lesions; and 4) the presence of abnormal ossification centers.

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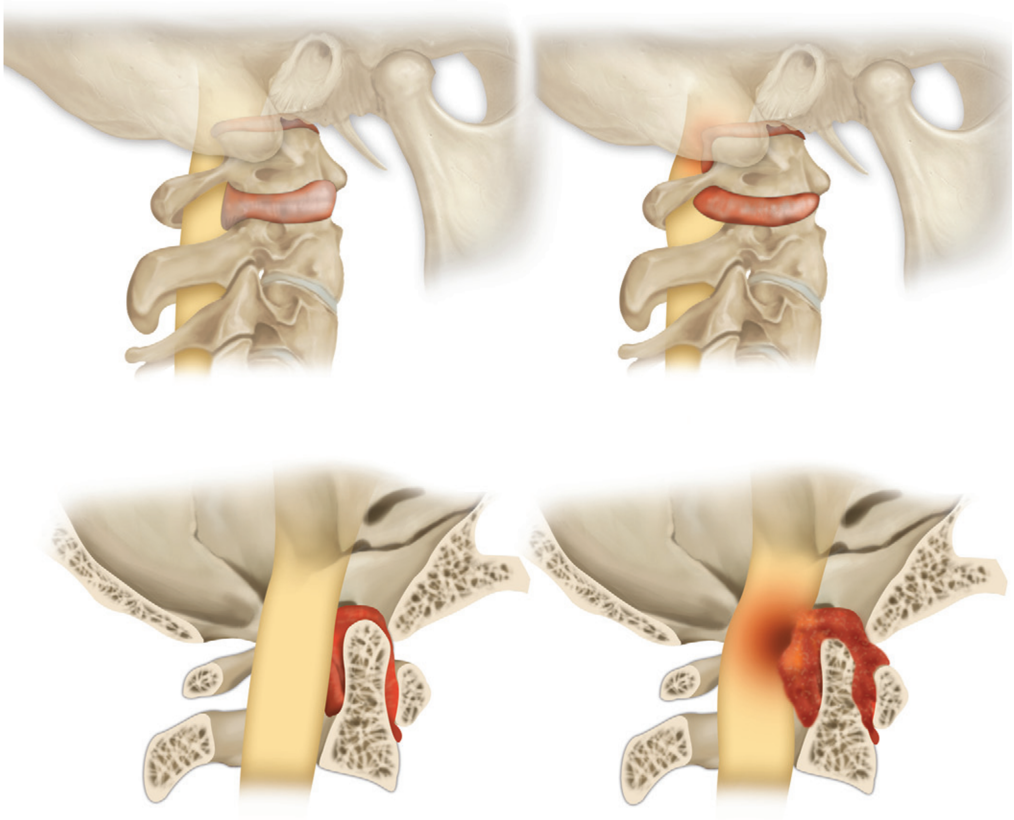

Figure 9-3 Instability causes the dens to move superiorly and posteriorly, compressing the brainstem; synovitis causes fibroblasts to proliferate and allows granulation tissue to form a periodontoid pannus, which can become large enough to compress the cervicomedullary junction.

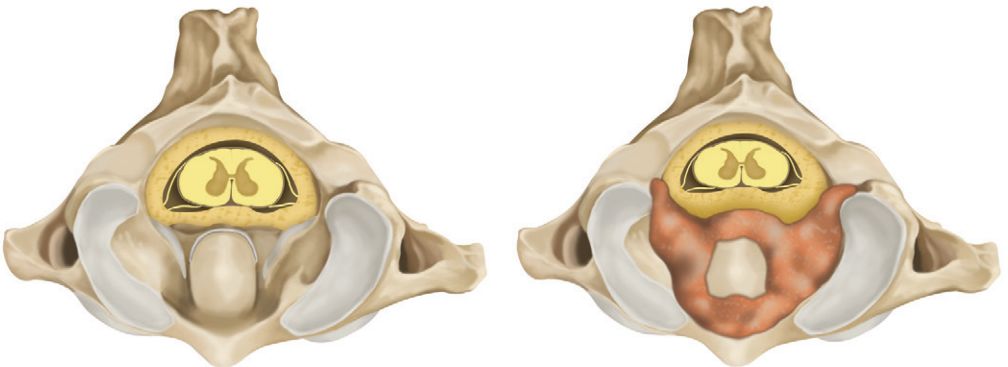

Figure 9-4 In the axial section depicted here, the odontoid pannus has become large enough to compress the cervicomedullary junction.

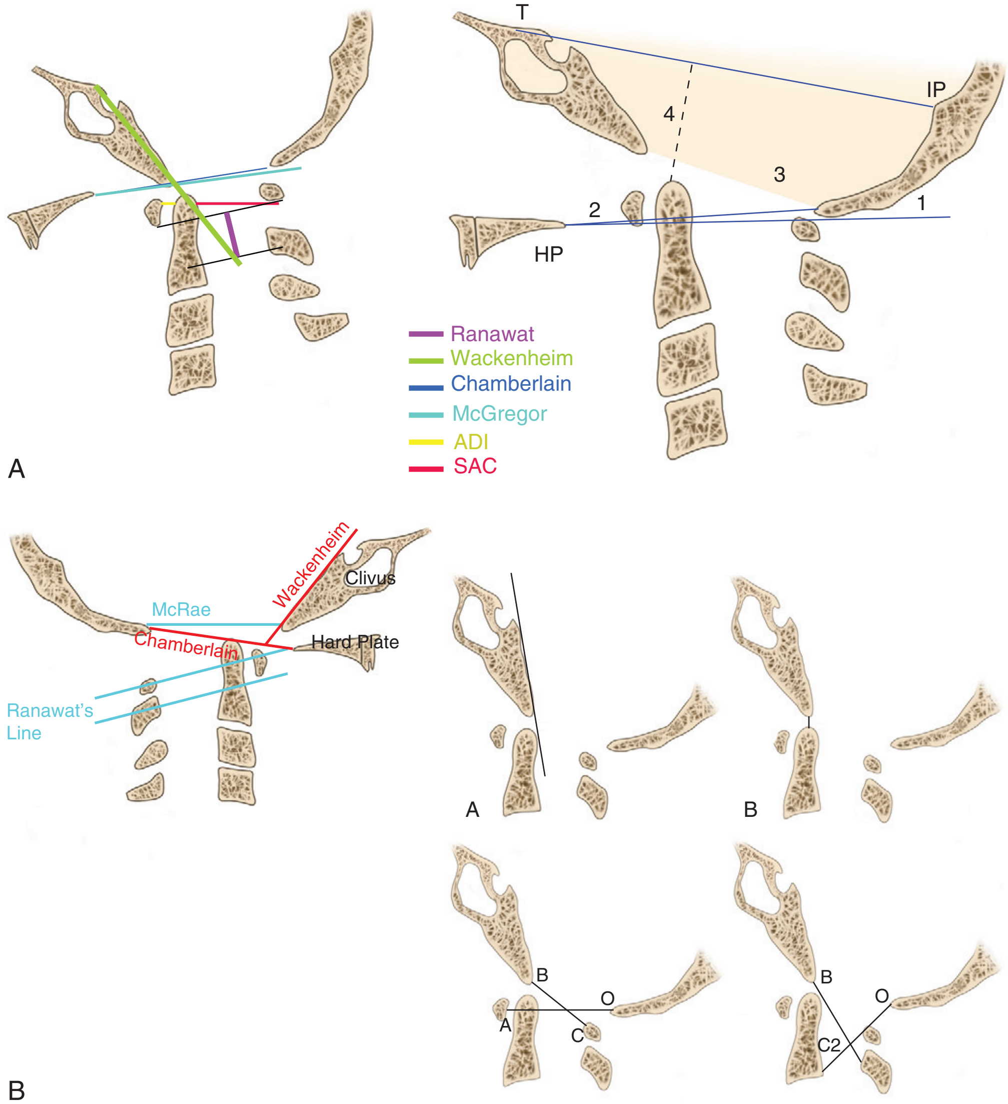

Figure 9-5 Rheumatoid spondylitis classification. Measurements of superior migration of the odontoid are cranial migration distance, basilar or cranial settling, and impaction.

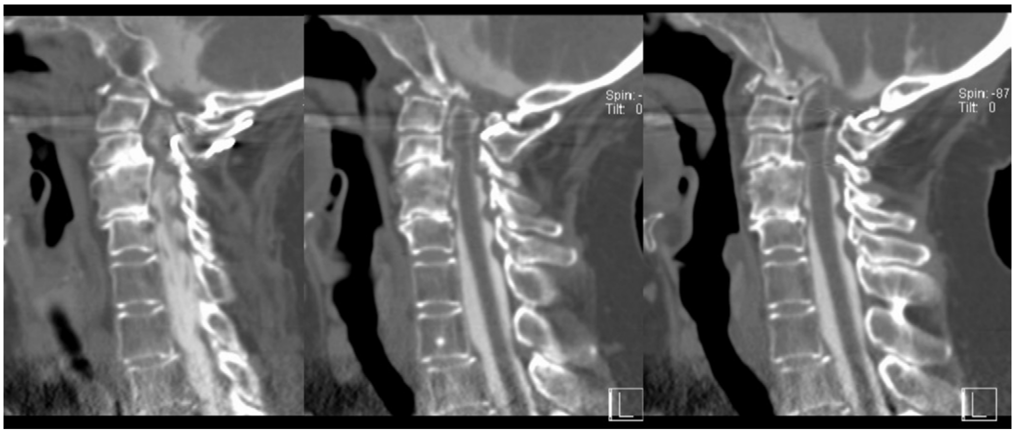

Figure 9-6 Preoperative sagittal computed tomographic myelogram shows cranial settling secondary to dens fracture.

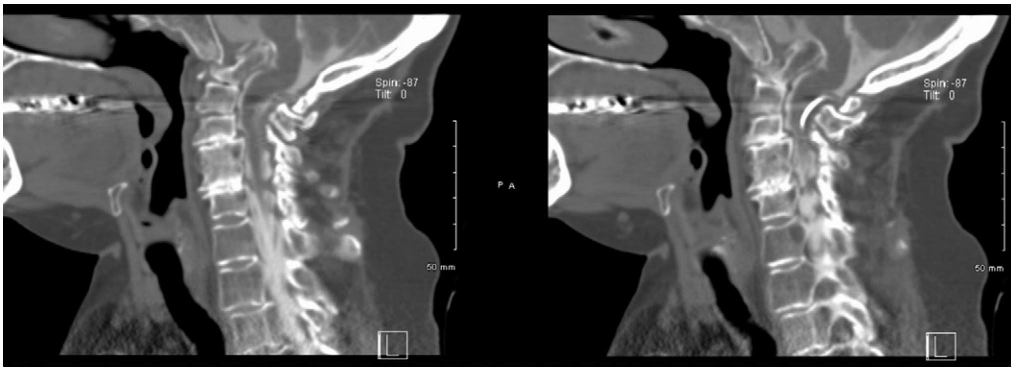

Figure 9-7 Preoperative sagittal computed tomographic myelogram shows cranial settling and basilar invagination secondary to dens fracture.

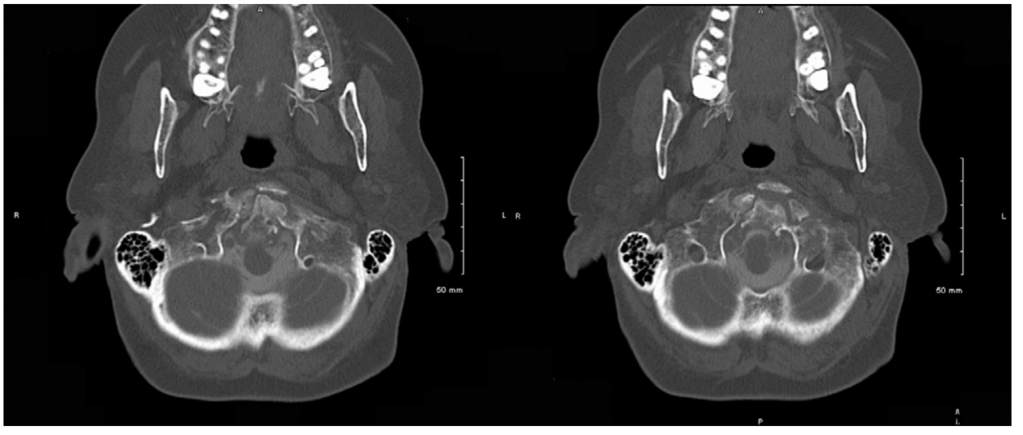

Figure 9-8 Preoperative axial computed tomographic myelogram shows cranial settling and basilar invagination secondary to dens fracture.

Figure 9-9 Preoperative sagittal T2-weighted magnetic resonance imaging shows cranial settling and basilar invagination secondary to rheumatoid pannus.

Figure 9-10 Postoperative lateral cervical spine radiograph shows occipital to C4 fusion.

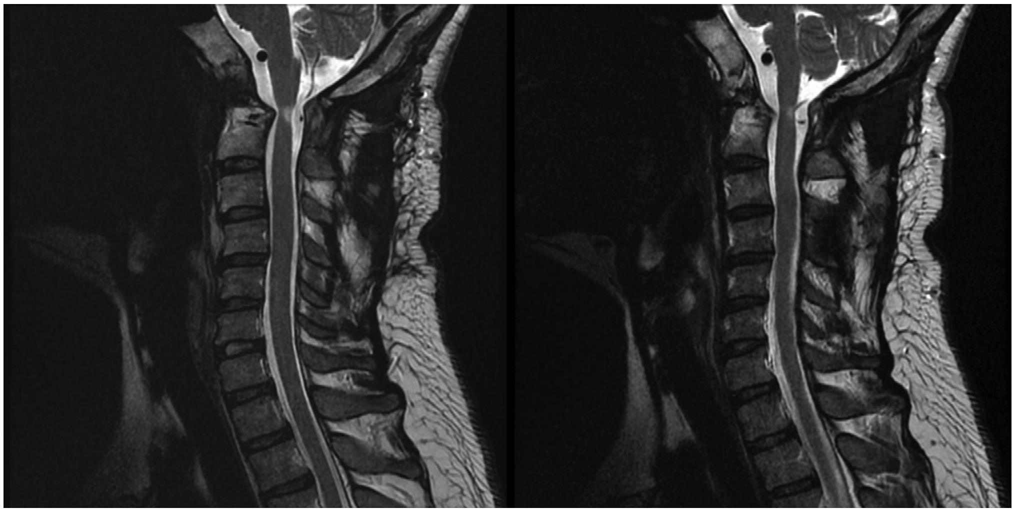

Figure 9-11 Postoperative sagittal T2-weighted magnetic resonance imaging shows decompressed cervicomedullary junction after transoral decompression and posterior occiput to C4 fusion.

Figure 9-12 Preoperative sagittal T1 fluid-attenuated inversion recovery magnetic resonance imaging shows a large rheumatoid pannus with cervicomedullary stenosis.

Figure 9-13 Sagittal computed tomographic scan shows rheumatoid arthritis with pannus.

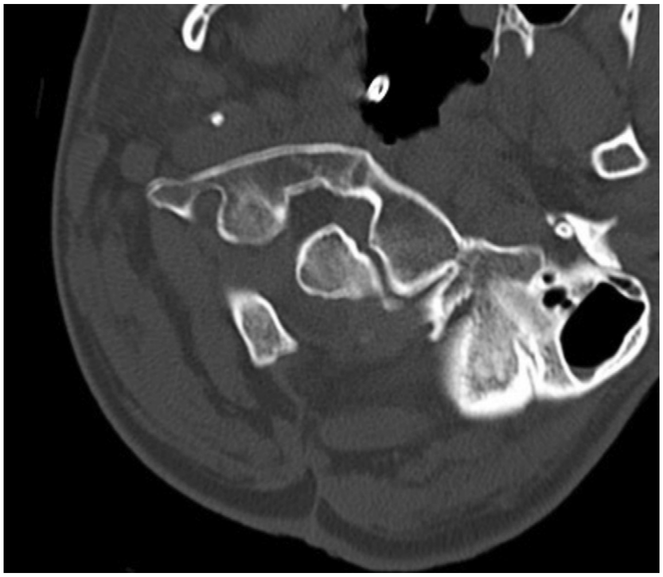

Figure 9-14 Axial computed tomographic scan shows rheumatoid arthritis with pannus.

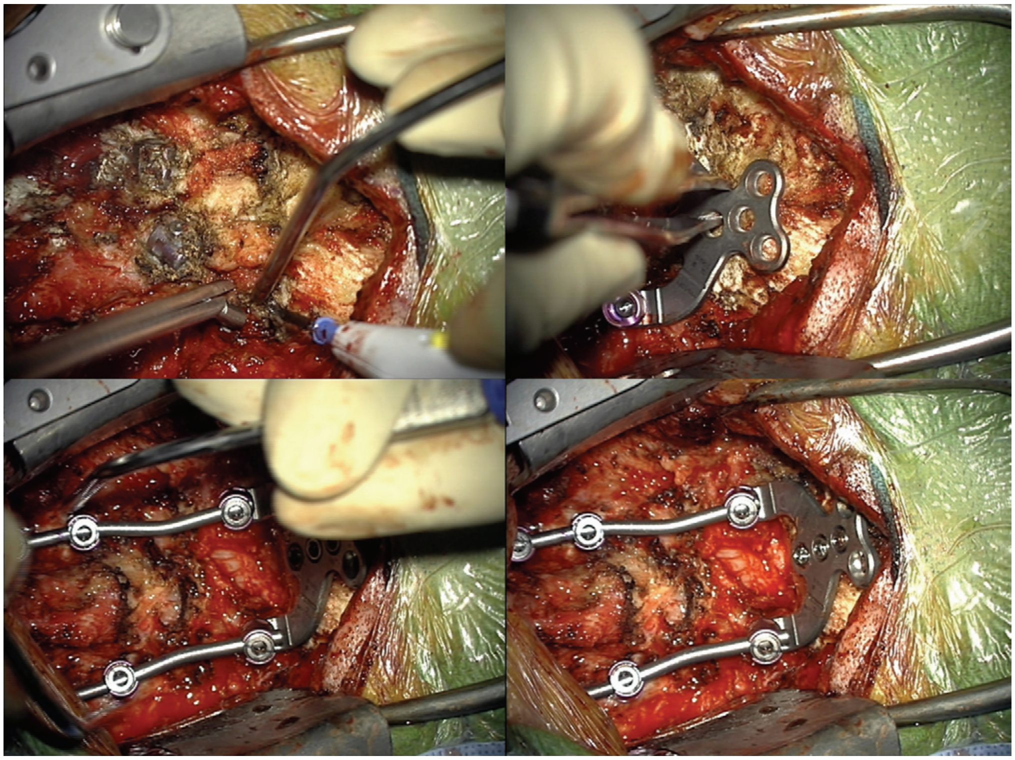

Figure 9-15 Intraoperative photos showing a stand-alone rigid posterior fixation for treating spinal compression attributable solely to atlantoaxial subluxation or cranial settling. *Upper left,* Bony removal to prepare occipital plating. *Upper right,* Positioning of occipital plate. *Bottom,* Completed construct, O-C4 fusion.

The approach to the lesion or deformity is dictated by the location and nature of the compression. In select cases, stand-alone rigid posterior fixation is adequate for treating spinal compression attributable solely to AAS or cranial settling that may be reduced with traction (Figs. 9-15 and 9-16). In addition, when preoperative dynamic images support that the CVJ compression is reducible, and a periodontoid pannus does not cause significant neural compression, rigid posterior fixation of C1–C2 usually allows involution of the pannus, and direct surgical removal is unnecessary (Figs. 9-17 through 9-19).

Figure 9-16 Postoperative lateral cervical spine film shows occipital to cervical fusion for rheumatoid pannus.

Figure 9-18 Preoperative myelogram shows rheumatoid arthritis at C1–C2. The patient underwent an occipitocervical stabilization with rods and wiring.

Figure 9-17 Preoperative lateral plain film radiography shows rheumatoid arthritis at C1–C2. The patient underwent an occipitocervical stabilization with rods and wiring.

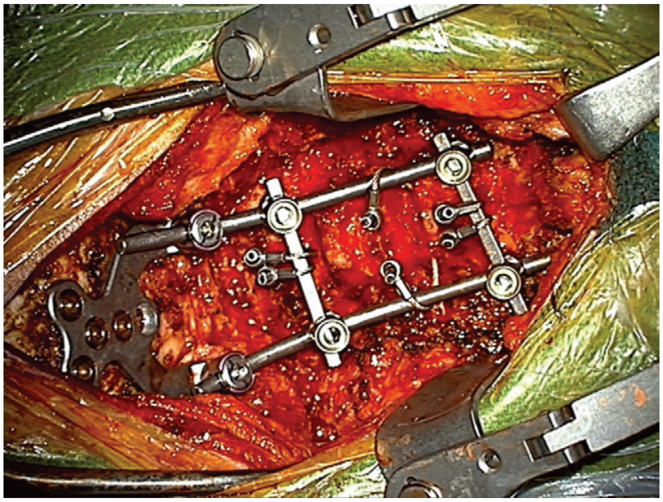

Figure 9-19 Intraoperative view of occipitocervical stabilization.

Access to the superior cervical spine via the posterior pharyngeal wall has been used for years to drain retropharyngeal abscesses, but in 1909, Kanaval described the transoral approach to the CVJ when he removed a bullet lodged between the foramen magnum and the arch of C1.[1] It was not until the 1940s that it was first used in the treatment of spinal abnormalities. In 1962, Fang and Ong published the first series of patients to undergo transoral decompression for irreducible atlantoaxial abnormalities, and decompression was frequently used to treat infections.[2]

TRANSORAL APPROACH

The transoral-transpharyngeal approach remains the gold standard for anterior approaches to the cervical spine (Figs. 9-20 and 9-21). In cases where preoperative dynamic or traction films demonstrate fixed deformities—that is, the atlantoaxial dislocation is irreducible, and it is accompanied by neural compression or a large rheumatoid pannus—the surgical route for direct midline decompression is by the transoral approach. Generally, this approach is used for irreducible, ventral, extradural compression of the spinal cord either by cranial settling or by C1–C2 subluxation.

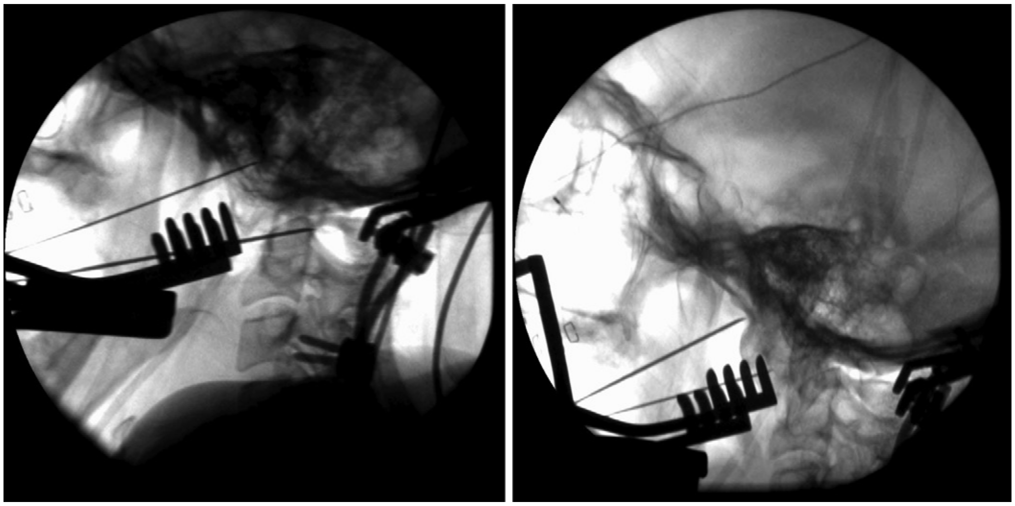

Figure 9-20 Intraoperative images show intraoral views of decompression. The patient underwent transoral odontoidectomy with occiput to C5 fusion.

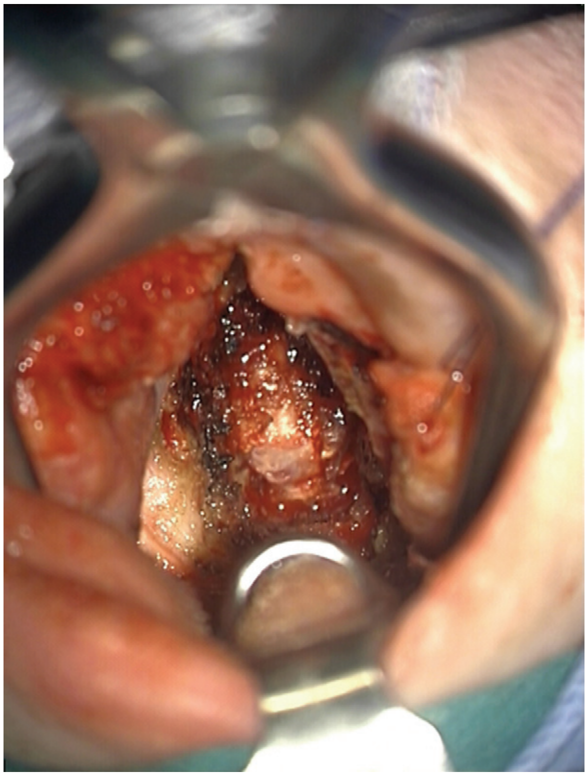

Figure 9-21 Intraoral view of odontoid decompression. The patient also underwent posterior occiput to C5 fusion.

However, specific criteria have been determined as thresholds for surgical intervention via this route:

- Vertical subluxation shortens the distance between the center of the lower end plate of C2 and the palatooccipital line to less than 34 mm in men and 29 mm in women.
- A maximal atlanto-dental interval (ADI) of greater than 7 mm is evident on dynamic radiographs.
- A posterior ADI of 14 mm or less is apparent.
- A large periodontoid pannus causes anterior cord compression.
- Motion-induced neck pain or sensory changes are reported.
- C2 nerve root entrapment results from C1–C2 subluxation.

Given that the RA patient population usually has multiple comorbidities, the medical status of these patients should be carefully evaluated before any surgical procedure.

The transoral approach allows for direct midline access to the pathology from the inferior third of the clivus to the C2–C3 disk space. Significant synovitis of the temporomandibular joint (TMJ) can restrict jaw opening and narrow the surgical corridor; in patients who cannot open their mouths more than 2.5 to 3 cm, a midline open-door maxillotomy allows access from the upper clivus to C3. A mandibular osteotomy with midline glossotomy can also be used if the TMJ is severely ankylosed, thus limiting the exposure of the open-mouth view. Proximal extension can be achieved by splitting the soft palate in the midline with retraction of the uvula superiorly. Additional superior exposure can be achieved by osteotomy of the hard palate.

Preoperative Preparation

Range of motion of the TMJ should be assessed to ensure adequate exposure. The degree of neck motion must also be evaluated to ensure no neurologic injury from intraoperative neck manipulation. Cultures of the oral and nasal cavities must be obtained before surgery to rule out sepsis. Patients with Down syndrome or thick tongues may pose additional challenges to exposure. In severely debilitated patients with impaired swallowing or respiratory function, a tracheostomy tube may need to be placed preoperatively. Additionally, if the nutritional status is poor, a preoperative gastrostomy tube should be placed.

Anesthesia and Equipment

Awake or fiberoptic intubations may be needed for mechanically unstable or neurologically compromised patients to minimize neck manipulation. The oral cavity is then packed with gauze to prevent fluid from entering the esophagus. For most transoral procedures, tracheostomy is not needed;

either an oral or armored nasal tracheal tube may be placed and retracted laterally in the oral cavity. Patients remain intubated for several days postoperatively to allow retropharyngeal swelling to subside. Radiographs may be obtained to document normal prevertebral soft-tissue shadows before extubation. A nasogastric tube (NGT) is placed preoperatively to empty the stomach, and the same tube may be used postoperatively for nutritional support.

Prior to starting the procedure, the oral cavity is washed with antimicrobial agents, followed by hydrogen peroxide, and then a saline wash; the oral mucosa, tongue, and retropharynx are coated with a 1% hydrocortisone cream to prevent swelling of those structures. Topical hydrocortisone may also be used postoperatively every 6 hours for a few days to prevent lip swelling.

Equipment

- Fluoroscopic C-arm
- Operating microscope
- Bipolar and Bovie cautery
- Electrophysiologic monitoring
- Transoral self-retaining retractor
- Red rubber catheter
- Periosteal elevator
- Drill with cutting diamond burrs with long extensions
- Long-handled pituitary rongeurs
- Long-handled ring and spoon curettes
- Hemostatic Gelfoam or surgical wool
- Fibrin glue
- Lumbar drain
- Bone graft

Patient Positioning

The patient is placed in the supine position with a lateral tilt toward the surgeon, and the head is fixed in a rigid Mayfield clamp for stable head and neck positioning, or it may be padded on a horseshoe headrest with 10 to 15 degrees of neck extension. If a Mayfield clamp is used, the single pin should be placed directly rostral to the external auditory meatus, whereas the dual-pin side should be evenly spaced anteroposterior to the external auditory meatus. For patients who have been reduced under traction, 5 to 10 lb weights are maintained to preserve normal alignment and to slightly extend the neck. A lateral radiograph of the upper cervical spine is obtained to confirm proper positioning.

Surgical Technique

A transoral self-retaining retractor is placed that consists of a tongue, retropharyngeal, and soft palate retractor. The tongue and mandible, along with the endotracheal tube, are retracted in the caudal direction with rostral countertraction applied to the upper alveolar margin. A rubber guard is used to protect the teeth and gums, and tongue retraction is released every 20 minutes to prevent congestion. Mobilizing the uvula superiorly provides for additional exposure; this can be done by inserting a red rubber catheter transnasally and suturing it to the uvula. By slowly withdrawing the catheter from the nose, the uvula is raised into the nasopharynx and pulled out of sight.

Local anesthetic with epinephrine is injected submucosally at the back of the pharynx, and a vertical or H-shaped incision for wider exposure is made through the mucosa; this is retracted to expose the deep muscle layer. The longus colli and longus capitis muscles are then elevated off the foramen magnum, C1, and C2 using Bovie cautery. Palpation of the anterior tubercle of the atlas is critical for orientation and adequate decompression. The body of the axis and the base of the clivus can also be used as midline landmarks. The anterior longitudinal ligament and the atlanto-occipital ligaments are then visualized and stripped. With the aid of a periosteal elevator, the bony landmarks—including the body of the axis, anterior arch of the atlas, and caudal clivus—are visualized and ready for decompression with a long, angled, 3-mm match stick high-speed drill. Bony removal can be continually assessed by an intraoperative microscope or fluoroscopy. Lateral exposure of up to 2 cm on either side of midline is accepted and will prevent entry into the eustachian tube, which may injure the hypoglossal nerve, and damage to the vertebral artery.

To remove the odontoid process, the apical and alar ligaments must be separated carefully to avoid a cerebrospinal fluid (CSF) leak, which may be difficult to repair. To prevent this, ensure the caudal clivus is removed. A fascial autograft, which could be taken from the fascia lata of the thigh, should be used and supported with the addition of fibrin glue. A lumbar drain should also be placed to reduce the CSF pressure and allow the graft to heal. A cutting burr may be used initially, followed by a diamond burr and Kerrison rongeurs with pituitary grasps, which are then used to safely remove additional bony fragments. In rheumatoid patients with basilar invagination, noncalcified, reactive granulation tissue must be carefully dissected and removed (Figs. 9-22 and 9-23). The dura will then fall forward, and pulsations can be visualized. If pulsations are not seen, the dura has not been adequately decompressed. In patients with significant basilar invagination or large pannus, the anterior rim of the foramen magnum may need to be resected to gain access to, and ultimately remove, the migrated odontoid. Attempt to remove this fragment in one piece as a single maneuver.

Closure begins with meticulous hemostasis. Gelfoam or cellulose wool is often used along with bipolar cautery; however, the surgeon should minimize use of cautery in attempts to preserve the posterior oropharynx tissue and its viable mucosal edges. Next, the longus colli muscles are reapproximated, and the posterior pharyngeal musculature and mucosa are closed in layers with 3-0 absorbable sutures. Any gauze placed during intubation is removed from the mouth, and the soft palate is reapproximated with interrupted absorbable sutures. A 1% hydrocortisone ointment is then rubbed generously on the surrounding structures to minimize postoperative swelling.

In most cases, after odontoidectomy, instability is assumed, and posterior stabilization or halo–vest application is needed. Because of chronic traumatic fractures, pseudotumor formation, and large pannus, pathologic changes occur at the CVJ that render it unstable. A posterior stabilization procedure may be done on the same day or in a delayed fashion.

It is important to remember that a fixed degenerated joint is not a stable joint. The number of levels of the cervical spine to fuse posteriorly depends on the severity of the instability, bone quality, and any subaxial instability that might be present.

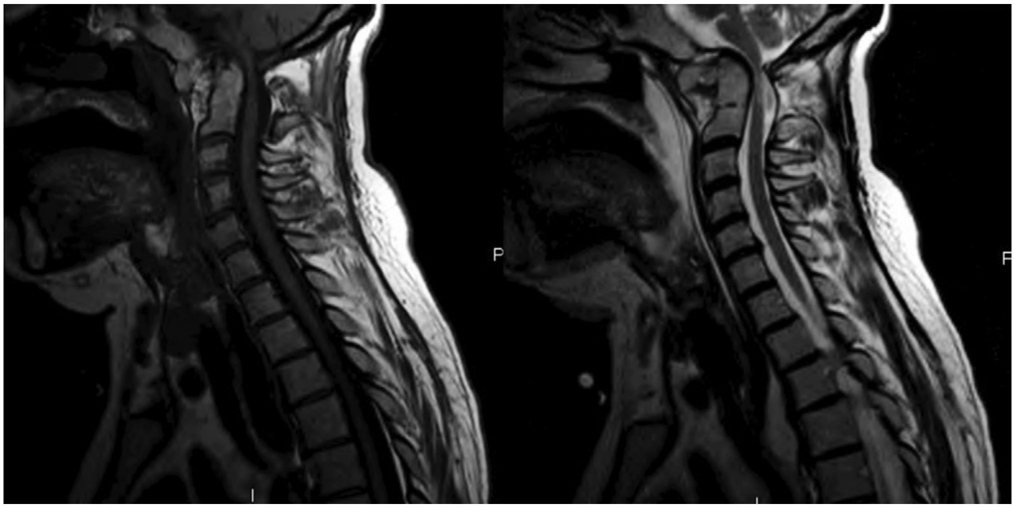

Figure 9-22 T1-weighted magnetic resonance imaging (MRI) (*left*) and T2-weighted MRI (*right*) show rheumatoid arthritis with pannus and basilar invagination.

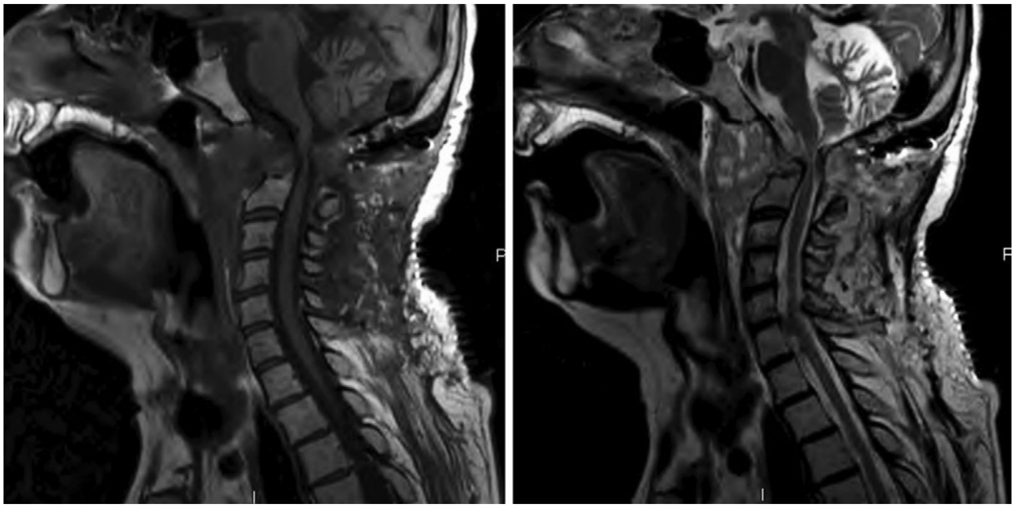

Figure 9-23 T1-weighted magnetic resonance imaging (MRI) (*left*) and T2-weighted MRI (*right*) show a large rheumatoid pannus and basilar invagination that have resulted in severe cervicomedullary compression.

EXTENDED TRANSORAL PROCEDURES

Given the limited caudal, rostral, and lateral access through the standard transoral approach, extended transoral approaches have been described to allow direct exposure of the clivus to C4 without obstruction by cranial nerves or vessels. General considerations and preoperative preparation have already been reviewed. Here, we concentrate on surgical technique alone.

Open-Door Maxillotomy

A horizontal Le Fort I mucoperiosteal incision is made above the mucogingival fold, from one maxillary tuberosity to the other, to expose the maxillary buttresses. The face is then degloved until the nasal apertures and septum are visible; the septum is then detached, and the vomer is retracted laterally. The mucoperiosteum should not be too aggressively stripped to maintain the blood supply to the maxilla. Temporary titanium plates are then screwed into position to measure for proper alignment and to avoid postoperative malocclusion. A Le Fort I osteotomy is then made with a reciprocating saw with careful separation of the nasal septal mucosa; if the dura has been violated, this tissue may be flapped posteriorly to aid in closure at the end of the case. A midline sagittal incision is then made in the oral mucosa and palatal mucoperiosteum, which is reflected back along the line of the hard palate osteotomy. The soft and hard palate are divided and reflected laterally. Using a curved osteotome, the maxillary tuberosities are separated from the pterygoid plates and are rotated inferiorly and laterally. Additionally, the vomer can be removed to expose the anterior sphenoid sinus. The soft palate is then divided using sharp dissection and ensuring deviation to one side of the uvula posteriorly. A transoral retractor and a maxillotomy plate are then positioned to keep bony structures out of the field and to expose the posterior nasopharynx from the sphenoid sinus to the upper cervical spine.

Next, exposure of the clivus and craniocervical junction is achieved by using a midline mucoperiosteal incision with lateral retraction of the underlying pharyngeal muscles. Bony structures are then removed as described earlier, taking care to leave the posterior cortical surface of the clivus and dura intact. This layer is then removed using number 1 and 2 Kerrison up-biting instruments, and the posterior and deeper cortical shell of the clivus is removed to reveal the underlying dura. Significant hemorrhage may be encountered at this stage, specifically at the upper part of the clivus, but it can be controlled with bone wax and Surgicel.

Median Mandibulotomy and Glossotomy

Caudal extension may be useful in patients who have limited mouth opening as a result of arthritis of the TMJ or any craniofacial/intraoral anomaly that may limit adequate decompression. First, a preoperative tracheostomy must be performed for this approach. Next, the head is fixed in a Mayfield clamp system, and a midline lower labial incision is made that extends inferiorly to the hyoid bone. Ensuring this cut is in the midline allows for preservation of the inferior portion of the orbicularis oris muscle and ensures postoperative mouth function. The incision on the chin may be Z-shaped for a cosmetic scar. In the mouth, the mucosal incision extends to the lower buccal sulcus, in front of the mandibular origin of the genioglossus and geniohyoid muscles, and to the frenulum of the tongue. The mandibular periosteum is cut in the midline, and both leaves are elevated laterally no more than 1 cm. Too lateral of an elevation puts the mental cutaneous branches of the mandibular nerve at risk.

Titanium plates are then temporarily drilled to the anterior surface of the mandible to allow for equal approximation of the mandible at the end of the case. Using a reciprocating saw, a midline mandibular osteotomy is then made between the central incisors, and the mandibular halves are swung laterally. At this point, the tongue may be retracted inferiorly, or, for additional exposure, the lingual frenulum, genioglossus, and geniohyoid muscles may be divided. This is done using monopolar cutting cautery, and if done in the midline, critical neural and vascular bundles are avoided. Each half of the tongue is pulled laterally and held in place using self-retaining retractors. This exposes the surgeon deeply to the epiglottis and to the level of C4. At this stage, the same steps as the open-door maxillotomy approach are used.

Endoscopic-Assisted Anterior Approach

In the most recent literature, an updated version to the classical transoral microsurgical decompression is provided. Here, the incision is made above the soft palate; this limits postoperative swallowing dysfunction and minimizes exposure to oral bacteria by complete isolation of the oral cavity. Moreover, it is possible to remove the odontoid process without disturbing the C1 ring, owing to the more caudal surgical route. With this method, no tracheostomy or feeding tube is needed. Some downsides to this approach include that only piecemeal removal of CVJ pathology is obtained, and obese, barrel-chested, or severely kyphotic patients do not qualify for this procedure.

Posterior-Only Approach

When direct anterior decompression is not indicated and stabilization is needed at the CVJ, a posterior-only approach may be used (see Fig. 9-19). The decision to stabilize with or without a decompression must also be weighed. Numerous techniques have been described for posterior occipitocervical fixation with or without decompression. Posterior CVJ decompression is performed with a suboccipital craniotomy, a cervical laminectomy, or both. Again, using a radiolucent operating room table, an appropriately sized Mayfield clamp is used for optimal head and neck positioning. Using this method, the neck may be manipulated intraoperatively to provide flexion or extension as needed.

Next, an incision is made from the inion to the mid or lower cervical spine, depending on the number of subaxial levels involved. The fascia is encountered, and the midline avascular raphe with converging posterior musculature is visualized. Dissection with monopolar coagulation cautery is used and is carried down to the spinous processes. The posterior prominence of C2 is identified, and subperiosteal dissection is continued, exposing out laterally to the facet capsules just above C2–C3. At this point, the posterior ring of C1 is exposed in a similar fashion and is carried out laterally on both sides.

Several key structures must be properly identified and avoided at this stage. First, along the posterior arch of C1 and 15 mm lateral to the midline, an indentation identifies the extracranial course of the vertebral artery and the surrounding venous plexus. Second, between the arch of C1 and the pars interarticularis of C2 below this is the exiting C2 nerve root with its large venous plexus. If entered, it is most appropriate to pack the area with hemostatic agents and continue dissection on the contralateral side; additional use of Bovie cautery tends to worsen the bleeding. If a large C2 ganglion is present, sectioning of the nerve root may be done, thereby increasing visibility. Third, the posterior occipital and atlantoaxial membranes in this region dive deeply and become invested in the underlying dura, and incidental durotomy can occur during exposure.

After C1–C2 joint exposure, manual reduction of a C1 anterior subluxation can be reduced by placing a Penfield number 4 instrument into the C1–C2 joints bilaterally and, using fluoroscopic guidance, levering C1 back onto C2. Biomechanically sound plate, rod, and screw constructs can now be placed, ensuring that key anatomic landmarks are identified. Pedicle screws and C1–C2 transarticular screws are placed prior to lateral mass fixation because their trajectory is dependent on local anatomy.

The final step should be occiput fixation (Fig. 9-24). Before connecting this construct to the occiput hardware, however, alignment of the CVJ must be confirmed by x-ray. Closure is achieved in layers using absorbable suture material, and an attempt should be made to close the fascia to the underlying C2 spinous process.

Combined Anterior and Posterior Approach

As mentioned above, after an anterior procedure, instability is usually assumed, and posterior stabilization or halo–vest application may be needed and should be addressed. It is not uncommon for an anterior procedure to be followed by a posterior one, and this is used to obtain maximal decompression and stabilization.

Postoperative Care

Sterile wound dressing should remain in place for 2 days, and the patient should be maintained in a rigid collar and mobilized early when possible. Prolonged intubation may be required to allow for swelling to subside; however, immediate extubation may be appropriate for routine cases. An NGT should be maintained to avoid postoperative wound infection and to decompress swallowed blood from the stomach. It should not be manipulated, and the patient should be kept NPO (no food by mouth) for 7 days, after which the diet is advanced from clear liquid to solids after soft palate and oropharynx examination. Postoperatively, 15 to 24 hours of antibiotics is standard. If additional stabilization is required, those details should be addressed in the postoperative period, and postoperative imaging may also be considered (Fig. 9-25).

Initial outpatient evaluation and wound check is done at 10 to 14 days, 6 weeks, 3 months, 6 months, 1 year, and yearly for 5 years. AP and lateral x-rays are obtained at each visit, and flexion-extension views are obtained at 3 months and thereafter as needed.

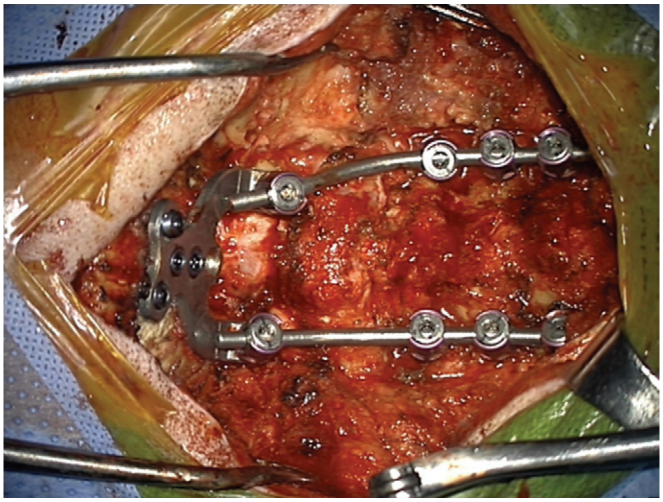

Figure 9-24 Posterior view of occiput to C5 fusion for rheumatoid pannus with basilar invagination.

Complications

Complications may occur, but these can often be avoided if certain pitfalls are realized: Vascular injuries may occur, especially if any manipulation of C1 has occurred that causes surgeon disorientation, or when beginning dissection lateral to the midline. Failure to appreciate rotatory subluxation of C1 onto C2 may also result in the surgeon being unaware that the vertebral artery is in the approach to the midline. The marginal sinus and vertebral arteries are most at risk; however, the carotid and anterior spinal artery in the mandibular-split approach may also be injured. In this case, local packing and pressure are used to control bleeding. Postoperative angiography should be considered to evaluate for any dissections or occlusions that may have occurred.

Small dural tears may occur that can be closed with fibrin glue. Larger CSF leakage may occur if the dura is violated, and a preoperative lumbar drain should be considered if this is expected. Nasal septal flaps, fascia, muscle, or dural substitutes may also be tacked into place and then reinforced with fibrin glue in large dural tears. If a CSF leak is not recognized and is left untreated, retropharyngeal abscesses and meningitis may occur; 6 weeks of broad-spectrum triple antibiotics are used to treat such circumstances, and this may require additional trips to the operating theater for surgical drainage procedures.

Soft-tissue swelling may occur as a result of venous congestion and may necessitate prolonged intubation, which may lead to other complications. As mentioned earlier, occasionally releasing the tongue retractor and application of topical or intravenous steroids may hinder this process.

Rough handling of the retropharyngeal soft tissue and wound edges may increase bleeding and may affect viability of the wound. Wound dehiscence may result from suboptimal closure and/or early feeding and may require repeat primary closure. If delayed dehiscence occurs, an abscess or other infection should be ruled out. Palate incompetence, dysphagia, and nasal regurgitation may result from wound complications and may require speech and diet therapy for

Figure 9-25 Postoperative computed tomographic scans, sagittal (*left*) and axial (*right*) views, show resected dens and occiput to C5 fusion.

oral retraining exercises. Percutaneous gastrostomy should always be considered preoperatively when performing any of these approaches.

Dislocation of the mandible must also always be examined for and corrected before the end of the procedure. Failure to achieve complete lateral decompression or leaving bony edges and fragments behind may also be pitfalls in these approaches. Hardware failure and pseudarthrosis may pose a problem in the systemically affected RA patient. If the stability of the construct is in jeopardy, early intervention is required.

Cranial nerve palsies may occur, such as from hypoglossal nerve injury, but also cranial nerves IX, X, and XI may be damaged, and care should be taken to avoid critical nerve bundles. Brainstem injury may occur as a result of damage to local perforating arteries or from violation of arachnoid planes, which can cause direct injury.

With careful attention paid to patient selection, patient preparation, surgical technique, and postoperative care, complications are reduced to less than 5% with these approaches.[3]

Summary

The transoral approach and its extended variations are quite effective in exposing midline pathology from the clivus to C4. Ventral cervicomedullary decompression through this approach can yield excellent recovery, because this method provides for direct removal of the pathology. A thorough knowledge of embryology, anatomy, and common pitfalls is crucial to gain the best possible outcomes and to always ensure patient safety.

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10 Craniovertebral Junction Instabilities and Surgical Fixation Techniques

FAHEEM SANDHU

Overview

Occipitocervical (OC) instability affects a number of patients every year and is associated with significant morbidity. It is due to the lack of firm articulation between the occipital bone of the skull and the cervical vertebrae and is a potentially dangerous condition that can progress to dislocation or subluxation and subsequent damage to the spinal cord, medulla, and cervical or cranial nerve roots. Instability can arise from many different disorders, including but not limited to primary conditions such as congenital anomalies, spontaneous disassociation of the atlantoaxial junction, traumatic dislocation, rheumatoid arthritis, degenerative bone disease, inflammatory or infectious lesions, neoplasms, and secondary conditions arising from cervical laminectomy, decompression, fusion, or other surgical intervention.[1,2]

Patients with OC instability frequently require operative intervention to stabilize the craniovertebral junction. Foerster[3] documented the first OC fusion in 1927, and many fusion techniques have been described since.[4] Stabilization techniques have evolved from the use of bone graft with titanium wire and external halo orthoses to more recent techniques that have used screws, rods, and plates to obtain internal fixation without the need for external stabilizers.[5] Internal fixation may prove to be superior, because external ring halo stabilization is not without complications and morbidity, and it may not provide adequate stabilization.

OC instability can result from various congenital, degenerative, inflammatory, infectious, neoplastic, or traumatic processes. In pediatric patients, laxity and immaturity of the craniovertebral ligaments predisposes this population to OC instability. Patients with OC instability are usually treated primarily with conservative measures, including external bracing, physical therapy, and activity modification. However, many patients will have persistent instability that frequently requires operative fixation and stabilization through OC fusion. Additionally, patients with atlantoaxial instability who are not candidates for atlantoaxial fixation or who have failed previous attempts at atlantoaxial fixation may also require OC fusion.

The evolution from OC instability to dislocation or subluxation can result in considerable damage to the spinal cord, medulla, and nerve roots. Thus in patients suffering OC instability, the rigidity and durability of surgical fixation is of supreme importance. Over time, stabilization methods have evolved from the use of semirigid techniques and titanium cable and wire constructs with external halo stabilizers to more recent rigid internal fixation techniques, as previously mentioned.[5]

Foerster[3] first pioneered OC fusion techniques in 1927. Hamblen expanded on Foerster's and others' techniques to develop a procedure that used iliac crest autograft and wire to stabilize the occipitocervical junction (OCJ).[6,7] This *Hamblen technique* called for prolonged external stabilization with a Minerva plaster jacket for 4 to 6 weeks and a halo collar for an additional 3 to 6 months.[1] In the early 1990s, Jain and colleagues[8] obtained occiput–C2 stability by placing a bridge of bone posterior to the foramen magnum. This bridge, or artificial atlas, was used to mediate fusion with the C2 lamina using conventional wiring techniques.[8]

In an effort to obtain better internal fixation, several authors developed techniques using some combination of titanium cables, wires, hooks, rods, and bone grafts. In 1993, Sonntag and Dickman[9] described a technique that used U-shaped threaded rods to facilitate stabilization of the OCJ. The rod was attached with wires passed through burr holes in the occiput with sublaminar wires at C1 and C2. The levels fused were then decorticated, and morcellized bone was placed to assist arthrodesis. Fehlings and colleagues[4] described a similar technique but also used bone grafts and interspinous wires to help facilitate fusion. However, these techniques offered only semirigid fixation and required postoperative external stabilization.

In the late 1990s, Faure and colleagues[10] pioneered a technique that used hooks attached to the occiput, laminar hooks made to facilitate a lamina-to-lamina clamp, and contoured rods to facilitate the remaining stabilization. Paquis and colleagues[11] described a similar technique in which hooks were screwed to a rod to facilitate the stabilization of the OCJ. Alternatively, they stated that screws and rods or plates could also be used to facilitate OC fusion.[11] In 2003, Singh and colleagues[12] studied a technique that used a precontoured titanium loop (OMI Loop, Ohio Medical Instrument Company, Cincinnati) to facilitate fusion of the OCJ. The loop construct was found to provide immediate fixation of the OCJ with high bone fusion and low failure rates. The Hartshill-Ransford loop and Luque rods with a Hartsfill rectangle[13,14] also performed similar functions. These techniques were among the first that did not require postoperative stabilization.[2,5]

Screws and plates or rods have become a prominent technique in OC fusion and provide further rigidity to the OCJ. Pait and colleagues[15] described an "inside out" technique, in which a lateral mass plate was contoured to match the occipital bone and cervical lordosis. The plate was secured with flathead screws placed under the occipital bone in the epidural space with the threads protruding from burr holes and by nuts placed on the outside of the occiput. This technique led to 100% fusion in patients with rheumatoid arthritis.[16] In addition, Vale and Cahill and colleagues[17] described a technique using a T-shaped plate that facilitated rigid stabilization of the OCJ and which can be attached to both the occipital plate and lateral mass screws on cervical vertebrae. Several screw-and-rod systems are available today, and many of these can transition to the occiput using a plating system. These systems offer immediate rigid stabilization without the need for prolonged postoperative external stabilization.

Several biomechanical studies have been conducted to assess the stability of different fusion techniques. In 1999, Abumi and colleagues[18] demonstrated that occipital plate, rod, and screw systems provide a high rate of fusion and sufficient correction of misalignment in the OCJ region.

The use of bone morphogenic proteins (BMPs) has been shown to improve fusion rates in the lumbar spine.[19] Fifty-three patients in the study received BMP intraoperatively as an adjunct to allograft bone placement and instrumentation, and 45 patients had traditional iliac crest autograft. Of the BMP patients, 88% had successful fusion operations with good early fusion and no evidence of fusion failure at the most recent follow-up, whereas the autograft iliac crest group had only 73% fusion. As BMPs become more widely used, it is possible that the rate of early fusion will be increased in patients undergoing OC fusion. This could reduce the rate of fusion failure and lead to fewer reoperations and fewer delayed complications.

Regardless of the technique used to fuse the OCJ, additional precautions must be taken in the operating room to ensure successful fusion. Specifically, the surgeon must understand the optimal position of the OCJ before attempting fusion. Phillips and colleagues[20] wrote that OC "neutral" is considered to be the most functional position of the cranium on the cervical vertebrae and further posited that "neutral position" is defined radiologically as the position in which the subject looks straight ahead during a standard lateral cervical radiograph. They used the occipital cervical angle (using the McRae line and the superior end plate of C3) and distance to estimate the position of the OCJ.[16] In addition, Takami and colleagues[21] stated that proper alignment of the craniovertebral junction angle could help prevent postoperative complications such as dysphagia, dyspnea, and subaxial subluxation.

Furthermore, the decision to proceed with OC fusion should be carefully considered, because the procedure often results in the loss of 10 to 15 degrees of sagittal rotation. OC fusion in the pediatric population is also complicated by the potential for limitation of future growth, long-term construct failure requiring reoperation, and the development of secondary deformities at adjacent subaxial levels. However, two independent studies with long-term postoperative follow-up showed no growth limitation in patients who underwent atlantoaxial fixation.[22,23] Potential intraoperative complications include venous hemorrhage, vertebral artery injury, and dural tear. Delayed complications include wound infection, loss of reduction as a result of construct slippage, and pseudoarthrosis.

Anatomy Review

The OCJ is an anatomically and biomechanically complex region of the spine that presents unique challenges in operative management. The discussion of surgical techniques will be limited to posterior approaches for the purposes of this chapter. The posterior approach to the upper cervical spine and OCJ first begins with incision of the skin and dissection of the subcutaneous tissues in the avascular midline raphe. Once the bony structures are encountered, subperiosteal dissection is performed to expose the occipital bone, posterior rim of the foramen magnum, posterior arch of the atlas, and the spinous process, lamina, and lateral mass of the axis (Fig. 10-1). With these elements exposed, it is then possible to proceed with decompression and fixation as indicated.

The bony anatomy of the OCJ is defined by the occipital bone, the atlas, and the axis. The occipital bone makes up the most posterior and inferior portions of the cranial vault. Its curved posterior surface, or squamosa, serves as the point of attachment for the semispinalis and rectus capitis muscles, which define the superior and inferior nuchal lines, respectively. The occipital bone is thickest in the midline, where a thick keel lies along the intracranial surface below the transverse sinus; this thickness is greatest at the level of the occipital protuberance (10 to 18 mm) and decreases inferiorly toward the foramen magnum (3 to 8 mm). Lateral to the midline and inferior to the external occipital protuberance, the occipital bone quickly becomes thinner, where it is 2 to 8 mm. Therefore the midline occipital keel provides the thickest surface for screw purchase in OC fixation (Fig. 10-2).

The inferior surface of the occipital bone carries the occipital condyles at either side of the foramen magnum. The condyles articulate with the superior articulating facets of the atlas. Although occipital plates are commonly used for OC fixation, it is sometimes not possible or desirable to place instrumentation in the occipital bone, either because

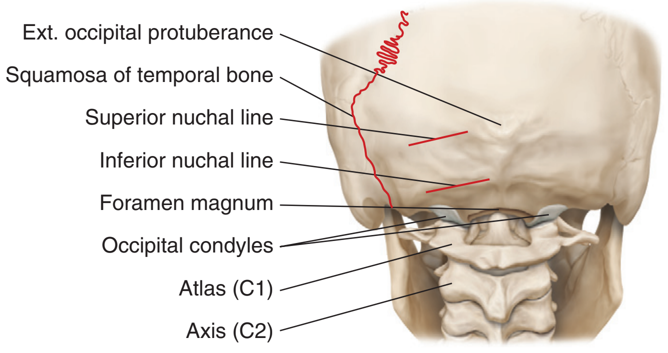

Figure 10-1 Major bony structures encountered at the occipitocervical junction.

of anatomic irregularities, previous occipital surgery, or lack of surface area for bony fusion. In these cases, some authors have advocated placement of occipital condyle screws. Morphometric analysis of the occipital condyle has revealed that it is a boxlike structure situated at approximately a 20-degree medial angle from posterior to anterior. The average dimensions of the condyles have been shown in studies of cadaveric specimens and computed tomography (CT) to be approximately 10 mm in height (craniocaudal), 10 mm in width (mediolateral), and 22 mm in length (anteroposterior). Therefore, the occipital condyle can provide an additional or alternate fixation point for OC fixation (Fig. 10-3).

Below the occiput, the first cervical vertebra, or atlas, articulates with the occipital condyles on either side of the foramen magnum. The posterior arch of the atlas extends posteriorly and, along with the spinous process of the axis, serves as an important anatomic landmark when performing the initial exposure. The atlantooccipital membrane is a thin layer encountered deep to the cervical musculature; it connects superiorly to the posterior rim of the foramen magnum and inferiorly to the upper border of the arch of the atlas.

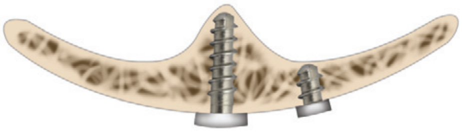

Figure 10-2 Cross-section through the occipital bone demonstrates the relative thickness of the midline occipital keel and the thinner occipital squamosa.

Several important vascular structures are found in the vicinity of the OCJ, most notably the paired vertebral arteries. In the subaxial spine, the vertebral arteries are transmitted through the transverse foramina of the cervical vertebrae as the arteries ascend cranially. At the level of the axis, the arteries turn laterally and posteriorly before ascending to enter the transverse foramen of the atlas. After exiting the transverse foramen of the atlas, the arteries turn medially and posteriorly to travel in a groove along the superior surface of the posterior arch of the atlas, the *sulcus arteriosus;* this constitutes the horizontal segment of the third portion of the vertebral artery, and this sulcus can usually be identified 15 to 18 mm lateral to the midline. This horizontal portion is located posterior and slightly inferior to the atlantooccipital joint. The artery then courses medially and anteriorly to pierce the atlantooccipital membrane and enter the dura (Fig. 10-4).

Several venous structures are also encountered in the OCJ. At both the atlantooccipital and atlantoaxial junctions, the epidural venous plexus is found posterior to the joint space and adjacent to the vertebral artery, and it can be the source of significant intraoperative bleeding. At the foramen magnum the marginal sinus is occasionally encountered, and farther on laterally, the emissary vein of the occipital condyle is found (Fig. 10-5). The major intracranial dural sinuses must also be considered when planning OC fusions. The transverse sinuses are usually found at the level of the external occipital protuberance and course laterally along the intracranial surface of the occipital bone. Occasionally, the occipital sinus is found along the midline of the occipital bone, running from the foramen magnum to the confluence of the sinuses, and it is sometimes found within the occipital bone itself. This must be considered in OC fixation, because it can be injured and may produce bleeding during midline occipital plating.

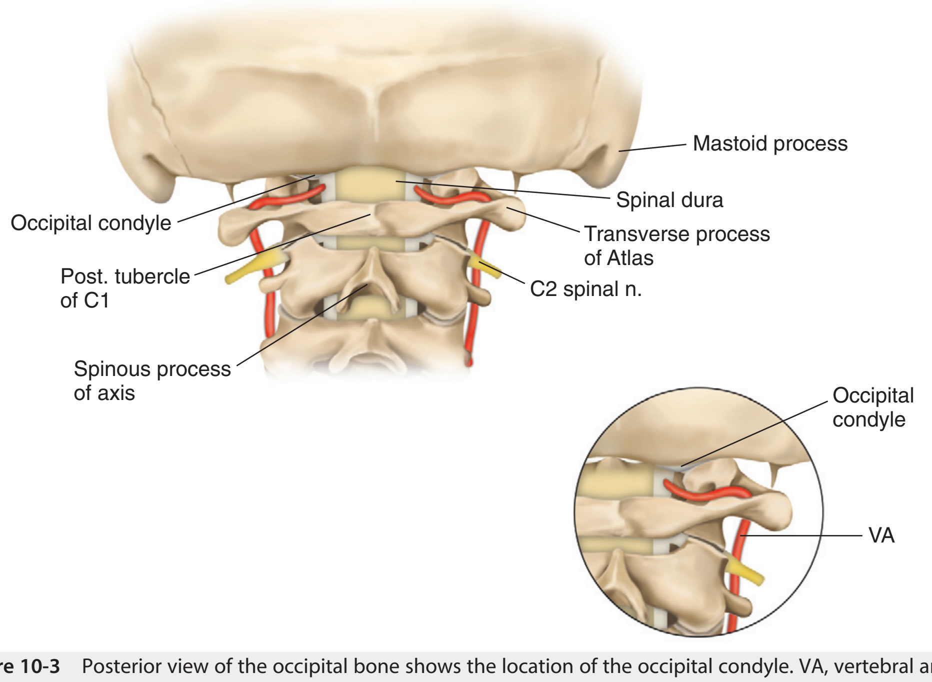

Figure 10-3 Posterior view of the occipital bone shows the location of the occipital condyle. VA, vertebral artery.

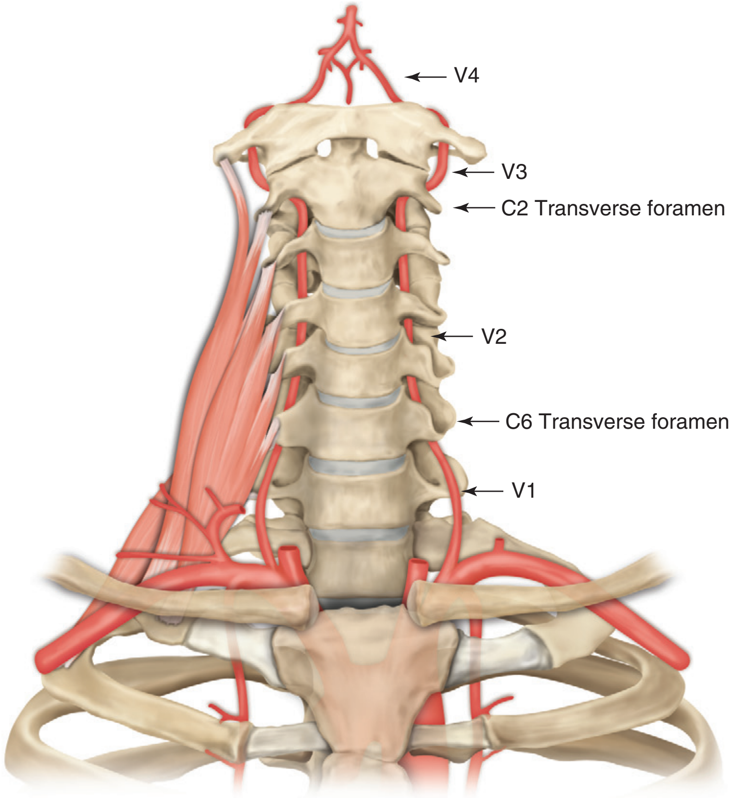

Figure 10-4 Posterior view demonstrates the complex anatomy of the vertebral arteries in relation to the bony anatomy of the occipitocervical junction. VA, vertebral artery.

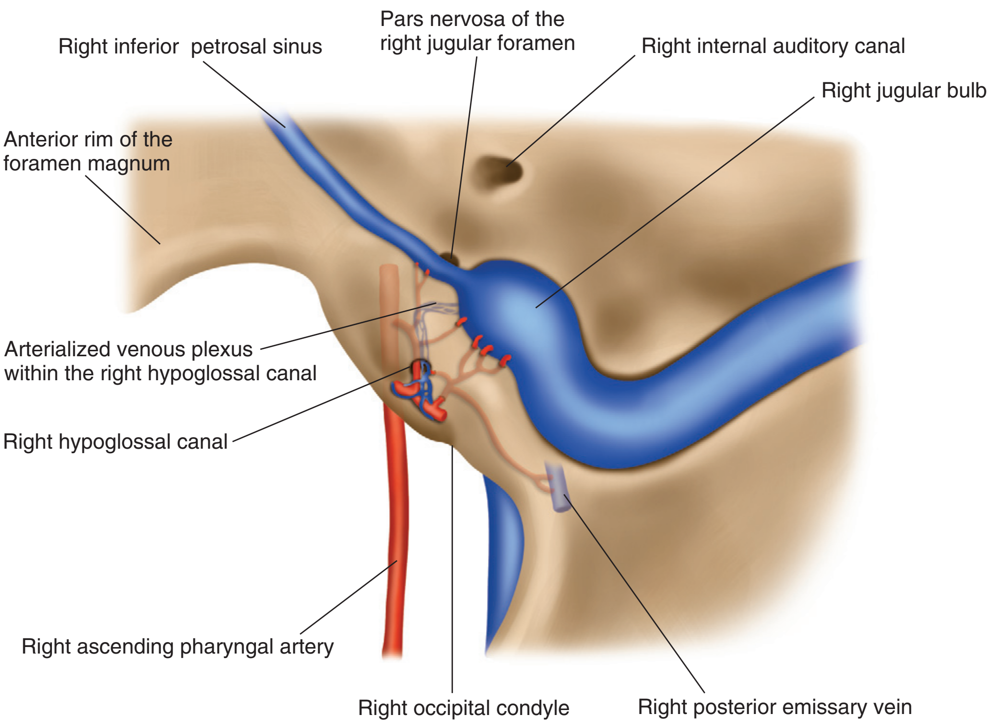

Figure 10-5 Venous structures of the occipitocervical junction, including the condylar emissary vein and the epidural venous plexus.

Indications

- Occipitocervical instability (Fig. 10-6)
- Atlantoaxial instability with previously failed fixation or need for cranial extension because of a high risk of fusion failure with atlantoaxial fixation

Operative Technique

EQUIPMENT

- Radiolucent operating table
- Mayfield head holder (consider radiolucent head holder)
- Intraoperative fluoroscopy or CT
- Headlamps and optical loupes
- Monopolar and bipolar electrocautery
- High-speed drill
- Straight and angled curettes
- 2- to 5-mm Kerrison punches
- Instrumentation (plate, screws, wires, rods)
- Bone graft (local or distant autograft, allograft, etc.)
- Three-dimensional radiographic study (CT or magnetic resonance imaging [MRI]) to assess the anatomy of the craniovertebral junction, especially the suitability of C1, C2, and occipital bone for instrumentation and the location of the vertebral artery

POSITIONING

In cases of OC instability, the patient should be brought to the operating room in some form of external orthosis, rigid cervical collar, or halo–vest, depending on the degree of instability. The patient is intubated without extending the neck to avoid subluxation and subsequent neurologic injury. This can be accomplished with the patient awake or sedated and with the aid of fiberoptic laryngoscope visualization. Once the patient is intubated, a Foley catheter is placed in the bladder, and an arterial line is placed for intraoperative hemodynamic monitoring. If intraoperative neuromonitoring is to be used, the leads should be placed at this point. The patient's head is then fixed in the Mayfield head holder, and the patient is carefully turned to the prone position. It is important during this maneuver to maintain neutral position of the OCJ to avoid causing subluxation. If the patient is in a halo-vest orthosis, the halo and vest are left in place, and the patient is carefully turned to the prone position. Once the patient has been properly positioned, the back of the vest is removed to facilitate surgery. Intraoperative neuromonitoring can detect neurologic changes during patient positioning, which could indicate spinal cord injury from abnormal cervical motion. With the patient in the prone position, the head is fixed in the Mayfield holder, and the alignment of the OCJ is confirmed with lateral fluoroscopy. It is important to achieve neutral anatomic alignment at this point to avoid improper alignment during arthrodesis. The patient is then secured to the operative table, pneumatic compression devices are placed, and the field is prepped and draped. The posterior iliac crests should be draped into the field if autograft bone is needed for the arthrodesis (Fig. 10-7).

APPROACH

A midline skin incision is made down to the deep cervical fascia from the level of the inion to the level of C4 or lower, depending on the levels of the subaxial spine that will be involved in the fusion construct. Electrocautery is used to dissect the muscles and soft tissue off the occipital bone and posterior elements of C1 and C2 in a subperiosteal fashion, taking care to avoid excessive vertebral manipulation. The exposure is carried laterally to expose the occipital bone and the lateral elements of C1 and C2. This ensures adequate exposure for the placement of instrumentation and provides a good surface for bony fusion. Care must be taken

Figure 10-6 Lateral radiograph of an 88-year-old male demonstrates destruction of the C2 vertebral body from metastatic prostate cancer and anterior subluxation of the cranium.

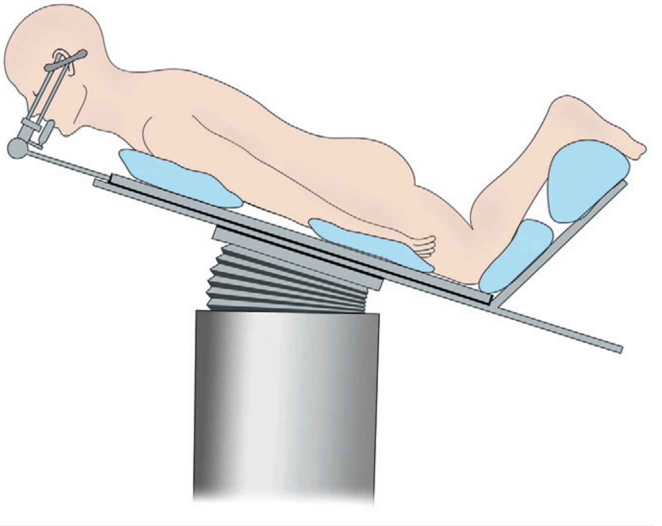

Figure 10-7 Lateral fluoroscopic image shows neutral anatomic positioning in preparation for occipitocervical fixation.

during dissection of the superior aspect of the posterior ring of C1, because the vertebral artery is found in the sulcus arteriosus 15 to 18 mm lateral to the midline.

ARTHRODESIS

Occipital Plating

Several options are available for occipital plating in OC fixation; these include midline, lateral, and combination systems. It is important to consider the individual patient's anatomy when selecting a plating system. Careful review of preoperative imaging, especially CT, will help to determine the optimal system and the length of screws to be used to anchor the plate.

- Plating is usually performed after atlantoaxial instrumentation and any subaxial instrumentation has been performed. This is generally accomplished with C1 lateral mass and C2 pedicle, pars, or translaminar screws; C1–C2 transarticular screws; and subaxial lateral mass screws (Fig. 10-8). These techniques are described in subsequent chapters.
- With the soft tissues cleared from the occipital bone, and with atlantoaxial instrumentation in place, the selected plates are brought into the field, where the plate is contoured to match the curvature of the occipital bone and to ensure optimal fixation.
- The occipital bone is then drilled with the plate in place in order to place the occipital screws. Either a power drill or hand drill is used to penetrate the occipital bone; this is typically done under fluoroscopic visualization or with stereotactic navigation to avoid violation of the dura. The drilled hole is then probed and tapped before screws are inserted. In the midline, 10- to 12-mm screws can usually be placed safely, whereas in the lateral occipital bone, 6- to 8-mm screws are usually used (Fig. 10-9).
- With the plate in place, rods are then contoured and connected to the atlantoaxial and/or subaxial instrumentation if used. The rods are then secured with locking screws.
- The exposed occipital bone can then be decorticated along with the exposed portions of C1 and C2 in preparation for bone grafting. Autologous tricortical iliac crest or rib graft, cadaveric strut, bone chips, bone putty, or some combination thereof can then be placed to promote bony fusion.

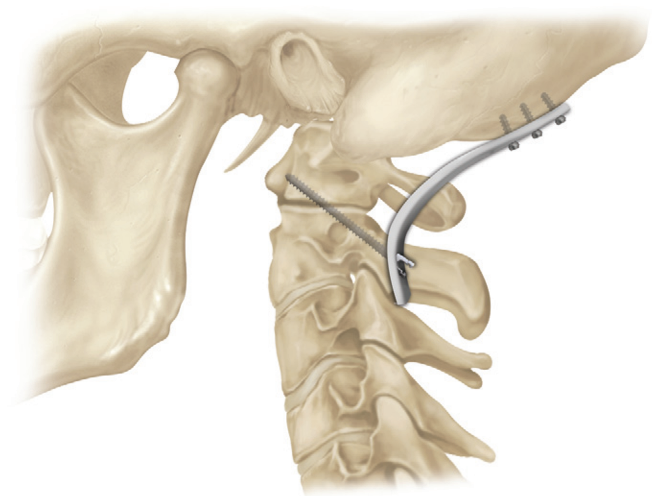

Figure 10-8 Lateral view of C1–C2 transarticular screw fixation with a lateral occipital plating system. The C1–C2 transarticular screw serves as the lower point of fixation to the lateral plate, which is affixed to the lateral occipital bone with screws.

Occipital Bolt or "Inside-Out" Technique

The occipital bolt technique is an alternative to occipital plating, in which occipital fixation is achieved with paramedian bolts placed in the suboccipital bone through bilateral burr holes. This technique permits more robust fixation points to the suboccipital bone than other lateral fixation systems. The bolts can be placed either from an "outside-in" or "inside-out" technique. As with any occipital screw placement, the risk of screw pullout and intracranial hematoma exists. The inside-out technique was developed to circumvent some of these complications. Additionally, the bolt technique leaves more occipital bone exposed as a surface for bony fusion.

- After exposure of the suboccipital bone and cervical spine, the lateral plate or rod is brought into position and is contoured to conform to the acute angle of the occiput and cervical spine. This can be facilitated with a plate or rod template and correlated to the placement of any cervical instrumentation. As with occipital plating, cervical fixation can be accomplished with C1 lateral mass and C2 pars/pedicle screws, C1–C2 transarticular screws, and subaxial lateral mass screws. Cervical instrumentation can be placed before or after the occipital bolt, depending on the surgeon's preference.
- Once the rod is contoured and the position of the occipital bolt is confirmed, a 1-cm burr hole is created in the suboccipital bone superior to the desired bolt location. This burr hole is then connected to the bolt location with a trough drilled at the same width as the selected bolt. The bolt is then inserted into the burr hole and is slid down the trough to the desired position (Fig. 10-10).
- With the bolt in place, the lateral plating system can then be loosely attached, and the remaining cervical instrumentation can be placed at C1 and C2 and at any subaxial levels to be included in the fixation construct. In most cases, it is necessary to contour the occipital bone and the laminae of C2 and C3 to allow the plate to lie flush on the bone. This provides for a low-profile construct (Fig. 10-11).
- Alternatively, if a screw-and-rod system is to be used, the precontoured rod can be brought into the field and affixed to cervical instrumentation.
- The exposed occipital and cervical bone is then decorticated in preparation for bone grafting. Autologous tricortical iliac crest or rib graft, cadaveric strut, bone chips, bone putty, or some combination thereof can then be placed to promote bony fusion.

Occipital Condyle Screw

Occipital condyle screws offer an additional fixation point in the occipital bone and have been shown to be

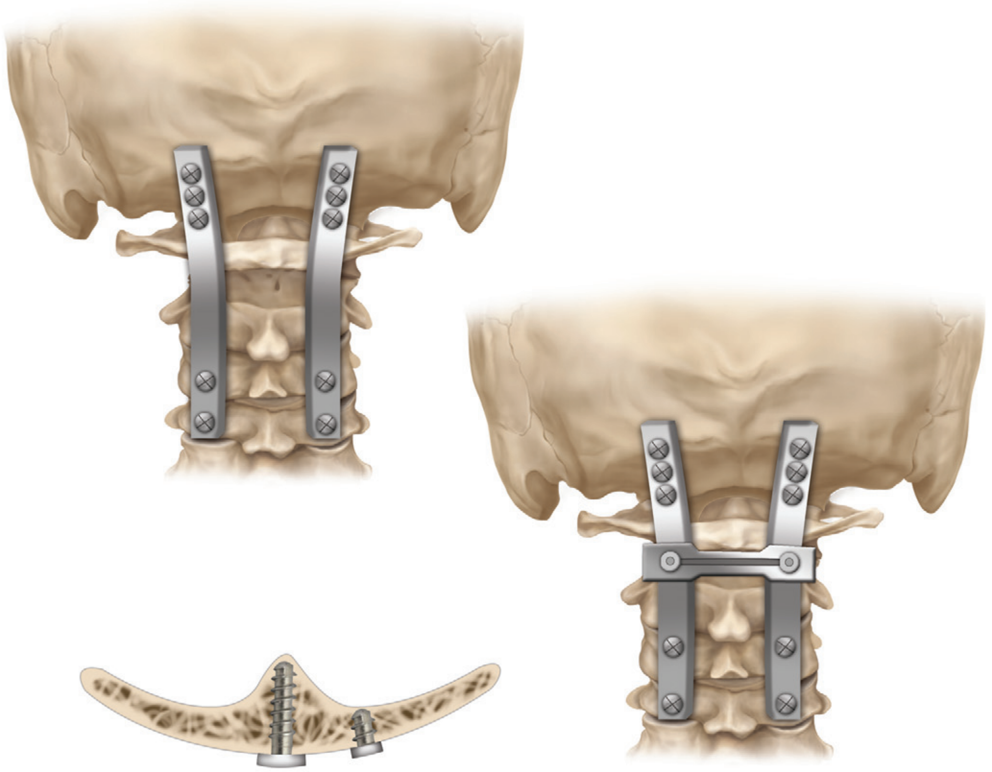

Figure 10-9 Posterior view of a lateral plating system affixed to the lateral occipital bone with (*right*) and without (*left*) a cross-link brace. The lower drawing again demonstrates the relative thickness of the occipital keel and the longer screw that can be placed there.

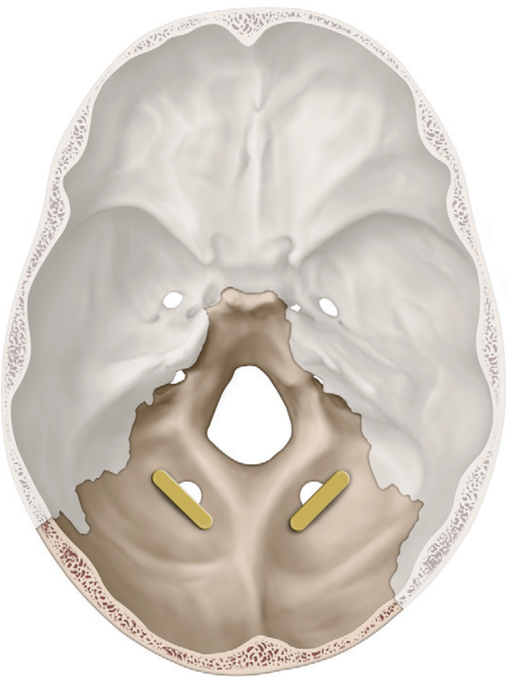

Figure 10-10 Placement of occipital bolts via the inside-out technique. The drilled trough and bolts seated along the intracranial surface of the occipital bone are visible.

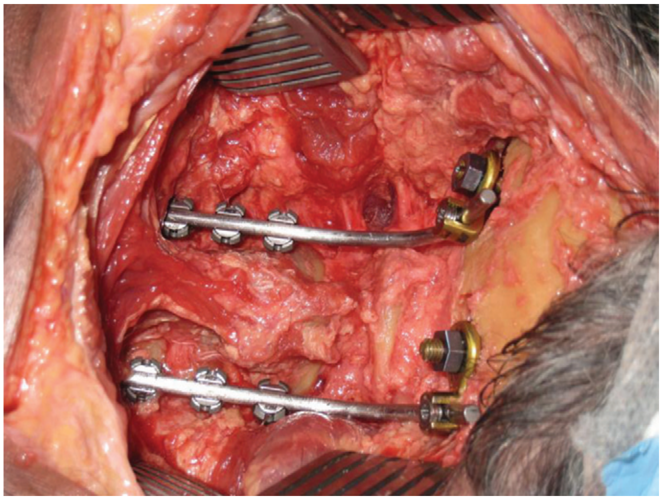

Figure 10-11 Intraoperative photograph of bilateral occipital bolts affixed to C2–C4 lateral mass screw-and-rod construct.

biomechanically equivalent to occipital plating. They are particularly useful when patients have undergone previous decompressive surgery of the occiput or for those who have decreased surface area for fusion for other reasons. Careful review of the preoperative CT with sagittal and coronal reconstructions is necessary to determine the suitability of the condyles for screw placement and the length and trajectory of the screws.

- After the occiput and posterior elements of C1 and C2 have been exposed in a subperiosteal fashion, exposure of the occipital condyle can proceed. Using a combination of blunt and sharp dissection and electrocautery, the soft tissues and fat of the condylar fossa are dissected away from the atlantooccipital joint. The posterior rim of the foramen magnum can be followed laterally to aid with identification of the condyles.
- It is important to protect the vertebral artery inferiorly and laterally during this dissection. Venous bleeding is frequently encountered around the atlantooccipital joint and adjacent to the vertebral artery. This bleeding is usually controlled with direct pressure and Gelfoam or Surgifoam.
- Once the condyle is identified, the posterior emissary vein should be identified, coagulated with bipolar cautery, and divided sharply.
- A starting point is then identified for the condyle screw, usually 5 mm lateral to the foramen magnum and 1 to 2 mm superior to the atlantooccipital joint (Fig. 10-12). A high-speed drill or awl can be used to penetrate the cortical surface of the condyle, and a hand drill is then used to drill the remainder of the screw trajectory; this is done under fluoroscopic guidance or with intraoperative navigation. The ideal trajectory is usually 20 degrees medial and 5 to 10 degrees superior, but this will vary from patient to patient (Fig. 10-13). Screw length will also vary, but 20-mm screws can frequently be placed. The holes are then tapped, and the selected screw is advanced.

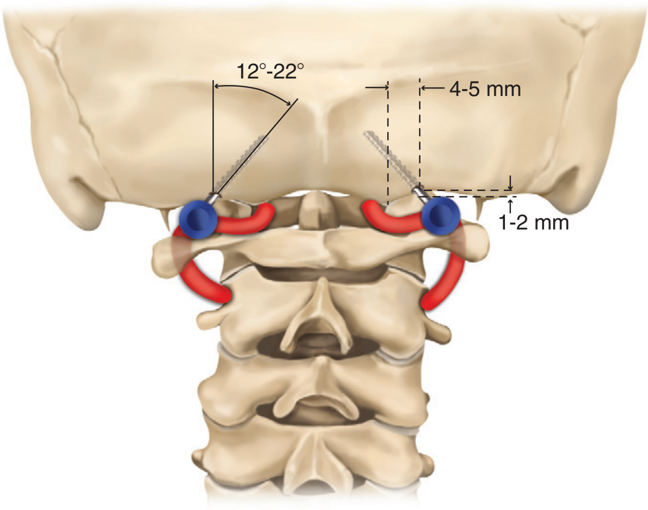

Figure 10-12 Starting point and trajectory for the placement of bilateral occipital condyle screws. Note the proximity of the vertebral artery to the screw starting point.

- These screws can then be connected to any atlantoaxial instrumentation with contoured rods, which are locked into place (Fig. 10-14). Bone graft is then placed and secured before closure.

Occipitocervical Wiring: Historic Technique Useful in Some Circumstances

Wiring has largely been supplanted by plate and screw-and-rod constructs but may be useful in some situations in which patient anatomy is not favorable for the placement of screws or plates. Because this technique does not provide rigid fixation, external orthosis is required postoperatively, usually for several months.

- With the bony surfaces exposed and the proper alignment confirmed on fluoroscopy, straight and curved curettes are used to dissect the atlantooccipital membrane from the posterior rim of the foramen magnum.

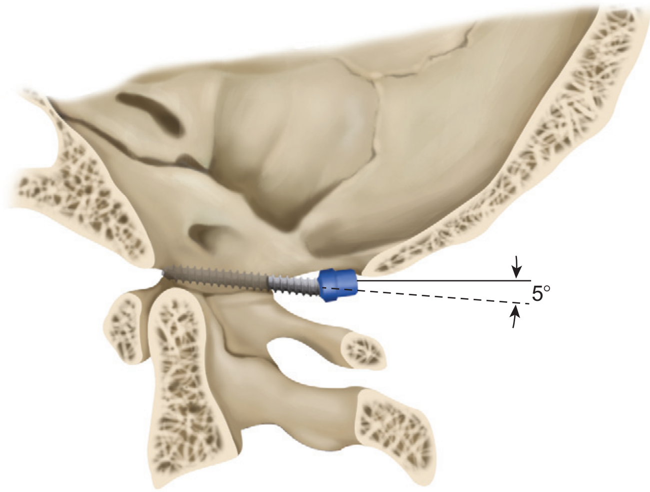

Figure 10-13 Lateral drawing shows the slight cephalad angulation of the occipital condyle screw.

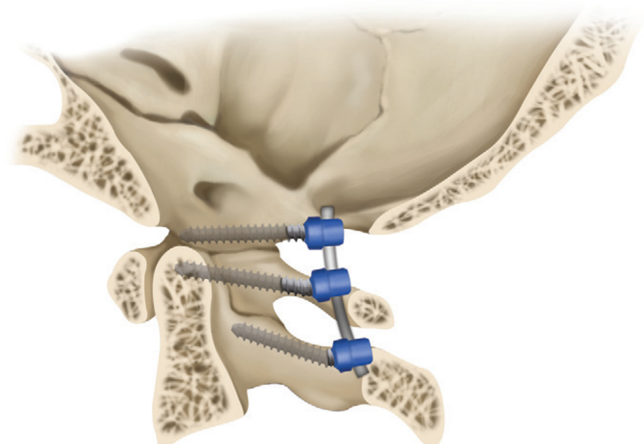

Figure 10-14 The occipital condyle screw connected to a C1–C2 lateral mass–pedicle/pars screw construct via a contoured rod.

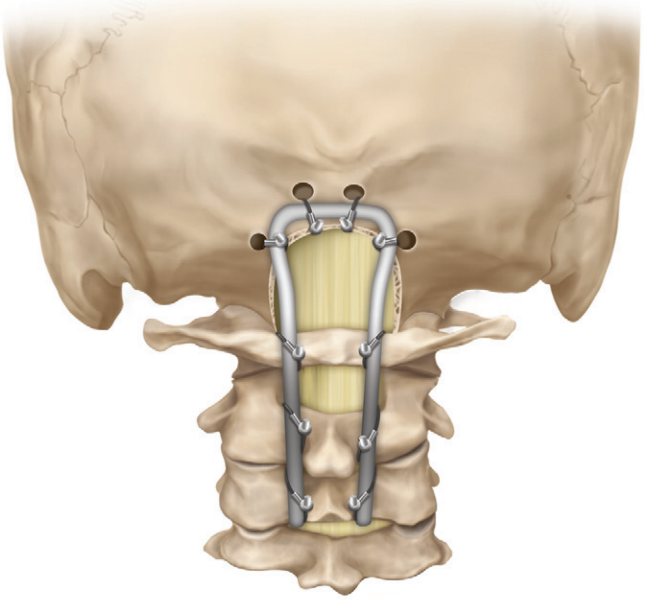

Figure 10-15 Drawing of an occipitocervical rod-and-wire construct. The contoured rod is placed and secured with wires or cables passed through burr holes in the occipital bone and with sublaminar wires or cables in the axial and/or subaxial spine.

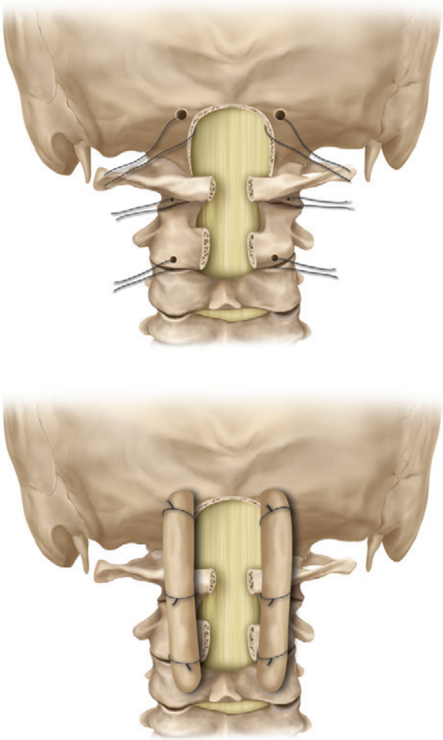

Figure 10-16 Wiring technique for strut bone grafts to occipital bone via burr holes and to the lamina of C1 and C2 after decompression. This and other wiring techniques do not offer initial stability and require a rigid external orthosis (e.g., halo device with vest) postoperatively.

- Using a high-speed drill, holes are drilled in the occipital bone on either side of the foramen magnum, taking care not to injure the dura covering the cerebellum. A dural elevator is then used to separate the dura from the occipital bone in the direction of the foramen magnum to permit the passage of wires or cables (Fig. 10-15).
- Alternatively, two holes can be made in the occipital bone on either side of the midline. The dura is carefully dissected from the occipital bone, and wires or cables are passed.
- Notches are then created in the inferior and superior margins of the lamina of C1 and C2 bilaterally at the lateral aspect of the lamina and in line with the drilled hole in the occipital bone. Again using curved and straight curettes, the ligamentum flavum and dura are cleared from the deep surface of each lamina to permit passage of wires or cables.
- It is then possible to pass braided cable or stainless steel wires from the holes in the occipital bone through the foramen magnum and under the C1 and C2 lamina bilaterally.
- Strut bone grafts, either autograft or cadaver allograft, are then brought into the field. The laminar surface of the bone graft should be notched to accommodate the lamina, and for the occipital wire, the most rostral end should be notched or a hole should be drilled (Fig. 10-16). The surface of the C1 and C2 laminae and the occipital bone are then decorticated to promote bony fusion. The bone grafts are laid in place and secured with cable clamps or by twisting the wires with wire holders. Bone chips can be placed for increased fusion strength.
- After surgery, patients should be kept in a rigid halo orthosis until solid fusion occurs, usually 3 to 4 months.

Postoperative Care

- After undergoing OC arthrodesis, patients should expect to remain in the hospital for 3 to 7 days, depending on the preoperative functional status and medical comorbidities. Additional stabilization with either a rigid cervical collar or halo–vest orthosis should be continued. Halo–vest stabilization is necessary when rigid fixation is not achieved intraoperatively, such as when occipital and sublaminar wiring is used, or when a high risk for pseudoarthrosis is present because of poor bone quality, nutritional status, or other factors.
- Intravenous antibiotics are typically continued for 24 hours following surgery or until any drains are removed. Prophylaxis against deep venous thrombosis with mechanical devices is recommended, and chemoprophylaxis should be considered in high-risk patients.
- Early ambulation is also recommended to reduce the risk of thrombosis and to accelerate return to function. Most patients will benefit from evaluation and treatment by physical and occupational therapy specialists.
- Evaluation of swallowing function is also recommended, because many patients will have some degree of postoperative swallowing dysfunction.

Complications

As with any surgical procedure, OC arthrodesis is associated with inherent risk of complications. However, specific complications unique to posterior cervical surgery and surgery of the craniocervical junction merit discussion. These include injuries to the vertebral arteries, intracranial venous structures, and neurologic structures as well as instrumentation failure, pseudoarthrosis, dysphagia, acquired spinal deformity, and malalignment of the craniocervical junction.

VASCULAR COMPLICATIONS

- Vertebral artery injury is perhaps the most feared complication of OC fusion. Injury can occur during any stage of the operation, from the exposure to the placement of instrumentation, and great care should be taken to identify and protect both vertebral arteries. Preoperative imaging should be reviewed to identify the course of the arteries and to avoid intraoperative injury. The true incidence of vertebral artery injury is unknown but has been reported in as many as 10% of cases.
- If injury to the vertebral artery is suspected, the vessel should be dissected to control bleeding and to attempt repair. It is then especially important to avoid injury to the contralateral artery, which may require an alternative method of OC fixation. Postoperative angiography is imperative to further identify and repair any injury, and the vessel may ultimately need to be embolized to control bleeding.
- Injury to the intracranial venous sinuses is also possible during OC fusion. This can occur during placement of an occipital plate or occipital wires. This bleeding can usually be controlled with direct pressure or placement of instrumentation, but it should be avoided if possible. Intraoperative fluoroscopy or CT-based navigation can help ensure proper instrumentation placement and avoidance of the major venous structures.
- Other vascular complications include venous thrombosis and arterial thrombosis or thromboembolism of the vertebral arteries. These can manifest in a delayed fashion, or in the case of arterial thromboembolism, they can present with symptoms of embolic stroke. The use of mechanical prophylaxis and chemoprophylaxis in the postoperative period remains controversial but should be considered, especially in patients at high risk of thromboembolic events (previous thromboembolism, prolonged time to mobilization, multisystem trauma, and underlying prothrombotic states).

NEUROLOGIC COMPLICATIONS

- Injury to the spinal cord and nerve roots can occur during any spinal surgery. Patients with craniocervical instability can suffer neurologic injury during positioning as a result of subluxation or improper alignment. Additionally, the spinal cord or nerve roots can be injured during the placement of instrumentation secondary to improper screw placement and passage of sublaminar wires or cables. Intracranial hematomas and cerebellar injuries can also occur with drilling of the occiput, passage of occipital wires, and placement of occipital plate screws.
- Violation of the dura can also occur in OC fixation and can lead to persistent cerebrospinal fluid leak, pseudomeningocele formation, and meningitis. If a dural tear is encountered, attempts should be made to repair the injury primarily. In revision surgery, especially with previous decompression, it may be helpful to perform dissection with the aid of the operative microscope to identify the dura and avoid injury.
- The C1 and C2 nerve roots exit the spinal canal and pass posterior to the atlantooccipital and atlantoaxial joints respectively. During placement of C1 lateral mass screws or occipital condyle screws, these nerves can be stretched or injured and sometimes need to be sacrificed. Injury to these nerves can result in troublesome postoperative parasthesias or pain in the affected dermatome, so care should be taken to avoid injury or sacrifice of these nerve roots if possible.
- Intraoperative fluoroscopy or CT-based navigation systems can help to ensure proper placement of instrumentation and thereby helps to prevent most neurologic complications.

BIOMECHANICAL COMPLICATIONS

- With innovations of technique and instrumentation, the rate of fusion after OC arthrodesis has improved in recent decades. Some authors report fusion rates as high as 100%. Nonetheless, the risk of fusion failure and pseudoarthrosis exists and can be a problematic complication. Ensuring optimal postoperative care that includes proper nutrition, diabetes control, and smoking cessation may help minimize fusion failure. In addition, the use of autograft bone should be considered, especially in patients predisposed to pseudoarthrosis.
- Fusion of the OCJ abrogates motion at the levels involved in the construct and could increase motion at subaxial levels, leading to adjacent-level degeneration and the development of deformities in the subaxial spine. This is frequently unavoidable, but it could be more likely with longer multilevel constructs that end in the midcervical spine; therefore instrumentation should be limited to the fewest number of levels needed to achieve rigid arthrodesis and stabilization. If deformities subsequently develop, patients may require repeat surgery and extension of instrumentation.
- Fixation of the OCJ in a nonneutral position can also occur and can result in troublesome postoperative symptoms. This can be avoided with meticulous attention during patient positioning and operative planning. Malalignment of the head with relation to the cervical spine can limit functionality and result in disability, low back and neck pain, and dysphagia. Occasionally, patients with improper alignment require repeat surgery to correct the OC orientation.

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11 Odontoid Fractures and Screw Fixation

MARCUS D. MAZUR and MEIC H. SCHMIDT

Overview

Odontoid fractures account for 5% to 15% of all cervical spine injuries and are seen more frequently in elderly patients.[1-3] The Anderson and D'Alonzo system for odontoid fractures is widely used to classify these injuries (Fig. 11-1).[4] Distinctions are made between fractures at the tip of the odontoid (type I), the base of the odontoid (type II), and the body of the axis (type III). Each fracture type is associated with a particular pattern of healing and outcome. Type II fractures are the most common odontoid injury[5]; they are associated with high morbidity and mortality and may be physiologically prone to poor healing. They produce atlantoaxial instability, because the integrity of the atlantoaxial complex is compromised, and this enables abnormal movement that may result in compression of the cervical spinal cord and subsequent injury. Fractures across the base of the odontoid involve considerably less trabecular bone, which is the site of fracture repair, than the body of the axis and the odontoid process itself. Consequently, type II fractures have lower rates of healing and are treated differently from type I and type III fractures, most of which are managed effectively with nonsurgical bracing.

Nonoperative management of type II odontoid fractures with immobilization in a rigid brace or halo-vest orthosis is associated with high mortality and significant failure rates,[6] but several surgical options are available. Historically, posterior atlantoaxial fusion was performed using Gallie and Brooks wire fixation. Although this continues to be a viable alternative in children and in patients with contraindications to screw fixation because of vascular or bony anomalies, wire fixation is not adequate in most patients, because it provides poor biomechanical stiffness in flexion and extension, and it cannot counteract anteroposterior shear forces. Current posterior atlantoaxial screw-fixation techniques involve placing screws either across C1 and C2, such as C1–C2 transarticular screws, or into each vertebra separately, such as lateral mass screws placed in C1 and C2 that are connected with a rod. Posterior screw-fixation methods have excellent rates of bony fusion but are technically demanding and are very damaging to the muscles. Furthermore, fusion of the atlantoaxial complex, which provides the largest amount of rotation in the cervical spine, restricts this movement more than 50%.[7]

Since its introduction in the early 1980s,[8] anterior fixation of type II and some rostral type III odontoid fractures has gained popularity. In this procedure, a screw is placed from the base of the axis, across the fracture fragment, to the distal tip of the odontoid. This allows the fracture fragments to be realigned directly and allows the distal tip to be brought into approximation with the axis. Direct anterior screw fixation provides immediate atlantoaxial stability and theoretically preserves C1–C2 motion, because it avoids arthrodesis, keeping the C1–C2 joints intact.[9] Either one or two screws have been used for fixation. Theoretically, the use of two screws provides increased stability by preventing rotation of the odontoid relative to the body of C2, and this may be the preferred technique in patients with poor bone quality. Despite this theoretical benefit, no difference in load-bearing strength, flexion-extension and rotational stiffness, or union rate has been demonstrated consistently in biomechanical or clinical studies.[10]

Direct anterior screw fixation of type II and shallow type III odontoid fractures is an excellent motion-preserving operation in appropriate patients. When performed correctly, atlantoaxial stability is restored immediately, the likelihood of fracture healing is high, and patients maintain anatomic movement along the C1–C2 axis.[9]

Indications

- Type II fracture that courses obliquely from the anterosuperior to the posteroinferior portion of the dens (Fig. 11-2)

Contraindications[11]

- An oblique fracture line from posterosuperior to anteroinferior that would parallel screw trajectory
- Poor bone quality resulting from severe osteoporosis, comminution of the fracture, additional fractures of the body of C2, or type II fractures with severe angulation and/or displacement that cannot be completely reduced preoperatively
- A barrel chest, short neck, subaxial cervical spondylosis, or severe thoracic kyphosis that would impede appropriate drill and screw placement
- Severe spinal canal stenosis
- Remote odontoid fractures or those with delayed diagnosis
- Incompetent transverse atlantal ligament that results in atlantoaxial instability regardless of whether the odontoid process remains intact
- Pathologic odontoid fractures
- Difficulty in swallowing

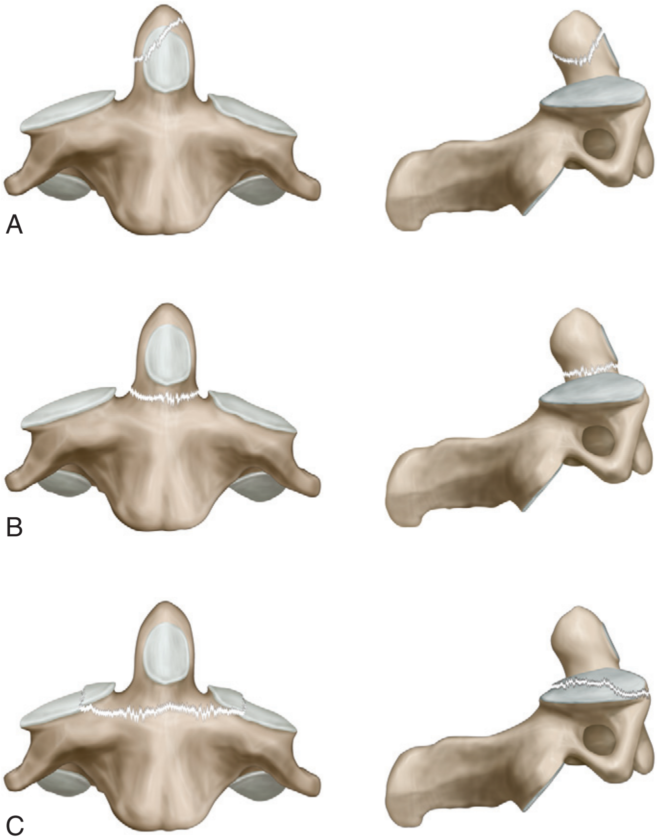

Figure 11-1 Anteroposterior and lateral views illustrate the Anderson and D'Alonzo classification of odontoid fractures.

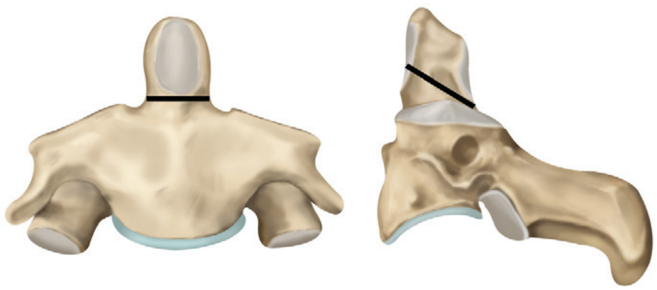

Figure 11-2 Lateral view of C2 depicts a Grauer type IIB injury, which is ideal for anterior screw fixation.

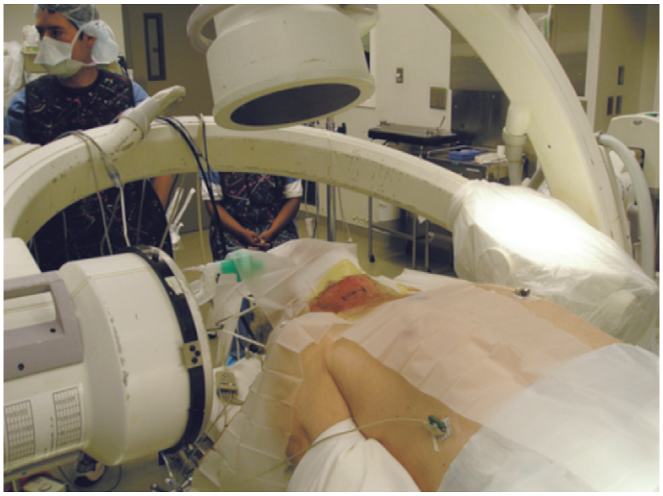

Figure 11-3 Biplanar fluoroscopy is used to obtain simultaneous anterior-posterior and lateral views so that immediate changes in fracture alignment or placement of instrumentation are confirmed.

Operative Technique

EQUIPMENT

- Operating table with radiolucent head and shoulder region
- Rigid head positioning
- Traction weights
- Biplanar fluoroscopic C-arm
- Anterior cervical access instruments
- Two-piece odontoid retractor system
- Odontoid drill guide system

PATIENT POSITIONING

- The patient is placed supine on the operating table with a pad under the shoulders to induce extension of the neck.
- A radiolucent bite block or jaw distractor is used to keep the mouth open.
- Radiographic exposure of the odontoid is confirmed in the anterior-posterior (AP) and lateral planes. Biplanar fluoroscopy is used to obtain simultaneous AP and lateral views so that immediate changes in fracture alignment or placement of instrumentation are confirmed (Fig. 11-3).
- The patient's head is extended as much as possible without causing repeat dislocation of the fracture. Adequate extension of C2 enables the screw trajectory to be directed accurately along the axis of the odontoid process, and gentle flexion and extension maneuvers are performed to achieve optimum fracture reduction.
- Halter, halo, or tong traction is used to hold the head immobile. Poor head positioning and inadequate fracture reduction at the time of surgery create a propensity for posterior malalignment of the odontoid.
- Improper positioning or poor patient body habitus may render screw insertion difficult or impossible. The presence of a direct trajectory must be verified under fluoroscopy before surgery is started (Fig. 11-4).
- If satisfactory positioning cannot be achieved, the attempt at anterior screw fixation should be abandoned.

INCISION AND SOFT TISSUE DISSECTION

- The patient's neck is prepped and draped, and a unilateral incision is made at the C5 level using a skin crease (Fig. 11-5).
- The platysma is then elevated and divided, and the superficial cervical fascia is seen. This fascia is incised longitudinally along the medial border of the sternocleidomastoid muscle, which then is retracted laterally (Fig. 11-6).
- The superior belly of the omohyoid muscle running transversely is undermined and divided, revealing the middle cervical fascia (see Fig. 11-6).
- After the middle cervical fascia is opened, blunt dissection is used to open a plane medial to the carotid sheath

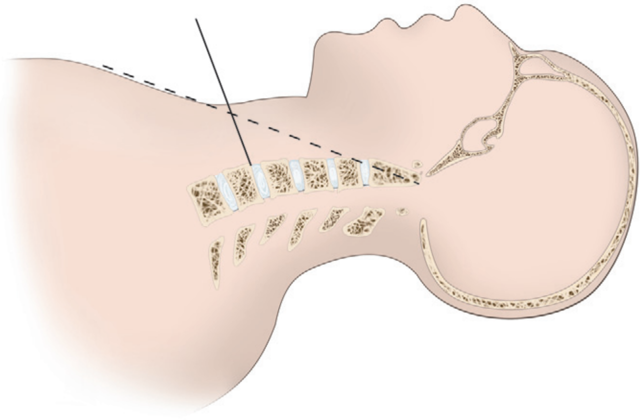

Figure 11-4 Lateral view of chest, neck, cervical spine, and odontoid shows a straight trajectory for screw placement. The guide system clears the chest, enters the incision at the C5 level, and has a direct trajectory to the inferior lip of C2, continuing to the tip of the odontoid.

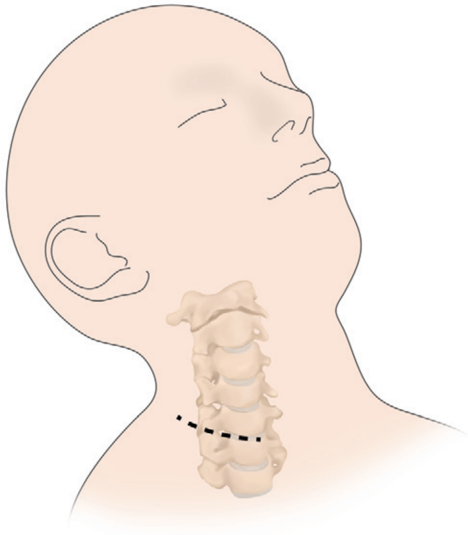

Figure 11-5 Incision planned at the C5–C6 level.

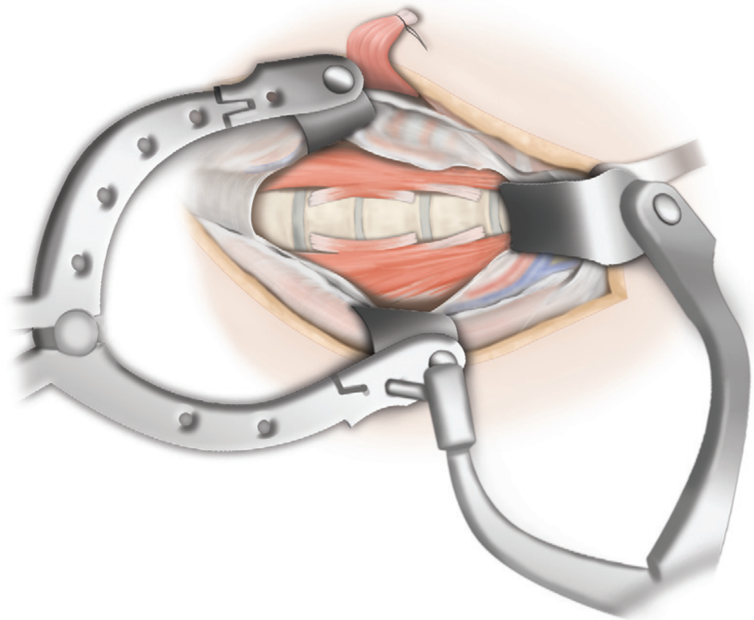

Figure 11-6 From superficial to deep, the sternocleidomastoid is retracted laterally, the omohyoid muscle is divided, the middle cervical fascia is incised, the carotid sheath is retracted laterally, the trachea and esophagus are retracted medially, the prevertebral fascia is incised, and the vertebral bodies of C2–C6 are exposed.

and lateral to the trachea and esophagus (see Fig. 11-6). Dissection is continued to expose the anterior surface of the spinal column.

- The cervical vertebrae can be palpated, and blunt dissection is carried up to the anterior inferior surface of the C2 vertebral body; this is confirmed radiographically.
- The prevertebral fascia over the vertebral bodies is incised at the C5–C6 level (see Fig. 11-6).
- Sharp, large-toothed Caspar retractor blades are inserted beneath the musculus longus colli bellies medially and laterally. The blades are secured with a self-retaining retractor. The two-piece retractor system designed for this approach has both transverse and longitudinal blades (Fig. 11-7).
- The space anterior to the precervical fascia is opened and retracted by the longer longitudinal blade. This protects the visceral structures and allows the surgeon access to the anterior inferior border of the C2 vertebral body.
- Blunt dissection is continued in the retropharyngeal space to identify the entry point under the anterior lip of C2. If a single screw is to be placed, a midline entry point is chosen. If two screws are to be placed, a paramedian position 2 to 3 mm off the midline is used.

PLACEMENT OF K-WIRE AND DRILL GUIDE SYSTEM

- Entry should be under the anterior lip of C2 and not on the anterior body of the vertebra. Incorrectly positioning

Figure 11-7 Two-piece retractor system in place with transverse blades inserted beneath cuff of longus colli muscle medially and laterally. The longitudinal blade retracts precervical soft tissue cephalad.

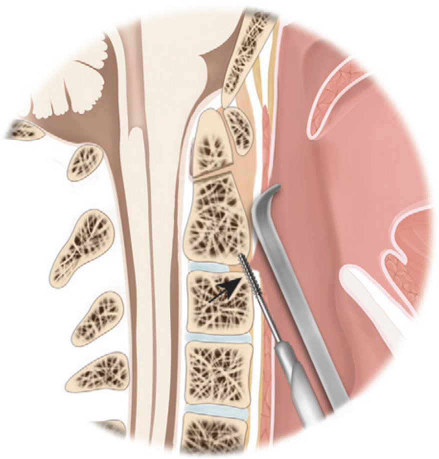

Figure 11-8 Selection of entry point under anterior lip of C2 vertebral body using a K-wire.

screw entry at the anterior body of C2 increases the likelihood for posterior angulation that may lead to a persistent anterior fracture gap, loss of fracture reduction, prolonged healing time, and subsequent nonunion. Placing the entry point too close to the anterior surface of the C2 vertebral body also carries the risk of causing breakout of the K-wire, drill bit, or odontoid screw through the anterior vertebral body. Selection of a poor entry point predisposes to inadequate screw purchase and risk of hardware failure, namely screw breakout or pullout.

- After the precise entry point is identified (Fig. 11-8), a 2-mm K-wire is inserted under biplanar fluoroscopy into the entry point on the inferior edge of C2 and is advanced 3 to 5 mm into the C2 vertebral body.
- A shallow groove is carved on the anterior face of the C3 vertebral body for the drill guide. This is created by placing a hollow 8-mm drill over the K-wire and rotating it by hand (Fig. 11-9).
- A tunnel is created that extends from the anterior face of C3 through the C2–C3 disk and annulus. Drilling is stopped before removing any of the C2 vertebral body.
- The drill guide system is formed by mating the inner and outer drill guide tubes and placing them over the K-wire (Fig. 11-10). First, the outer guide tube is positioned under fluoroscopic guidance, so its spikes are firmly set into the face of C3. This allows for gentle manipulation to align the C2 and C3 vertebrae relative to the odontoid and C1 for an accurate screw trajectory (Fig. 11-11). Next, the inner guide tube is inserted and extended through the previously created trough until it meets the inferior edge of C2.
- The guide tubes are then secured. Next, the K-wire is replaced with the 2.7-mm drill bit.
- Under biplanar fluoroscopic guidance, a hole is drilled from the inferior edge of C2 to the odontoid apex (Fig. 11-12). A right-angled driver attachment can be used to clear the patient's chest while drilling, if necessary.

SCREW PLACEMENT

- After an appropriate-sized hole is drilled to the apex of the odontoid, the inner guide tube is removed, and a tap is used to cut threads into the pilot hole (Fig. 11-13).
- The screw is inserted through the guide tube and is advanced under fluoroscopy into the threaded pilot hole to the odontoid apex. Lag screws with a nonthreaded proximal shaft are used to enable the distal fragment to be approximated to the body of C2. The screw is positioned so that the screw head is recessed at the inferior border of C2 with the screw tip engaged in the odontoid's apical cortex (Fig. 11-14) to ensure bicortical fixation (Fig. 11-15).
- A second lag or fully threaded screw can be placed using the same method (Fig. 11-16).
- Fracture stability is confirmed by flexing and extending the patient's neck under fluoroscopy.
- The retractors are then removed, hemostasis is carefully achieved, and the esophagus is checked for injury caused by retraction. The platysma layer is closed using interrupted absorbable sutures. Fine interrupted subcuticular stitches and sterile adhesive strips are used to reapproximate the skin.

Postoperative Care

- Patients are closely monitored for airway and neurologic deterioration.
- Diet can be advanced as tolerated, depending on esophageal edema and swallowing difficulties. Patients with dysphagia should be closely monitored to prevent aspiration.
- Patients with evidence of osteopenia or associated cervical fractures are maintained in a cervical collar until healing across the fracture site is evident on follow-up radiographs or CT scans.

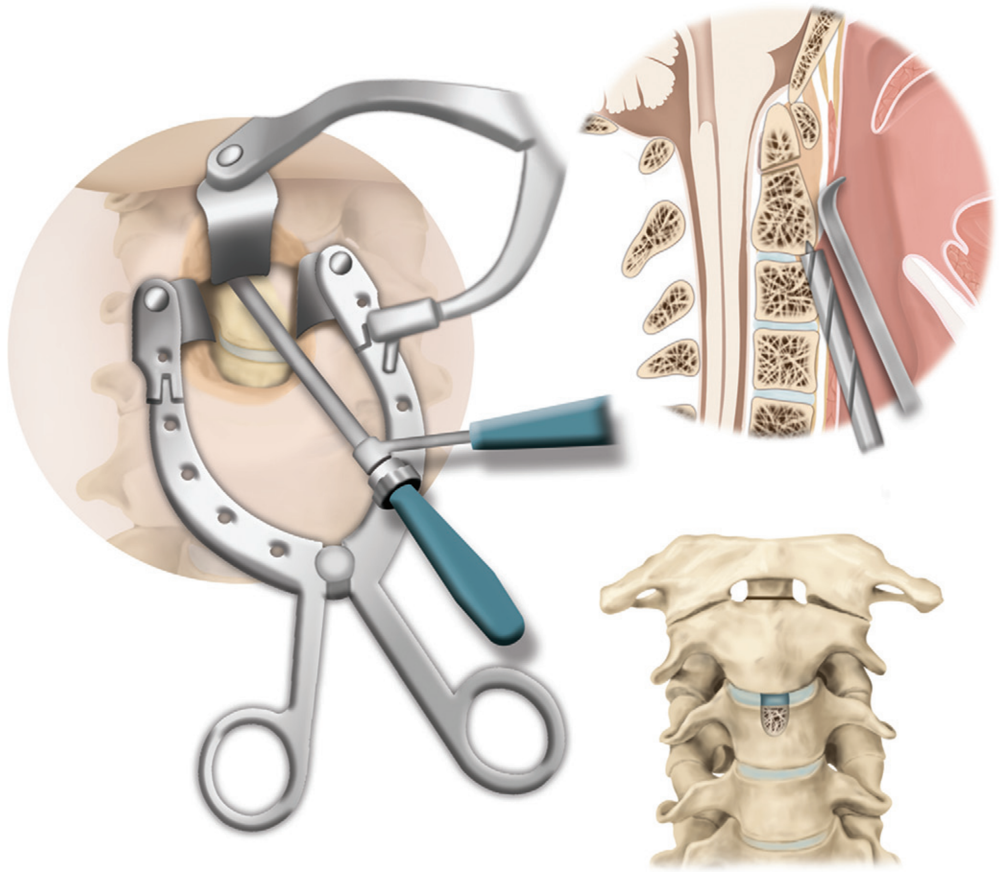

Figure 11-9 Lateral view of in situ drilling. This illustrates the drill carving a groove on C3 and the C2–C3 disk but stopping at the C2 body.

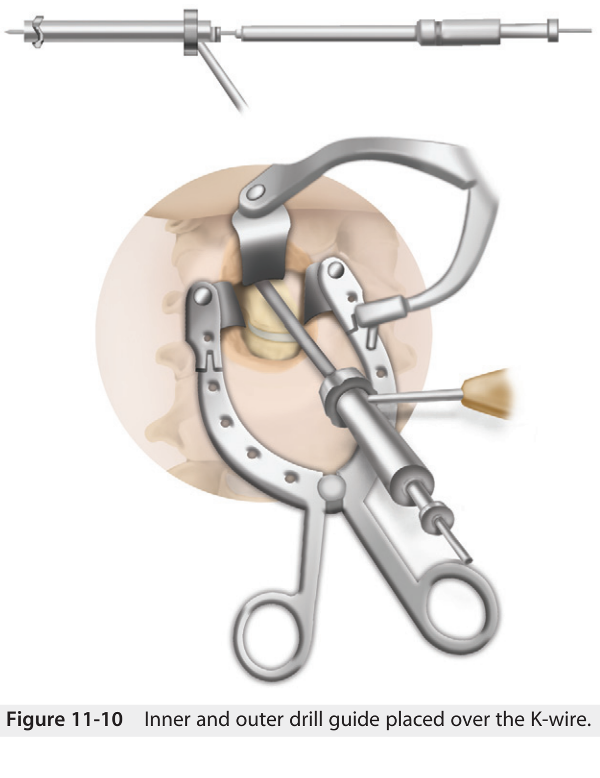

Figure 11-10 Inner and outer drill guide placed over the K-wire.

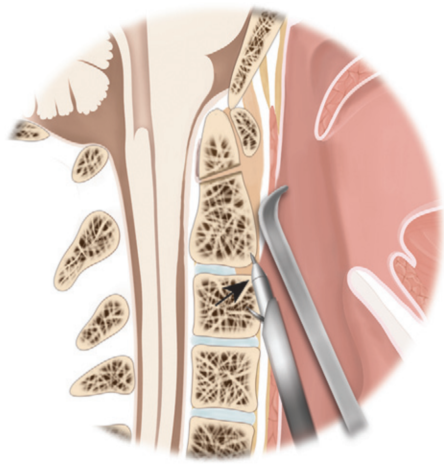

Figure 11-11 Outer drill guide spikes affixed to C3 vertebral body. The inner drill guide is advanced in the previously created groove to the inferior lip of C2.

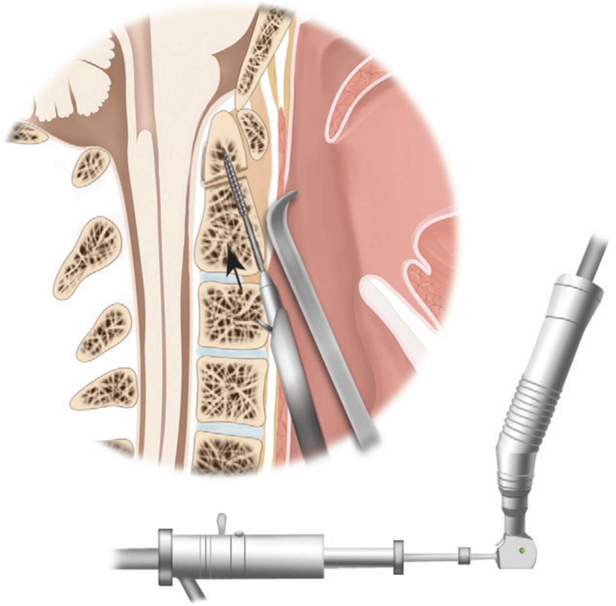

Figure 11-12 The hole is drilled to the apex of the odontoid.

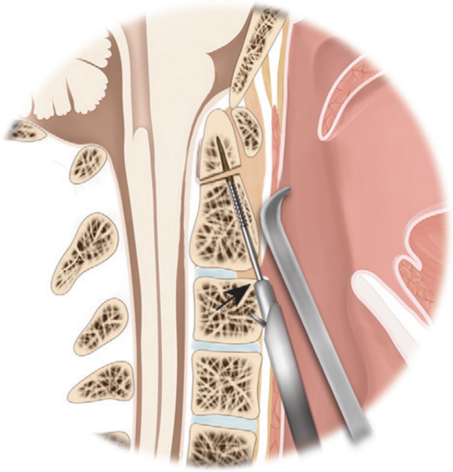

Figure 11-13 The tap cuts threads in the pilot hole.

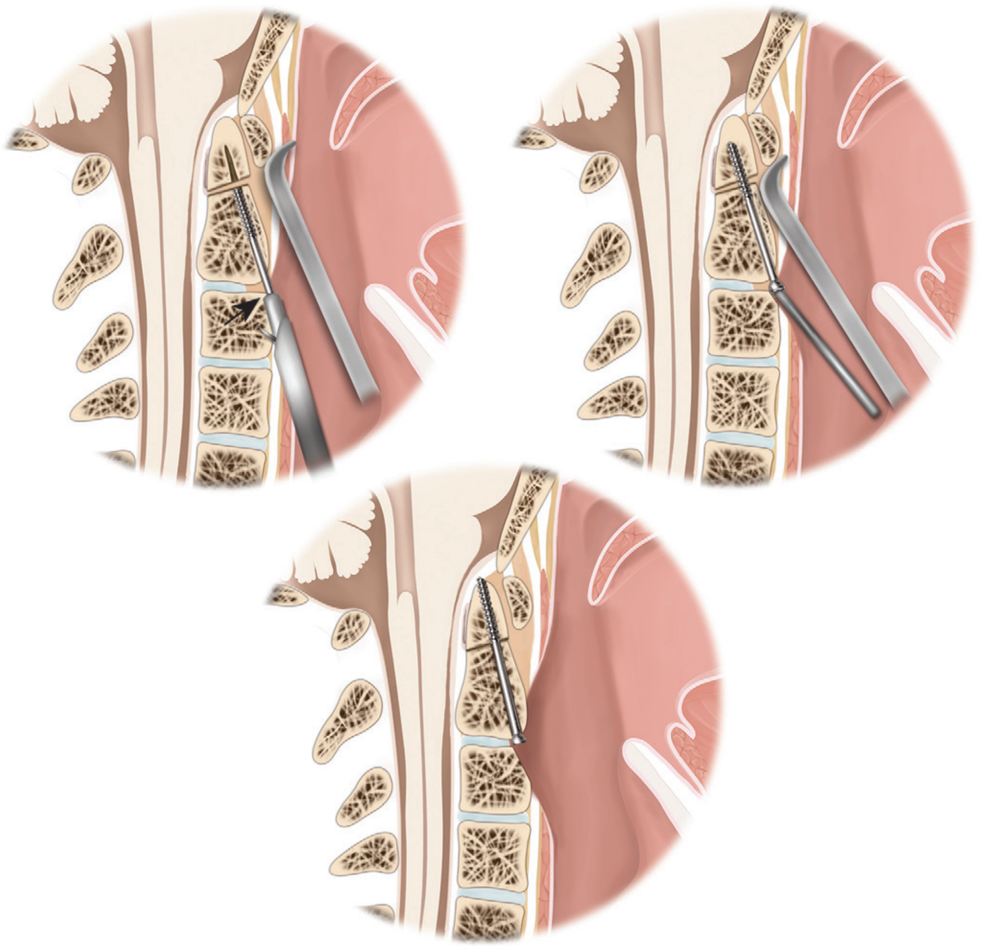

Figure 11-14 Lag screw placement.

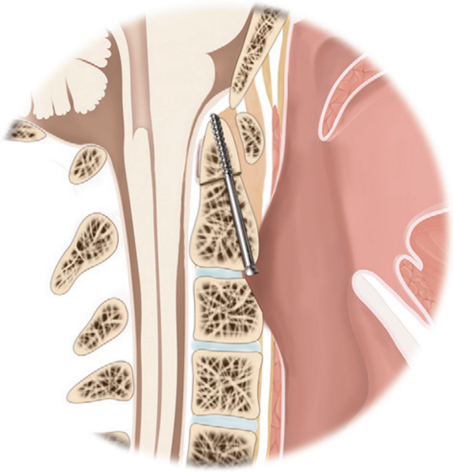

Figure 11-15 Bicortical fixation of lateral C2. Cortical bone and cancellous bone are distinct. The screw is positioned so as to engage cortical bone at the C2 vertebral body and at the tip of the odontoid.

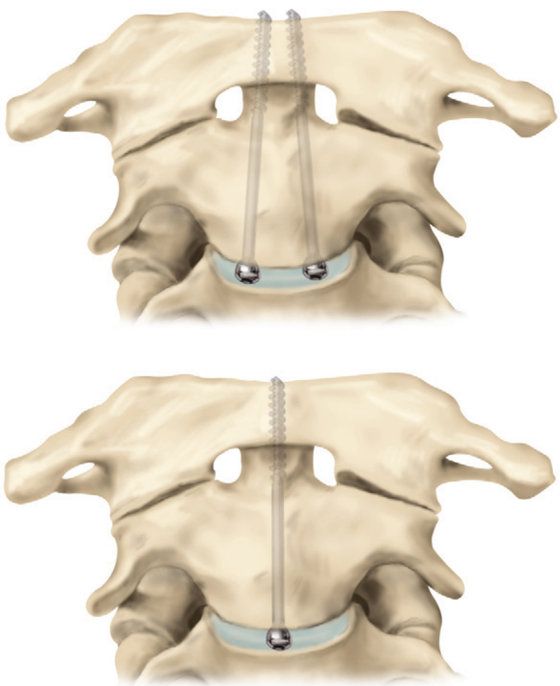

Figure 11-16 Two drawings of C2 in anterior-posterior view. Placement of a lag screw in midline position is shown along with placement of two screws in paramedian position, one lag and one fully threaded.

Technical Variations

- Image guidance in combination with neuronavigation provides an alternative to fluoroscopy for real-time intraoperative data acquisition and accurate placement of instrumentation.
- Odontoid screw instrument systems that use noncannulated drill bits have been developed to replace cannulated drill guides placed over a K-wire.
- Minimally invasive techniques for performing odontoid screw fixation have been described, such as endoscopic or percutaneous placement of odontoid screws and the use of tubular retractor systems. Theoretical advantages of minimally invasive surgery include less tissue disruption and better preservation of annulus, disk, and bone. The inability to use a drill guide that affixes to the spine, however, precludes manipulation of the C2 vertebral body and thereby limits the ability to align fracture fragments.

Complications

- The most common complication after surgery is a nonunion of the odontoid fracture, in which case a posterior C1–C2 fusion is recommended. This may be preceded by hardware failure, such as screw backout or breakout through the anterior cortex of C2. Inadequate fracture reduction also increases the risk of nonunion.
- Major site-specific complications of anterior odontoid screw fixation include neural injury, esophageal or pharyngeal perforation, hemorrhage, and airway obstruction.
- Patients undergoing odontoid screw fixation are more likely to receive tracheotomies, contract pneumonia, and develop swallowing or vocal cord problems. These complications occur more frequently in elderly patients, in whom the incidence of postoperative dysphagia is high.[12] Many elderly patients may require diet modification or nasogastric tube placement after surgery.

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12 C1–C2 Trauma Injuries and Stabilization Techniques

M. YASHAR S. KALANI, IMAN FEIZ-ERFAN, and CURTIS A. DICKMAN

Overview

Fractures of the atlas and axis are often seen in the setting of trauma to the craniocervical junction (CCJ). Injuries to these vertebrae can induce instability and result in devastating neurologic injury. Atlantoaxial instability is present once the transverse ligament has been disrupted, the odontoid process has been fractured, or both. Unless the transverse ligament is avulsed with its bony base, the chance of healing is slim with external immobilization alone.[1] Therefore, internal fixation is often necessary to treat such instability. Depending on the type of odontoid fracture, surgical fixation may be indicated to achieve fusion.[2,3] Atlantoaxial instability can also result from vertical distraction that damages the atlantoaxial joint and capsule. If the injury is severe, internal fixation and fusion may be necessary.[4] This chapter describes operative techniques used to fixate and fuse traumatic injuries of the atlas and axis.

General Operative Techniques for Posterior Atlantoaxial Fixation

The patient is log-rolled into a prone position. Somatosensory evoked potentials (SSEPs) can be monitored to achieve safe positioning. When present, the halo ring is attached to the Jackson table. After the suboccipital portion of the head is shaved, the CCJ area is prepared and draped in a sterile fashion. The skin over the iliac crest on either side is also prepared in case an autologous graft becomes necessary.

After positioning and before the surgery begins, a fluoroscopic image should be obtained to verify that cervical alignment is maintained. The intent is to place the patient in a neutral head position, if possible. Next, an incision is made from the external occipital protuberance to C4–C5. The lower extent of the incision depends on the patient's local anatomy, thickness of the neck, redundancy of tissues, and the desired level of fusion or fixation. After the skin has been incised, dissection proceeds to the spinous process of C2–C3, or further if necessary.

Subperiosteal dissection is performed using monopolar cauterization. Because this segment is very unstable, periosteal elevators should be applied with care. Too much pressure exerted on the posterior bony elements can cause motion at the subluxed level.

After the spinous process, lamina, and posterior arch of C1 are exposed, gentle dissection continues laterally over the facet joints of C2–C3 and C3–C4 and, if necessary, over those at other levels. Injury to the vertebral artery should be avoided, especially at the C1–C2 complex and overlying the arterial sulcus of C1. At this point, gentle subperiosteal dissection and bipolar cauterization are preferred over monopolar cauterization. If brisk venous bleeding is encountered, it is usually a warning sign that the vertebral artery is near. After the bony structures are exposed, several methods of fixation are possible.

C1–C2 Lateral Mass–Pars Interarticularis Screw Fixation

If screw fixation of the atlantoaxial junction is desired, screws can be placed in the lateral mass of C1 and in the pars interarticularis of C2. If necessary, screws can be placed into the lateral masses on the subaxial spine; this technique is reviewed elsewhere in this text. This section reviews placement of screws into the C1 lateral mass and pars interarticularis of C2.

After the C1 posterior arch is exposed completely, an air drill is used to drill the pilot hole for the screw within the underside of the lamina of C1, where it joins the C1 lateral mass (Fig. 12-1, *A*). A drill is used to make a pilot hole in the C1 lateral mass under fluoroscopic guidance; the lateral mass screw should have a slight medial and superior angulation (fewer than 10 degrees, see Fig. 12-1, *B* and *C*). Care is taken to avoid injuring the vertebral artery. A number 4 Penfield dissector is inserted along the medial aspect of the C1 lateral mass to delineate its medial border.

Under direct lateral fluoroscopic visualization of the medial border, the sagittal angle is identified. Unicortical purchase is desired. Bicortical purchase can injure structures anterior to the spine and should not be attempted. At this point, the length of the screw is measured; the diameter of the screw depends on the local anatomy. Again, the medial border of the occiput of the C1 junction is palpated with a number 4 Penfield dissector to ensure that the cortex is not violated.

Next, the venous plexus around the medial and superior side of the C2 pars interarticularis is cauterized with the bipolar device, cut with microscissors, and compressed with Nu-Knit (Johnson & Johnson, Arlington, TX) or Gelfoam (Upjohn, Kalamazoo, MI) and cottonoids. A pilot hole is drilled in the inferior side of the lateral mass of C2 at the midportion of the C2–C3 facet joint and into the C2 pars interarticularis, which has been exposed to the junction of the C1–C2 articulation. To visualize the trajectory of the screw, the C2 nerve root is retracted rostrally with a number

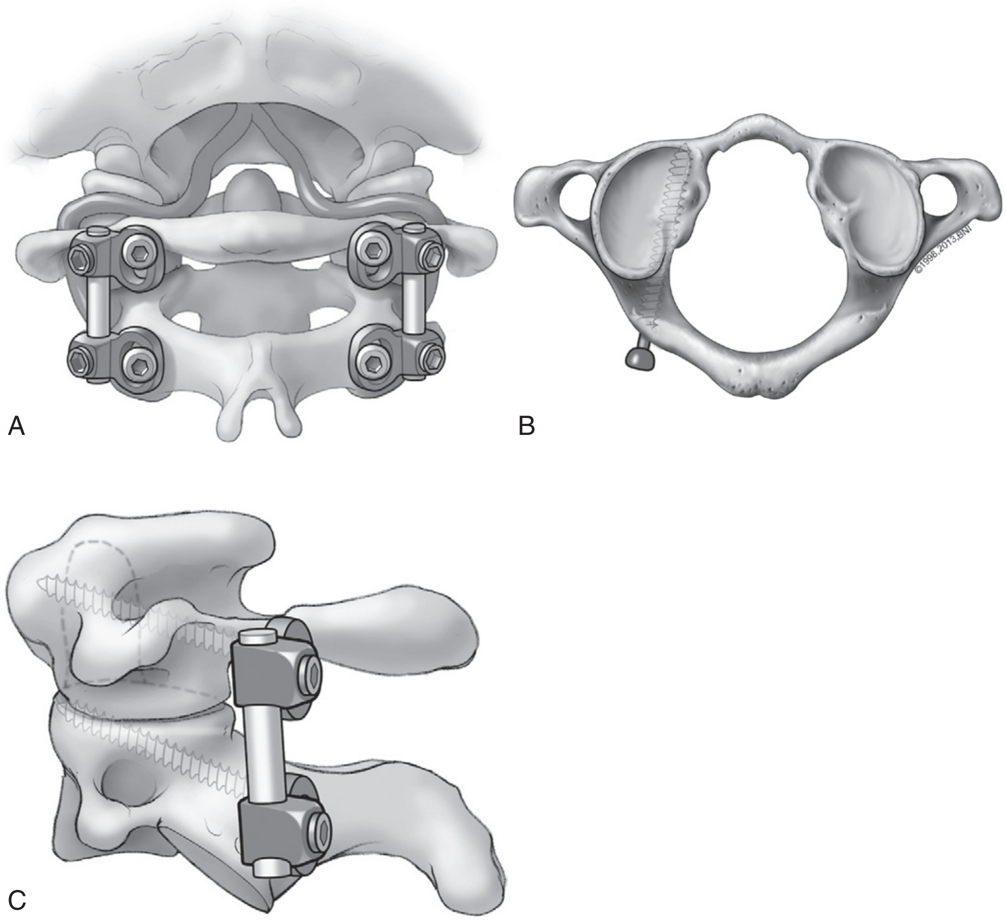

Figure 12-1 **A,** C1–C2 fixation with C1 lateral mass and C2 pars screw-and-rod instrumentation. The entry point of the C1 lateral mass screw is at the inferoposterior surface of the posterior arch of C1 at its junction with the C1 lateral mass. In the axial and sagittal planes, the C1 lateral mass screw is angled medially (**B**) and upward (**C**) fewer than 10 degrees. (**A** and **C,** From Gonzalez LF, Theodore N, Dickman CA, et al: Occipitoatlantal and atlantoaxial dislocation. *Operative Techniques Neurosurg* 7(1):16–21, 2004. **B,** Courtesy the Barrow Neurological Institute.)

4 Penfield dissector. A 10- to 15-degree medial angulation is used for the pars interarticularis screw (Fig. 12-2, *A*); the sagittal trajectory misses the C1–C2 joint (see Fig. 12-2, *B*). Lateral fluoroscopy is also used to guide the drilling. Usually, the C2 pars interarticularis screw is short and measures less than 12 mm.

C1–C2 Lateral Mass–Pedicle Screw Fixation

The exposure is the same as that used for the C2 pars screw. The landmark for the insertion of the C2 pedicle screw is the cranial margin of the C2 lamina (Fig. 12-3).[5,6] Using a high-speed drill, the insertion site is demarcated. A Penfield instrument can be used to identify the superomedial surface of the C2 pedicle by placing it into the interlaminar space along the top margin of the C2 lamina. The angle of insertion of the pedicle screw should be 15 to 25 degrees medial to the midline in the transverse plane. Next, the hole is drilled and tapped. A ball-tip probe is used to confirm patency of the screw canal. Screws as long as 24 mm (20 to 24 mm) may be used in the C2 pedicle.

Atlantoaxial Transarticular Fixation

After the path is tapped, the screw is inserted. If a C1–C2 transarticular screw is required, the screw is angled toward the anterior tubercle of C1 using a slightly more medial pilot hole than that used for the C2 pars interarticularis screw (Fig. 12-4, *A*). However, there is almost no medial angulation of the screw, and the trajectory is straight up into the C1 lateral mass (see Fig. 12-4, *B*). The pars interarticularis of C1 and the C1–C2 articulation are dissected as described for placement of a C2 pars interarticularis screw. The length, which is usually about 40 mm, is again measured using the K-wire method. If a lag effect is desired, an end-threaded screw can be used instead of a fully threaded screw.

Atlantoaxial Translaminar Fixation

Although the C2 pedicle and transarticular screws provide an excellent point of fixation and fusion, screw insertion can be associated with significant violation of the foramen transversarium and vertebral artery injury. The C2 lamina

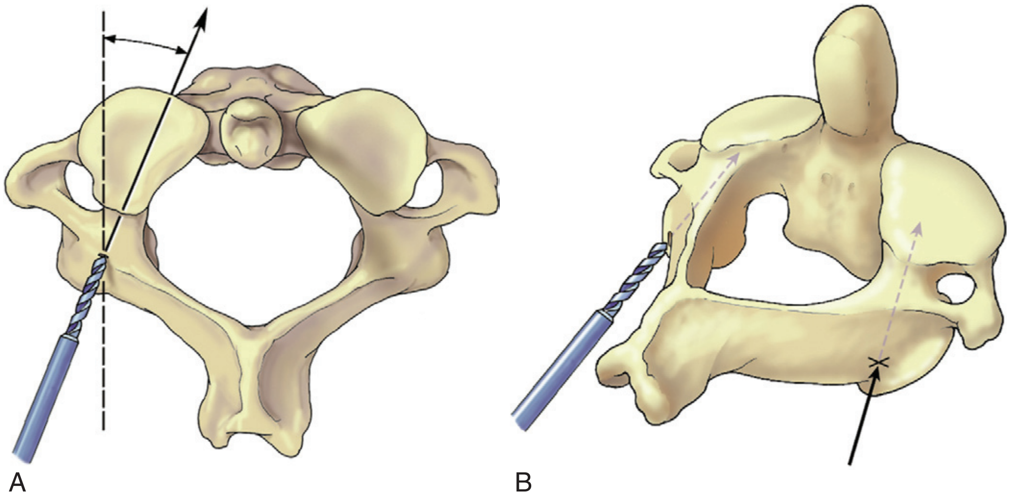

Figure 12-2 **A,** The C2 pars screw is angled medially 10 to 15 degrees. **B,** The sagittal trajectory of the C2 pars screw is angled slightly upward to follow the trajectory of the dissected pars interarticularis of the axis. The sagittal trajectory misses the C1–C2 joint. (Courtesy the Barrow Neurological Institute.)

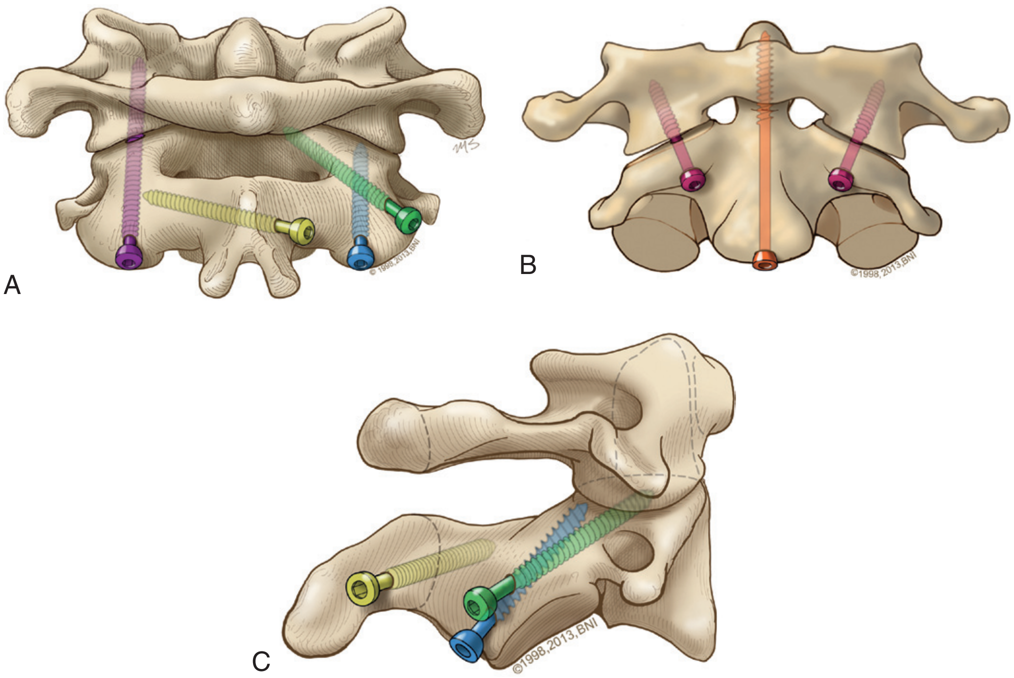

Figure 12-3 The various screw options for C1–C2 fusion. **A,** The yellow screw is a C2 translaminar screw, the purple screw is a C1–C2 transarticular screw, the blue screw is a C2 pars interarticularis screw, and the green screw is a C2 pedicle screw. **B,** The orange screw is an odontoid screw, and the red screws are C1–C2 facet screws. **C,** The yellow screw is a C2 translaminar screw, the blue screw is a C2 pars interarticularis screw, and the green screw is a C2 pedicle screw. (Courtesy the Barrow Neurological Institute.)

is large and provides an excellent platform for rigid fixation without placing the vertebral artery at risk (Fig. 12-5). This is in contrast to the transarticular screw that courses more closely to the vertebral artery and in some series has been associated with a higher likelihood of injury to the vertebral artery as it courses around C1. The C2 laminar screw is usually combined with a C1 lateral mass screw.

The technique used was originally described by Wright.[7,8] Using a high-speed drill, a small window is created at the union of the C2 spinous process and the rostral end of the lamina on the right side. Next, the contralateral lamina is drilled to 30 mm with a hand drill aligned along the angle of the exposed contralateral laminar surface. A ball-tip probe is used to inspect for breakthrough. A polyaxial screw, usually 4.0 by 30 mm, is inserted into the drilled cavity. The final screw-head position should be at the junction of the spinous process and lamina on the right. The same procedure is repeated on the left side for insertion of a polyaxial screw, and the lamina and facet joints are decorticated in the usual fashion with a high-speed drill. Using offset connectors, the C2 screw is connected via a rod to the C1 lateral mass screw and to other subaxial levels as needed. Autologous and nonautologous grafts can be packed to augment fusion.

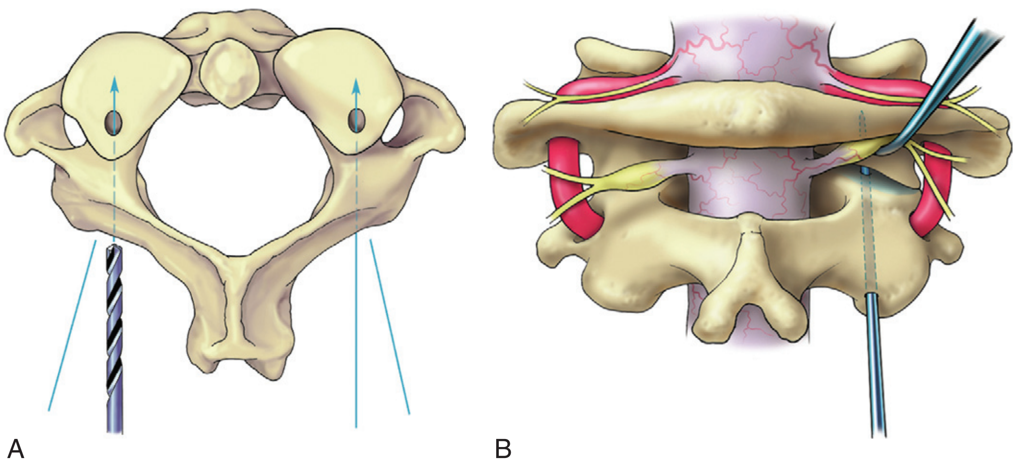

Figure 12-4 **A,** The entry point for a C1–C2 transarticular screw (*pointed out by the drill*) is slightly medial to the entry point for a C2 pars screw (*depicted by the angled line lateral to the drill*). **B,** There is almost no medial or lateral angulation of the C1–C2 transarticular screw in the coronal plane. The screw is aimed across the C1–C2 joint. (**A,** From Marcotte P, Dickman CA, Sonntag VK, et al: Posterior atlantoaxial facet screw fixation. *J Neurosurg* 79(2):234–237, 1993. reprinted with permission from Journal of Neurosurgery Publishing Group. **B,** Courtesy the Barrow Neurological Institute.)

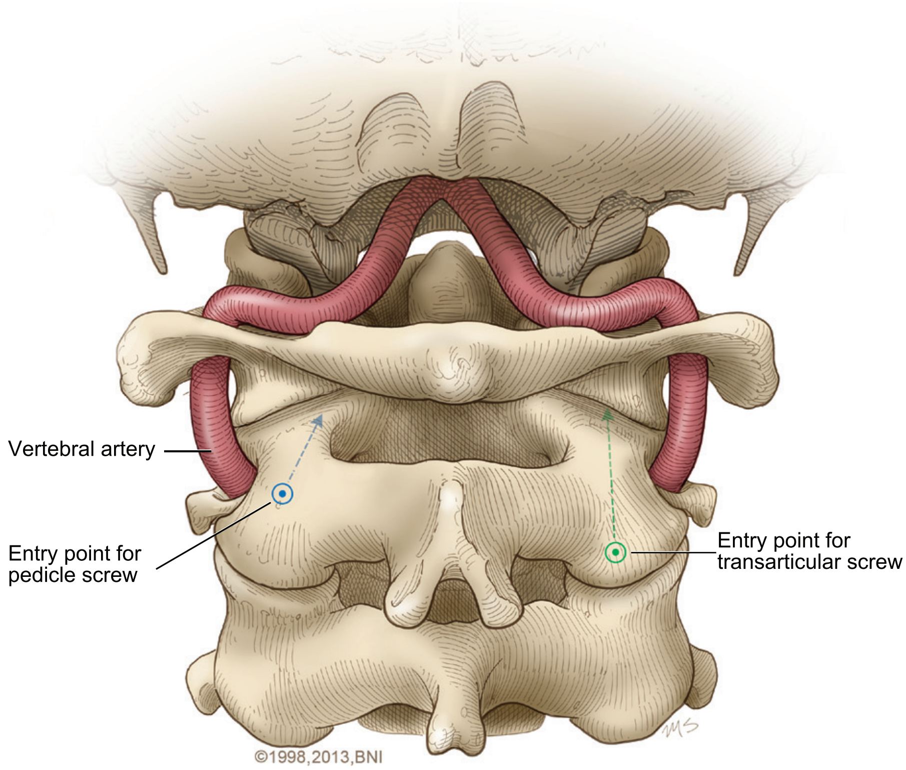

Figure 12-5 The orientation of the vertebral artery as it courses from the cervical spine to the intracranial compartment places it at risk during screw insertion. The entry sites for pedicle screw insertion and for transarticular screw insertion are shown. (Courtesy the Barrow Neurological Institute.)

Halifax Clamp Fixation

Halifax clamps (Codman, Raynham, MA) are designed to immobilize a single motion segment and are indicated to replace a lost posterior tension band; therefore the anterior and middle columns need to be intact to apply rigid fixation with Halifax clamps. In the craniocervical area, Halifax clamps have been inserted to provide fixation between C1 and C2 for cervical instability. However, they do not afford a more rigid construct than screw fixation for this area and therefore are rarely applied. Furthermore, Halifax clamps require intact bony structures, which can be compromised from fracture in a trauma case or from a laminectomy performed for decompression.

The laminae at C1 and C2 are freed from ligamentous tissue, and the epidural space is dissected. A bone strut is fitted between C1 and C2, and the bony surfaces are decorticated with a drill. Special clamp pliers are used to insert the clamps on each side of C1 and C2 (Fig. 12-6, *A*). The wires are clamped, and the screw is tightened between the two clamps using a right-angle screwdriver (see Fig. 12-6, *B*).

A bone strut is essential in the biomechanical construct created by Halifax clamps. Otherwise, the clamps would

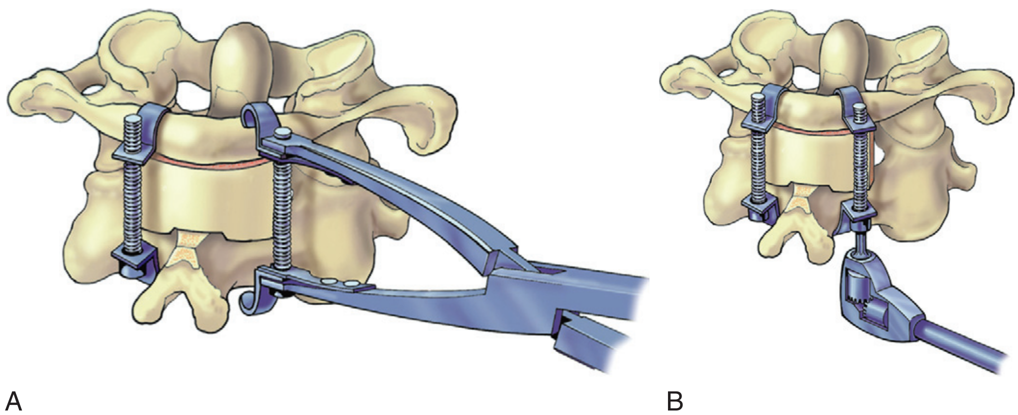

Figure 12-6 **A,** Halifax clamps are positioned and applied. **B,** A right-angled screwdriver is used to tighten the clamp. (Courtesy the Barrow Neurological Institute.)

loosen with neck extension. Because better techniques for internal screw fixation have been developed, Halifax clamps are now seldom applied to treat C1–C2 instability from trauma.

Atlantoaxial Wiring Techniques

Atlantoaxial wiring techniques are often applied in conjunction with atlantoaxial screw fixation to add stability to a construct, especially during flexion, and to provide fusion. However, wiring can be applied without screw fixation. Halo immobilization is recommended until bony fusion is achieved.

INTERSPINOUS FUSION

After bony exposure of C1–C2 is achieved posteriorly, the posterior occipitoatlantal membrane is removed. A high-speed drill is used to decorticate bony contact surfaces from the superior edge of the C2 spinous process and laminae and from the inferior edge of the C1 ring (Fig. 12-7, *A*). Kerrison rongeurs are used to make bilateral notches on the inferior surface of the C2 lamina to seat the wires (Fig. 12-7, *B*). An autologous iliac crest bone graft, usually about 4 cm long and 3 cm high, must be obtained for the posterior iliac crest. A Vicryl suture is passed beneath the lamina. Braided cables or wires, either a 20 gauge monofilament wire or double-strand 24 gauge wire, is looped and passed beneath the lamina of C1 (Fig. 12-7, *C*). The upper cortical edge is removed to create a bicortical autograft that is wedged between C1 and C2 (Fig. 12-7, *D*). The autograft is inserted on top, and the loop of wire is passed over the autograft to notch under the spinous process of C2. Doing so compresses the autograft between C1 and C2 (Fig. 12-7, *E*).

GALLIE FUSION

For this fusion technique, a unicortical piece of autologous bone, usually 5 to 8 mm thick, is harvested from the iliac crest. After decortication, the cable wire is looped and passed under the lamina of C1 and is then looped over the spinous process of C2 (Fig. 12-8, *A*). The graft is placed, and the free ends of the wire are wrapped around the autograft and tightened (Fig. 12-8, *B* and *C*).

BROOKS FUSION

In a Brooks fusion, two wires are passed sublaminarly beneath C1 and C2 (Fig. 12-9, *A*); the dura is visualized to avoid dural lacerations. Two cortical pieces of cancellous autograft are wedged on each side of the laminae of C1 and C2, and the two loops of wires are placed circumferentially around the laminae on each side to engulf the bone grafts; the wires are then tightened in place (Fig. 12-9, *B*).

Indications for Posterior Fixation and Fusion of the Upper Cervical Spine

Fixation of C1 and C2 is indicated for traumatic injury that involves vertical distraction between C1 and C2. However, the level at which conservative management fails is unclear. If significant distraction is evident on computed tomography (CT), magnetic resonance imaging (MRI), or both, surgical fixation and fusion can be performed safely to provide immediate stabilization of the unstable segment.[4] If the transverse ligament is insufficient, or if it is disrupted without avulsion of its bony insertion, as sometimes occurs with type II odontoid fractures, C1 needs to be fixated to C2 internally.[1,9] Either C1–C2 transarticular screws or lateral mass–pars interarticularis screws can be used, based on the surgeon's preference. The C2 pars interarticularis can be fixated for certain hangman's fractures.[10,11]

Anterior Approaches for Upper Cervical Spine Instability After Trauma

INDICATIONS AND TECHNIQUES

The most common indications for anterior fixation for craniocervical instability associated with trauma are type II

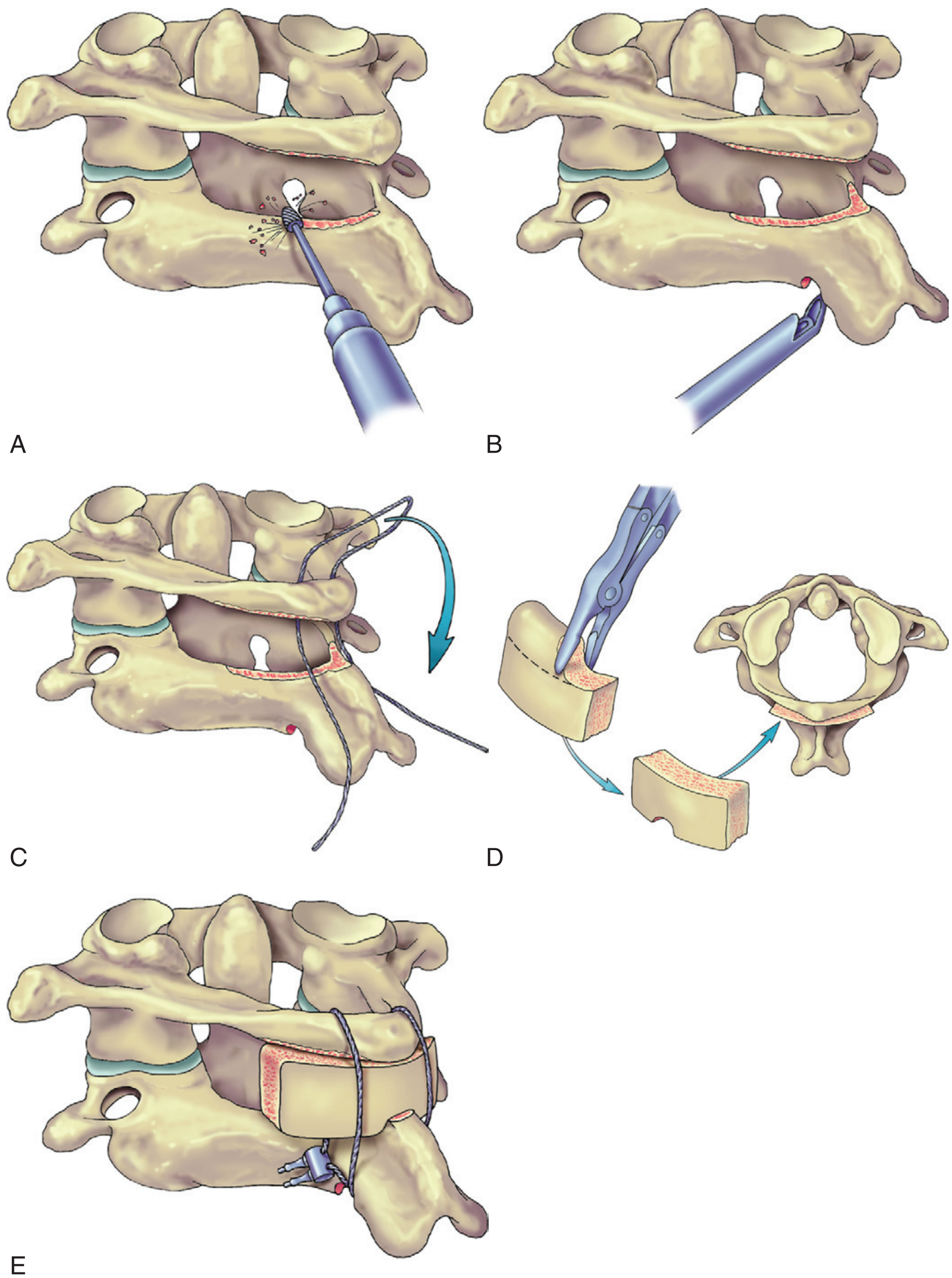

Figure 12-7 Interspinous fusion. **A,** The dorsal bony elements of C1 and C2 are decorticated with a high-speed drill to promote fusion. **B,** A notch is created in the caudal surface of the C2 spinous process to tighten the wire or cable after fusion. **C,** A cable is looped under C1 and over the spinous process of C2. **D,** A tricortical iliac crest autograft is decorticated to obtain a bicortical graft. A small wedge of bone is removed from the side facing C2; this is done so that the upper part of the C2 spinous process can be inserted into the notch created in the graft to enhance stability of the construct. **E,** Final construct after the autograft has been wedged between C1–C2 and wired into place. (Courtesy the Barrow Neurological Institute.)

odontoid fractures and failure of fusion after rigid external orthosis. If a type II odontoid fracture is encountered with comminution at its base or with a dislocation of more than 6 mm, the chances of fusion occurring with halo immobilization are less than with open reduction and internal fixation.[2,3]

Odontoid screw fixation proceeds with a transverse incision made in the neck crease at C5. The approach is usually performed from the right side, but a left-sided approach can be performed if preferred. The platysma is divided, and dissection proceeds along the medial aspect of the sternocleidomastoid muscle medial to the sheath of the carotid artery. The dissection remains lateral to the trachea and esophagus. The prevertebral fascia, which is reached at C5–C6, is bluntly dissected upward with gentle strokes of sponges held in a hemostat clamp. After the C2–C3 disk space is identified, the midline is dissected and identified. Usually, the anterior rim of the inferior end plate of C2 can

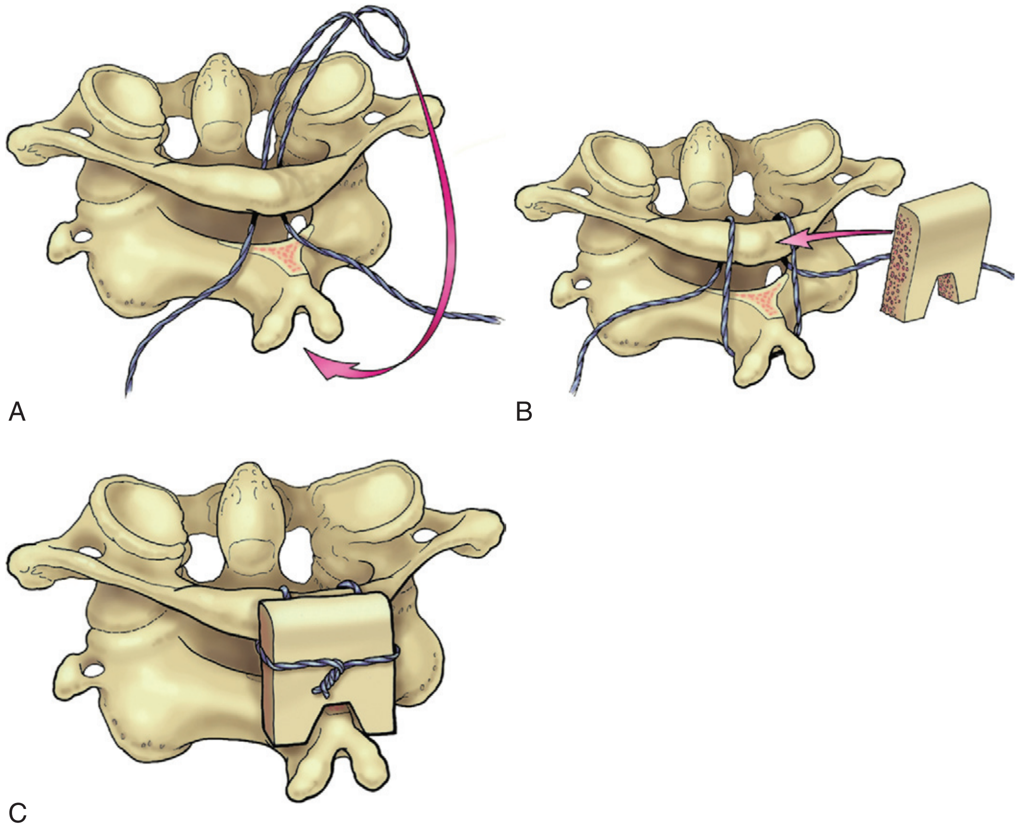

Figure 12-8 Gallie fusion. **A,** A wire is looped under the C1 lamina and over the C2 spinous process. **B,** The autograft is notched to fit the C2 spinous process. **C,** The autograft is secured with the free ends of the wire to complete the Gallie fusion construct. (Courtesy the Barrow Neurological Institute.)

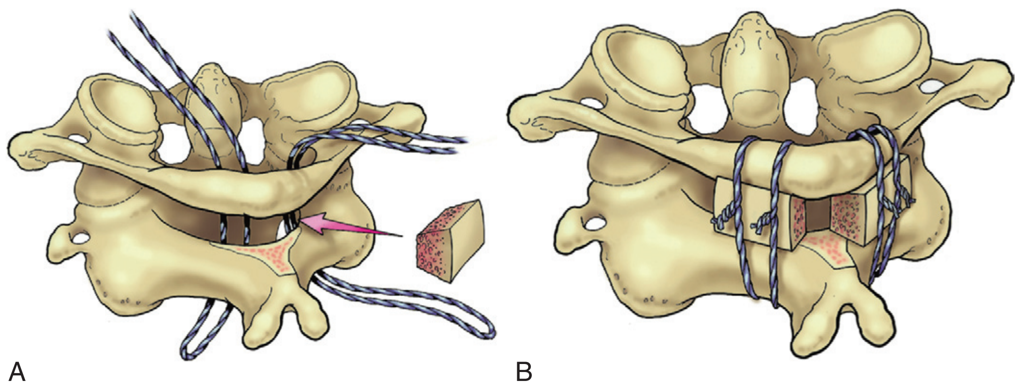

Figure 12-9 Brooks fusion. **A,** Two loops of wire are passed from the top to beneath the laminae of C1 and C2 bilaterally, and the two pieces of iliac crest autograft are wired to C1 and C2 on each side. **B,** In the final construct of the Brooks fusion, wires are wrapped around the C1 and C2 laminae and are twisted over the bone graft to secure the graft. (Courtesy the Barrow Neurological Institute.)

be drilled with an air drill. A minimal anterior diskectomy at C2–C3 may be needed to place the drill guide under the end plate of C2 in a midline position as defined by anteroposterior (AP) and lateral biplanar fluoroscopy. The sagittal trajectory of the odontoid screw is verified with lateral fluoroscopy. Under biplanar fluoroscopy, the long K-wire is drilled with a powered hand drill across the fracture into the odontoid process.

The screw length is measured using the K-wire method. A cannulated end-threaded screw is placed over the K-wire into the odontoid process across the fracture site, and the K-wire is removed (Fig. 12-10, *A*). A lag effect is created to capture and reduce the dislocated fracture (see Fig. 12-10, *B*). Placement of a single screw is sufficient to obtain adequate fixation.

ANTERIOR ATLANTOAXIAL FACET SCREW FIXATION

This technique is rarely applied. Its major indication is failed posterior atlantoaxial fusion and instability with destruction of posterior elements of C1 and C2. A transverse skin incision is usually made on the right side in the neck crease

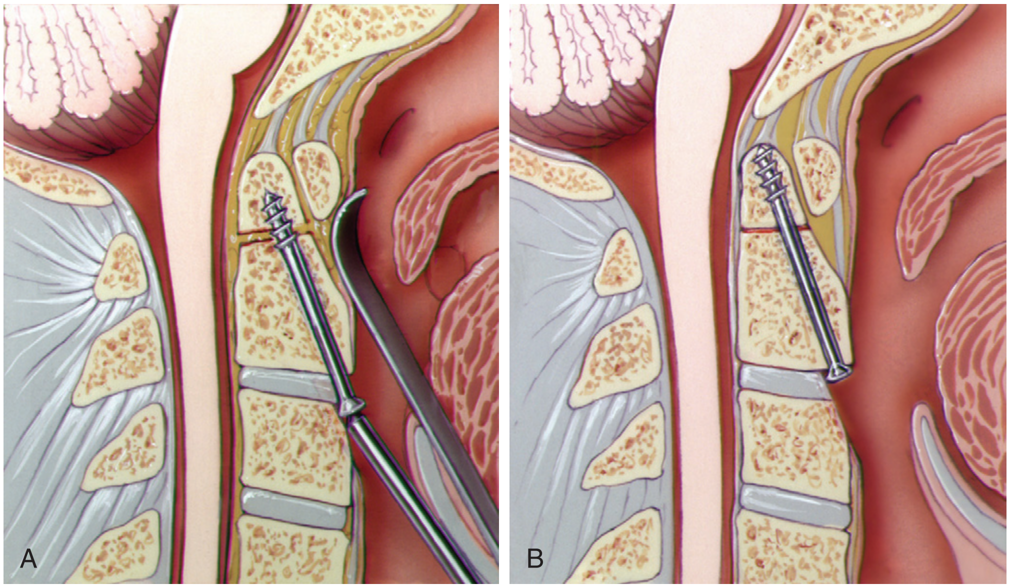

Figure 12-10 **A,** A lag screw is placed across the odontoid fracture. **B,** The lag effect created by the end-threaded screw pulls the fractured fragment down to reapproximate the fracture line. (Modified from Apfelbaum RI: Anterior screw fixation for odontoid fractures. In Rengachary SS, Wilkins RH (eds): *Neurosurgical operative atlas, vol 2.* Park Ridge, IL: American Association of Neurological Surgeons, 1992, pp 178–188, with permission from the American Association of Neurological Surgeons.)

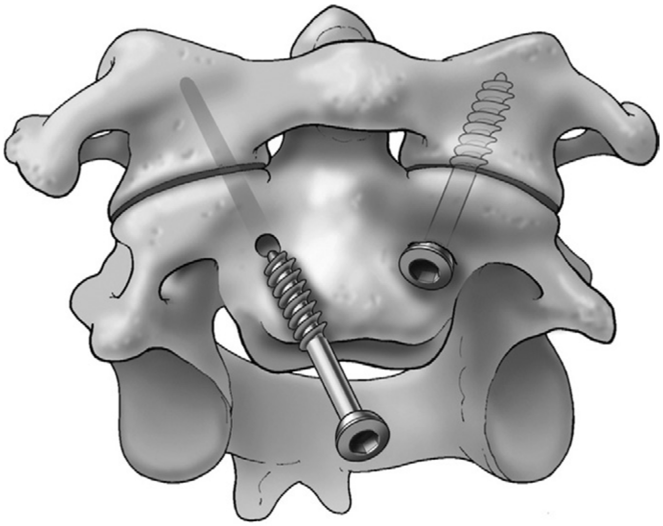

Figure 12-11 Anterior atlantoaxial facet screw placement requires 90 degree angulation of the screw in the coronal plane in relation to the joint space to avoid injuring neurovascular structures. (Used with permission from Barrow Neurological Institute)

over the C5–C6 interspace. Soft-tissue dissection proceeds in the usual manner through the prevertebral fascia, which is scraped rostrally to the atlantoaxial facet joint; the atlantoaxial joints are decorticated on both sides with curettes. The groove between the superior facet and the body of the axis are localized anatomically, and a bone awl is used to penetrate the bone at the point where the screw will be inserted. Next, the pilot holes are tapped. To avoid potential injury to the vertebral artery, the angle must not be directed too far laterally. The joint space should be crossed in a 90 degree angle in the coronal plane (Fig. 12-11). The diameter of screws used ranges from 3.5 to 4 mm, and they are typically 22 to 25 mm long. This technique is not recommended for osteoporotic patients or in patients with a fracture of the superior articular facets, vertebral body of C2, or lateral mass of C1. The afferent course of the vertebral artery must be verified.

Conclusion

Diverse techniques of fixation and fusion of the upper cervical spine are available. For most instances of traumatic instability in this region, open reduction and internal fixation are the preferred management techniques. Newer rod-screw constructs are applied posteriorly and have become more popular than wiring techniques alone, because they offer immediate stability. In trauma patients, the placement of internal fixation devices is sometimes aided by the use of neuronavigation. However, detailed knowledge of anatomy and local pathology is imperative for successful implantation of hardware in this territory.

Compared with external immobilization, internal fixation has become a safe and highly effective method for facilitating fusion and for preventing future posttraumatic deformity. Consequently, internal fixation has gained widespread acceptance and application for the management of unstable traumatic injuries of the upper cervical spine.

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SECTION B

Mid and Lower Cervical Spine

13 Surgical Anatomy and Biomechanics in the Mid and Lower Cervical Spine

TIEN V. LE and JUAN S. URIBE

Overview

An essential element to surgery of the spine is a thorough understanding of its anatomy and biomechanics. The cervical spine is part of the axial skeleton of the neck. The structural characteristics of the *subaxial cervical spine,* defined as C3 to C7, is unique, and it plays an important role in influencing physiology and pathophysiology as well as the approach to surgical management. This chapter will discuss the fundamental anatomic and biomechanical considerations of this important region of the cervical spine.

Surface Anatomy

Much can be interpreted by visual inspection and palpation of the neck surface. An understanding of the surface anatomy (Fig. 13-1) can aid in planning a surgical skin incision, which would then dictate which vertebral levels can be approached.

The rostral limits of the neck are the mandible and mastoid bone, and the caudal limits are the manubrium and clavicle. In addition, T1 and T2 are typically above the level of the manubrium because of the anterior and inferior obliquity of the first rib.

Multiple palpable landmarks of vertebral levels lie anteriorly. The hyoid bone is at the level of C3, the thyroid cartilage is at C4, and the cricoid cartilage is at C6. Also palpable at C6 is the carotid tubercle, or Chassaignac tubercle, the anterior tubercle of the transverse process of C6 that separates the carotid artery from the vertebral artery. Clinically, the carotid tubercle can be compressed against the carotid artery in certain instances, such as with supraventricular tachycardia.

Posteriorly, the C7 spinous process is indicated by the easily palpated vertebral prominence, but it may actually represent C6 or T1 on occasion.

Vertebral Column

In general, the five vertebral bodies of the subaxial cervical spine are composed of a body, pedicles, lateral masses, lamina, and spinous processes. The vertebral bodies are mobile segments joined anteriorly by the intervertebral disk, comprising an anterior joint and two facet joints posteriorly (Fig. 13-2). A primary role of the subaxial cervical spine, and the vertebral column as a whole, is to resist compressive forces; the compressive strength increases with descending levels. The normal cervical curvature is a shallow lordosis of 16 to 25 degrees that begins at the dens and ends at T2. The points of maximal flexion-extension are midway at C4–C5 and C5–C6, whereas the points of maximal lateral bending tend to be higher, at C2–C3, C3–C4, and C4–C5. The least mobile segment is C7–T1.

VERTEBRAL BODY

The vertebral body is the axial load-bearing element of the vertebral column. Structurally, the height of the vertebral body increases descending down the spine, with the exception of C6, where this relationship is slightly reversed. The C6 vertebral body can be shorter than C5 or C7.

The vertebral body is cylindrical and convex ventrally, and the vertebral arch projects dorsally. A thin outer shell of compact cortical bone surrounds the internal soft and porous cancellous bone that contains bone marrow; this characterizes the vertebral body structure. The cortical bone is arranged in vertical lamellae, which increases resistance to compressive forces. The internal cancellous bone is in a trabecular arrangement similar to columns. Vertebral bodies are wider in the transverse, rather than ventral-dorsal, diameters and are sized progressively larger with descending levels. They are typically 17 to 20 mm wide.

End Plates

The vertebral body end plates are the concave surfaces of thick cortical bone adjacent to the fibrocartilaginous intervertebral disks and a thin layer of cartilage about 1 mm thick. The end plate is strongest and most dense peripherally. The cartilaginous end plates are the superior and inferior thinner surfaces of the intervertebral disk, and they are the transition components of the intervertebral disk and the end plates. The lamina cribrosa, composed of calcium, fuses the vertebral end plate with the cartilaginous end plate. This sievelike surface permits osmotic diffusion and provides for a pathway for nutrients to reach the disk.

Uncal Process

The uncal process is a rostral projection on either side of the vertebral body that gives it a rostrally concave shape in the coronal plane. It receives the rounded caudal aspect of the adjacent rostral vertebral body to form an

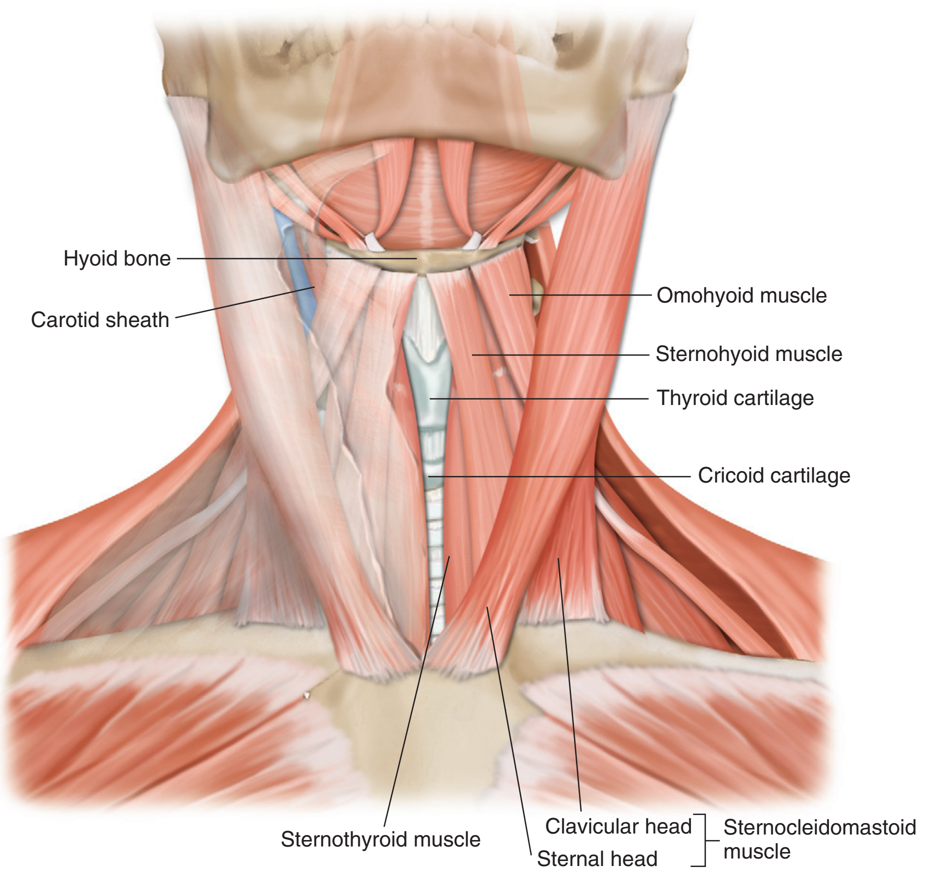

Figure 13-1 Surface anatomy correlates. The sternocleidomastoid (SCM) muscle, hyoid bone, thyroid cartilage, and cricoid cartilage are easily identified on visual inspection of the skin surface and by palpation. The hyoid bone approximates C3, the thyroid cartilage approximates C4, and the cricoid cartilage approximates C6. The carotid sheath lies medial and deep to the SCM.

uncovertebral joint, and it can sometimes overlap the next level by a third of the vertebral body height. The uncovertebral joints play a role in limiting lateral translation, and they contribute to the coupling of lateral bending and rotation of the spine. From a surgical perspective, the uncovertebral joints define the lateral borders for an anterior corpectomy or diskectomy, and they also aid in defining the midline during anterior cervical plate placement.

Transverse Process

The cervical transverse processes are unique in that they contain the transverse foramina from C1 to C6. The vertebral artery is transmitted through these foramina, which are formed from the lateral surface of the pedicle, the dorsal surface of the anterior tubercle, and the ventral surface of the posterior tubercle.

In addition, a prominent nerve root groove on the rostral surface carries the exiting nerve root of the corresponding level. An important relationship to bear in mind is that this groove is dorsal to the transverse foramen.

Neural Foramen

The neural, or intervertebral, foramen transmits the exiting cervical nerve roots. Unlike the atlantooccipital and atlantoaxial levels, which have partial foramina, the subaxial cervical spine has true foramina with four distinct walls. The pedicles form the rostral and caudal walls. The ventral wall is made of the vertebral body rostrally and the uncovertebral joint overlying the disk space caudally. The dorsal wall is made of the facet joint capsule. The nerve roots exit above the like-numbered pedicle via the nerve root groove of the transverse process in close proximity to the cervical disk and uncovertebral joint. As a result of the close proximity, a degenerated uncovertebral joint or facet joint can lead to stenosis of the intervertebral foramen and compression of the nerve root.

Anterior and Posterior Tubercles

The anterior tubercle arises from the rostral vertebral body and projects laterally. It serves as the origin of the anterior scalene, longus colli capitis, longus colli cervicalis, and ventral intertransversus muscles. The posterior tubercle is the origin of the splenius cervicalis, longissimus, levator scapulae, middle scalene, posterior scalene, and iliocostalis muscles. It arises from the midportion of the lateral mass and projects ventromedially to join the anterior tubercle.

Pedicles

The pedicles are the dorsolateral projections of the vertebral body. They connect the vertebral bodies with the lateral masses. As opposed to the thoracic and lumbar spines, they are short, small, and medially oriented in the subaxial

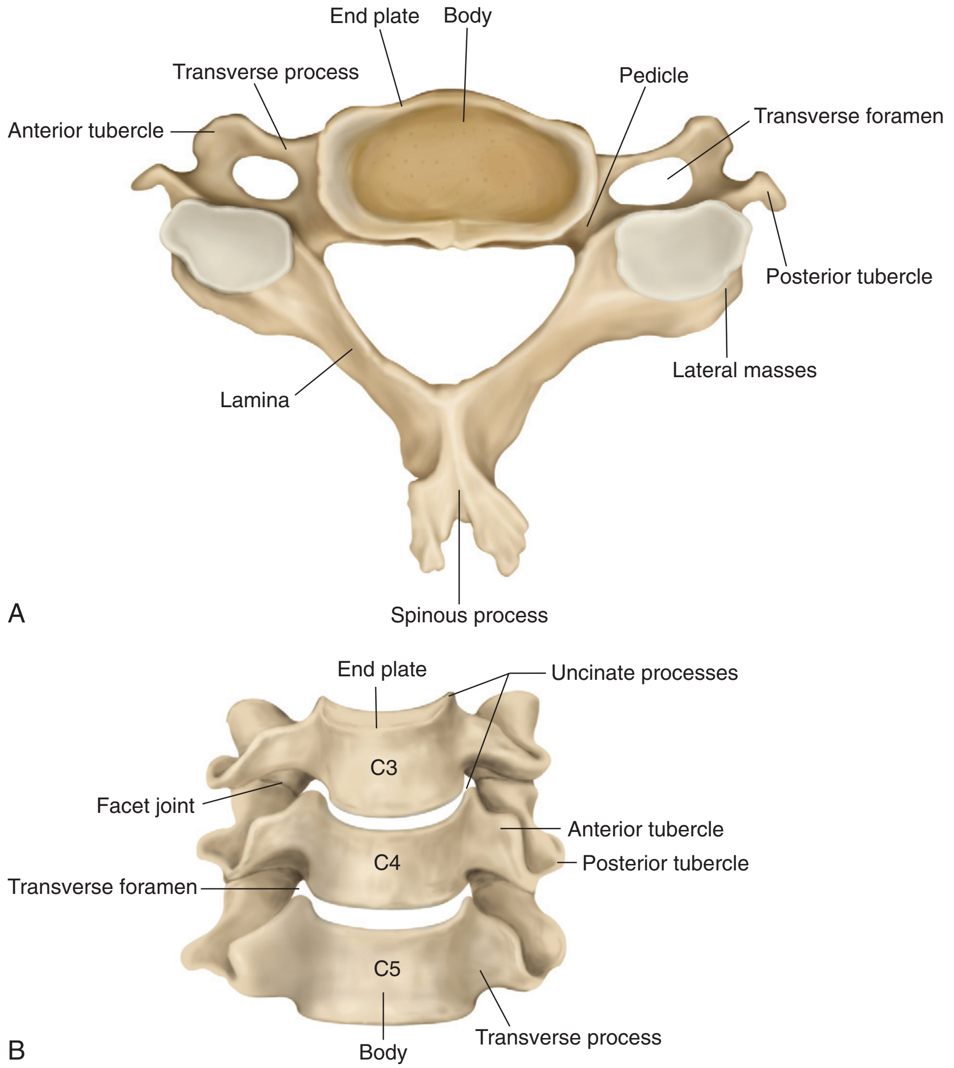

Figure 13-2 Representative subaxial cervical vertebra. **A,** Axial view. **B,** Coronal view.

cervical spine. As a result, lateral mass screws are typically used when instrumentation is required.

Another regional difference of these pedicles is that they arise midway between the rostral and caudal vertebral body, unlike the thoracic and lumbar regions. The sagittal pedicle height increases gradually with descending levels. The transverse pedicle width decreases from the cervical to midthoracic area.

Spinal Canal

The dorsal concavity of the vertebral body forms the ventral aspect of the spinal canal, which is triangular in shape in the axial view. The lateral borders are the medial pedicles, and the dorsal borders are the ventral lamina. In the subaxial cervical spine, its anterior-posterior (AP) diameter decreases with descending levels. At C3, it measures approximately 17 mm, whereas it measures 15 mm at C7.

Lateral Mass

The lateral mass is a cylindroid, flattened, short structure dorsolateral to the pedicle that is actually the pars interarticularis, with the superior and inferior articulating surfaces of the facet joint on either end. The dorsal transverse process is anterior, the pedicle is ventromedial, and the lamina is medial. The nerve root is in very close proximity at each level. The sagittal diameter can range from 12 to 18 mm. Lateral masses can be used for instrumentation given the diminutive size of the subaxial cervical pedicles. In general, the size and volume tends to decrease with descending levels down to C7, a transitional level at which the lateral mass is actually thinner, and the pedicle is wider here than at the levels above.

Facet Joint

The facet joint is a coronally oriented synovial joint protected by a thin capsule. In the sagittal plane, facet joints are oriented at approximately 45 degrees. The facet joints are supplied by the vertebral, ascending pharyngeal, deep transverse cervical, supreme intercostal, and occipital arteries; the dorsal branches of the spinal nerves innervate the facet joints.

Compared with the intermediate orientation of the thoracic spine and the sagittal orientation of the lumbar spine, the coronal orientation of the subaxial cervical facet joints accounts for the varying magnitudes of rotation of these regions, because they do not significantly limit spinal movement in any direction or in rotation, except in extension. The cervical spine has a wide range of motion in flexion, extension, lateral bending, and rotation. Fortunately, the vertebral bodies are able to equally resist axial loading and translation instability. Thus instability can be managed adequately by applying a posterior tension band, as long as the vertebral bodies are intact.

Facet joints do not substantially support axial compressive loads unless the spine is in extension. Quantitatively, facets and the facet joint capsules can absorb approximately a fifth of the total compressive loads applied to the lumbar spine segment. Flexion-extension is distributed throughout the cervical spine a total of 60 to 75 degrees, and sagittal translation is limited to 2 to 3 mm at all cervical spine levels. This is a function of the facets, disks, and ligaments; thus small increases in translation may be harmful.

Lateral bending is a prominent movement, however. Between C2 and C5, there are 10 to 12 degrees of lateral bending per level. At C7–T1, there are only 4 to 8 degrees. As with other spinal levels, lateral bending is coupled with other motions, such as axial rotation; this leads the spinous processes of lower levels to rotate in the opposite direction.

Lamina and Spinous Processes

The lamina are thin dorsomedial structures that encase the posterior spinal canal. They often overlap the adjacent level and are continuous with the spinous processes, which are often small and bifid in the subaxial cervical spine.

INTERVERTEBRAL DISK SPACE

Disk Space

The cartilaginous end plates of the bordering vertebral bodies are the rostral and caudal boundaries of the disk space. The anterior and PLLs are the ventral and dorsal borders, respectively. The uncal process limits the disk space laterally.

Intervertebral Disk

The intervertebral disks extend from end plate to adjacent end plate. Each disk is composed of the nucleus pulposus centrally and is surrounded by the annulus fibrosus, which is composed of collagen and elastin fibers (Fig. 13-3).

Annulus Fibrosus

The annulus fibrosus is a peripheral rim that consists of an alternating layer of collagen fibers that pass obliquely from the vertebral body above and below, arranged in a helicoid manner. There are several layers, and each layer's fibers are oriented in the same fashion; the orientation of the fibers in adjacent layers differs by 30 degrees.

Nucleus Pulposus

The nucleus pulposus is centrally located and is made of a soft, pulplike, highly elastic mucoprotein gel with a high water content. Regional geometric variations parallel the morphologic differences between the various regions of the spine; for instance, the cross section of the disk increases from C2 to T1. Any load resisted by the vertebral body is transferred to the adjacent caudal vertebral body through the intervertebral disk. The heterogeneity of the material properties of the vertebral bodies and the disk makes the mechanism of load transfer complex, and age-related changes add to this. The first component to fail in a functional spinal unit is the end plate, not the disk.

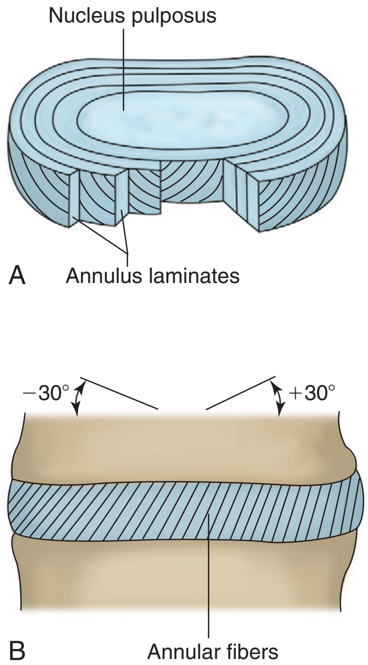

Figure 13-3 Intervertebral disk. **A,** The nucleus pulposus is central; annulus fibers are concentric and peripheral. **B,** The disk lies between adjacent vertebral bodies. Each layer of annulus fibers is oriented in the same fashion, but the orientation of the fibers in adjacent layers differs by 30 degrees.

SPINAL CORD

Spinal Cord and Nerve Roots

Dentate ligaments that arise from the pia and attach to the dura suspend the spinal cord. Eight cervical nerve roots exit via neural foramina immediately rostral to the corresponding pedicle, and the pedicle enlarges with descending levels, with a maximal cross section at C6. Nerve roots occupy approximately a third of the neural foramina and are covered by a venous plexus and epidural fat.

The spinal cord also participates with the vertebral column in configurational changes as a result of changes in body positioning. The primary effects occur at the level of distraction, with large initial displacements occurring with small force levels. This is followed with the cord and then stiffening with additional stretch or distraction, requiring higher load levels.

In flexion, the spinal cord elongates within the canal and decreases in the AP diameter. In extension, the cord shortens and increases in AP diameter. Tensile forces are least at the center of the cord, and shear forces are greatest toward the center. Irreversible damage can occur with 30% spinal cord compression.

Spinal Cord Blood Supply

The primary blood supply to the subaxial cervical spine is through the vertebral artery. Other contributors include the ascending pharyngeal, occipital, and deep cervical arteries. Two vertebral artery branches must be noted: the *ventral branch* is transmitted across the midportion of the lateral surface of the vertebral bodies below the transverse process and below the longus colli muscles, and it contributes to the blood supply of the ventral vertebral body through the accompanying ventral vertebral body arterial plexus; the *dorsal branch* enters the neural foramen and gives off three additional branches, the first of which is transmitted along with the nerve roots and supplies the spinal cord, anastomosing with the anterior and posterior spinal arteries. The second branch supplies the inner surface of the lamina and ligamentum flavum. The third branch contributes to the supply of the dorsal vertebral body through the accompanying dorsal vertebral body arterial plexus, which passes beneath the PLL.

The anterior spinal artery, two posterior spinal arteries, and the segmental medullary arteries supply the subaxial cervical spinal cord. The anterior spinal artery originates from the vertebral arteries, and the posterior spinal arteries originate either from the vertebral arteries or the posterior inferior cerebellar arteries.

The venous drainage of the spinal cord includes three anterior and three posterior veins. An anterior and posterior venous plexus surrounds the spinal cord. The anterior venous plexus is most pronounced medial to the pedicles.

The Batson plexus is the internal vertebral venous plexus that extends from the coccyx to the occiput. It consists of many small, valveless veins that run ventral and dorsal to the thecal sac and merge at the neural foramen; the Batson plexus then exits the spinal canal, along with the nerve roots, and flows into the external venous plexus. The external venous plexus is represented in the cervical region by the vertebral veins, which form a veil around the vertebral artery and subsequently anastomose with the condylar, mastoid, occipital, and posterior jugular veins.

Neurovascular Structures

CAROTID SHEATH

The carotid sheath contains the internal jugular vein laterally, vagus nerve dorsally, common carotid artery medially, and the lymphatic plexus (Fig. 13-4). A branch of the hypoglossal nerve also crosses ventrally. The carotid sheath is lateral to the visceral space and ventral to the prevertebral fascia, the sternocleidomastoid (SCM) muscle covers it ventrally, and it enters the carotid triangle from the thorax.

The common carotid artery is the most medial structure. It bifurcates in the carotid triangle 1 cm above the rostral border of the thyroid cartilage. The carotid sinus lies just before the bifurcation to serve as a baroreceptor.

The vagus nerve travels dorsally in the carotid sheath between the carotid artery and internal jugular vein, and it gives off two important branches that run in the neck to supply the larynx, the superior and inferior (recurrent) laryngeal nerves.

The internal jugular vein is the most lateral structure. It receives the thyrolinguofacial trunk and the idle thyroid vein(s).

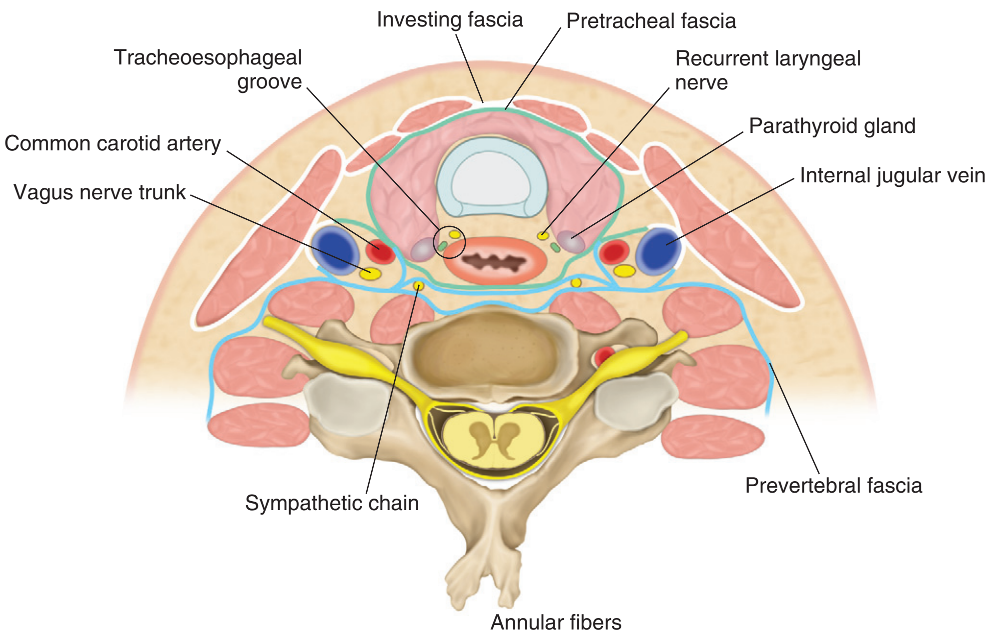

Figure 13-4 Carotid sheath and cervical fascia. The carotid sheath encloses the internal jugular vein, common carotid artery, and vagus nerve. Note the sheath's lateral location relative to the pretracheal fascia; this corridor is often used for anterior cervical operations. The deep cervical fascia—including the investing, pretracheal, and prevertebral fascial layers—should also be noted, along with the recurrent laryngeal nerve within the tracheoesophageal groove.

Superior Laryngeal Nerve

The superior laryngeal nerve extends from the lower end of the nodose (inferior) ganglion of the vagus nerve. Its course is medial to the carotid sheath, and it bifurcates near the tip of the greater horn of the hyoid bone to supply motor innervation to the inferior pharyngeal constrictor and cricothyroid muscles. It also provides sensory innervation to the larynx and the base of the tongue. Overretraction injury can lead to early voice fatigue, difficulty in producing high notes, and decreased gag reflex that leads to greater risk of aspiration.

Inferior (Recurrent) Laryngeal Nerve

The inferior, or recurrent, laryngeal nerve first descends and then ascends from the thorax in the tracheoesophageal groove and enters the inferior pharyngeal constrictor to supply motor innervation to the intrinsic laryngeal muscles (Fig. 13-5). It also receives all sensory innervation below the glottis. On the left, the nerve loops under the aortic arch and has already reached the tracheoesophageal angle when it arrives at the base of the neck. Because of this, retraction of the viscera to the opposite side of the neck does not submit it to excessive tension. The same cannot be said of the right side, however. The right recurrent laryngeal nerve loops around the right subclavian artery, and the nerve has not yet reached the viscera when it arrives at the base of the neck. It is more anterior, more lateral, and less vertical than its counterpart on the left, which explains a greater risk of retraction injury in lower cervical spine approaches. Damage to the right recurrent laryngeal nerve results in hoarseness, and the incidence of vocal paralysis ranges from 2% to 12%, and it mainly occurs in right-sided approaches.

Hypoglossal Nerve

This nerve exits from the hypoglossal canal, enters the carotid triangle deep to the dorsal belly of the digastric muscle, and courses between the carotid artery and the internal jugular vein before turning medially to enter the substance of the tongue. It gives off the superior branch to the ansa cervicalis, which innervates the strap muscles.

Sympathetic Chain

The sympathetic chain lies within the prevertebral fascia ventral to the longus colli muscles. Branches of the sympathetic chain from the inferior cervical ganglion surround the vertebral artery. Injury during anterior approaches can lead to an ipsilateral Horner syndrome.

Vertebral Artery

The vertebral artery has a mean diameter of 4.5 mm and is divided into four segments (Fig. 13-6). Segment V1 is the preforaminal segment; its origin is at the dorsal aspect of the subclavian artery, where it courses medial to the anterior scalene to enter the transverse foramen of C6. V1 runs between the longus colli and the anterior scalene muscles, and it enters the foramen at C6 in 90% of cases.

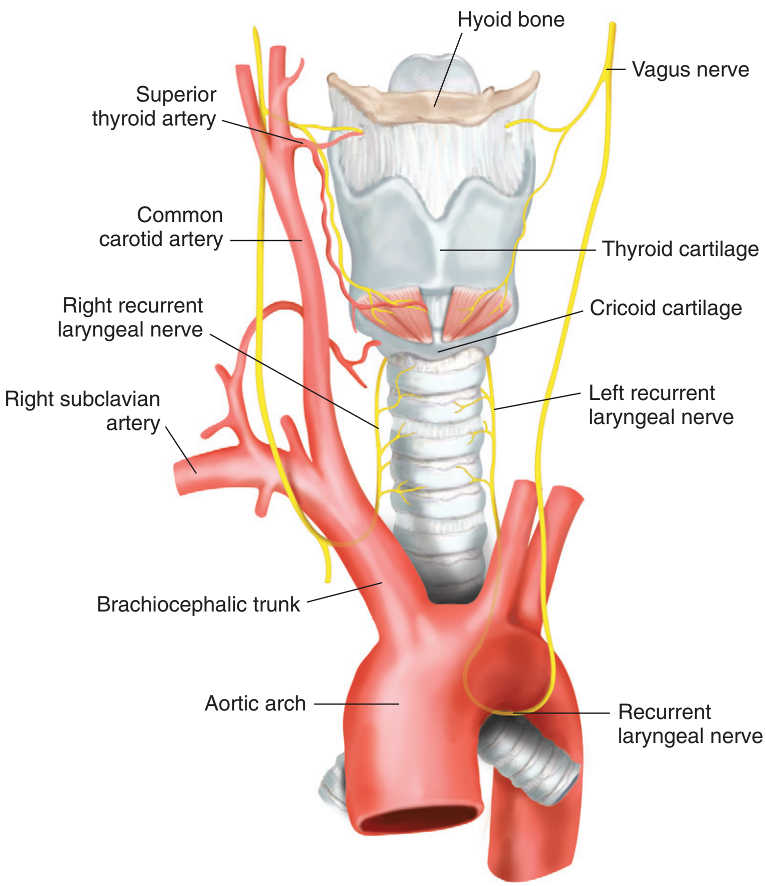

Figure 13-5 Recurrent laryngeal nerve. The nerve loops around the aortic arch on the left and around the subclavian artery on the right.

In the remaining 10%, C3, C4, C5, or C7 can receive the vessel; therefore its length varies. V2 is the foraminal segment, where it ascends through the foramina from C6 to C2, and V3 is the segment within C2, where it courses medially in a groove bearing its name to eventually exit and penetrate the atlantooccipital membrane. Finally, V4 is the intradural segment from the atlantooccipital membrane, before it joins its counterpart to form the basilar artery. Only the V1 and V2 segments are relevant to the subaxial cervical spine.

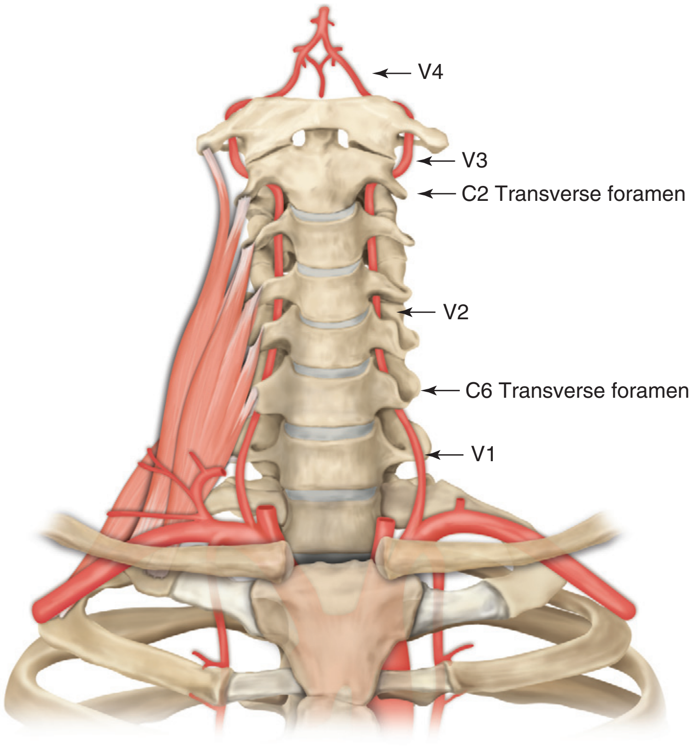

Figure 13-6 Vertebral artery segments. The subaxial cervical spine contains the V1 and V2 segments. V3 extends from the C2 transverse foramen to the atlantooccipital membrane, and V4 is the intradural segment. Note that the vertebral artery typically enters at the C6 transverse foramen.

Viscera

The visceral space is ventral to the vertebral bodies. It can be divided into three layers, which are all contained within the visceral fascia. The *superficial endocrine layer* contains the thyroid and parathyroid glands. The *middle respiratory layer* contains the larynx and trachea. Finally, the *deep gastrointestinal layer* contains the pharynx and esophagus. Overretraction of these elements during an anterior exposure can lead to dysphagia and dysphonia.

If the inferior thyroid artery is encountered and must be ligated, it is advisable to ligate the vessel away from the thyroid gland, because the recurrent laryngeal nerve is in close approximation to the vessel. This close approximation also exists with the superior thyroid artery and the external laryngeal nerve, again dictating ligation away from the thyroid gland.

Ligaments

Ligaments are multilayered structures composed of elastin and collagen. They allow normal spinal motion while restricting excessive spinal motion, and they are essential for alignment and intervertebral stability. Multiple ligaments are involved in the subaxial cervical spine to accomplish this (Fig. 13-7).

In general, a ligament responds to tensile forces, and effectiveness depends on the morphology and lever arm through which it acts. The anatomic location and strength under tensile forces need to be considered; that is, ligaments

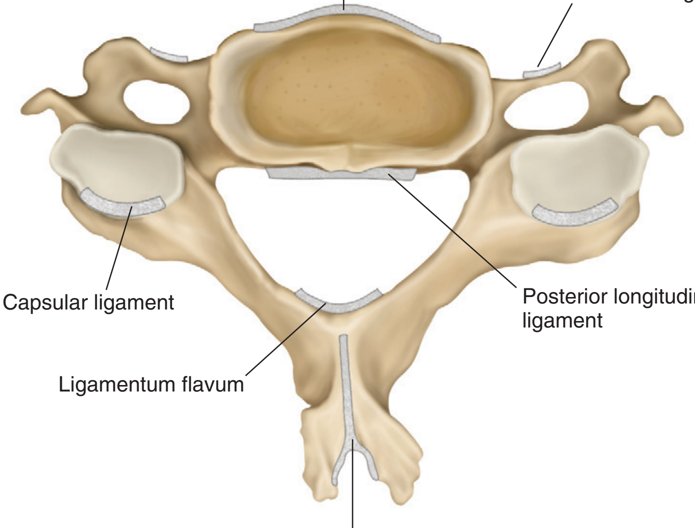

Figure 13-7 Ligaments of the subaxial cervical spine.

farthest from the instantaneous axis of rotation have the highest strength to resistance in general. Ligaments on the convex side of the spinal curvature are generally stronger. A very strong ligament that functions through a short lever arm may contribute less to stability than a weaker ligament working through a longer lever arm.

ANTERIOR LONGITUDINAL LIGAMENT

The anterior longitudinal ligament (ALL) is attached to the ventral surfaces of the vertebral bodies and intervening disks. The entire length spans from the skull base to the sacrum, and in conjunction with the anterior halves of the intervertebral disks, its main function is to act as an anterior tension band to prevent hyperextension of mobile segments. The ALL is composed of longitudinal fibers and is multilayered; the superficial fibers extend four or five levels, the middle layer binds the vertebral bodies and the disks over three levels, and the deep fibers span to just the adjacent end plates. The ALL is thickest over the concavity of the vertebral body, blending into the periosteum.

POSTERIOR LONGITUDINAL LIGAMENT

The posterior longitudinal ligament (PLL) is attached to the disks on the dorsal surface of the vertebral bodies. It is composed of longitudinal fibers that also span the entire vertebral column. At its rostral extent, it fans out to become the tectorial membrane, and it continues caudally to the sacrum. The main function of the PLL is resistance to hyperflexion. Its fibers spread thinly at the disk level, and it narrows at the middle of the vertebral body; thus the most common site of disk herniation is at the dorsal paramedian region of the intervertebral disk. The deep layer extends only to the adjacent vertebrae, but the stronger superficial fibers span several levels. This deep layer attaches very closely to the dorsal annulus but loosely to the vertebral body, where it is also much thinner.

In general, ligamentous structures dorsal to the nucleus act as a posterior tension band to protect against hyperflexion. Although the PLL is a relatively strong ligament that plays a role in resistance to hyperflexion, from a biomechanical perspective, its failure strength is the lowest among those ligaments involved in this function. This is due to the length of its lever arm, or distance from the instantaneous axis of rotation; the farther away from the instantaneous axis of rotation, the higher the failure strength tends to be. For example, in descending order, the failure strength for some ligaments that resist hyperflexion are the capsular ligament, ligamentum flavum, and PLL.

LIGAMENTA FLAVA

The ligamenta flava are segmental discontinuous ligaments high in elastin content and yellow in appearance. They are the most elastic tissues in the human body. The ligaments traverse adjacent lamina in a shinglelike fashion and are actually composed of broad, paired ligaments that connect adjacent spinal laminae on either side. Each ligament arises from the ridge on the lower half of the ventral surface of the caudal lamina and projects to the inner surface of the adjacent rostral lamina. The longitudinal midline cleavage plane and the ability for it not to go lax under hyperextension minimize the chance of buckling under normal extension movements; this decreases the likelihood of thecal sac compression. This cleavage plane also extends laterally to become confluent with the ventral aspect of the facet joint capsule.

CAPSULAR LIGAMENTS

Capsular ligaments are composed of fibers oriented in a perpendicular fashion relative to the articular surfaces of the facet joints. These ligaments attach the adjacent vertebra to the articular joints, and they play a role in limiting flexion and rotation. Under normal physiologic conditions, the ligaments are loose, but they become taut with increasing movements. They are longer and more slack in the cervical region.

LIGAMENTUM NUCHAE

The ligamentum nuchae is composed of the interspinous and supraspinous ligaments. The interspinous ligaments, composed mostly of elastin, are found between adjacent spinous processes. The supraspinous ligament is also mostly composed of elastin and involves only C7 of the subaxial cervical spine; the apex of C7 is its most rostral extent. Together, these two ligaments form the ligamentum nuchae, which runs from the inion to the spinous process of C7, divides the paraspinal muscles, and serves as an attachment site for the nuchal musculature and the midline avascular plane during the posterior midline approach. It serves to limit flexion to a significant degree because of its long lever arm.

INTERTRANSVERSE LIGAMENTS

The intertransverse ligaments connect adjacent transverse processes and have little biomechanical effect on the cervical spine.

Fascia and Musculature

FASCIA

Investing Layer

The investing layer is the most superficial of the three layers of fascia and is a thick fascia that completely surrounds the neck. Ventrally, the investing layer splits to cover the SCM muscle, trapezius muscle, submandibular gland, and parotid gland. It connects rostrally to the hyoid bone, caudal border of the mandible, zygomatic arch, mastoid process, and superior nuchal line. It splits caudally to attach to the ventral and dorsal surfaces of the sternum (suprasternal space), and it forms the roof of both the ventral and dorsal cervical triangles.

Pretracheal (Visceral) Layer

The pretracheal, or visceral, layer is also called the *middle cervical aponeurosis*. It envelops the subhyoid muscles: the sternohyoid, sternothyroid, and omohyoid muscles. The omohyoid muscle runs along the lateral border of this layer and is found deep to the infrahyoid muscles surrounding the visceral space. The visceral space includes the thyroid gland, trachea, and esophagus. Rostrally it is attached to the hyoid bone and thyroid cartilage, extends caudally to the dorsal surface of the clavicles and sternum and into the mediastinum, and laterally it blends into the carotid sheath. The thyroid vessels run deep to this layer.

Prevertebral Layer

The prevertebral layer surrounds the vertebral column and its musculature, including scalenus and longus groups, and comprises a ventral alar layer and dorsal prevertebral layer. Subsequently, a potential space ventral to the vertebral bodies extends from the skull base to T12 and communicates with the mediastinum, and surgeons must be aware of this.

Within the fascia and ventral to the longus colli muscle lies the cervical portion of the sympathetic chain. These fibers form the superior cervical ganglia, which pass to the internal carotid artery to innervate the ipsilateral pupil (third order). Interruption of this innervation leads to ipsilateral Horner syndrome.

VENTRAL MUSCULATURE

Superficial Layer

Platysma. The playsma is a thin muscle of facial expression, usually 1 to 3 mm thick. It runs from the mandible to the clavicle, obliquely downward and backward, and immediately under the skin and subcutaneous fat. Neurovascular bundles going to and from the skin penetrate it. The platysma extends from the mandible to the level of the second rib and laterally to the acromion process.

Sternocleidomastoid. The SCM muscle runs obliquely downward and forward. Rostral attachments are the mastoid and occipital bones, and caudal attachments are the sternum and clavicle. The SCM turns the head to the contralateral side and flexes the head ipsilaterally. It divides the neck into triangular regions, which will be discussed below.

Deep Layer

Scalenus Group. The scalenus muscle group is composed of the anterior, medial, and posterior scalene muscles. These arise from the transverse processes of the subaxial cervical spine and project to the first and second ribs, and they help elevate the rib cage during respiration. The scalenes are innervated by the ventral rami of C4–C8.

Longus Group. The longus muscle group includes the rectus capitis anterior, longus capitis, and longus colli muscles that arise from the ventral vertebral body, transverse processes, and basilar portion of the occiput. The longus muscles project caudally along the ventrolateral aspects of the cervical and upper thoracic vertebral bodies, and they serve to flex the head and cervical spine. Innervation is through the ventral rami of C1–C6.

Infrahyoid Group. The infrahyoid muscles are the rostral continuation of the truncal rectus muscular system. The four muscles of this group include the sternohyoid, sternothyroid, omohyoid, and thyrohyoid muscles. The ansa cervicalis innervates the first three, and the thyrohyoid is innervated by C1 via the hypoglossal nerve. The infrahyoid muscles assist in swallowing and mastication, and they also assist with flexion of the cervical spine and lowering of the head. The omohyoid muscle runs along the lateral border of the pretracheal layer of the cervical fascia. It sometimes has to be divided through its anterior belly to facilitate an approach to the lower cervical levels.

DORSAL MUSCULATURE

In general, the dorsal musculature acts as a group of active tension bands that provide balanced support of the vertebrae in the upright position. Erector muscles provide symmetric and sagittal bracing and support, and they maintain lordosis of the cervical spine. Loss of strength, such as with atrophy, can lead to a loss of lordosis that in turn leads to kyphotic deformity and ultimately to sagittal imbalance. Lateral tension bands provide symmetric support to keep the cervical spine vertical in the coronal plane. Any asymmetry can lead to deformity and abnormal curvature.

The thick masses of muscles on each side of the spine are spread out into three layers. All the muscles are innervated by the dorsal rami of several consecutive spinal nerves. The ligamentum nuchae, composed of the interspinous and supraspinous ligaments, separates the right and left layers. It is attached posteriorly by the cervical fascia.

Superficial Layer

The superficial layer includes the trapezius, splenius, and levator scapulae muscles. The trapezius is the most superficial, followed by the splenius group. The origin of the splenius muscles is from the ligamentum nuchae and the spinous processes of C6–T1. The splenius capitis inserts along the lateral third of the superior nuchal line and the mastoid process, and the splenius cervicis inserts into the posterior tubercles of the transverse processes of C1–C4. These muscles may produce extension, lateral bending, and rotation of the head or neck.

Intermediate Layer

The intermediate layer includes the erector spinae group: the semispinalis medially, iliocostalis laterally, and longissimus in between. All three share a common origin at the iliac crest, sacrum, and caudal lumbar spinous processes. The semispinalis group inserts along the spinous processes of the cervical spine, with capitis and cervicis divisions; it arises from the transverse processes of T1–T6 and inserts medially between the superior and inferior nuchal lines. The semispinalis cervicis muscle originates from the transverse processes of the lower cervical and upper thoracic spine and inserts on the cervical spinous processes.

The longissimus group inserts onto the mastoid process, and the iliocostalis group inserts into the posterior tubercles of the transverse processes of C4–C6. These muscles can extend or laterally bend the neck.

Deep Layer

The deep layer is also known as the *transversospinalis group,* because it lies in the angle of the spinous and transverse

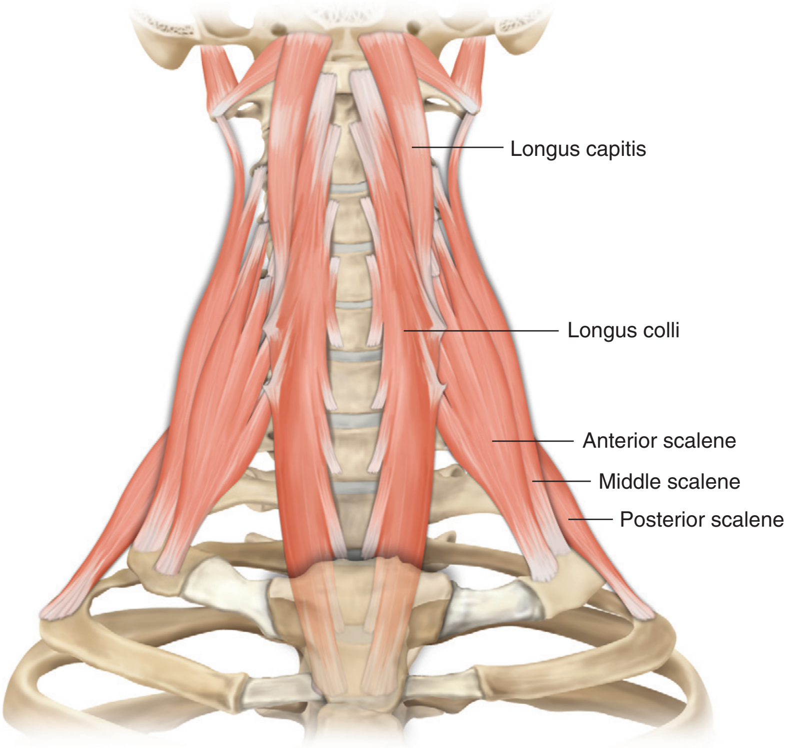

Figure 13-8 Deep anterior muscles. The longus colli are often used to help establish the midline during anterior cervical approaches.

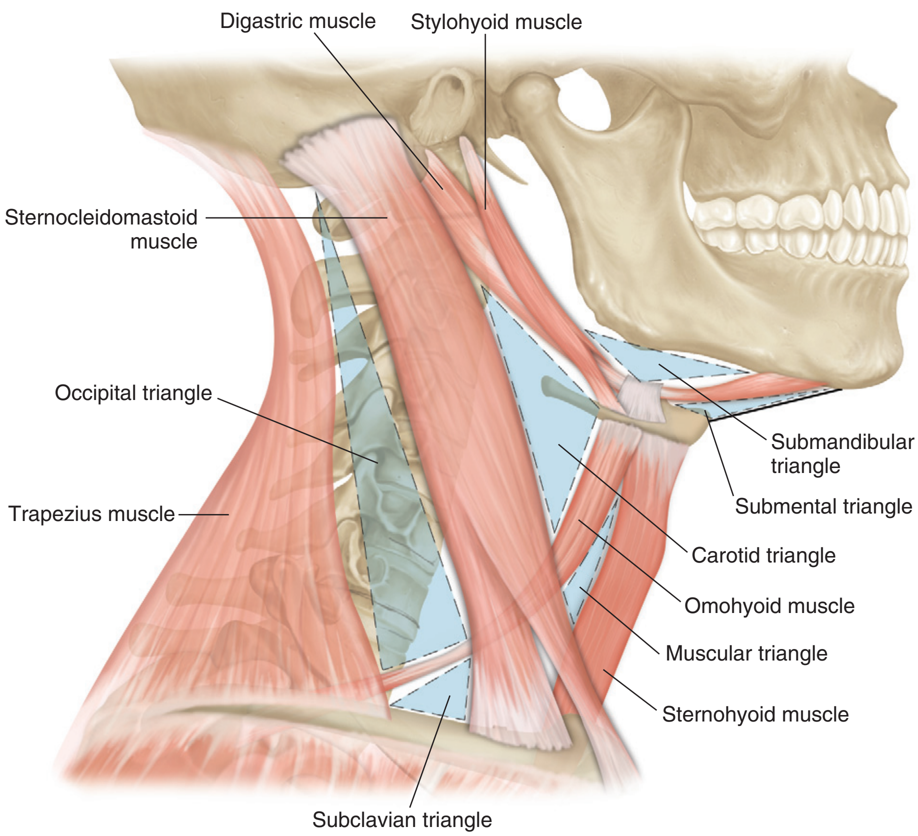

Figure 13-9 Cervical triangles. The anterior triangle is composed of the four subtriangles anterior to the sternocleidomastoid (SCM) muscle. The posterior triangle is composed of the two subtriangles posterior to the SCM muscle as depicted.

processes. This deepest layer lies against the spinous processes and laminae; the muscles fan out from the transverse process of a given level to three or four adjacent overlying laminae (Fig. 13-8).

CERVICAL TRIANGLES

The SCM divides the ventral neck into ventral and dorsal cervical triangles (Fig. 13-9). The ventral triangle has four subtriangles, and the dorsal triangle has two subtriangles.

Ventral Triangle

The ventral triangle borders are the medial edge of the SCM, the inferior border of the mandible, and the midline of the neck. The four subtriangles are the 1) submental, 2) submandibular, 3) carotid, and 4) muscular triangles. The *submental triangle* is bordered by the hyoid body and the ventral bellies of the left and right digastric muscles; the floor consists of the two mylohyoid muscles. The *submandibular triangle* is bordered by the anterior and posterior bellies of the digastric muscle and the inferior border of the mandible; the floor consists of the mylohyoid, hyoglossus, and middle constrictor muscles, and the hypoglossal nerve is an important structure that passes through this triangle. The *carotid triangle* is bordered by the ventral border of the SCM, the rostral edge of the rostral belly of the omohyoid muscle, and the caudal edge of the dorsal belly of the digastric muscle. Important structures in this triangle include the bifurcation of the common carotid artery, internal jugular vein laterally, vagus posteriorly, and ansa cervicalis. The muscular triangle is bordered by the median plane of the neck, caudal edge of the rostral belly of the omohyoid muscle, and medial border of the SCM. The infrahyoid muscles and neck viscera can be found here.

Dorsal Triangle

The dorsal triangle is bordered by the lateral edge of the SCM, ventral trapezius border, and middle third of the clavicle. The roof is the deep cervical fascia that covers the dorsal triangle. The scalenus posterior, scalenus medius, levator scapulae, and splenius capitis muscles and the lateral extension of prevertebral fascia form the floor. The posterior belly of the omohyoid divides the posterior triangle into a large, rostral occipital triangle (the occipital artery exits at its apex) and smaller caudal subclavian triangle (the subclavian artery lies deep to it). The external jugular vein is the confluence of the posterior auricular and posterior division of the retromandibular vein at the angle of the mandible. It courses over the SCM to enter the dorsal triangle caudally en route to the subclavian vein 2 cm above the clavicle.

14 Anterior Cervical Diskectomy and Fusion

JAY RHEE and JEAN-MARC VOYADZIS

Overview

Cervical spondylosis and disk degeneration can lead to radiculopathy and myelopathy from progressive foraminal or central stenosis. A 14 year epidemiologic study from Rochester, Minnesota, found the incidence of cervical radiculopathy to be 83.2 per 100,000 population.[1] The majority of the cases were secondary to chronic degenerative arthropathy of the cervical spine. Although the majority of patients suffering from symptomatic cervical spondylosis or intervertebral disk herniation will improve with conservative therapy, many will have persistent or worsening symptoms that require surgery.[1,2]

The anterior approach provides a safe and effective corridor to the subaxial cervical spine in cases of instability or anterior pathology. First described by Robinson and Cloward, the anterior cervical diskectomy and fusion (ACDF; Fig. 14-1) has become an established and commonly performed operation.[3,4] Once a decompression of the intervertebral disk and neural foramen is performed, an intervertebral graft is inserted to maintain disk space height and enhance fusion. The choice of graft material will be dictated by surgeon preference, and multiple pathologic levels may be treated in the same operation. Upon placement of an autograft or allograft, an anterior cervical plate may be placed to span the most rostral to the most caudal vertebral bodies included in the diskectomies. Although the efficacy of anterior cervical plating for single-level operations remains controversial, plating for multilevel fusions has been shown to decrease pseudarthrosis rates.[5] Furthermore, studies suggest that instrumentation maintains sagittal balance through the segments within the construct, even in single-level fusions.[6,7]

Indications

- Intractable or progressive cervical radiculopathy or myelopathy refractory to conservative management with evidence of spondylosis or disk herniation causing foraminal or central stenosis at corresponding level on imaging
- Cervical diskitis
- Drainage of anterior cervical epidural abscess
- Diskogenic cervical headaches[8]
- Anterior cervical tumor
- Degenerative or traumatic cervical subluxation
- Traumatic cervical instability

Contraindications

- No absolute contraindications
- Prior neck irradiation
- Prior anterior neck surgery
- Tracheostomy
- Primary posterior pathology (hypertrophied ligamentum flavum)
- Ossification of the posterior longitudinal ligament (may require corpectomy or posterior decompression)
- Severe osteoporosis

Operative Technique

EQUIPMENT

- Radiolucent operating table
- Intraoperative fluoroscopy
- Optical loupes
- Headlights
- Operative microscope
- Radiolucent self-retaining cervical retractor
- Monopolar and bipolar electrocautery
- Metzenbaum scissors
- Kittner swabs
- Cloward handheld retractors
- Caspar pins with left- or right-sided retractor, depending on the side of approach
- Pneumatic drill
- Kerrison rongeurs, sizes 1 through 3
- Pituitary rongeur
- Straight and curved curettes
- 18-gauge spinal needle
- Intervertebral graft material (autograft, allograft)
- Plate-and-screw system (optional)
- Jackson-Pratt drain (optional)

PATIENT POSITIONING

- The patient is placed supine on the radiolucent operating table with the head toward anesthesia.
- Upon induction of general anesthesia, the patient is intubated. If significant central stenosis or myelopathic symptoms are present, care is taken to avoid extension of the neck. This may require fiberoptic intubation.
- The patient's head is placed on a horseshoe or padded donut.

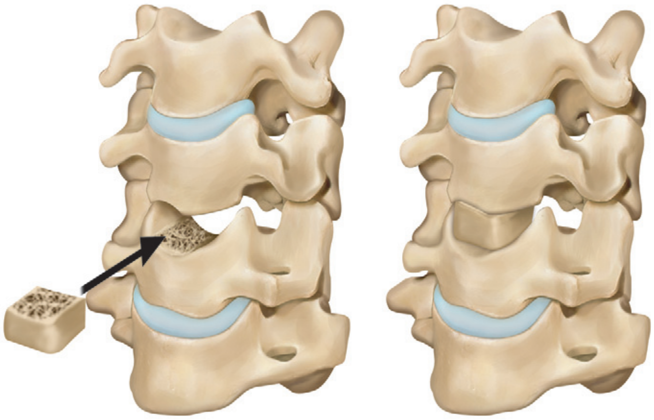

Figure 14-1 Illustration of the Smith-Robinson technique. A rectangular diskectomy is performed, allowing both central and foraminal decompression followed by insertion of an intervertebral graft.

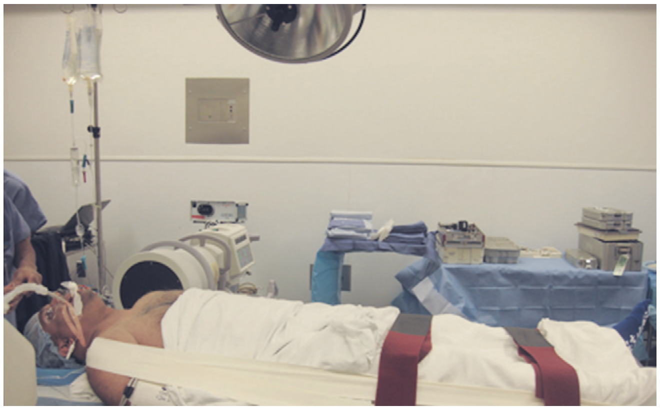

Figure 14-2 The final operative position has the patient secured supine in mild neck extension with a small roll placed transversely across both shoulders. The head is toward anesthesia; the fluoroscopy machine is positioned transversely at the level of the cervical spine in preparation for localization. The shoulders are gently retracted caudally and are taped in place for better radiographic exposure of lower cervical levels.

- A small roll is placed under the shoulders transversely to facilitate cervical lordosis.
- The elbows and wrists are padded to prevent compression neuropathy, and the arms are tucked to the patient's sides.
- Intraoperative fluoroscopy is placed at the level of the cervical spine transversely in preparation for a lateral view.
- When the patient's shoulders obscure imaging of the operative levels, they may be retracted caudally with tape (Fig. 14-2).
- If planning an iliac crest autograft, the ipsilateral crest is elevated and rotated contralaterally by placing one pillow beneath the ipsilateral buttock.

MARKING THE INCISION

- The side of approach is based on surgeon preference. Despite the more lateral location of the right recurrent laryngeal nerve, studies reveal no increase in risk of nerve injury between left- and right-sided approaches.[8-10]

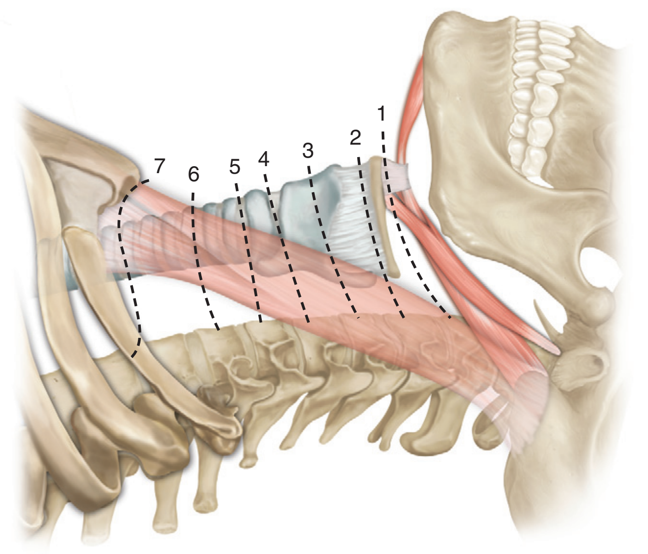

Figure 14-3 Anatomic landmarks for marking incisions.

Figure 14-4 Left paramedian incision along a natural skin crease in preparation for a C5–C6 anterior cervical diskectomy and fusion.

The sagittal orientation of the cervical intervertebral disks is approximately 15 degrees rostral; therefore positioning the patient lying on the right side for a right-handed surgeon—or conversely, lying on the left side for a left-handed surgeon—will facilitate diskectomy.

- A transverse incision is marked out from the midline to the lateral border of the sternocleidomastoid (SCM) muscle. The marking should be placed along a natural skin crease or along the Langer line for improved cosmesis. The level of the target disk(s) dictates the rostral or caudal location of the incision (Figs. 14-3 and 14-4).
- For C1–C2 and C2–C3, the incision is placed 1 cm below the angle of the mandible. A mandibular osteotomy may be required for access to vertebrae in a patient with a short neck.
- For C3–C4, the incision is placed just caudal to the level of the hyoid bone.

- For C4–C5, the incision is placed at the level of the thyroid cartilage.
- For C5–C6 and C6–C7, the incision is placed at the level of the cricoid cartilage.
- C7–T1 may be accessible in certain patients with longer necks. In these cases, the incision is placed as low as possible, just above the clavicle.
- These guidelines for the marking of incisions should be confirmed with lateral fluoroscopy.
- To obtain an iliac bone autograft, an 8-cm oblique line is marked 6 cm lateral to the anterior superior iliac spine.

PREPARATION AND DRAPING

- Once the incision is marked, the operative field is isolated with circumferential 10 × 10 cm adhesive drapes.
- The skin is sterilized in standard fashion.
- The iliac incision is prepared if autograft harvesting is planned (see the section on autograft harvesting).
- Both cervical and iliac incisions are isolated with sterile towels. A clamp is placed over the iliac incision for localization through the sterile drapes, and a thyroid drape is placed over the cervical incision.
- The base of the intraoperative fluoroscopy machine is placed opposite the surgeon; it is draped carefully to avoid contamination of the sterile field and is moved rostrally toward anesthesia. The operative microscope is placed behind the primary surgeon opposite the fluoroscopy machine.

INCISION AND SOFT TISSUE DISSECTION

- Local anesthetic is injected into the incision site.
- The skin is incised transversely along the marking with a scalpel to expose the subcutaneous layer, which in turn is dissected until the longitudinal fibers of the platysma are visible (Fig. 14-5).
- The platysma is cut transversely with electrocautery in the same plane as the skin incision (Fig. 14-6).
- The external jugular vein or its branches may be encountered; these may be dissected, retracted, or ligated if necessary.

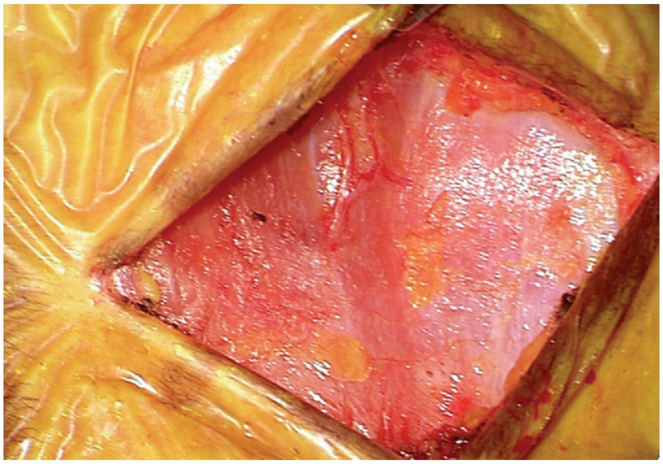

Figure 14-5 A left-sided transverse skin incision is made, exposing the longitudinal fibers of the platysma muscle.

- The subplatysmal areolar layer is undermined both rostrally and caudally to facilitate exposure and retraction.
- The SCM muscle is identified, and the anterior cervical fascia on its medial border is incised (Fig. 14-7).
- Deep to the anterior cervical fascia lies a loose areolar layer, between the SCM and infrahyoid (omohyoid and sternothyroid) muscles. This plane is exposed using blunt and sharp dissection.

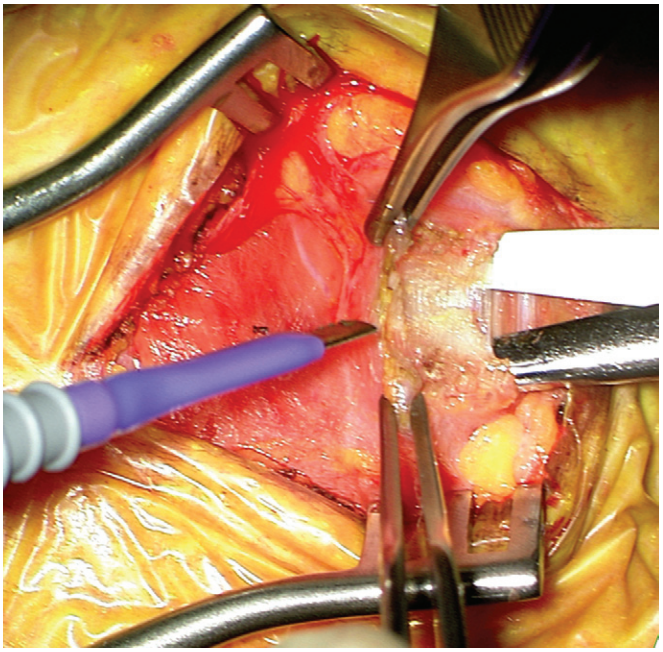

Figure 14-6 The platysma is bluntly dissected and elevated from underlying structures with Metzenbaum scissors, then incised transversely with monopolar electrocautery.

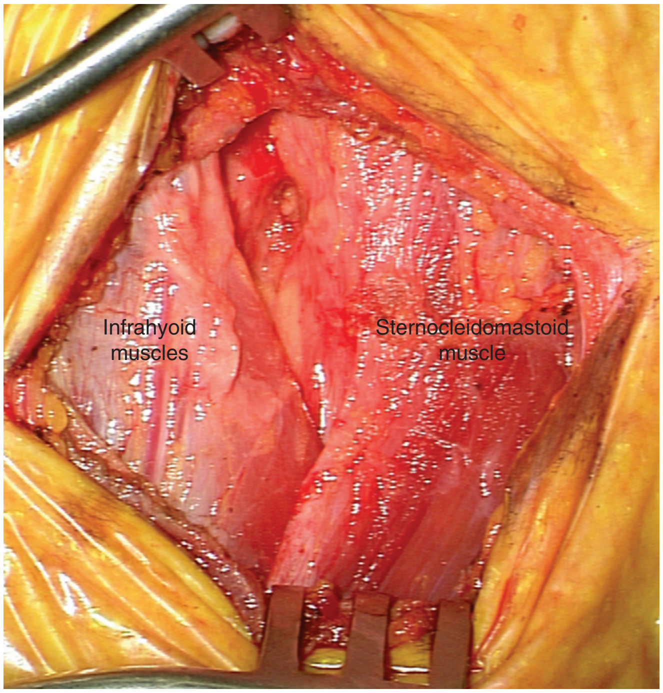

Figure 14-7 Anterior cervical fascia on the medial border of the sternocleidomastoid muscle has been incised to reveal a natural plane.

- The transverse belly of the omohyoid muscle may obscure access to this corridor, especially if the procedure involves C5 to C6. If medial retraction proves inadequate, the omohyoid may be transected.
- The carotid artery is palpated and retracted laterally with a Cloward handheld retractor.
- Another Cloward retractor protects the infrahyoid muscles, trachea, and esophagus medially. The anterior vertebral column may be palpated at this stage.
- The middle cervical fascia immediately deep to the retractors is held under tension. This layer is dissected bluntly with Kittner swabs to expose the prevertebral fascia (Fig. 14-8).

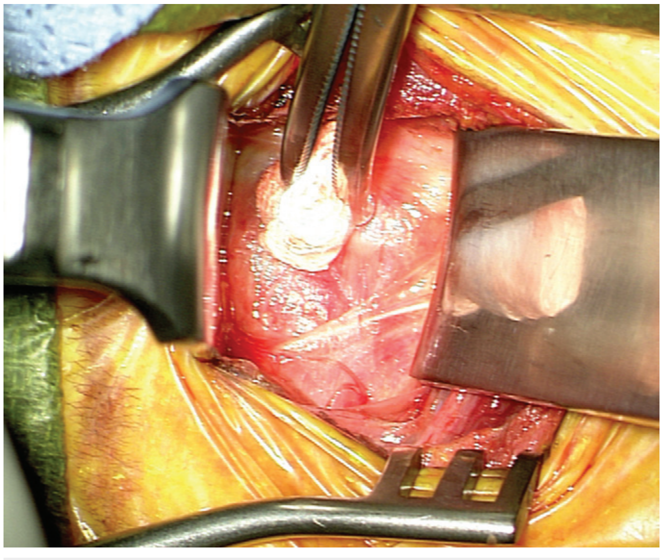

Figure 14-8 Using Cloward handheld retractors, the infrahyoid muscles, trachea, and esophagus are retracted medially; the sternocleidomastoid muscle and carotid sheath are retracted laterally. This places the middle cervical fascia under tension; the fascia is dissected bluntly with Kittner swabs.

EXPOSURE OF THE VERTEBRA

- The prevertebral fascia is dissected in similar fashion, until the vertebral column and bilateral longus colli muscles are visible.
- An 18-gauge needle is inserted into the disk space of interest. The tip of the needle is bent twice to prevent inadvertent placement of the needle into the spinal canal (Fig. 14-9).
- A lateral fluoroscopic image is taken to confirm the correct disk space.
- The longus colli muscles and the anterior longitudinal ligament are dissected subperiosteally with monopolar cautery up to the uncovertebral joints bilaterally (Fig. 14-10). When operating at the C3–C4 and C4–C5 levels, the surgeon may encounter the inferior thyroid vein and artery; these vessels may be ligated if necessary. The superior laryngeal nerve may extend from the vagus nerve in the carotid sheath toward the thyroid cartilage, and care must be taken to avoid injury to this nerve.
- Once the longus colli muscles are sufficiently mobilized, a depth gauge is inserted up to the anterior vertebral surface. Self-retaining retractors are chosen based on the depth measurement, and the blades are placed beneath the longus colli muscles bilaterally. The blades are distracted until the uncovertebral joints are visualized. Care must be taken to identify the midline.
- A second self-retaining retractor may be placed in the cephalocaudal direction to facilitate exposure. This step is often unnecessary in single-level procedures but is helpful when exposing multiple disk levels (Fig. 14-11).
- 12- to 14-mm Caspar pins may be hand drilled into the vertebral bodies immediately rostral and caudal to the target intervertebral disk to provide distraction.

DISKECTOMY AND FORAMENOTOMY

- Any overhanging anterior osteophytes are removed with rongeurs to fully expose the disk space.

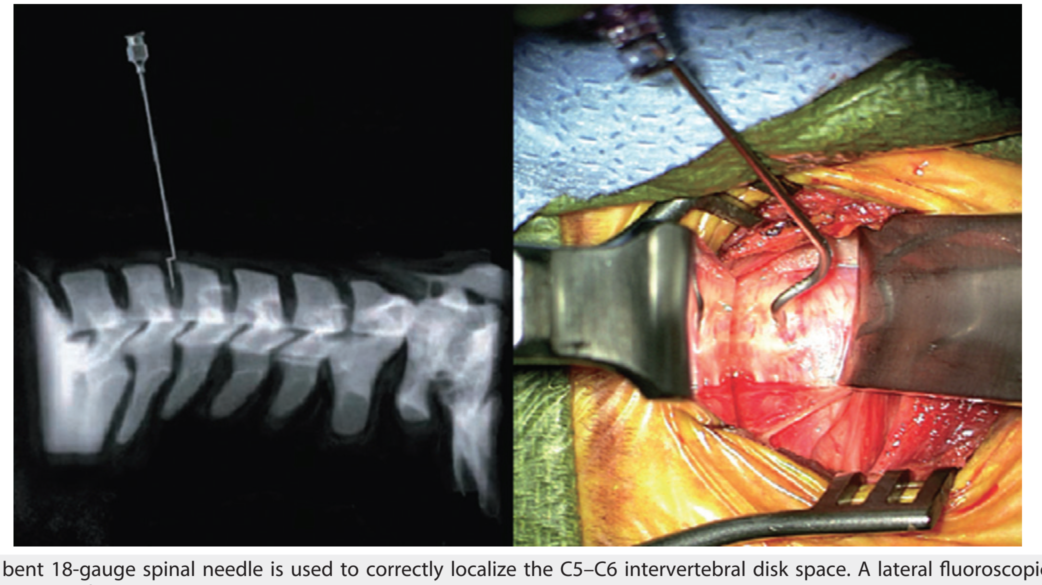

Figure 14-9 A bent 18-gauge spinal needle is used to correctly localize the C5–C6 intervertebral disk space. A lateral fluoroscopic image and an intraoperative image are shown.

- A 15 blade scalpel is used to incise a 10- to 12-mm rectangular opening in the annulus. The lateral extent of this incision should not extend past the most medial portion of the uncinate process bilaterally (Fig. 14-12).
- The incised portion of the annulus is removed with a pituitary rongeur. The remaining portion of the intervertebral disk and cartilaginous end plates are removed carefully with 2- to 3-mm curettes, 1- to 3-mm Kerrison rongeurs, and a pituitary rongeur (Fig. 14-13).
- The operative microscope may be utilized for the remainder of the diskectomy and foraminal decompression. The microscope must be placed so that the view is midline and perpendicular to the vertebral column. An oblique view of the operative field may predispose the surgeon to skive unilaterally toward a vertebral artery.
- A pneumatic drill is used to remove posterior osteophytes and prepare the disk space for graft placement (Fig. 14-14). The osseous end plates must be preserved, because these will prevent subsidence of the graft into the vertebral bodies. The intervertebral disk space is typically oriented rostrally 10 to 20 degrees, which requires angling of the microscope in similar fashion.
- With completion of the diskectomy, the posterior longitudinal ligament is exposed and subsequently removed with a #1 or #2 Kerrison rongeur (Fig. 14-15).
- Osteophytes and portions of the uncinate process that extend into the neural foramen in cases of foraminal stenosis can be removed with Kerrison rongeurs. The microscope may be tilted to enhance the lateral view of the neural foramen.
- A blunt hook is gently inserted to the neural foramen and central canal to ensure adequate decompression.
- Epidural bleeding is managed with bipolar electrocautery and thrombin-soaked Gelfoam.

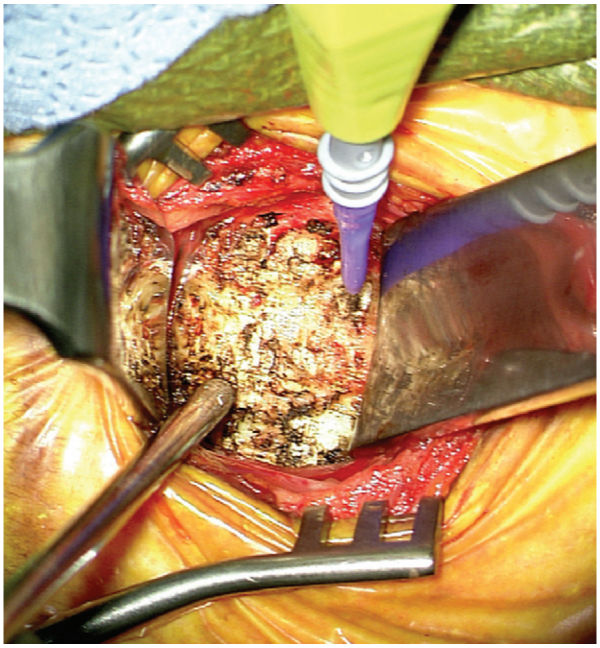

Figure 14-10 Exposure of the anterior vertebral surface and disk space. The anterior longitudinal ligament and longus colli muscles are dissected subperiosteally.

INTERVERTEBRAL GRAFT

- The disk space height is measured with a series of temporary sizing spacers inserted sequentially, starting with the smallest, until one fits tightly into the disk space. A graft of the same size is selected and gently tamped in place, until the graft is flush with the anterior border of the vertebra (Fig. 14-16). Available graft materials include autologous iliac crest, titanium, carbon fiber, and polyetheretherketone (PEEK).
- A typical cervical intervertebral graft measures 12 mm transversely, 8 to 12 mm in the anterior–posterior (AP) dimension, and 6 to 10 mm vertically.
- Once the graft is placed, the Caspar distractor and pins are removed. A bone wax cone on the end of a Kittner swab is used to immediately plug the pin site holes as they are removed.
- A lateral radiograph is taken to confirm proper placement.

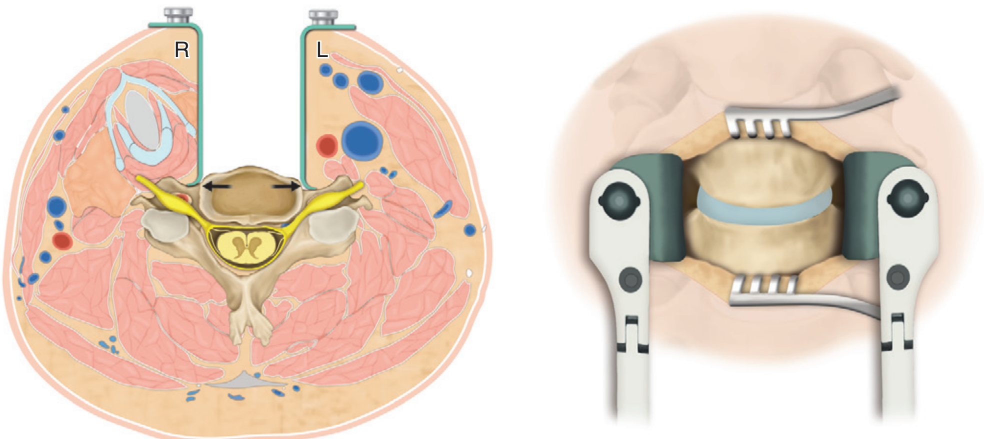

Figure 14-11 Cross-sectional (*left*) and anterior (*right*) images of the final position of the self-retaining retractors. The teeth of the laterally oriented blades are tucked beneath the longus colli muscles (*arrows*). Identification of the midline will prevent lateral deviation and vertebral artery injury during diskectomy.

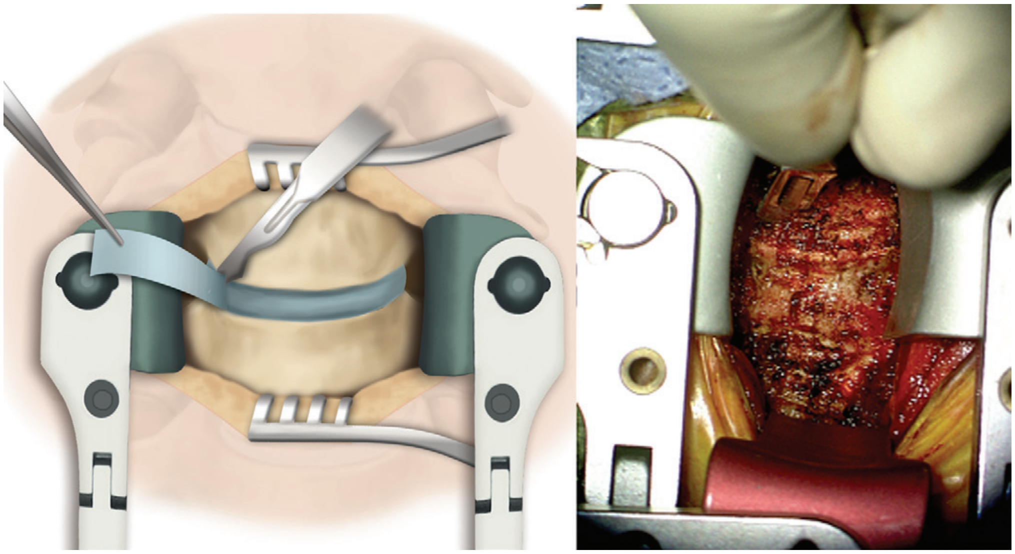

Figure 14-12 Schematic (*left*) and intraoperative (*right*) views demonstrate incision through the anterior annulus.

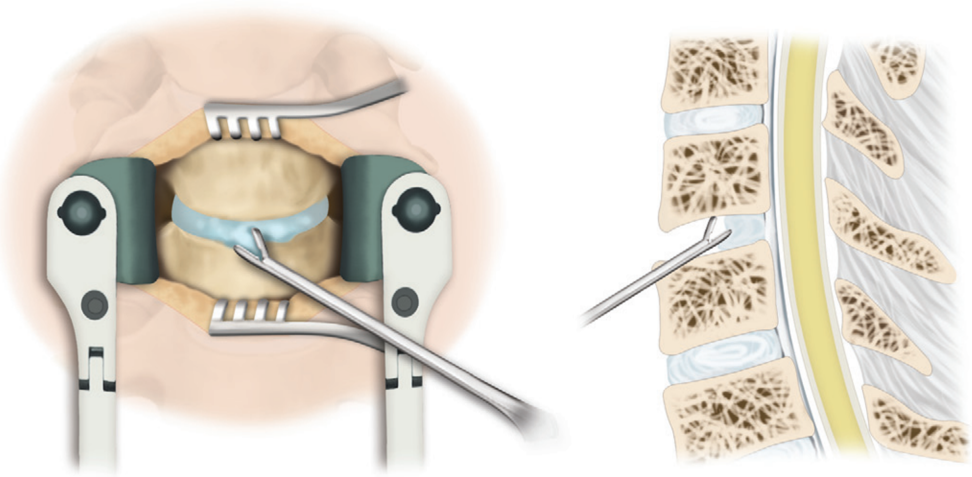

Figure 14-13 Pituitary rongeurs, Kerrison rongeurs, and curettes are used to remove disk space material.

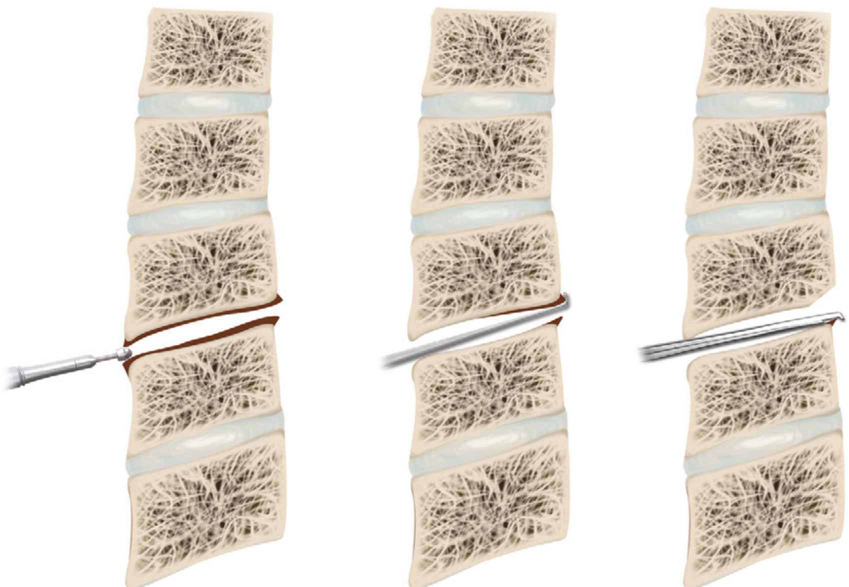

Figure 14-14 The cartilaginous end plates and osteophytes are carefully drilled and removed with curettes and Kerrison rongeurs to create a rectangular bed for placement of an intervertebral graft.

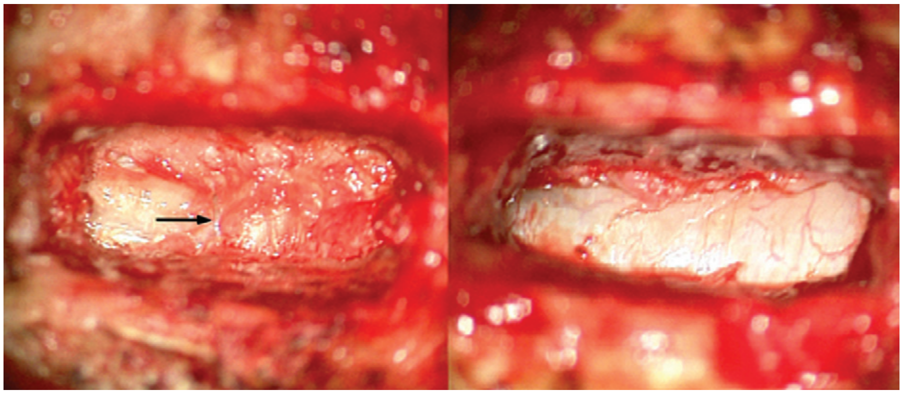

Figure 14-15 *Left,* The posterior longitudinal ligament is exposed with a small rent (*arrow*) to reveal the dura posteriorly. *Right,* The posterior longitudinal ligament is removed with Kerrison rongeurs to ensure complete decompression of the spinal canal.

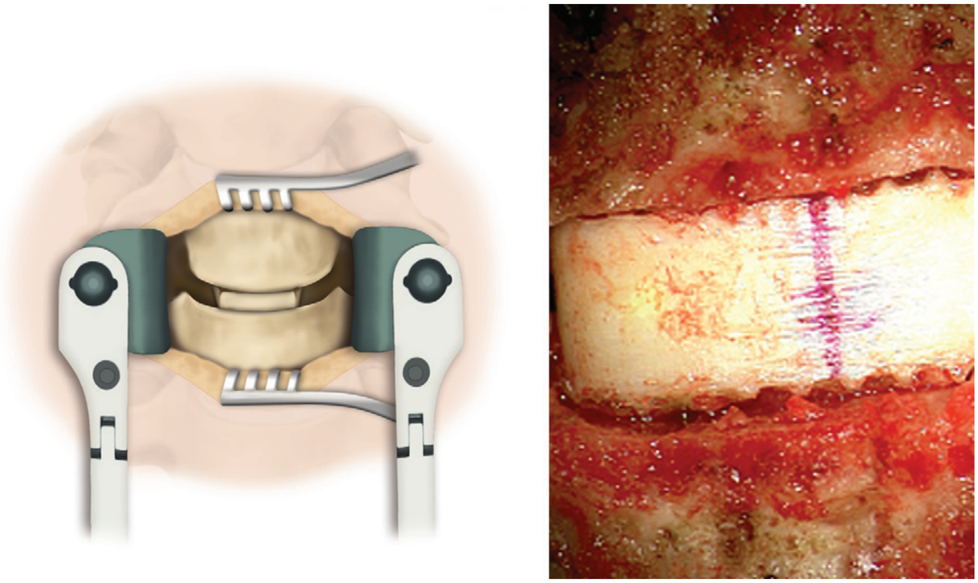

Figure 14-16 The intervertebral graft is inserted flush to the anterior vertebral surface and the superior and inferior end plates. The graft is mildly oversized to prevent graft migration and promote fusion.

CERVICAL PLATING

- The anterior vertebral margins are flattened.
- An appropriately sized plate is chosen and affixed to the rostral and caudal vertebral bodies with screws (Fig. 14-17).
- Lateral and AP radiographs may be taken to ensure proper placement of all instrumentation.

AUTOGRAFT HARVESTING

- The prepared disk space is measured.
- An 8-cm incision is made 6 cm lateral to the anterior superior iliac spine.
- The fascia lata is incised, and the muscle is dissected subperiosteally.
- Once the soft tissue is removed and sufficient iliac crest is exposed, two parallel cuts separated by the height of the prepared disk space are made perpendicular to the iliac crest. The distance between these cuts should be greater than 2 mm from the disk space to allow distraction and final tailoring. An oscillating saw is preferred over osteotomes, because the latter may cause microfractures that can compromise the load-bearing capacity of the graft.
- A third cut along the base is made with the oscillating saw to free the graft.
- The graft is measured and tailored for the disk space.
- This process is repeated for multilevel procedures.

CLOSURE

- The soft tissues are inspected, and hemostasis is achieved with cautery.
- If persistent bleeding is present, a drain may be placed in the subplatysmal layer.
- The platysma is closed with interrupted 3-0 absorbable suture.
- The skin is closed with subcuticular absorbable suture.
- The incision is cleaned and dressed in standard fashion.

Postoperative Care

- Following extubation, the patient is monitored for airway obstruction and neurologic compromise.

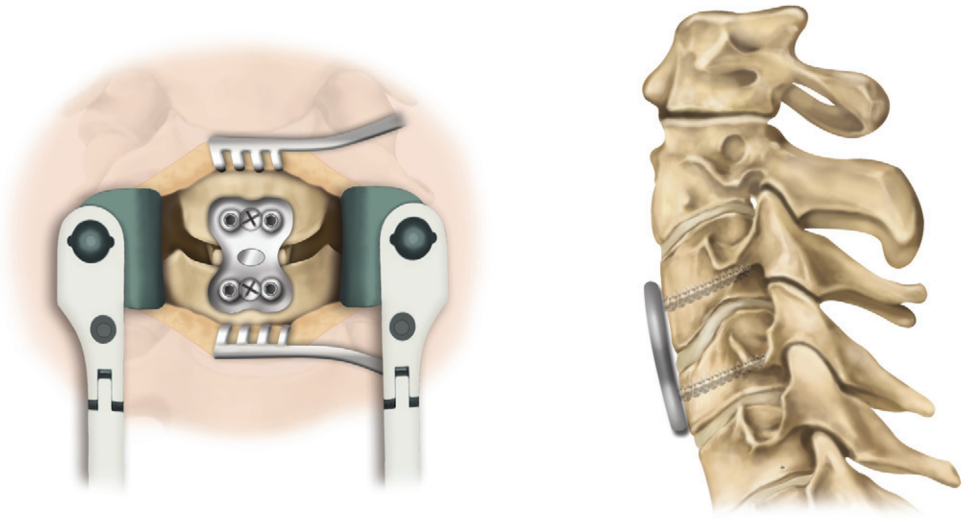

Figure 14-17 The cervical plate is in midposition, spanning the disk space evenly. The sagittal view (*left*) shows the plate is flush with the anterior vertebral surface.

- The patient may be placed in a soft or hard collar.
- A liquid diet is ordered and advanced as tolerated. Esophageal edema from retraction may require a liquid or soft diet for the first 1 to 2 days after surgery.
- Early ambulation is encouraged.
- Transient posterior cervical and shoulder pain may develop as a result of stretching of the facet capsule from the intervertebral graft.
- An oral narcotic is prescribed along with an intravenous breakthrough medication if needed. A muscle relaxant may be helpful for spasmodic discomfort.
- Patients are typically discharged the day following surgery.
- Postoperative radiographs are typically taken before discharge.

Complications

- Neurologic decompensation or new deficit may result from intraoperative cord or nerve root injury, graft migration, or epidural hematoma formation. If this is discovered, an immediate radiograph, CT scan, or MRI should be obtained to rule out a treatable etiology.
- Neurologic deficit or airway obstruction from a wound hematoma typically develops within the first 12 hours postoperatively. If a hematoma is palpable or tracheal deviation is appreciated in the setting of dyspnea, the incision should be opened immediately.
- In susceptible patients, stroke may result from carotid retraction. Proper preoperative workup should include evaluation of carotid atherosclerotic disease in select patients.
- The patient should be instructed to inspect the incision regularly for signs of wound infection.
- Delayed neurologic deterioration may indicate epidural abscess, graft dislocation, subluxation, and intervertebral collapse, which would require urgent surgical treatment.
- Postoperative fluid collection may indicate a cerebrospinal fluid (CSF) leak or esophageal injury, which would require immediate reexploration.
- Delayed swallowing difficulty may result from anterior plate dislodgment, causing esophageal obstruction.
- Hoarseness typically results from intraoperative recurrent laryngeal nerve injury. The majority of cases are transient secondary to retraction, and patients should recover within 3 to 6 months. Persistent hoarseness necessitates laryngoscopy for visualization of the vocal cords and further evaluation by an otolaryngologist.

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15 Endoscopic Anterior Cervical Foraminotomy (Jho Procedure)

HAE-DONG JHO, DIANA H. JHO, and DAVID H. JHO

Overview

The optimal surgical treatment of degenerative cervical spine disease that involves radiculopathy and/or myelopathy would be direct surgical removal of compressive pathology while preserving segmental motion. To achieve these surgical goals, anterior cervical foraminotomy techniques were developed, and these were previously reported by the senior author as the "Jho procedure."[1,2] Historically, modern surgical techniques for degenerative cervical spine disease were introduced more than a half-century ago as anterior approach (anterior cervical diskectomy) and posterior approach decompression procedures. Although anterior cervical diskectomy directly targets the compressive pathology, usually soft-disk herniation or spondylotic spurs, the approach itself involves removing structural elements important for segmental motion. In comparison, posterior decompression techniques can usually preserve segmental motion but in many cases do not remove the compressive pathology directly.

The classic anterior cervical approach involves total disk removal, often followed by bone graft fusion. Minor technical modifications have been made over the years that have included various amounts of removal of the vertebral column, various sources of bone substitutes, fusion-enhancing materials, and use of metal implants. Although anterior cervical diskectomy achieves one goal, that of directly removing compressive pathology, loss of segmental motion occurs as a result of complete disk removal at the intervertebral space performed to access the pathology. Bone graft fusion is done to fill the vacant intervertebral space, which also results in loss of segmental motion and sometimes exacerbates degenerative disease at adjacent levels. Reconstruction with spinal fusion and metal implantation is done to compensate for the removal of anatomic structures related to the surgical approach pathway of exposure; it is not because of the focal removal of compressive pathology itself. In attempts to maintain segmental motion, disk arthroplasty has been recently introduced to reconstruction after anterior cervical diskectomy. However, the value of installing a foreign device to maintain motion remains to be established.

From traditional posterior laminectomy techniques in the 1960s a classic posterior approach emerged that involves cervical laminectomy or laminoplasty, with or without posterior foraminotomies. Recently, this approach has been further refined into endoscopic or microscopic posterior foraminotomies. However, posterior approaches often provide indirect compensatory decompression but fail to achieve direct removal of compressive pathology commonly located ventral to the compressed nerve root or spinal cord. Reduction or loss of segmental motion may also occur with some posterior approaches, especially when spinal fusion is used in conjunction with laminectomies to eliminate potential exacerbating dynamic factors and/or delayed kyphotic deformities.

The Jho procedure was developed to overcome the deficits of classic anterior and posterior cervical procedures in selected patients to optimize the achievement of surgical goals. Microsurgical anterior cervical foraminotomy was first reported by H.D. Jho in 1996 under the minimally invasive concept of "functional spine surgery," in which compressive pathology is directly removed via an anterior approach, and the remaining disk and functioning motion unit is preserved without the use of implants or bone fusion.[1] The technique originally reported for anterior cervical foraminotomy involved removal of the uncovertebral juncture, the most lateral part of the intervertebral disk, to access the compressive pathology. Once the surgical access is made, the soft disk and/or bone spurs that comprise the compressive pathology are excised. This surgical approach directly addresses the compressive pathology with access via the lateral portion of the spinal column, and it results in effective preservation of the integral spinal column structures so that segmental motion remains intact, and bony fusion is not necessary.

Originally, the Jho procedure was performed under the operating microscope; hence the surgery was also called *anterior cervical microforaminotomy.*[2] Several variations of the surgical technique gradually evolved to achieve surgical goals more efficiently while minimizing surgical impact to the spinal column and functioning motion unit. Further variations on this technique evolved from the concept that the trajectory from the skin incision to the surgical target in the sagittal plane of the cervical spine directs where a bone opening should be made to access the target pathology efficiently and effectively. Thus the surgical technique became tailored, depending on the trajectory, as determined by the nature of the pathology and cervical anatomy. The following four variations of anterior cervical foraminotomy have been progressively developed: *transuncal approach,* or type 1 Jho procedure; *upper-vertebral transcorporeal approach,* or type 2 Jho procedure; *lower-vertebral transcorporeal approach,* or type 3 Jho procedure; and *anterior cervical foraminoplasty,* or type 4 Jho procedure.

In addition, the use of the operating microscope in anterior cervical microforaminotomy evolved into the utilization of a purely endoscopic technique in anterior cervical foraminotomy. Microscopic visualization has a limited view through the small bony opening because of its straight, tubular viewing access with an inwardly coning configuration. Even if the operating microscope is tilted to visualize the medial, inner aspect of the spinal canal, the view at the surgical target can be limited despite providing a three-dimensional image. An endoscope was adopted to overcome this limitation in surgical view and can provide an outwardly coning viewing configuration with a flask-shaped view that allows for wide, enhanced visualization at the surgical target region, although the image is two dimensional. In this chapter, technical aspects of anterior cervical foraminotomy are described; the term *rostral-caudal* is used interchangeably with *upper-lower* or *superior-inferior* when referencing the vertebral bodies that border the level of target pathology.

Surgical Indications for Anterior Cervical Foraminotomy (Jho Procedure)

Surgical indications are the same as those for conventional anterior cervical diskectomy or corpectomy, and patients often come in for an alternative surgical option after receiving a recommendation for conventional anterior fusion surgery or posterior approaches. However, although most conventional anterior procedures can take care of bilateral radicular symptoms, anterior foraminotomy provides decompression only at the ipsilateral nerve root and, if required, it provides spinal cord decompression further medially. The contralateral nerve root, if symptomatic, must be addressed via a contralateral approach at another time; we have not performed simultaneous bilateral approaches.

Conservative treatment for a minimum of 6 weeks was first attempted, unless profound motor weakness or significant myelopathy was evident. Initial use of anterior cervical foraminotomy was limited to cervical radiculopathy caused by soft-disk herniation or stenosis with bone spur formation. From there, application of the technique and its evolved variations were expanded to include decompression of the spinal cord for spondylotic stenosis, to treat ossification of the posterior longitudinal ligament (OPLL), for removal of extradural or intradural spinal tumors, for syringosubarachnoid shunt placement, or to address any other pathology that required an anterior approach. Because significant improvement was noted in neck pain and/or headaches with this operation, patients with neck pain and/or headaches were also operated on even if they did not have myelopathy or radiculopathy.

All patients had preoperative magnetic resonance (MR) scans, and some patients required myelocomputed tomography or simple computed tomography (CT) scans, particularly when MR scans showed surgical artifact from a previous surgery with anterior fusion and metal implant, or when MR scans were contraindicated. Occasionally, CT scans without myelogram were used as a diagnostic tool when a patient's symptoms and pathology in a CT scan would match each other well. Intraoperative somatosensory-evoked potential (SSEP) monitoring was used in all patients in the early series; but as experience has grown, the value of intraoperative SSEP or motor-evoked potential (MEP) has been questionable. Now, we do not use intraoperative monitoring in most cases, except for medicolegal considerations.

All patients were kept overnight in the hospital as a standard protocol, except for the earliest patients who received surgery on an outpatient basis and those who insisted on going home on the same day of the surgery. All patients were advised to obtain follow-up MR scans and dynamic cervical spine roentgenograms 6 weeks postoperatively.

Surgical Tools and Techniques

SURGICAL INSTRUMENTS

When microscopic surgery was performed, a slender power drill with a 2-mm diamond drill bit and various curettes were used. Once pure endoscopic surgery was adopted, endoscopic equipment and instruments were used. Surgical instruments required for this procedure include endoscopes with 0, 30, and 70 degree lenses and associated appendages, such as the light source plus a video imaging system, an endoscope lens-cleansing device, a rigid endoscope holder, and specifically designed surgical instruments that can accommodate the endoscopic environment.

Endoscopes

The endoscopes we use are rod-lens endoscopes 4 mm in diameter and 18 cm in length. One set consists of five endoscopes: one with a zero-degree lens, one with a 30 degree lens angled toward the light source, one with a 30 degree lens angled away from the light source, one with a 70 degree lens angled toward the light source, and one with a 70 degree lens angled away from the light source (Fig. 15-1). However, a zero-degree endoscope is the basic working configuration used for most applications. Because the endoscope provides a wide-angle view, the zero-degree endoscope usually provides adequate views for exposure at the nerve root and at the spinal cord. However, the 30 degree endoscope angled toward the light source can be used when a more angled view toward the spinal cord is desired, and a 30 degree endoscope angled away from the light source can be used when a more angled view toward the nerve root at the neural foramen is desired. A 70 degree endoscope is usually not necessary for this operation.

Endoscope Lens Cleanser

An endoscope lens-cleansing device is required to keep the lens clear, so the surgeon can continually operate without interruption (Fig. 15-2). The device consists of a disposable irrigation tube that passes through an electric-powered motor. The endoscope is placed through a rigid tubular irrigating sheath connected to the irrigating tube, and the irrigation tube is connected to a saline bag hung on a pole. This motor-powered irrigation device is controlled by a foot pedal to flush saline forward. When the foot pedal is released, the motor reverses its rotary direction and draws the saline back from the tip of the endoscope for 1 to 2 seconds. The forward flow of irrigating saline cleans the lens, and the

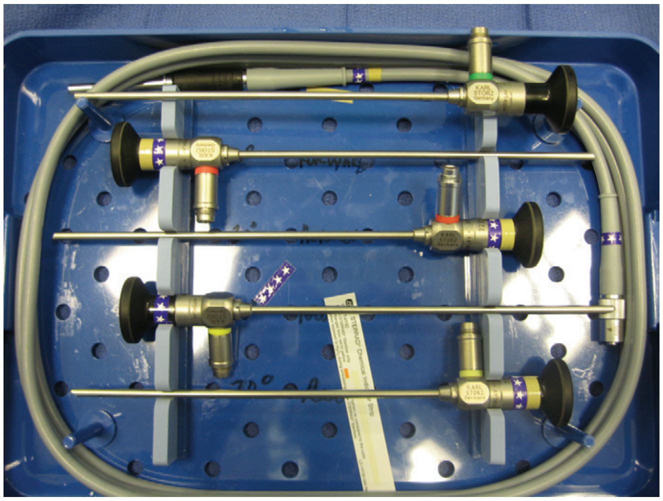

Figure 15-1 The endoscopes we use are 18-cm rod-lens endoscopes that are 4 mm in diameter. One set consists of five endoscopes with different lenses: a sero-degree endoscope, a 30-degree lens angled toward the light source, a 30-degree lens angled away from the light source, a 70-degree lens angled toward the light source, and a 70-degree lens angled away from the light source. The use of a 0-degree endoscope alone is usually sufficient for this operation.

reverse flow clears away water drops at the tip of the endoscope. Although this device is not yet ideal, it helps the surgeon significantly in the task of keeping the endoscope lens clean without removal of the endoscope from the surgical site.

Endoscope Holder

An appropriate endoscope holder is another piece of essential equipment required to perform this operation bimanually. An endoscope holder is mounted to the operating table not only to provide steady video imaging on a video monitor but also to allow the surgeon to use both hands freely, similar to microscopic surgery. The holder must provide rigid fixation of the endoscope, and its holding terminal must be compact and slender to render adequate operating space around the endoscope shaft for the surgeon to maneuver surgical instruments.

Two types of endoscope holders are currently available, but both are not yet ideal. One is a simple manual holder with multiple joints that can be tightened by hand; the other is a holder with joints powered by nitrogen gas and controlled with a single button. Manual holders are inconvenient to maneuver with releasing, repositioning, and tightening; they also have limitations in flexibility for reaching certain positions. Nitrogen gas–powered devices are more expedient than manual types but are not as smooth as the operating microscope in releasing and locking at various positions. Currently, we use an Aesculap holder for spine applications (Fig. 15-3). We prefer to use the Aesculap holder for spine endoscopy, but holding terminals are not yet ideal for endoscopic spine surgery. We modified the holding terminal to make it more slender and compact. Sagging of a few millimeters after release of the power button is another suboptimal feature of the Nitrogen-powered holders. The power button must be released with the expectation of a few millimeters of sagging and shifting at the endoscope tip.

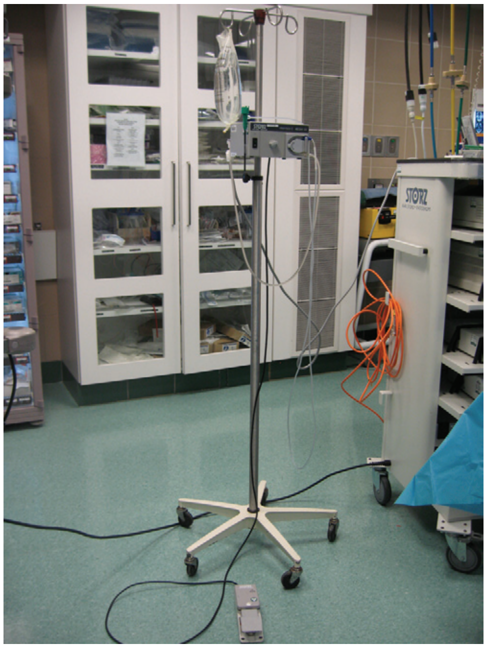

Figure 15-2 Endoscope lens cleanser. This device consists of a disposable irrigation tube that passes through an electric-powered motor. The endoscope is placed through a rigid tubular irrigating sheath connected to the irrigating tube, which is connected to a saline bag hung on a pole. This motor-powered irrigation device is controlled by a foot pedal to flush saline forward. When the foot pedal is released, the motor reverses its rotary direction and draws the saline back from the endoscope tip for 1 to 2 seconds. The forward flow of irrigating saline cleans the lens; the reverse flow clears away residual water drops at the tip of the endoscope.

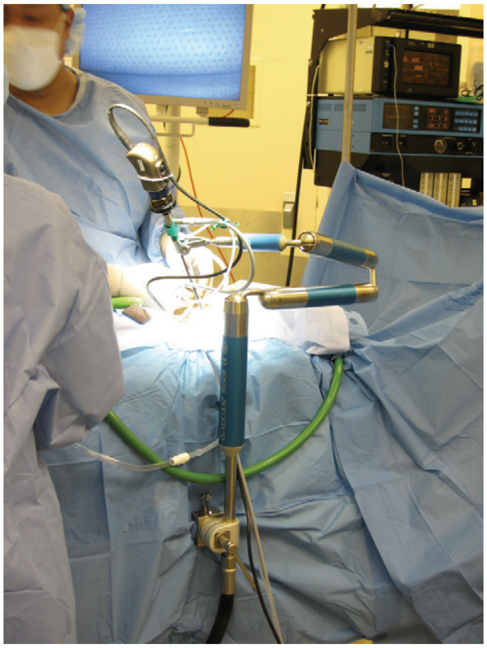

Figure 15-3 Endoscope holder. Currently, we use an Aesculap holder for spine applications. This nitrogen gas–powered device is controlled with a push button at the holding terminal. Despite a few millimeters of sagging after release of the power button, this device provides steady fixation of the endoscope for stable video imaging, and it allows a surgeon to use both hands.

Endoscopic Surgical Instruments

Because the region of bone removal in anterior cervical foraminotomy requires high precision, a fine drilling device is required. We use a Midas telescoping tubular drill with a 2-mm diamond bit. The drill bit tip can be progressively extended as the depth of drilling advances. Other commercial drill products that have comparable systems also are available. Although an ultrasonic bone cutter is available commercially, we have not actually used it in this procedure; we are concerned with the possibility of impaired endoscopic view from the mist of continual irrigation spray. Bipolar forceps are shaped to accommodate the endoscopic surgical environment, and the blades of the bipolar forceps are parallel to each other, similar to a single-bladed instrument, once the forceps are approximated. Various surgical curettes and other endoscopic instruments were customized and developed to function efficiently within the uniquely curved endoscopic surgical trajectory.

Surgical Technique

Most of the equipment and instruments are similar to those used in conventional cervical spine surgery. Operation was performed under the operating microscope in earlier cases, but it has since evolved to pure endoscopic surgery. A thin-bladed cervical retractor system is used to keep the split longus colli muscle apart to expose the uncovertebral juncture.

POSITIONING

All operations were performed under general endotracheal anesthesia. In the past, when SSEP was used, baseline SSEP waveforms were obtained before positioning the head, and these were continuously followed until the end of surgery. Now, we usually do not use intraoperative SSEP or MEP. Patient positioning is similar to that for conventional anterior diskectomy, keeping the head straight (without turning) and the neck neutral (without extension). Gentle neck extension with a small bolster under the shoulders may be done only if sufficient spinal canal is demonstrated on MR scans to provide room for the spinal cord. Caution during neck positioning is important to prevent position-induced injury to the spinal cord, especially if patients experience exaggerated symptoms by neck extension preoperatively, or when severe spinal cord compression is noted in MR scans. Cervical traction devices are not used. Significantly obese patients with short, thick necks may require 2-inch adhesive tape for application of gentle skin traction at the chin superiorly and at the anterior chest wall inferiorly.

SURGICAL EXPOSURE OF THE UNCOVERTEBRAL JUNCTURE

The skin incision site is judged by finger palpation of the C6 transverse tubercle, which is typically palpable just medial to the sternocleidomastoid (SCM) muscle. The surgical target area related to the mandibular angle and larynx is reviewed in reference to MR scans of the cervical spine along with the location of the vertebral arteries, being mindful of anatomic variants. The skin incision starts 1 or 2 cm laterally from the midline and extends laterally across the medial margin of the SCM muscle for approximately 3 to 5 cm in total length. Although the center of surgical exposure is usually 3 to 4 cm lateral from the midline, it must be adjusted to the size of the neck. Patients with large necks require a longer skin incision to maintain a 20 degree lateral-to-medial trajectory angle toward the surgical target.

At the anterior portion of the cervical spine, the surgical target anatomy is the uncovertebral juncture covered by the longus colli muscle. Picturing this in axial view, the surgical trajectory angle is determined by an extension line from the very medial margin of the inlet neural foramen to that of the outlet. When this line is extended toward the skin, it is the key exposure point of the skin. The platysma may be split longitudinally along the direction of the muscle fibers or, alternatively, it may be cut parallel to the skin incision.

The medial border of the SCM must then be defined, with clean dissection carried down to the prevertebral fascia just medial to the SCM. The carotid artery on the working side is identified with finger palpation, and a Meyerding retractor is placed just medial to the carotid artery. The tracheoesophageal structure is slightly and gently displaced medially and held with the Meyerding retractor, although not as much exposure of the anterior cervical column is needed as in conventional anterior cervical diskectomy. The perimeter of exposure at the lateral portion of the cervical column is just over the longus colli muscle.

For upper cervical spine surgery, an intraoperative radiograph is obtained to corroborate the correct level of surgery. However, for lower cervical spine surgery, finger palpation of the surgical anatomy at the anterior column of the cervical spine and C6 transverse tubercle is often sufficient for the identification of the correct level of surgery, although a confirmatory radiograph may still be done.

By palpating the transverse tubercles, the extent of the longus colli is identified. The longus colli is split just medial to the transverse tubercles rostral and caudal to the intervertebral disk level, being careful to avoid injury to the sympathetic trunk and to fibers located laterally along the longus colli. A cervical retractor system is applied between the split longus colli muscle fibers to maintain exposure of the uncovertebral juncture. The original description mentioned sectioning of the medial part of the longus colli muscle, but this soon evolved to splitting the longus colli muscle to allow its preservation.

At this point, an endoscope is brought into the surgical site, and the vertebral artery is defined just lateral to the uncinate process under endoscopic visualization. The vertebral artery pulsation is easily visible lateral to the uncinate process, and the proximal transverse processes of the rostral and caudal vertebrae are then defined. Because the surgical site is small, the close-up panoramic endoscopic view often improves surgical visualization compared with the operating microscope.

ORIGINAL DESCRIPTION OF MICROSURGICAL ANTERIOR CERVICAL FORAMINOTOMY

As previously mentioned, the original technique for microsurgical anterior cervical foraminotomy was reported as a new approach for cervical disk herniation in 1996.[3] In the original description, the lateral 5- to 8-mm portion of the uncovertebral juncture was drilled and removed, which eventually evolved into less bone removal. The vertical dimensions of bone removal originally extended from the inferior margin of the rostral vertebra's medial transverse process to the superior margin of the caudal vertebra's medial transverse process, usually measuring 7 to 10 mm in total length. Bone removal is performed using a 2 mm cutting bit in a slender high-speed drill. The intervertebral disk is kept largely intact, and opening of the posterior longitudinal ligament (PLL) is sometimes done to confirm an adequate decompression from the lateral portion of the spinal cord to the nerve exit behind the vertebral artery. It is possible for venous bleeding to be cumbersome while the PLL is open. Once adequate decompression is accomplished, the platysma and subcutaneous tissue are closed with 3-0 absorbable sutures. The surgical incision site is infiltrated with a local anesthetic, and skin is closed with absorbable stitches or adhesive glue.

The original technique involved the removal of a few millimeters of width of the most lateral portion of the uncovertebral juncture in a medial-to-lateral direction as a surgical conduit to the compressive pathology. However, this technique was soon modified, because the end result of bony removal often became more superfluous than required, and concern for potential vertebral artery injury frequently made the start of bone removal farther medial than truly necessary. In addition, bone opening at the uncovertebral juncture did not always produce an optimal access to the target pathology, depending on the surgical trajectory from the skin incision. Technical refinements into four major subtypes of anterior cervical foraminotomy followed. In addition, the use of the operating microscope was changed to the use of an endoscope to maximize the visualization through a tiny bony opening.

EVOLUTION OF ANTERIOR CERVICAL FORAMINOTOMY (JHO PROCEDURE)

Type 1: Transuncal Approach

When the surgical trajectory from the skin incision to the target pathology is perpendicular to the sagittal plane of the cervical spine, a bone opening at the anterolateral spine should be made along this trajectory line. Particularly for C4–C5 or C5–C6 operations, a routine skin incision at the upper or middle portion of the neck will produce such a perpendicular surgical trajectory. In this case, the uncinate process lies directly along the perpendicular surgical trajectory (Fig. 15-4, *A*).

The skin incision to the point of bone exposure is similar to the general description of the anterior cervical foraminotomy approach. The most medial portions of the transverse processes of both upper and lower vertebrae are identified and exposed. Often the pulsation of the vertebral artery is notable between the two transverse processes. The vertebral artery is dissected off laterally from the lateral portion of the uncinate process. Because the uncinate process often protrudes laterally far beyond the line drawn between the medial margin of the upper and lower transverse foramina, the most lateral extent of the uncinate has to be well defined in relation to the vertebral artery. The periostium of the uncinate is kept at the vertebral artery side for extra protection of the vertebral artery. Then, the most lateral 2-mm portion of the uncinate is drilled just medial to the vertebral artery toward the PLL (see Fig. 15-4, *B*).

The compressing pathology has to be exposed rostrally from the normal margin of the rostral vertebra and caudally to the normal margin of the caudal vertebra. The caudal-to-rostral exposure must be performed in reference to the end plates of the caudal and rostral vertebrae along with the intervertebral disk space posteriorly. The vertical extent of bone removal is usually about 5 mm in length. Because of the natural lateral-to-medial incline of a surgical trajectory from the surgeon's standing at the side of the patient, the surgical trajectory will slightly incline medially when bone drilling advances toward the spinal canal. Drilling must therefore be maintained laterally, initially leaving a very thin rim of cortical bone on the nerve root and vertebral artery.

Once the PLL is exposed posteriorly, the thin layer of uncinate cortical bone that was left attached at the nerve root is dissected and removed. Additional compressing pathologies, such as herniated soft disk and/or bone spurs, are then removed off the nerve root and lateral portion of the spinal cord. Often the PLL is opened to expose the dura mater at the most lateral portion of the spinal cord and proximal nerve root to detect any hidden migrated disk fragments. When the PLL is opened, the ligament should be opened medially in front of the spinal cord, because the epidural vein is located at the junction between the nerve root and the spinal cord. Copious epidural bleeding can occur when the PLL is opened laterally.

Herniated disk fragments or bone spurs are removed with variously curved curettes (see Fig. 15-4, *C* through *G*). Awareness is necessary to avoid damaging the thin bony wall of the medial uncinate to maintain the integrity of the intervertebral disk. When spinal cord decompression is required, a specially designed curette system is used to achieve further medial decompression by undercutting the compressive pathology posterior to the rostral and caudal vertebral bodies. Surgical closure is made using the aforementioned techniques.

Type 2: Upper Vertebral Transcorporeal Approach

The term *upper vertebral transcorporeal approach* refers to the location of the bone opening at the lateral portion of the upper vertebra to the intervertebral disk. This technique involves creating a bone opening at the inferolateral portion of the upper vertebra when the anterior–posterior (AP) surgical trajectory inclines caudally (Fig. 15-5, *A*). This approach is most often used in C6–C7 or C7–T1 surgery but is also commonly used with other levels, when the skin incision is made purposefully cephalad.

When the vertebral artery is known to enter at the C6 transverse foramen on preoperative MR scans, intraoperative radiography is not necessary for C6–C7 or C7–T1 surgery, because the vertebral artery entrance into the C6 transverse foramen is visible at the time of surgery. The vertebral artery is exposed with removal of a 2-mm medial portion of the transverse process at the upper vertebra. Bone opening is then made at the inferolateral 2- to 3-mm

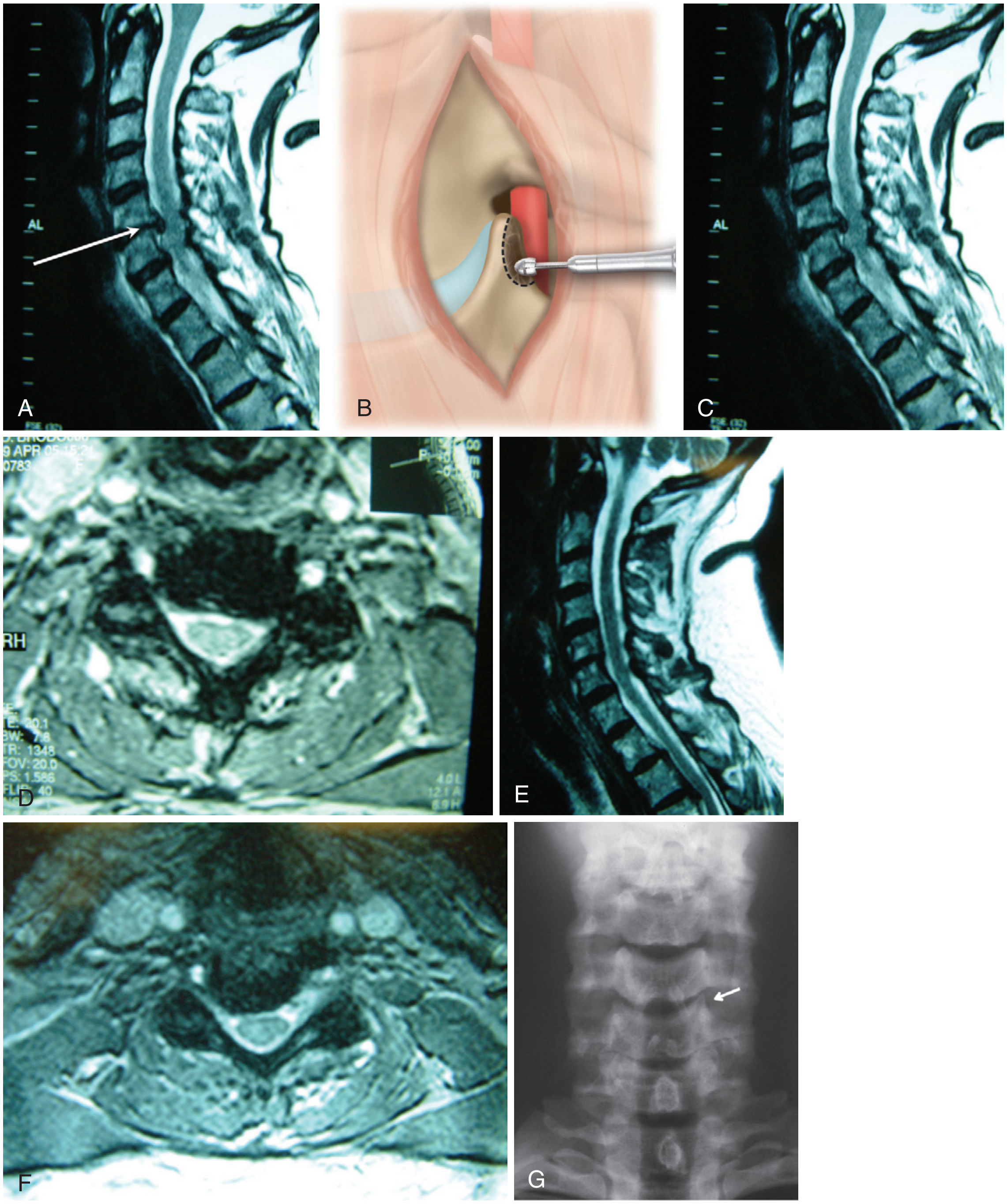

Figure 15-4 Transuncal approach: Jho procedure type 1. **A,** The surgical trajectory from the skin incision to the target pathology must be perpendicular to the longitudinal axis of the spine for this technique. **B,** Schematic illustrates the transuncal approach from the left side: the medial portion of the upper and lower transverse process and the vertebral artery are defined; the lateral 2-mm portion of the uncinate process (*dotted area*) is drilled toward the posterior longitudinal ligament. Preoperative magnetic resonance (MR) scans, T2-weighted sagittal (**C**) and axial views (**D**), show bone spur compressive pathology at the left-sided spinal cord canal and neural foramen at C5–C6. MR scans taken 6 weeks postoperatively; T2-weighted sagittal (**E**) and axial views (**F**) confirm good decompression at the spinal cord and left-sided C6 nerve root. **G,** Anteroposterior view of cervical spine radiograph shows bone opening at the lateral margin of the left-sided uncinate process (*arrow*).

portion of the upper vertebra with drilling toward the PLL (see Fig. 15-5, *B*). The surgical trajectory is directed toward the pathologic target through only the most posterior portion of the intervertebral end plate (see Fig. 15-5, *C* through *G*). Damage to the intervertebral end plate at the anterior two thirds of the intervertebral disk must be avoided.

The C7 nerve root tends to have a wide angle from the spinal cord, where it runs toward the outlet of the neural foramen. Thus the bone drilling has to be inclined a bit farther medially as it advances than for C5–C6 or C4–C5 surgery to prevent nerve root damage at the proximal nerve root area. Once the target area is exposed, the rest of the procedure is the same as described for other approaches.

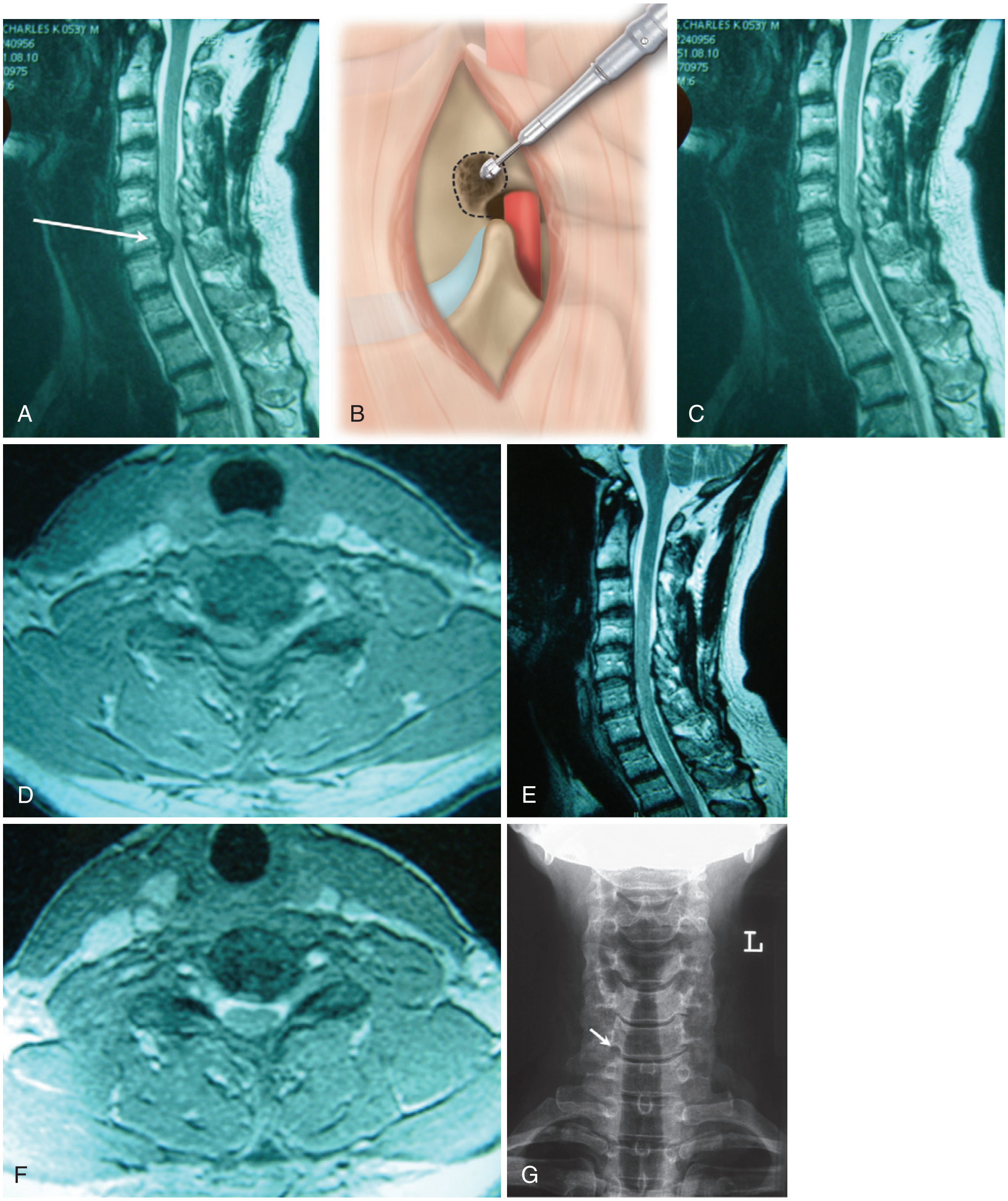

Figure 15-5 Upper vertebral transcorporeal approach: Jho procedure type 2. **A,** Anteroposterior (AP) surgical trajectory from the skin incision to the target pathology inclines caudally in this technique. **B,** Drawing shows bone opening at the lateral 2-mm portion of the inferolateral upper vertebra (*dotted area*) for a left-sided surgery; while drilling advances posteriorly, the anterior two thirds of the end plate should not be damaged. T2-weighted sagittal (**C**) and axial (**D**) magnetic resonance (MR) scans demonstrate ruptured disk herniation at the right-sided C6–C7 spinal canal. T2-weighted sagittal (**E**) and axial (**F**) MR scans taken 6 weeks postoperatively show good decompression of the right-sided C7 nerve root and spinal cord. **G,** AP view of the cervical spine radiograph demonstrates bone opening at the right-sided lateral inferior C6 vertebral body (*arrow*).

Type 3: Lower Vertebral Transcorporeal Approach

The term *lower vertebral transcorporeal approach* refers to the location of the bone opening at the lateral portion of the lower vertebra to the intervertebral disk. For a C3–C4 operation, or when a skin incision is made inadvertently more caudal than it should be at any cervical disk level, this technique is required. Because the surgical trajectory from the skin incision to the surgical target inclines cephalad, the bone opening must be made caudal to the surgical target (Fig. 15-6, *A*).

First, the medial portions of the transverse processes at the rostral and caudal vertebrae are identified. The superomedial portion of the transverse process at the lower

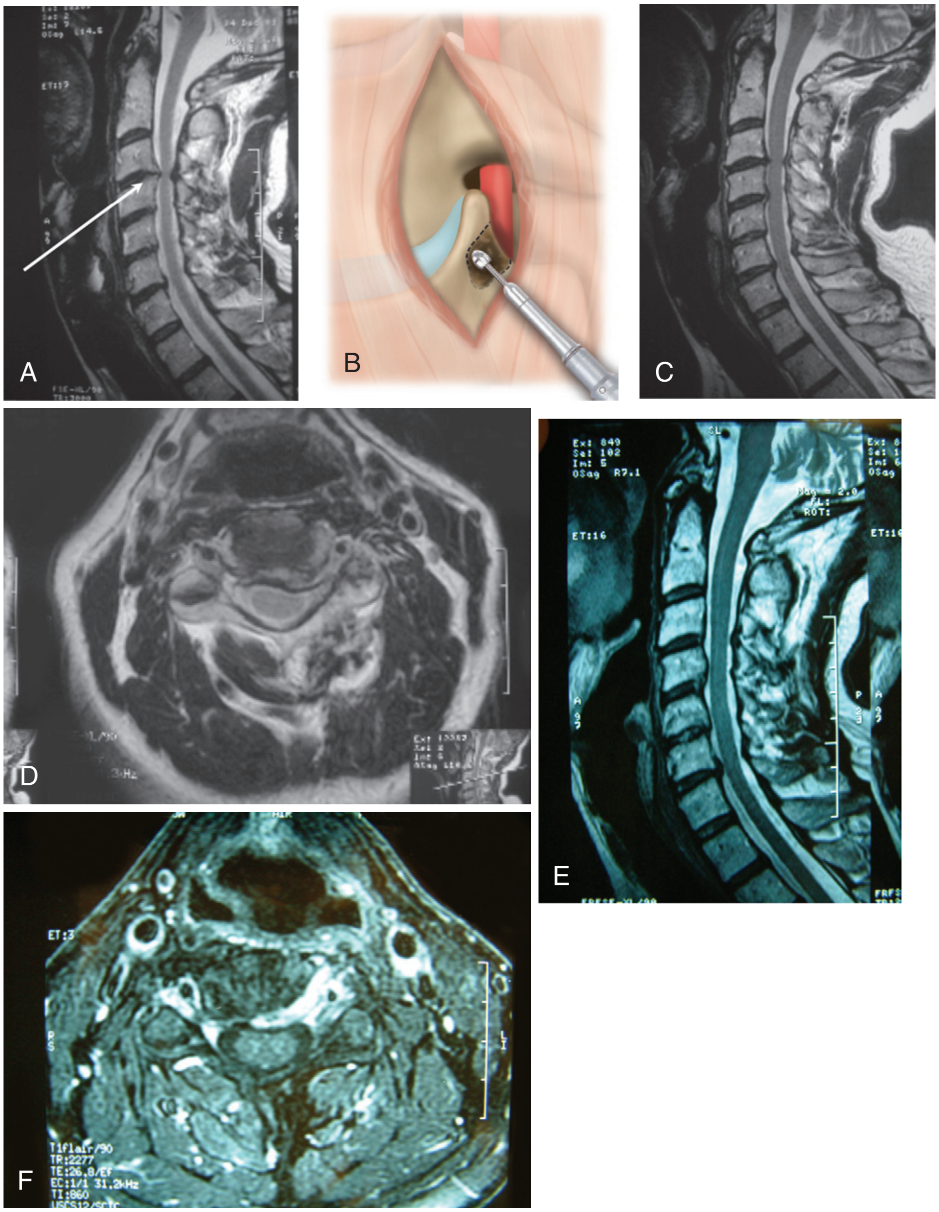

Figure 15-6 Lower vertebral transcorporeal approach: Jho procedure type 3. **A,** Anteroposterior (AP) surgical trajectory from the skin incision to the surgical target pathology makes a cephalad incline as demonstrated in a preoperative T2-weighted sagittal magnetic resonance (MR) view of a patient with left-sided C3–C4 stenosis. **B,** Schematic demonstrates the lower vertebral transcorporeal approach from the left side. The lateral 2-mm portion of the superolateral part of the lower vertebra or the base of the uncinate process (*dotted area*) is drilled toward the posterior longitudinal ligament. This technique is used when a foraminotomy is performed at a high cervical disk, such as at C3–C4. Thus the bone opening must be made at the lower vertebra to reach the target along the surgical trajectory. Preoperative MR scans, T2-weighted sagittal (**C**) and axial views (**D**), reveal C3–C4 and C4–C5 stenosis. Similar techniques can be used if a skin incision is made inadvertently caudal for surgery at other cervical levels. T2-weighted sagittal view (**E**) and T1-weighed contrasted axial view (**F**) MR scans taken 6 weeks after left-sided C3–C4 and C4–C5 anterior foraminotomy demonstrate good surgical decompression.

vertebra and the vertebral artery are identified. Just medial to the vertebral artery, the superolateral 2-mm wide portion of the lower vertebra is drilled away posteriorly using a 2-mm diamond drill bit (see Fig. 15-6, *B*). The total vertical dimension of bone removal is approximately 5 mm in length. A cephalad-directed surgical trajectory will lead the drilling posteriorly toward the target. In other words, a superior-posterior surgical trajectory from a bone opening at the rostral aspect of the lower vertebral body leads to the compressing pathology at the intervertebral disk while preserving the uncovertebral juncture at the ventral part of the cervical spine. Microdissectors and various curved-up curettes are used to remove compressing herniated soft disks or bone spurs. The nerve root and the most lateral portion of the spinal cord are released from compression (see Fig. 15-6, *C* through *F*).

The amount of bone removal posteriorly must be tailored depending on the extent of pathology. As drilling is advanced posteriorly, the surgical reference points include the end plate of the lower vertebra, followed by the intervertebral disk space and the end plate of the upper vertebra at the area of target pathology. The PLL is first exposed at the uncompressed portion just caudal to the compressing pathology; then it is exposed rostral to the compressing pathology. Drilling must be done with caution at the lateral portion, where the nerve root is located.

The thin cortical bone covering the nerve root is dissected and removed, followed by lifting the compressing pathology away from the PLL and removing it. The PLL can be opened medially with a microdissector and excised laterally, except when the MR scans do not suggest soft-disk herniation and the PLL fails to show any defect, in which case the PLL can be kept intact. As previously mentioned, removal of the PLL laterally can cause cumbersome epidural bleeding, because the epidural veins run between the two layers of the PLL at the lateral spinal cord canal.

When the PLL is opened longitudinally with a microdissector, the glistening white dura mater will be visualized. After the spinal cord dura mater is identified, the PLL can be excised. When spinal cord decompression is required, the compressing pathology is removed further medially along the posterior margin of the rostral and caudal vertebrae.

Type 4: Anterior Cervical Foraminoplasty

Sometimes the compressive pathology continues along the entire medial wall of the narrowed neural foramen, such as when spondylotic bone spur formation extends from the inlet, where the nerve originates from the spinal cord, to the outlet, where the nerve exits posterior to the vertebral artery. In this case, the nerve foramen must be enlarged along its entire longitudinal axis; the term *foraminoplasty* describes this procedure of remodeling the neural foramen to its larger normal shape by elimination of medial bone spurs along the longitudinal axis of the neural foramen. Because the compressive pathology usually exists at the medial wall of the neural foramen, an anterior approach toward the medial wall is most suitable for effectively eliminating the compressive pathology.

The 2 mm medial portion of the transverse process at the vertebral artery foramen is removed at both the upper and lower vertebrae. Then, the inferolateral portion of the upper vertebra, superolateral portion of the lower vertebra, and lateral 2-mm portion of the uncinate process are drilled toward the PLL (Fig. 15-7, *A*). Drilling has to be directed along the nerve passage from pedicle to pedicle to have complete decompression in the vertical dimension.

After the PLL is exposed, posterior bone spurs are excised in front of the lateral spinal cord. If spinal cord decompression is required, bone spurs anterior to the spinal cord are excised through a foraminoplasty hole. The PLL is excised, and the dura mater is exposed from pedicle to pedicle. Sometimes it is necessary to shave the superior portion of the pedicle of the caudal vertebra when the vertical dimension of the neural foramen is excessively narrowed, which is relatively common in elderly patients. For example, Figure 15-7 shows an 89-year-old man who developed left-sided C7 radiculopathy. A preoperative CT scan in axial view reveals severe neural foraminal stenosis along the entire longitudinal axis of the neural foramen (see Fig. 15-7, *B*). A left-sided C6–C7 foraminoplasty was performed. The postoperative CT scan in axial view demonstrates enlargement of the left-sided neural foramen (see Fig. 15-7, *C*).

SPINAL CORD DECOMPRESSION VIA ANTERIOR CERVICAL FORAMINOTOMY

Originally, the anterior cervical foraminotomy was developed for nerve root decompression by removing either herniated soft-disk material or spondylotic bone spurs. However, it naturally advanced to spinal cord decompression as well, because compressive pathology often extends to the spinal cord canal in addition to nerve root compression, even if patients have radicular symptoms only. For those patients, spinal cord decompression is also performed in addition to nerve root decompression, because the surgical access is already made to the pathology by an anterior foraminotomy. Compressive pathology at the neural foramen is somewhat cephalad to that on the spinal cord. This has to be kept in mind when the spinal cord decompression is required through one of the anterior foraminotomy techniques. Although the foraminoplasty technique is often used when spinal cord decompression is the main part of the operation,

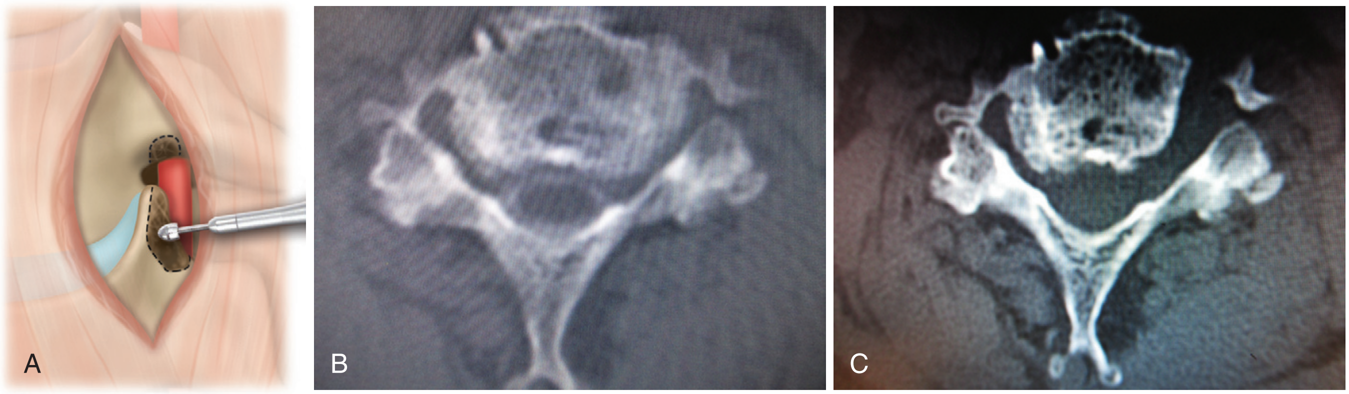

Figure 15-7 Foraminoplasty approach: Jho procedure type 4. **A,** Anterior cervical foraminoplasty schematic. The vertebral artery is defined by removal of a 2-mm portion of the transverse processes at the upper and lower vertebrae. This technique is used for spondylotic foraminal stenosis. The bone spurs along the medial wall of the neural foramen along the longitudinal axis of the neural foramen are trimmed with a high-speed drill. **B,** Preoperative axial computed tomographic (CT) scan of an 89-year-old man with left-sided C7 radiculopathy shows foraminal stenosis from the inlet to outlet of the neural foramen. **C,** Postoperative axial CT scan demonstrates enlarged left-sided neural foramen at C6–C7.

aforementioned various anterior foraminotomy techniques can be used depending on the location of the surgical pathology.

The 58-year-old man shown in Figure 15-8 developed a transient quadriplegia for about 20 minutes after an spine showed multilevel cervical stenosis; the C5–C6 level stenosis was most severe, with signal changes in the spinal cord (Fig. 15-8, *A* and *B*). CT scans of the cervical spine showed severe stenosis with bone spur formation (Fig. 15-8, *C* and *D*), and the patient underwent a left-sided C5–C6 anterior foraminoplasty (Jho procedure, type 4) for spinal cord decompression. Postoperative CT scans of the cervical spine taken on the day of surgery revealed good spinal cord decompression at C5–C6 (Fig. 15-8, *E* and *F*). Postoperative CT scan, coronal view (Fig. 15-8, *G*), showed a surgical entry area at the lateral aspect of the left-sided C5–C6 when compared with one preoperatively (Fig. 15-8, *H*). T2-weighted sagittal and axial MR scans of the cervical spine taken approximately 6 weeks postoperatively demonstrated good spinal cord decompression at the C5–C6 level (Fig. 15-8, *I* and *J*). The patient did well postoperatively.

These anterior foraminotomy techniques can also be used for spinal tumor surgery, such as for a meningioma located anterior to the spinal cord or a neurofibroma located intradurally and/or extradurally as a dumbbell-shaped

Figure 15-8 T2-weighted sagittal (**A**) and axial (**B**) magnetic resonance (MR) scans reveal severe stenosis with a signal change in the spinal cord at C5–C6. Sagittal (**C**) and axial (**D**) computed tomographic (CT) views also demonstrate severe stenosis with spondylotic bone spurs. Postoperative CT scans, sagittal (**E**) and axial (**F**) views, show good decompression at the spinal canal. **G,** Postoperative coronal view CT scan demonstrates surgical entry at the left-sided lateral aspect of C5–C6 (*arrows*). **H,** Compare with a preoperative scan. Postoperative T2-weighted sagittal (**I**) and axial (**J**) MR scans depict good decompression at the C5–C6 level.

tumor. Multilevel spinal cord decompression for ossification of the PLL or severe spondylotic stenosis also is performed with these anterior foraminotomy techniques. In earlier cases, multilevel surgery was performed on as many levels as pathology would extend (Fig. 15-9, *A* through *D*). However, this has been refined to multistage operations, generally to address two levels at a time with each stage of surgery. Surgical closure is the same as previously described.

Postoperative Management

Postoperatively, all patients are now kept overnight in the hospital as standard protocol; the earliest described patients received outpatient surgery, and some patients insisted on going home on the same day of surgery. Postoperative pain is relatively minor with this approach, and most patients are prescribed oral narcotic analgesics, although some decline to take them. Patients are allowed to resume normal routine activities immediately following surgery; a cervical collar is not necessary, nor should one be used. The surgical wound is exposed to air right after surgery when adhesive glue is used on the skin; it is exposed the following day when subcuticular sutures and a bandage are applied, and exercise and showering are allowed the following day. Although light exercise is encouraged right after surgery, contact sports activities and heavy weightlifting are delayed for 4 to 6 weeks. Return to office-type work is allowed within a few days, but return to physically laborious jobs is delayed for 4 to 6 weeks. All patients should have postoperative contrast-enhanced MR scans and dynamic radiographs 6 weeks postoperatively as a routine protocol.

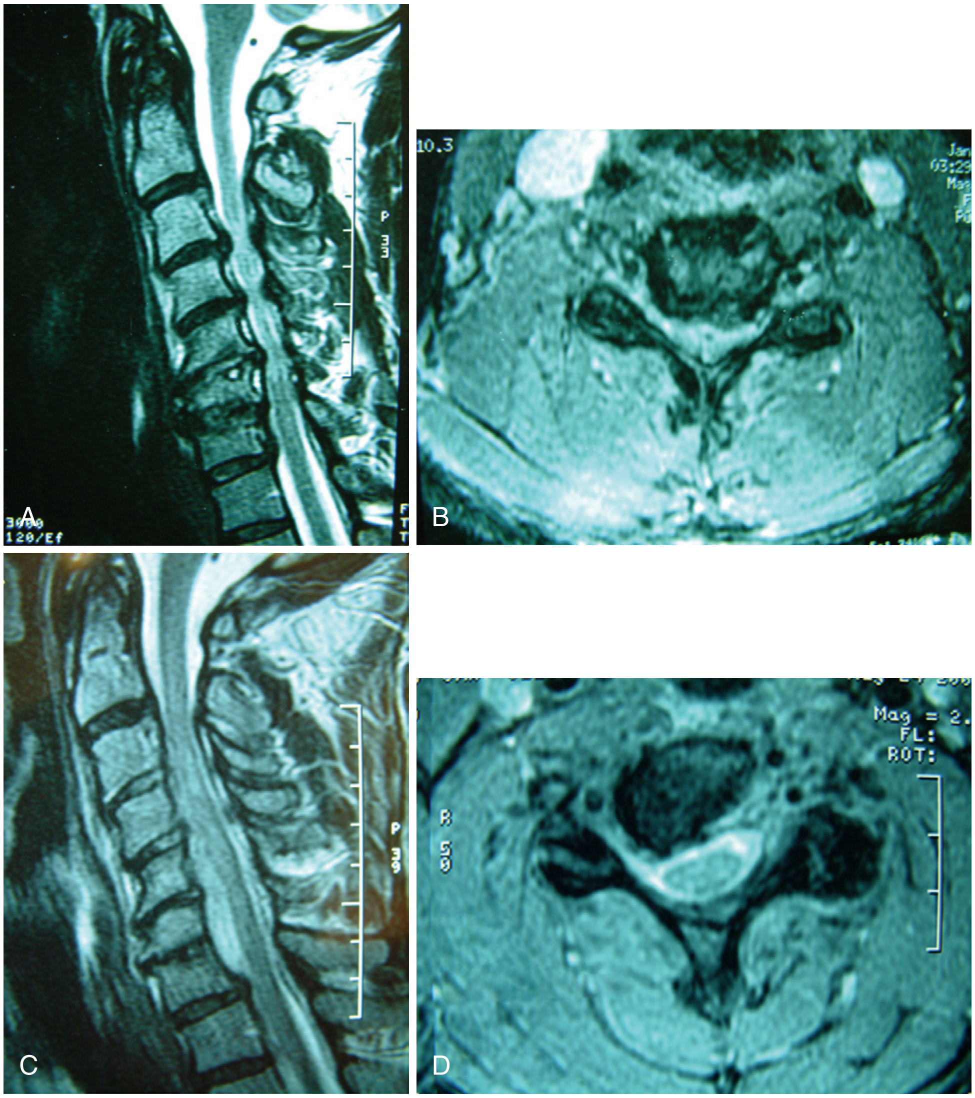

Figure 15-9 This 48-year-old man with severe myelopathy underwent left-sided multilevel anterior foraminotomy and spinal cord decompression from C3 through C7. T2-weighted sagittal (**A**) and axial (**B**) view magnetic resonance (MR) scans show severe spinal cord compression at multiple levels from C3 through C7. Axial view is at the level of C5–C6. Postoperative MR scans, T2-weighted sagittal (**C**) and axial (**D**) views, demonstrate good decompression from C3 through C7.

Surgical Results

We previously reported our series of 104 patients who met the following study criteria: unilateral cervical radiculopathy that had not responded to conservative treatment after at least 6 weeks, or at least 4 weeks if patients exhibited profound motor weakness; imaging studies that confirm pathoanatomic features corresponding to the clinical symptoms; no previous cervical spine surgery; and no significant spondylotic stenosis causing spinal cord compression. Of these 104 patients, 45 were men, and 59 were women; ages ranged from 26 to 74 years with the median age being 46 years. Compressive pathology was spondylotic spurs in 44 patients (42.3%), soft-disk herniation in 54 patients (51.9%), and a combination of the two in 6 patients (5.8%). The duration of symptoms ranged from 4 weeks to 156 months (mean 17.6 months), and follow-up periods ranged from 12 to 86 months (median 36 months). In addition to radiculopathy, preoperative symptoms included severe neck pain in 83 patients (79.8%) and significant occipital head pain in 11 patients (10.6%). Surgical results were graded: "excellent" meant that the patient exhibited complete resolution of all symptoms; "good" indicated that the patient experienced relief of radiculopathy but still experienced occasional minimal to mild residual, nonradicular discomfort; "fair" meant that the patient exhibited mild residual radiculopathy with or without mild to moderate residual, nonradicular discomfort; and "poor" meant that the patient continued to exhibit significant radicular symptoms with or without nonradicular discomfort, and it included those whose symptoms were unchanged from or worse than the preoperative condition. Among 104 patients, 83 (79.8%) demonstrated excellent results, 20 (19.2%) showed good results, and 1 (1%) experienced a fair outcome. No patient had a poor outcome, and none were unchanged or worse. One patient developed diskitis, which resulted in spontaneous fusion at the operated level following antibiotic treatment; his radiculopathy resolved well. One patient developed transient position-related hemiparesis, which resolved in 6 weeks, and two developed transient Horner syndrome, which resolved in 6 weeks.[4]

Discussion

Although variations in surgical trajectories to the cervical spine, such as lateral approaches, have been reported, the notion of diskectomy with bone fusion was retained.[3,5-7] By adhering to this idea, conventional anterior cervical disk surgery evolved over a half century into complete removal of the intervertebral disk with bone graft fusion and metal implant.[8] The more recent methods using arthroplasty with artificial disks attempt to reestablish the motion segment but still rely on complete diskectomy, although the superiority and validity of an artificial disk implant over conventional spinal fusion surgery remain to be proven.

The original description of anterior cervical foraminotomy involved not only new surgical techniques that use access via an anterolateral route through the uncovertebral juncture but also introduced the novel concept of functional spine surgery,[1] the goal of which entails preservation of the motion unit while achieving direct removal of the compressive pathology. The original description involved removal of the most lateral 5-mm portion of the uncovertebral juncture as a surgical access to the compressive pathology, followed by wide decompression of the nerve root from its origin at the spinal cord to its exit posterior to the vertebral artery. Then the subsequent evolution of our surgical techniques was reported.[2,4,9-17]

Generally, the intervertebral disks of the cervical spine in the sagittal plane incline cephalad from an anterior-to-posterior direction; therefore the surgical approach involved in the originally described foraminotomy usually arrives at the superior portion of the pedicle and inferior portion of the surgical target. To compensate for this, the surgical trajectory must be inclined cephalad while proceeding posteriorly. The skin opening also has to line up with the surgical trajectory of this foraminotomy; thus the skin incision must be made more cephalad than in conventional anterior diskectomy, and the anterior bone opening is also shifted cephalad to arrive at the surgical target efficiently. The anterior bone opening is made at the most lateral portion of the upper vertebral body to arrive naturally at the surgical target when the foraminotomy hole is advanced posteriorly perpendicular to the longitudinal axis of the spinal column.

The posterior one-third portion of the AP surgical trajectory involves the intervertebral juncture, which is the posterior portion of the uncovertebral juncture and usually comprises the actual compressive pathology. This technique consists of bone opening at the upper vertebrae; thus it is termed an *upper vertebral transcorporeal approach*. When an AP surgical trajectory is perpendicular to the longitudinal axis of the spine, the bone opening must be made at the lateral portion of the uncinate; hence, the variant technique is called a *transuncal approach*. When the surgical trajectory inclines cephalad, a *lower vertebral transcorporeal approach* must be adopted, with a bone opening made at the lateral lower vertebrae. The medial 2-mm portion of the vertebral artery is exposed to minimize the amount of bone removal at the vertebral body. When a narrowed neural foramen requires reconstruction into a larger normal shape, *anterior foraminoplasty* is performed, with direct removal of the medial bone spurs along the longitudinal axis of the neural foramen. Since the introduction of these refined surgical techniques, others have also reported their own experiences with anterior cervical foraminotomy.[18-20]

Biomechanical effects of various techniques of anterior cervical foraminotomy on the cervical spinal column have yet to be fully tested. However, clinical findings sometimes contrast with cadaveric biomechanical studies, which may be explained in part by the fact that live patients undergo healing at the surgical site, whereas cadaver specimens lack this ability, as well as by the factor of increased specimen fatigue with repeated testings.[21-29] Kotani and colleagues[30] reported that unilateral foraminotomy reduced 30% of spinal stiffness in their cadaver study and raised the question of spinal instability. However, their specific technique of foraminotomy involved an annulotomy and partial diskectomy, along with a medial-to-lateral removal of the uncinate process, instead of a lateral-to-medial approach.

In live patients, one of the most common preoperative complaints is stiffness and limited range of motion in the cervical spine, particularly lateral head turn to the symptomatic side. Most patients experienced a significant improvement of these complaints postoperatively, such that their head turn toward the operated side improved significantly. However, they usually continued to have limitation in their range of motion opposite to the operative side related to unoperated degenerative spondylotic disease. When anterior cervical foraminotomy is performed correctly, improvement can be seen in the stiffness and decreased range of motion associated with cervical spondylotic disease toward normal ranges. Thus improved range of motion can be a beneficial effect observed in live patients with various techniques of anterior cervical foraminotomy, akin to some other types of operative treatment of arthritic joint disease in various parts of the body. However, excessive or inadvertent removal of disk, ligament, or bone beyond the target range can theoretically result in spinal instability, just as in any type of spine surgery.

Although the surgical risks of anterior cervical foraminotomy have been minimal in our experience, permanent and serious complications theoretically exist as in any type of anterior cervical spine surgery. Major potential concerns include vertebral artery injury, Horner syndrome, recurrent disk herniation, infection, spinal cord injury, and spinal instability. Because the cervical sympathetic nerve and chain pass along the lateral margin of the longus colli, Horner syndrome can occur if sympathetic nerves are damaged by traction injury or complete section while dissecting the longus colli. In our experiences, patients with Horner syndrome all recovered over time.

Vertebral artery injury is a risk in any situation but is a particular concern in anatomic variations in which the vertebral artery enters the transverse foramen through C4 or C5 instead of the common location at C6. When the lateral aspect of the cervical spine is exposed with splitting or dissecting the longus colli, the surgeon must be mindful if a vertebral artery courses through the muscle at the level of dissection. The level of vertebral artery entry into the transverse foramen should be foreseen on preoperative MR scan to help avoid this injury. Because vertebral artery injury can result in brainstem stroke immediately or in a delayed fashion, especially with dominant or codominant vertebral arteries, significant damage may need to be repaired surgically with the aid of extended proximal and distal exposure.

Recurrent disk herniation through the surgical defect in the annulus is a delayed complication that can occur when the intervertebral disk is substantially violated. To prevent recurrent disk herniation, the foraminotomy hole must be minimal in size but large enough to provide adequate decompression. This recurrent disk herniation is extremely rare in our practice.

Spinal instability may also occur if bone removal is substantial.[19] When patients complain of significant neck pain postoperatively, spinal instability must be considered. When patients have significant spinal instability, fusion may be necessary. In our experiences, we have not had a single case that required spinal fusion as a result of spinal instability after this operation.

Other possible complications associated with conventional anterior cervical spine surgery are also relevant, such as cerebrospinal fluid leakage, epidural bleeding or hematoma, nerve root or spinal cord damage, wrong-level operation, infection, or wound hematoma. Hoarseness can theoretically occur, as it does after conventional anterior cervical spine surgery, but it is very unlikely, because the anterior foraminotomy technique involves the lateral aspect of the spinal column in its approach. Because of these potential complications, this minimally invasive form of surgery is not recommendable unless the surgeon is well trained or experienced in this particular type of surgery.

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16 Anterior and Posterior Endoscopic Approaches to the Cervical Spine

JUN HO LEE

Overview

Over the past decade, minimally invasive treatment of spinal disorders has become feasible with the application of percutaneous technologies. These percutaneous approaches to spinal problems have the merits of preservation of healthy tissues, shorter hospital stays, less postoperative pain, and consequently faster patient recovery. Percutaneous endoscopic diskectomy of the lumbar spine has been widely used for lumbar soft-disk herniation.[1] This technology and its clinical success have inspired and paved the way for similar minimally invasive approaches to the cervical spine.

Percutaneous endoscopic cervical diskectomy (PECD) could be considered a good alternative to the standard anterior cervical diskectomy and fusion (ACDF) in dealing with soft cervical disk herniations. The goal of this procedure is to decompress the spinal nerve root by percutaneous removal of the herniated mass and shrinkage of the nucleus pulposus under local anesthesia. Even though the ACDF still remains as the mainstay of surgical options for cervical disk herniation, it still requires entrance into the spinal canal with the accompanying risk of complications such as epidural bleeding, perineural fibrosis, graft-related problems, dysphasia, and hoarseness. The minimally invasive PECD under local anesthesia can avoid these complications with the maintenance of stability of the intervertebral mobile segment; it also provides the patient with excellent cosmetic effect and early recovery, and it does not preclude further open procedures, even in cases of failure.

In the early stage, the main target of this intradiskal procedure was the center of the disk, and its clinical application was limited.[2] Since the first description of cervical percutaneous diskectomy by Tajima and colleagues,[3] a remarkable evolution has occurred of various minimally invasive techniques for cervical disk diseases. These include chemonucleolysis using chymopapain,[4] automated percutaneous cervical diskectomy (APCD),[5] and the combination of chymopapain injection followed by APCD.[6] However, with the progress of endoscopic and instrumental technology, the extent of exploration with working channels has shifted to the posterior subannular portion, even to the epidural space, allowing definite removal of noncontained herniated fragments.[7-9]

Anatomic Considerations

Lee and colleagues[10] previously reported on the "safety zone" for the percutaneous cervical approach, which was determined by the sum of two distance calculations: the distances from the operator's fingertip to the digestive tract on the contralateral side and to the carotid artery on the ipsilateral side. This was ascertained at each cervical level after obtaining computed tomographic (CT) scans of the cervical spine at each level of the intervertebral disk, from C3–C4 to C6–C7, by manually pushing the airway in the same position and manner of diskography (Fig. 16-1). They also identified the anatomic structure at risk by simulated needle insertion toward the center of the disk through the safety zone. Their result was that at C3–C4, the safety zone was measured at 18.9 ± 6.6 mm. The superior thyroidal artery (STA) was located in the safety zone of C3–C4 in 86.7%. At C4–C5, the safety zone was measured at 23.5 ± 6.5 mm. The STA and the right lobe of the thyroid gland (TG) were located in the safety zone in 26.7% and 30%, respectively. At C5–C6, the safety zone was measured 33.7 ± 6 mm. The TG was located in the safety zone of C5–C6 in 76.7%. At C6–C7, the safety zone was 29.2 ± 4.5 mm. The TG was located on the approach plane in 90%. They concluded that the safety zone was wider at the distal level (C5–C6, C6–C7) than at the proximal level (C3–C4, C4–C5). The safest needle entry point should be between the pushing point of the airway and the pulsating point of the carotid artery. In addition, the needle should be approached toward the center of the disk, and reducing the finger distance (FD) to less than 5 mm from the ventral surface of the vertebral body is crucial to allow a low risk of pharyngoesophageal structure injury during percutaneous approach to the cervical spine.

When performing the cervical disk puncture, the surgeon must pay careful attention to the carotid artery medial to the sternocleidomastoid (SCM) muscle laterally and the tracheoesophageal trunk medially. The pretracheal fascia is fused on either side with the prevertebral fascia, completing a compartment composed of the larynx, trachea, TG/parathyroid gland, and pharynx-esophagus. When moved medially, all of these components move together, increasing the safety zone for the initial disk puncture. Laterally the carotid artery has an almost vertical path, overlying the

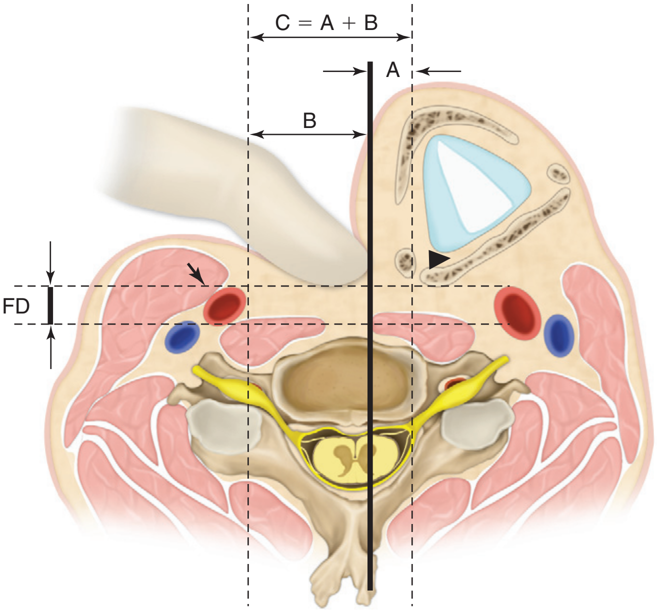

Figure 16-1 Schematic shows the "safety zone" (C) for the percutaneous cervical approach, which was determined by the sum of two distance calculations: from the operator's fingertip to the digestive tract on the contralateral side (A) and from there to the carotid artery on the ipsilateral side (B), by manually pushing the airway in the same position and manner of diskography. In addition, reducing the finger distance (FD) less than 5 mm from the ventral surface of vertebral body is crucial to allow a low risk of pharyngoesophageal structure injury. (From Lee SH, Kim KT, Jeong BO, et al: The safety zone of percutaneous cervical approach: a dynamic computed tomographic study. *Spine* 32:E569–E574, 2007.)

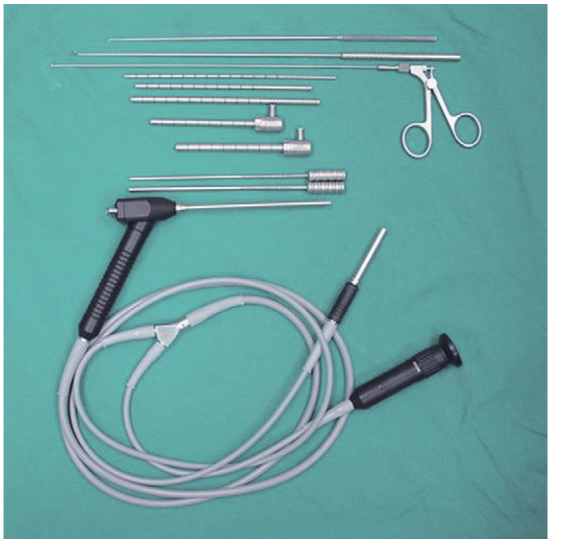

Figure 16-2 The cervical working-channel endoscope (WSH endoscopy set; Karl-Storz, Tuttlingen, Germany).

SCM muscle obliquely. The carotid artery is placed more medial from the medial edge of the SCM at the C3–C4 level and more laterally at the C6–C7 level. A more lateral puncture increases the risk of carotid puncture, whereas a more medial puncture increases the risk of injury to the hypopharynx and esophagus. The safest needle entry point is between the airway and the pulsating point of the carotid artery.

Surgical Indications and Relative Contraindications

Most patients with cervicobrachial neuralgia as a result of disk herniation respond well to medical treatment. However, symptoms related to perineural cicatricial fibrosis as a result of prolonged pressure on the nerve root could become irreversible. The occurrence or aggravation of a neurologic deficit even after an adequate period of conservative treatment therefore requires the consideration of surgical decompression. PECD is indicated in the surgical treatment of soft cervical disk herniation not contained by the posterior longitudinal ligament (PLL; ligamentous protrusion); this includes the central, lateral, and foraminal disk herniations confirmed by magnetic resonance imaging (MRI) or CT. A very bulky herniation is not a contraindication, as long as the patient has no myelopathic symptoms or signs.[7]

According to our previous series, the two major factors that predict an excellent long-term outcome after PECD were the symptom of radiating arm pain and the location of lateral disk herniation.[7,11] This observation can be explained by the fact that radiating arm pain and a foraminal or posterolateral soft disk herniation represent root compression by recently developed soft disk herniation; vague numbness and axial pain represent a relatively chronic, hard compression and therefore may be accompanied by other structural problems besides root compression.

In summary, the best indication for PECD seems to be a patient younger than 50 years, having a positive provocative test, without a bony spur greater than 2 mm, and regardless of the herniation size, location, and epidural leakage.[9,12]

PECD is contraindicated in patients with a severe neurologic deficit, segmental instability, acute pyramidal syndrome, progressive myelopathy, and other pathologic conditions such as tumor, fracture, infection, and nerve entrapment with scar tissue from previous surgery. Also contraindicated were migrated disks, calcified disk protrusions, ossification of the PLL, marked spondylosis with disk space narrowing (less than 3 mm), and neurologic or vascular pathologies that mimic disk herniations.[12]

Instruments and Equipment

INSTRUMENTS FOR THE ANTERIOR APPROACH

The oldest working channel made by Tajima[3] in 1981 was 2 mm in diameter and 8 cm in length. He added two dilators, one guide needle for diskography, and three forceps of various sizes: small, medium, and large. The small forceps were principally used for excision of osteophytes. Using medium and large forceps, Tajima performed diskectomy of the posterior disk. However, these instruments had the risk of easily breaking inside the disk during the procedure.

The recently developed cervical working-channel endoscope (WSH endoscopy set; Karl-Storz, Tuttlingen, Germany) is an advanced form of the cervical endoscope used for PECD (Fig. 16-2). It has a working cannula, 4.2 mm in outer caliber with a 1.9-mm central working channel and two additional ports, that has an integrated high-resolution endoscope, illumination, and irrigation. It allows surgeons to selectively remove the herniated disk via a holmium yttrium-aluminium-garnet (Ho:YAG) laser and microforceps under clear endoscopic visualization (Fig. 16-3). This new endoscopic system offers several advantages. First, selective disk removal by microforceps under direct endoscopic vision becomes possible. The working channel allows passage of the microforceps as well as the laser probe. Second, as the resolution and clearness of endoscopic vision is improved, we could explore the intradiskal and epidural anatomy in detail, especially the foraminal area. Better visualization of the operating field may reduce the degree of the learning curve. Finally, the side-firing rigid laser can be applied through the working channel. The side-firing laser is a safe and effective tool that helps to avoid damaging neural tissues, and it is powerful enough to vaporize the pathologic tissues, including fragile osteophytes.[11,13,14]

Endoscopic laser foraminoplasty in the cervical spine is also feasible with the WSH working-channel endoscope.[7,11] With the end-firing laser, bone sculpturing was almost impossible, because high-power lasering may cause critical damage to the adjacent neural tissues. In contrast, the side shot of a laser beam under high-resolution endoscopic vision is tremendously helpful for the elaborate sculpturing of the foraminal osteophytes, uncus, and inflamed fibrotic tissues without causing any neural injury.[7,11] Moreover, the Ho:YAG laser inherently has a high ablation effect while producing relatively little thermal necrosis. The laser irradiation can be performed with saline irrigation, and the tissue penetration of the Ho:YAG laser is approximately 0.3 to 0.5 mm deep. Therefore the tissue volume heated by the laser is very small, and the heat damage to the surrounding normal tissue is negligible.[11,13,14] Endoscopic laser foraminoplasty may play an important role for removing an extruded disk fragment by widening the narrow foramen. However, we do not believe that all the severe cervical foraminal stenosis can be treated by endoscopic laser foraminoplasty with the present technical restrictions.

INSTRUMENTS FOR POSTERIOR APPROACH

The rod-lens optics have an outer caliber of 5.9 mm. This contains an eccentric working channel 3.1 mm in diameter, an optical lens with the connecting light conductor system, and a channel for continuous irrigation (Fig. 16-4). The angle of vision is 25 degrees, and the beveled opening working sheaths are 6.9 mm in outer diameter. All these instruments and optics are Wolf products (Richard Wolf, Knittlingen, Germany).

Surgical Preparations and Techniques

ANTERIOR APPROACHING TECHNIQUE

The patient is placed in a supine position with the neck mildly extended on a radiolucent table. A plastic hood over the face enables communication with the anesthesiologist (Fig. 16-5). The C-arm of the fluoroscope is put in front, then in profile, and the level of the operation is carefully marked on the skin with a felt pen using a metallic instrument. The operation is typically conducted under local anesthesia and analgesia by neuroleptics, so the surgeons may immediately become aware of any changes in symptoms and signs of the patient. General anesthesia may be used in a few patients who want it or cannot tolerate the position; but under general anesthesia, the urgent need for conversion to open surgery may not be detected early. A solution of 1% lidocaine is usually used to infiltrate the skin and subcutaneous tissue.

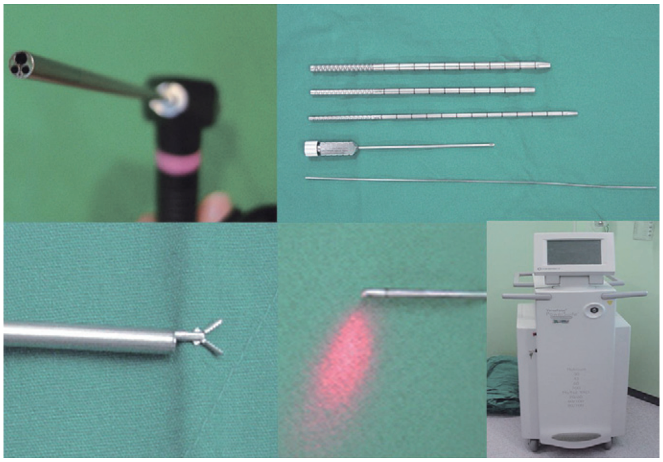

Figure 16-3 WSH endoscopy set (Karl-Storz, Tuttlingen, Germany) along with the serial dilators, a friable mechanical forceps, and a side-firing holmium yttrium-aluminum-garnet (Ho:YAG) laser. It has a 4.2-mm outer diameter working cannula with a 1.9-mm central working channel and two additional ports along with an integrated high-resolution endoscope, illumination, and irrigation.

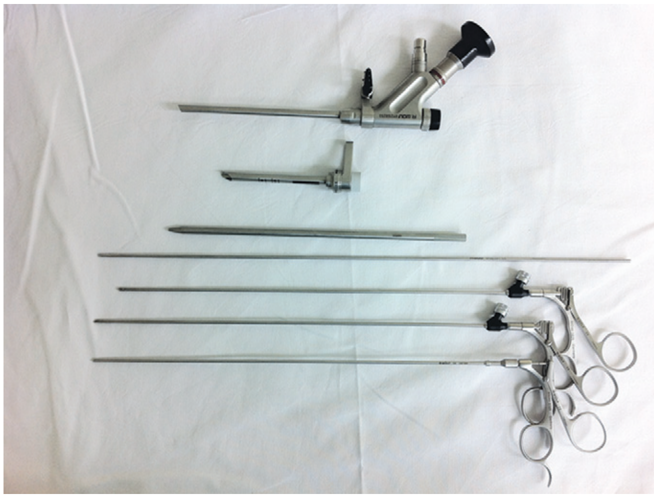

Figure 16-4 The posterior cervical working-channel endoscope (Richard Wolf GmbH, Knittlingen, Germany). This 5.9-mm (outer diameter [OD]) endoscope contains an eccentric working channel 3.1 mm in diameter, an optical lens with the connecting light-conductor system, and a channel for continuous irrigation. The angle of vision is 25 degrees, and the beveled-opening working sheaths are 6.9-mm OD.

Usually a paramedian approach (2 to 5 mm from the anterior midline) from the contralateral side was chosen. The surgeon gently pushes the trachea or larynx toward the opposite side with the index and middle finger and then applies a firm pressure in the space between the SCM and trachea and points toward the vertebral surface until the prominence of the anterior edge of the disk could be palpated (Fig. 16-6). The trachea and larynx are displaced medially, and the carotid pulsation is palpated on the lateral side. The 18-gauge puncture needle is then inserted through the space between the tracheoesophagus and the carotid artery. After confirming the midline position of this 18-gauge needle on the center of the anterior annulus by intraoperative fluoroscopy, the needle is advanced close to the posterior body line of the posterior disk space (Fig. 16-7). Then diskography with 10 mL Telebrix (Guerbert, France) and indigo carmine (Korean United Pharma, Seoul, Korea) is performed to confirm the presence of soft disk herniation and stain the nucleus blue in contrast with the neural tissue (Fig. 16-8). Up to 0.5 mL of contrast media is injected to specify the posterior part of the disk. Then a guidewire is inserted to replace the puncture needle, and a 3- to 5-mm skin incision is made to allow the passage of a serial progressive dilator (2 to 5 mm) along the guidewire to stretch the soft tissues (Fig. 16-9). Finally, the tip of the working cannula is hammered to reach the posterior part of the disk (Fig. 16-10), and the forceps should be reached at the end of the posterior margin to remove the herniated mass effectively, with care taken not to injure the spinal cord.

Identifying the normal PLL adjacent to the ruptured disk portion on the first step of the endoscopic manipulation is most important to delineate between the normal and pathologic portions (Figs. 16-11 through 16-13). The initial

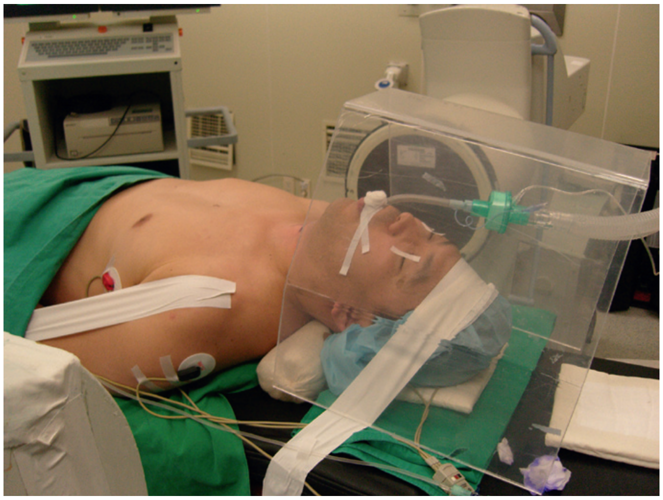

Figure 16-5 Preparation for the percutaneous endoscopic cervical diskectomy. The patient is placed in a supine position on a radiolucent table with the neck mildly extended. A plastic hood over the face enables communication with the anesthesiologist.

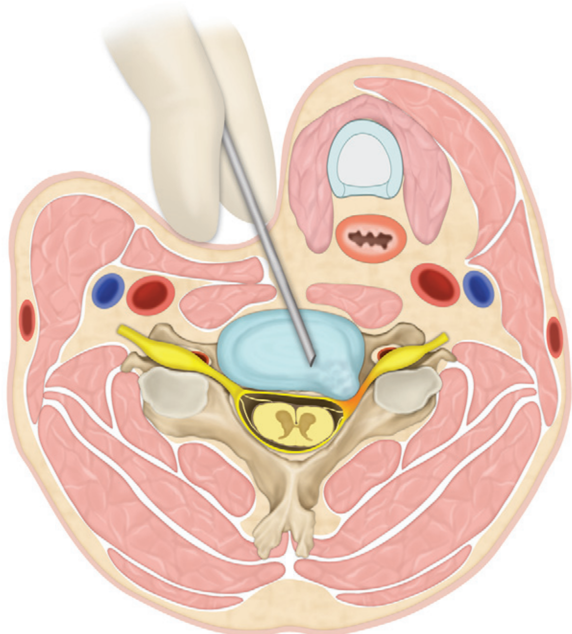

Figure 16-6 Safe needle insertion into the created space during percutaneous endoscopic cervical diskectomy. The surgeon gently pushes the trachea or larynx toward the opposite side with the index and middle finger, then applies a firm pressure in the space between the sternocleidomastoid muscle and trachea, and points toward the vertebral surface, until the prominence of the anterior edge of the disk can be palpated.

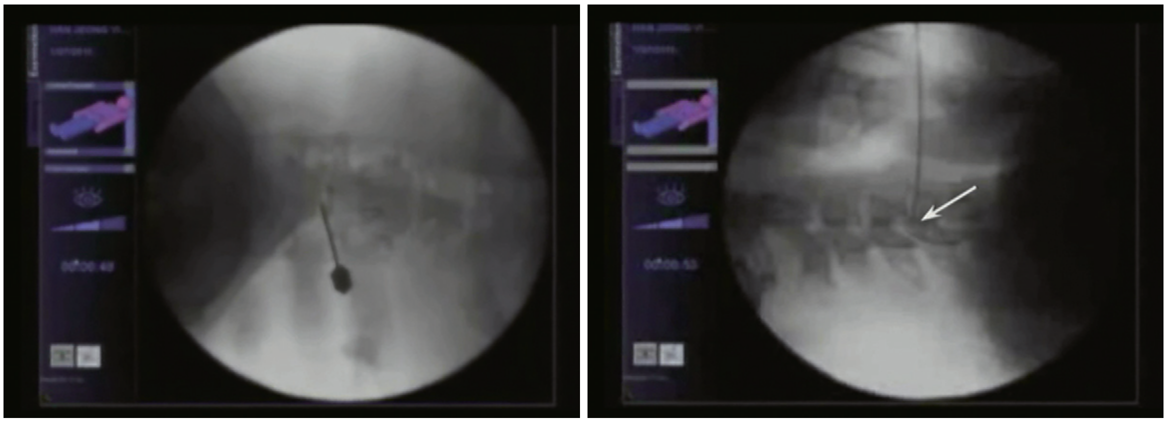

Figure 16-7 Intraoperative C-arm fluoroscopic anteroposterior (*left*) and lateral (*right*) views after needle insertion. After confirming the midline position of this 18-gauge needle on the center of the anterior annulus, the needle is advanced close to the posterior body line of the posterior disk space.

diskographic images indicate the depth required for the small disk forceps to remove the herniated fragments close to the PLL. Closely monitoring with fluoroscopy and direct endoscopic vision, the annular anchorage is loosened with a side-firing laser and small forceps. Extraction of the tail of the herniated mass, which is usually more fibrotic and collagenous, is attempted (Fig. 16-14). The intradiskal space is rinsed continuously with cefazolin-mixed cold saline through an irrigation channel for hemostasis and prevention of infection.

Endoscopic vision helps confirm the adequacy of decompression of the dural sac or the exiting nerve root (Figs. 16-15 and 16-16). A single stitch with a moderate localized pressure to control the bleeding completes the procedure. The patients are observed for 3 to 24 hours in the hospital and are then discharged with the cervical region braced with a Miami-Jackson collar for 3 to 14 days postoperatively. Rehabilitation exercises are usually started 4 to 6 weeks after the surgery.

POSTERIOR APPROACH

The patient is placed in the prone position under local anesthesia with the neck slightly flexed to make cervical spine curvature delordosated. The arms and shoulders are gently retracted caudally.

Most of the procedures are similar to the conventional posterior foraminotomy techniques described in the literature.[15] The line of spinal joints is marked under anteroposterior (AP) radiographic control. From this point on, the rest of the procedure is performed under lateral fluoroscopic control. Determinations of the corresponding segment, performance of skin incision, blunt insertion of a serial dilator onto the medial portion of facet joint, and insertion of a beveled-opening working cannula after removal of the dilator follow. After insertion of the endoscope, the rest of the procedure is performed under visual control along with continuous irrigation with cold saline mixed with antibiotics. The bony resection is started from the medial portion of the facet joint to start the foraminotomy procedure, followed by resection of the lateral portion of the ligamentum flavum. This bony resection is performed under endoscopic visual control using 3 mm drills (Fig. 16-17) and punches inserted through the 3.1 mm working canal.

Next, the lateral margin of the spinal cord and dura and its branching nerve root to decompress are fully identified. Targeted pathologic fragments beneath the spinal root are resected using microforceps, and hard spurs are removed using a Ho:YAG laser, or they are drilled with gentle retraction of the root to avoid possible postoperative dysesthesia. Depending on the location or number of pathologic targets, this procedure can be extended in a mediolateral or craniocaudal direction using the same skin entry.

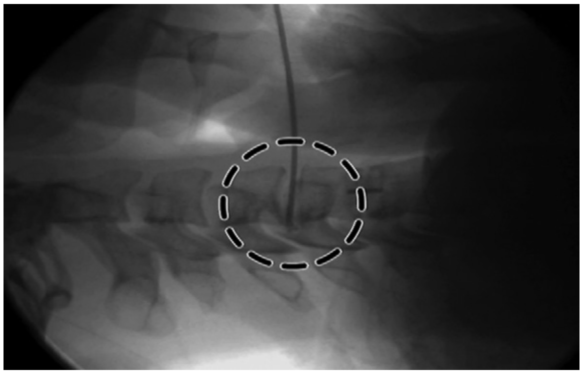

Figure 16-8 A lateral intraoperative fluoroscopic view after diskography using indigo carmine (indigotindisulfonate). Advancement of the needle close to the posterior body line is important to properly stain the actual herniated disk fragment (*dotted circle*).

SURGICAL TIPS

- Unless the surgeon actually feels the "hardness" of the ventral surface of the cervical vertebral body during the finger retraction of the tracheoesophageal trunk on the first phase of the procedure, do not insert the 18-gauge needle at all. If the surgeon feels that his or her finger is "floated over" from the actual surface of the hard bone, chances for needle injury or insult to the important vital organ inside the neck—hypopharynx, esophagus, or even carotid artery—would increase.
- Try to maintain the insertion angle for the needle or working sheath vertically as close as to 90 degrees over

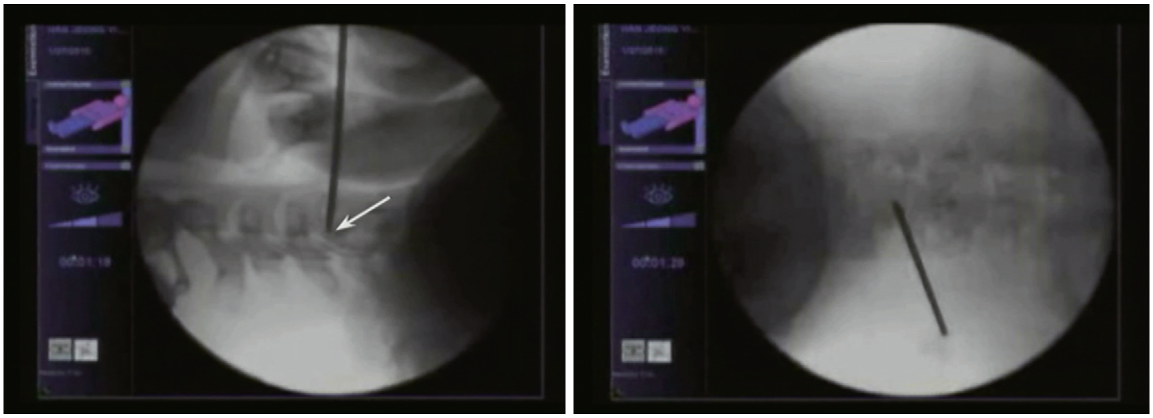

Figure 16-9 Intraoperative C-arm fluoroscopic anteroposterior (AP) (*left*) and lateral (*right*) views after the dilator insertion. Maintenance of proper location is important: midline on the AP view and as close to the posterior body line on the lateral view.

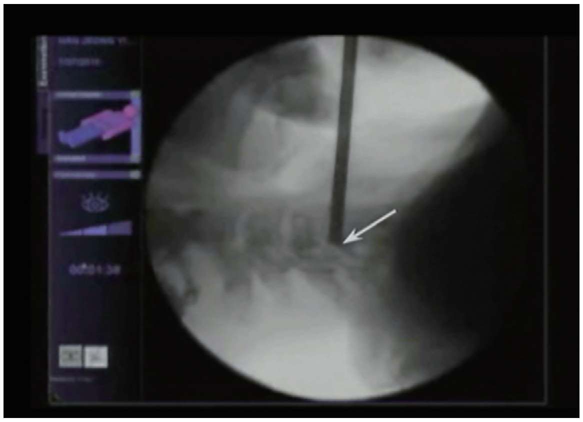

Figure 16-10 An intraoperative C-arm fluoroscopic lateral view after the working sheath insertion. The tip of the working sheath should be close to the posterior body line (indicated by *arrow*).

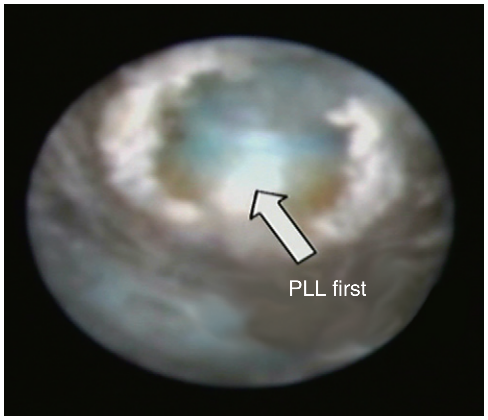

Figure 16-11 Intraoperative endoscopic view of the initial phase of percutaneous endoscopic cervical diskectomy. Finding the intact posterior longitudinal ligament on midline (*arrow*) is most important to define the "normal" portion from the "pathologic" portion where the base of herniated disk fragment is located.

Figure 16-12 Intraoperative endoscopic view shows a tear during the initial phase of percutaneous endoscopic cervical diskectomy. An intact posterior longitudinal ligament (PLL) and torn PLL with slight exposure of ventral dura are well demarcated.

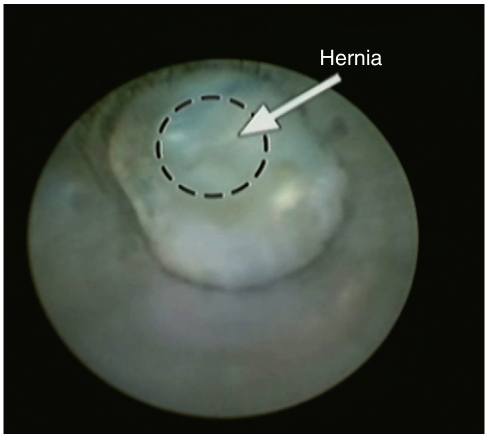

Figure 16-13 An intraoperative endoscopic view reveals a hernia during percutaneous endoscopic cervical diskectomy. Underneath the torn part of the posterior longitudinal ligament, slight exposure of blue-stained root of herniation is well visualized.

Figure 16-14 The removal of hernia during percutaneous endoscopic cervical diskectomy. The blue-stained main fragment of herniation is removed through the torn part of the posterior longitudinal ligament using mechanical forceps.

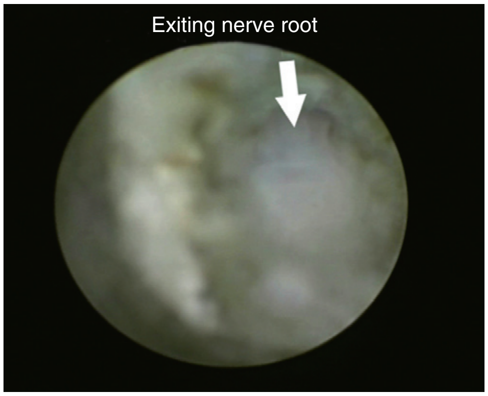

Figure 16-15 An intraoperative endoscopic view of the final phase of percutaneous endoscopic cervical diskectomy. The lateral margin of dura and its exiting nerve root are well exposed after full decompression.

the ventral surface of the cervical vertebral body or disk space while keeping the midline on the AP view and parallel to the disk space on the lateral view from the intraoperative fluoroscope (Fig. 16-18). Because most of the herniated disk fragments are located paracentral to the foramen laterally, starting the procedure from the midline, just beside the portion of herniation where the intact annulus or PLL remains, is strongly recommended to define intraoperative anatomic orientation inside the 1.9-mm narrow working channel. If an oblique insertion

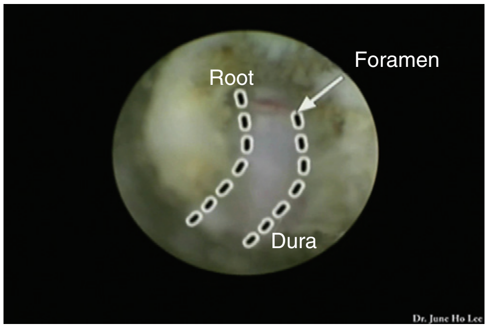

Figure 16-16 An intraoperative endoscopic view of the formen, root, and dura during percutaneous endscopic cervical diskectomy. Well-decompressed ventral dura from midline to the start of the foramen is exposed.

Figure 16-17 A 3 mm high-speed burr used during the posterior cervical endoscopic procedure for bony resection. A protective metallic hood covers one side and also the end tip of the burr.

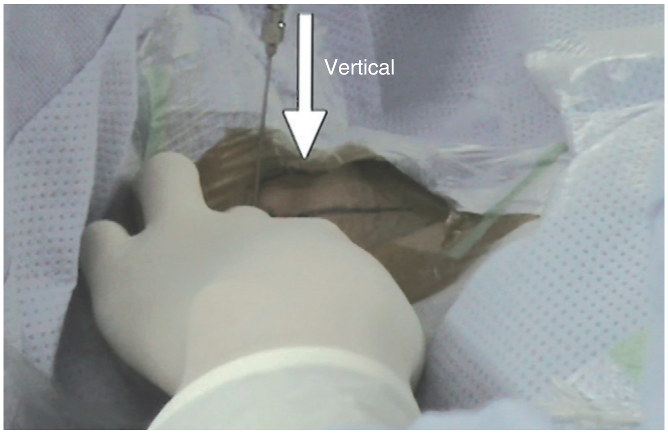

Figure 16-18 An intraoperative view after needle insertion during percutaneous endoscopic cervical diskectomy. The insertion angle is important: maintain the needle or working sheath vertically as close to 90 degrees as possible over the ventral surface of the cervical vertebral body or disk space.

angle has been initiated, the end of the working cannula would later be "lifted up" into the central nucleus, away from the actual herniated fragment, as the endoscope is levered later to access the lateral portion of the disk space or foramen (Fig. 16-19).

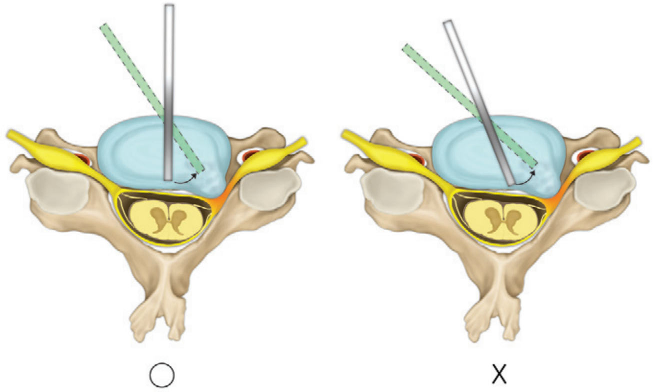

Figure 16-19 This illustration emphasizes the importance of maintaining the vertical degree of needle insertion for PECD (O). If an oblique insertion angle (XO) has been initiated, the end of the working cannula would later be "lifted up" into the central nucleus, away from the actual herniated fragment, as the endoscope is levered later to access the lateral portion of the disk space or foramen.

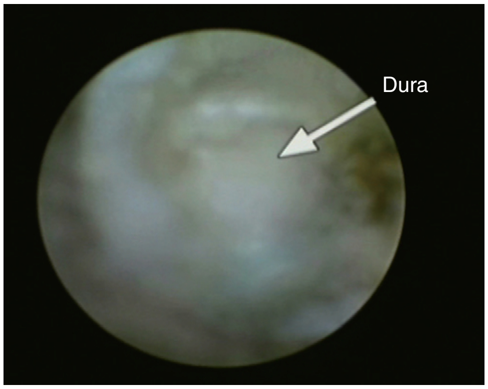

Figure 16-20 An intraoperative endoscopic view of the dura. Once the targeted disk fragment has been removed, the ventral surface of the dura will immediately expand close to the percutaneous longitudinal ligament. This might hinder the use of a forceps or laser tip over the dural surface for further decompression because of possible provocation of pain.

- A huge freed fragment is best removed during the final phase of the procedure, after adequate decompression and adhesiolysis from the posterior annulus or PLL in en bloc fashion. Once the fragment has been removed during the early phase of the operation, the previously compressed ventral dura or spinal cord would naturally expand during the procedure. This could hinder the further use of laser or forceps for the additional decompression for the possible remnant fragment because of its expansion close to the posterior margin of the vertebral body or PLL (Fig. 16-20). A minor surgical manipulation using forceps or possible heat transduction from the laser use over the ventral surface of dura or spinal cord would immediately provoke severe pain. In addition, continuous irrigation flow through the PLL defect from the removed herniation over the epidural space of cervical spine could increase the epidural pressure all the way up to the cranium and could possibly promote severe headache or even elicit a seizurelike attack from the patient.
- Try to maintain the end of the working cannula close to the posterior margin of the vertebral body on the lateral

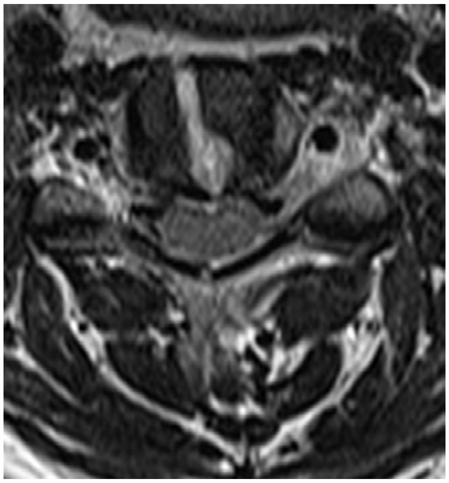

Figure 16-21 A postoperative, axial view magnetic resonance image (MRI) taken after PECD. Note the "split" tract inside the disk as the route of entry of the endoscope. The amount of resected disk is limited to the boundary of the original herniation close to the posterior margin of the vertebral body.

view to preserve the most of the central nucleus. Such wide decompression or the resection of the nucleus is not recommendable for the later preservation of disk height and stability (Fig. 16-21).

Controversies

Anterior cervical diskectomy techniques are commonly used in the treatment of cervical spondylotic radiculopathy, and the majority of spine surgeons advocate the use of an autogenous, allograft, or even artificial disk upon the completion of decompression. This reconstruction of the cervical spine is based on the theory that the disrupted ventral cervical anatomy combined with empty disk space after decompression would naturally collapse in kyphotic fashion when left alone, leading to postoperative axial neck pain associated with distorted cervical alignment or delayed radicular pain with compromise of the neural foramen. Over the past decade, there was lack of controversy about this procedure; indeed, the majority of surgeons did not hesitate to insert a graft or spacer into this surgically disturbed cervical spine, based only on this vague theoretical phenomenon without uncertainty or questioning.

Although sophisticated surgical treatments for cervical disk herniation have evolved throughout the twentieth century, this evolution is mostly related to the nature of the implants being inserted into the empty disk space. This sometimes leads to an extravagant placement of hardware lacking the evolution related to clarify the surgical opinions that have existed since the introduction of anterior cervical diskectomy without fusion (ACD). Is it important to preserve disk height and cervical spine alignment following surgery? Due to the paucity of literature that could answer this question, I am not fully empowered with scientific evidence about the relative merits of simple cervical partial diskectomy without introducing a bone graft or spacer. Moreover, there has been a recent report of a threefold increase in risk of developing adjacent-level disk degeneration in incorrectly needle-marked disks after ACDF at short-term follow-up, indicating that even minor needle-related trauma contributes to accelerated segmental degeneration.[16] These are all discouraging facts, and I shall refrain from justifying or emphasizing the minimal nature of the anterior cervical structures and disk violation using a small endoscope for the sake of preserving the cervical stability or alignment even without implant.

However, Sonntag and colleagues[17] reported in 1994 that after careful selection of the patients with isolated cervical soft disk herniation or focal osteophyte formation without instability, subluxation, malalignment, or loss of normal cervical lordosis, the number of patients who required a delayed fusion procedure could be reduced to less than 1.5%. With these promising results from the literature, and with the evolution of endoscopic and instrumental technology, the authors have pursued direct removal of disk pathology through PECD from the subjects that have met those selection criteria, leaving the majority of the anterior and central disk, anterior longitudinal ligament, and both upper and lower vertebral end plates intact. The theory would be that this selective evacuation of the intervertebral disk space without fusion might maximize the possibility to reduce the damage to the surrounding tissue and to dispense with bony or ligament resection, deterring the development of subsequent instability or malalignment while minimizing the fusion surgery–related complications.

From my series of 37 consecutive patients who had monoradiculopathy due to soft cervical disk herniations and were treated with PECD between September of 2003 and February of 2007, and who had their final follow-up radiograph and MRI examination between April and June of 2009, the radiographic changes are notable.[18]

The posterior disk heights and central disk height ratio were significantly decreased (3.6 mm to 2.6 mm, 30.3% to 24.5%, respectively; $P < .05$). The degenerative grades were significantly aggravated (average grade of 2.8 to 4.1, $P < .05$). The overall sagittal alignment was significantly improved (8.5 to 11.7 degrees, $P < .05$), and the regional Cobbs angle or range of motion was well maintained (1.9 to 2.3 degrees and 6.0 to 5.0 degrees respectively, $P > .05$). Four patients had recurrence or the development of progressing kyphosis and underwent ACDF consequently.

Despite this evidence of promoted degenerative process by radiographic assessment, the clinical outcomes were satisfactory: the Visual Analogue Score (VAS) for neck and arm dropped from a mean of 6.3 and 7.5 to 2.7 and 2.6, respectively; Neck Disability Index score improved from 46.8% to 17.2 % after PECD ($P < .05$).

Haden and colleagues[19,20] have shown that following ACD without fusion, the greater the preoperative disk height, the greater the amount of disk space collapse on the first year after the operation. However, they concluded that neither the loss of disk height nor disturbance of cervical alignment compromised the clinical outcome in their series of 140 patients. My series corresponds to the results from the above study and seems to be creating some controversy regarding the issue of true benefit of ACDF over ACD or PECD alone.[18]

Summary

The aforementioned procedure of direct fragmentectomy and decompression, using combined manual decompression by microforceps and the thermal effects of a Ho:YAG laser under direct endoscopic vision, is quite safe and effective for the treatment of soft cervical disk herniations. The advancements in the miniaturization of microsurgical instruments and fiberoptics, improved quality of fluoroscopic imaging, high-resolution digital video imaging endoscopy, and side-firing laser have all facilitated the development of PECD. Also, in my experience, a very low associated morbidity and rapid recovery result in a significant cost savings. However, longer follow-up studies based on a large number of series are required to assess the corresponding segment degeneration and stability as feared by most surgeons following the conventional fusion surgeries.

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17 Cervical Corpectomy, Fusion, and Vertebral Restoration Techniques

OMAR CHOUDHRI and STEPHEN I. RYU

Overview

Cervical corpectomy is a ventral cervical spine procedure for safe and effective neural decompression, deformity correction, and mechanical stabilization. The procedure typically involves removal of part or all of the cervical vertebral body over single or multiple segments and may include release of the posterior longitudinal ligament (PLL) and dural and vertebral decompression. The goal is neurologic improvement and bony fusion. Cervical corpectomy can be considered an extension of anterior cervical diskectomy and fusion procedures, and many of the same biomechanical principles apply.[1]

However, cervical corpectomy merits more biomechanical consideration, because it destabilizes the spine and alone introduces kyphosis and deformity. It is therefore almost always necessary that cervical corpectomy be combined with a stable vertebral restoration construct. Fortunately, we now have many options for anterior column reconstruction, including autograft bone, allograft bone, and a variety of cages of different materials. Many are similar to interbody applications, but given the longer graft constructs, column reconstruction carries a higher risk of graft complications, such as graft displacement and migration and adjacent segment degeneration.

Anterior cervical diskectomy and interbody fusion was first introduced in the 1960s for anterior decompression of the spinal cord. A wide variety of operative modifications were made to the initial techniques described by Cloward and by Smith and Robinson.[2,3] As anterior cervical diskectomies became well accepted, extended approaches led to cervical corpectomies.[4] Cervical corpectomy is now a widely performed procedure used to address pathology anterior to the cervical spinal cord including trauma, tumor, infection, deformity, degenerative disease, and metabolic conditions (i.e., ossified PLL).

Cervical corpectomy can be performed from C3–C7 and involves removal of vertebral body and the adjacent and intervening disk spaces. The lateral vertebral walls can be removed or left alone, as can the PLL and posterior bone, depending on the pathology being addressed. This can be done through a straight median or oblique approach. Cervical corpectomy requires careful and thoughtful surgical technique. Given the vital structures involved during exposure and bony removal, cervical corpectomy can be associated with significant morbidity in comparison with posterior cervical decompression and simple diskectomy. Carotid and vertebral artery, esophageal, tracheal, nerve, and soft-tissue injuries can be devastating if meticulous operative technique is not adhered to.

Cervical corpectomy must be combined with a reconstructive procedure that involves insertion of a graft into the corpectomy defect. The selection of the graft relies on many factors that include surgeon preference, available selection, type of lesion, and need for deformity correction. This choice is then linked to the operative techniques needed to optimize graft positioning and, ultimately, fusion. An internal fixation device, usually a plating system, is often used to further secure the construct, and whether to use posterior supplemental fixation is also an important consideration. These decisions can affect the incidence of acute and remote graft failure, recurrent neurologic symptoms, pseudarthrosis, and instrumentation failure; all of these may require additional surgery or interventions.[5,6]

Anatomy Review

Exposure for an anterior cervical corpectomy is done through an avascular fascial plane in the anterior triangle of the neck. The incision used is based on the cervical levels involved and the extent of the corpectomy. For a single-level or bilevel corpectomy, a horizontal incision along the skin crease is usually adequate. An oblique/longitudinal incision along the sternocleidomastoid (SCM) may be used for an improved exposure for corpectomy involving three or more levels. The levels and incision should be confirmed with fluoroscopy prior to incision.[7]

MUSCLES

The operative exposure involves recognizing the anterior border of the SCM and the strap muscles (sternohyoid, sternothyroid, thyrohyoid, and omohyoid; Fig. 17-1). The omohyoid is an important landmark muscle that runs from the superior border of the scapula to its insertion into the hyoid bone. It has two bellies with an intermediate tendon. The superior belly of the omohyoid can limit retraction but can be divided in the anterior triangle, although this is rarely necessary. The operative dissection plane is usually between the anterior border of the SCM laterally and the strap muscles medially. The longus colli muscles run from the lateral vertebral bodies out over the cervical bodies and cover the vertebral arteries, sympathetic chain, and cervical nerves.

VASCULAR ANATOMY

Once dissection is carried through the deep cervical fascia investing the SCM and strap muscles, the carotid sheath should be recognized (Fig. 17-2); it can be palpated by the carotid pulse and is retracted laterally. It should be left intact during the dissection because its contents include the carotid artery, internal jugular vein, and vagus nerve. The superior thyroid artery, lingual artery, and facial artery, which are branches of the external carotid artery, may be encountered and ligated, if necessary, at high cervical levels.

The vertebral artery (Fig. 17-3) courses lateral to the vertebral bodies and must be appreciated and protected during the corpectomy procedure. It contributes to the cerebral vasculature and, hence, injury to this artery can result in stroke. The vertebral artery arises from the subclavian artery on each side and enters the transverse process foramen at the level of the sixth cervical vertebra, but it can also enter at levels above and below C6. It courses through the transverse foramina lateral to the vertebral bodies, where it can potentially be injured between levels. It is crucial to be aware of the midline of the vertebral body, because erring too far laterally on either side could risk injury to the vertebral artery.

The sternal notch is used as a useful midline landmark. The uncovertebral joints at each adjoining disk level may be used to mark the midline. The corpectomy is often limited to the central 15 mm of the vertebral body to shield the vertebral artery with a wall of bone. In some instances the vertebral artery may be more medial than usual, and the extent of corpectomy should be limited in such cases. However, in some cases, skeletonization of the vertebral artery or resection of the transverse process is necessary and quite possible (i.e., total spondylectomy). An awareness of the location and course of the vertebral artery cannot be overemphasized.

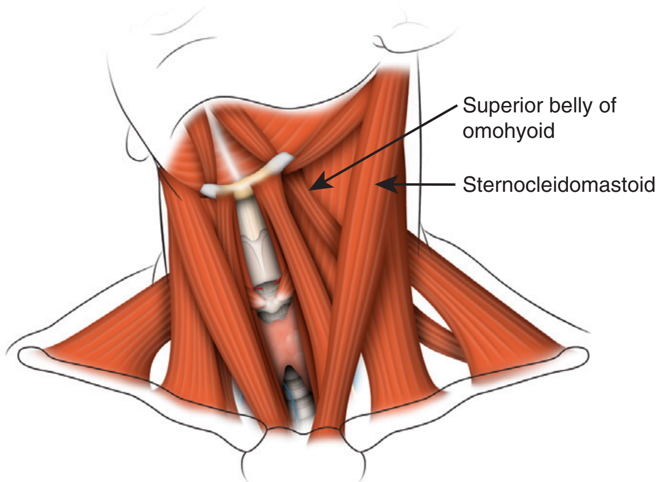

Figure 17-1 Anatomy of anterior cervical musculature encountered during a cervical corpectomy. A plane of dissection is present between the anterior border of the sternocleidomastoid and the strap muscles. The superior belly of the omohyoid can limit the exposure and may have to be transected.

VISCERAL STRUCTURES

The esophagus and trachea are encased in the pretracheal fascia and are retracted medially during the anterior cervical exposure (Fig. 17-4). The esophagus is soft and easily retracted, but it must be protected during drilling and prolonged retraction, because excessive esophageal retraction and resultant swelling can contribute to swallowing problems postoperatively. Retractors also protect the trachea medially, and given that postoperative swelling of the trachea and esophagus can be mildly annoying to life threatening, these injuries must be recognized and addressed quickly.

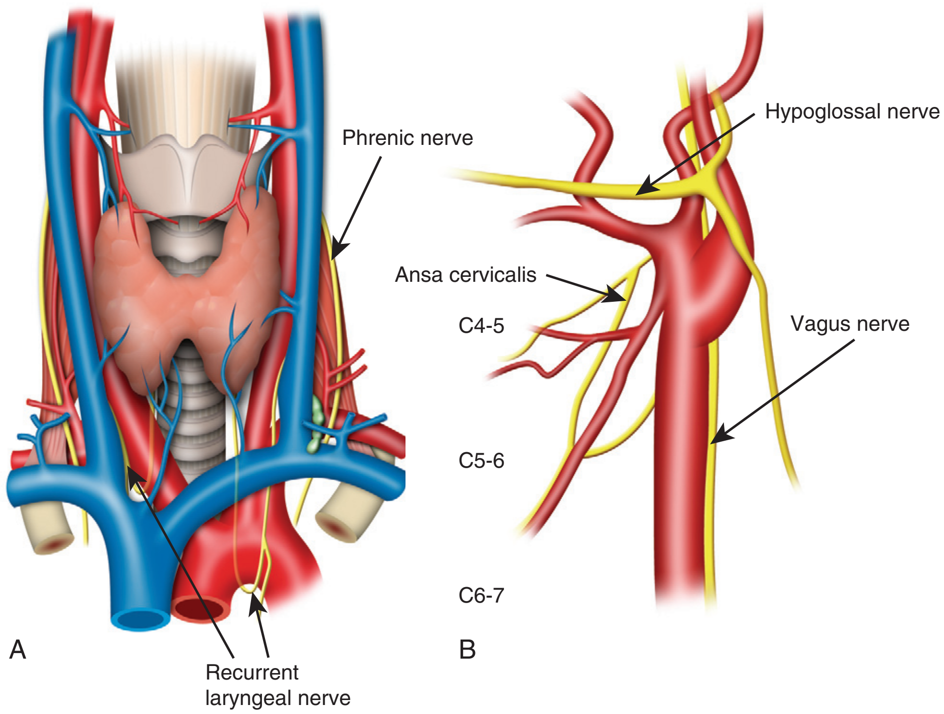

Figure 17-2 **A,** Neurovascular relationships in the neck and courses of the recurrent laryngeal and phrenic nerves. The recurrent laryngeal nerve normally runs in the tracheoesophageal groove. **B,** Lateral view of the anterior neck: the hypoglossal nerve may be encountered in high cervical exposures. The branches of the external carotid in relation to the ansa cervicalis and vagus nerve are also demonstrated.

NERVOUS SYSTEM STRUCTURES

Nerves along the approach to the target disk need to be considered (see Fig. 17-2, *B*). The ansa cervicalis travels around the strap muscles and can be injured, which can cause some strap muscle paresis that rarely causes functional disability. The laryngeal nerves, both recurrent and direct, can be injured; this may result in temporary or permanent vocal cord paralysis, which can result in aspiration risk. The sympathetic chain ganglia that travel along the longus colli should not be damaged, and injury should be recognized (Horner syndrome). Finally, the exiting nerve roots can be damaged near the vertebral artery with extreme lateral and posterior exposure while removing bone.

Figure 17-3 Course of the vertebral artery. The vertebral artery enters the transverse foramina starting at C6 and travels lateral to the vertebral body. The extent of corpectomy is hence initially limited to the central 15 mm, because proceeding too far laterally can place the vertebral arteries at risk of injury. The vertebral artery can be safely located and skeletonized.

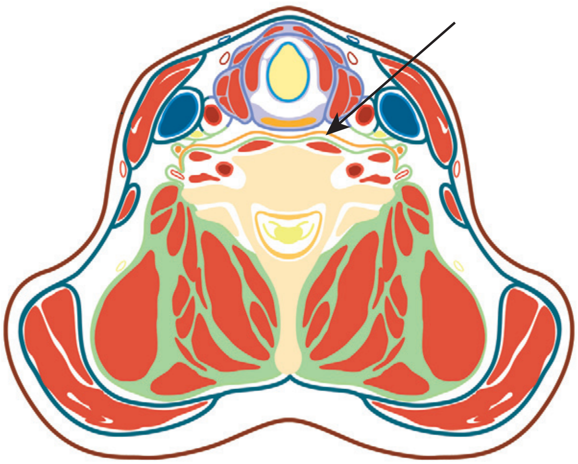

Figure 17-4 Cross-sectional anatomy of the neck at C6 (cricoid cartilage). Cervical fascial layers and the direction of fascial exposure in anterior cervical corpectomies (*arrow*).

Indications and Contraindications

INDICATIONS

- Spondylotic myelopathy
- Ossified PLL
- Degenerative or posttraumatic kyphosis
- Vertebral burst or compression fracture
- Vertebral body neoplasm
- Vertebral infection: osteomyelitis, ventral epidural abscess, cases of spondylodiskitis

CONTRAINDICATIONS (RELATIVE)

- Cervical stenosis limited to the disk space at single or multiple levels
- Multilevel stenosis with posterior ligamentous hypertrophy
- Extensive continuous ossified PLL
- Predominantly posterior compression
- Significant lordosis
- Developmental stenosis
- Prior anterior neck surgery or severe anterior soft-tissue injury
- Severe osteoporosis
- Previous irradiation
- Aberrant vertebral artery anatomy
- Severe deformity
- Medical comorbidities

Operative Technique

EQUIPMENT

- Sliding-top flat operating table
- C-arm fluoroscopy (highly recommended)
- Gel donut, towels, or other head stabilizer
- Traction or tongs (rarely)
- Tape restraints for shoulders
- Bovie with protected tip
- Bipolar electrocautery
- Lateral retractors (Cloward handheld) for dissection and localization
- 22-Gauge spinal needle for localization; avoid penetrating uninvolved levels
- Self-retaining retractor system (Shadow-Line [CareFusion, San Diego, CA], TrimLine [Medtronic, Minneapolis, MN], or Black Belt [Koros USA, Moorpark, CA]; Fig. 17-5)
- Caspar pins (12, 14, and 16 mm) and distractor
- High-speed drill with M8/matchstick drill bit; a 3-mm diamond bit for ossified PLL
- Hemostatics (FloSeal, Gelfoam, thrombin)
- Cottonoids half-inch and inch squares
- Operating microscope
- Neurophysiologic monitoring (recommended in many cases)

VERTEBRAL BODY RESTORATION TECHNOLOGIES

A variety of grafts can be used for vertebral body reconstruction after corpectomy (Tables 17-1 and 17-2). Each

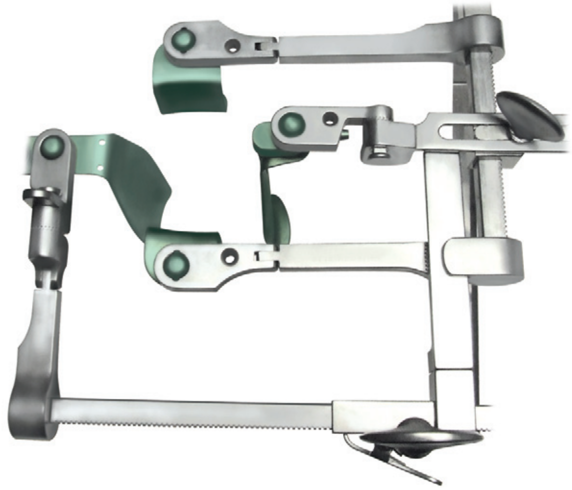

Figure 17-5 Example of a cervical self-retaining retractor system with mediolateral and superoinferior retractor blades in position.

has its own properties relative to biomechanics, fusion rates, and complications. The choice of a graft material is hence a critical consideration.

Bone Grafts: Autograft and Allograft

Bone strut grafts were the earliest materials used for bony reconstruction following corpectomy. Iliac crest is a common source for structural autograft. Fibular strut allograft and autograft as well as rib, radius, and other bones are uncommon bone sources. Sizing and shaping of the graft is critical to prevent graft extrusion and promote fusion, and union rates approach 85%.[8]

A tricortical iliac crest autograft provides more cancellous bone, which may facilitate an earlier successful fusion (Fig. 17-6). However, it is associated with significant donor-site morbidity, with symptoms that include prolonged pain, hematoma, muscle hernia, and lateral femoral cutaneous nerve injury. The curvature of the iliac crest makes it unsuited for spanning more than two vertebral bodies. A

Table 17-1 Vertebral Restoration Methods Following Cervical Corpectomy

Method	Pros	Cons
Bony autograft and allograft (tricortical iliac crest, fibular strut)	Relatively inexpensive Can be locally obtained Biocompatible Universal morphology Gold standard	Resorption Telescoping Poor shaping Difficult to fit Graft dislodgment Not recommended in cases of infection or tumors (can harbor bacteria or tumor cells) Instability
PMMA	Excellent mechanical properties under such compressive force Low cost Ease of handling Instantaneous stability No external orthosis Impervious to tumor invasion and radiation	Poor long-term fusion Exothermic reaction while settling that may injure the dura and spinal cord PMMA expansion may risk cord compression
Titanium mesh cages	Easy to size Easy to cut Easy to pack with bone Very strong Nonresorbable	Focal pressure on ring promotes collapse Cannot place under tension Graft dislodgment Telescoping Difficult to fit
Modular cages	Easy to size, size options Easy to fit height Easy to assemble Very strong Nonresorbable Radiolucence facilitates evaluation of fusion Teeth prevent migration Large center opening offers more bone graft–end plate contact Lateral openings facilitate fusion and vascularization Tantalum beads allow rapid localization Trapezoidal shape achieves proper sagittal alignment	Fixed incremental heights Near-solid constructions Not as strong as titanium Graft dislodgment Cannot stack while in situ
Expandable cages	Strong, nonresorptive Large end plate contact area End plate angulation fit capability Enables bone graft formation Continuous dynamic expansion Strong graft–end plate contact and resistance to pullout Universal approach Universal applications Ease of insertion Reduced end plate trauma Direct application/maintenance of interbody distraction force One-step kyphosis correction	Expensive Less space to pack bone Slow bony fusion

PMMA, polymethylmethacrylate.

Table 17-2 Cage Characteristics

	Bone	Static Cages	Modular	Expandable
End plate fit	Poor to good	Good	Good	Good to excellent
Height fit	Good	Good	Good	Excellent
Bone channel	Excellent	Excellent	Poor to good	Poor to good
Settling resistance	Good	Poor	Good	Good
Fully variable	Yes	Yes	No	Yes
Ease of use	Poor	Good	Poor	Excellent

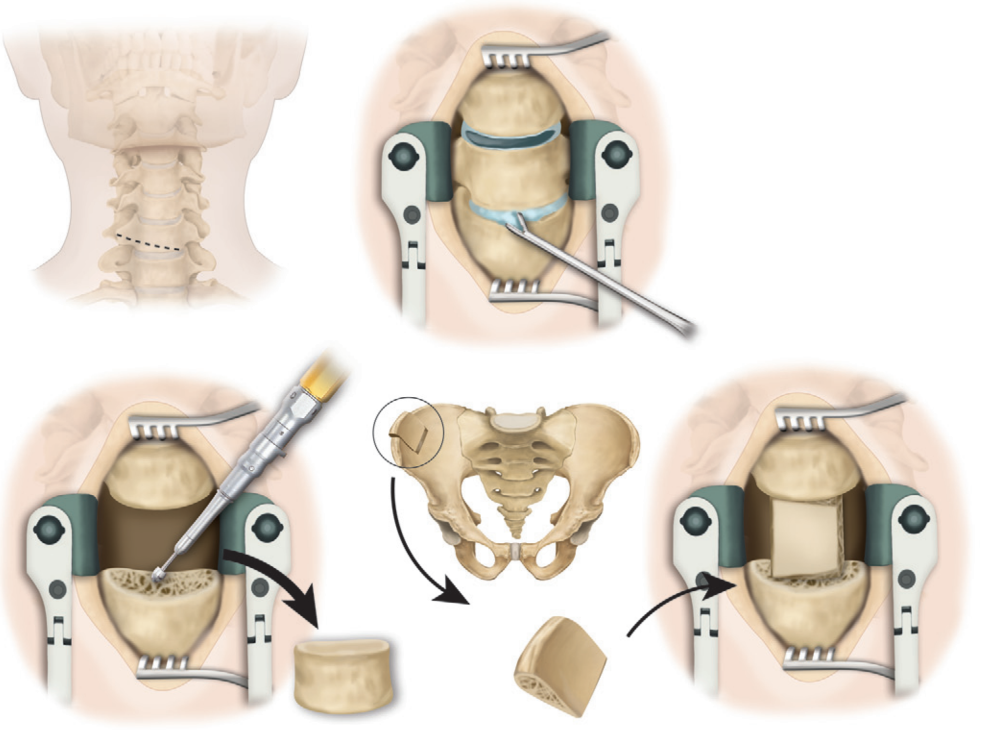

Figure 17-6 Tricortical iliac crest autograft can be harvested and sized appropriately to replace the vertebral body defect after a corpectomy.

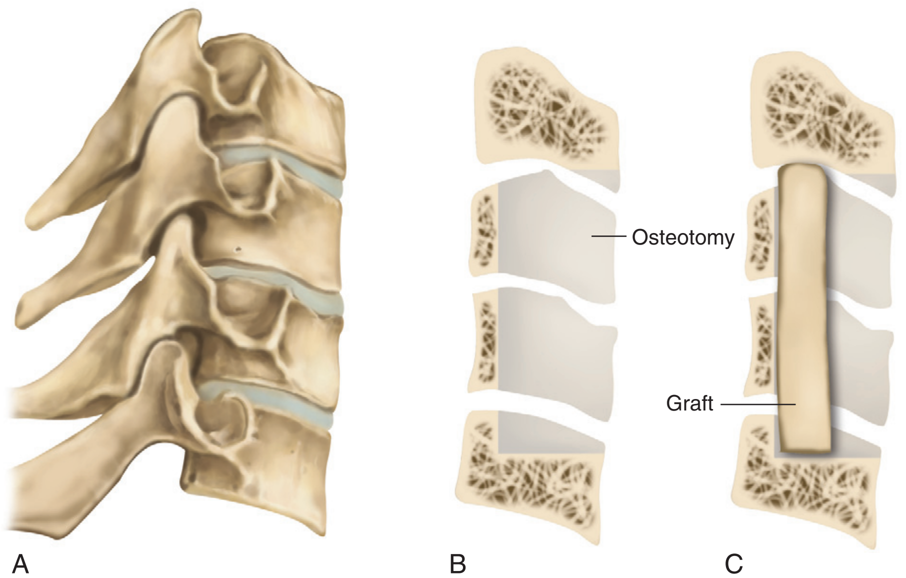

Figure 17-7 Steps to place a strut graft at the site of the corpectomy defect. **A,** Vertebral alignment before corpectomy. **B,** Partial corpectomy completed at two levels. **C,** Strut graft in place; the graft can be an allograft or autograft.

Figure 17-8 Lateral radiograph shows a fibular strut graft in place after a C4–C6 cervical corpectomy. Note that the fibular allograft central cavity has been filled with local autograft to provide improved fusion. An anterior cervical plate has been placed to prevent any graft kickout in the future.

fibular strut graft (Figs. 17-7 and 17-8) is most useful in multilevel corpectomies. A fibular graft has a central marrow cavity that can be filled with bone and provides a higher bone volume for fusion.

A variety of different operative techniques have been used to prevent graft extrusion, including notches and keyholing or dovetailing the end plates (Fig. 17-9).[9] They are well illustrated in the literature, and the two most common are the Whitecloud/LaRocca and the Zdeblick/Bohlman technique.[8-10] In the Whitecloud/LaRocca technique, the allograft fibula is notched at each end, and the superior and inferior vertebral bodies are notched at each end. The graft is impacted superiorly, and as traction is applied, the inferior portion of the graft is gently tamped into place. Notching allows the graft to be locked into the anterior cortices of the superior and inferior vertebral bodies.

The Zdeblick/Bohlman technique uses troughs drilled in the cortical end plates of vertebral bodies and insertion of the strut graft as a peg into the prepared end plates. The vertebral end plate is extremely important in preventing graft subsidence. The end plates of the adjacent vertebrae after corpectomy are preserved to prevent settling, and subchondral holes at the anterior margins of the end plates are created to fit the pegs of graft to facilitate acceptance.[10]

Polymethylmethacrylate Reconstruction

Polymethylmethacrylate (PMMA) is a reasonable option for vertebral reconstruction,[11] especially in cancer patients, because it provides inexpensive and immediate stabilization without bony fusion. It is unaffected by tumor invasion and is safe for patients who subsequently undergo radiation therapy. PMMA alone leads to construct failure, and a number of novel methods to augment PMMA to vertebral bodies have now been described that include use of Steinmann pins and internal screws and plates (Fig. 17-10), hooks, Harrington rods, Kirschner wires (K-wires), and chest tubes.[12]

Titanium Mesh Cages/Harms Cage

Titanium mesh cages have been widely used for spinal reconstruction since their introduction in 1986 (Fig. 17-11). These cages can be used as structural devices to contain autologous local bone or iliac crest bone graft, obviating the need to harvest structural bone grafts. Their advantages are that they can be customized to the exact size required, and the supply is unlimited. Disadvantages include increased cost, difficulty with end plate coverage, and difficulty assessing fusion status. Major complications are the result of subsidence and instrumentation failures, especially in patients with osteopenic bone. Cages with end plates or integrated screws address this. More subsidence is noted with titanium mesh cages, although this might not significantly alter the clinical outcome unless the subsidence is significant (>3 mm).

Modular Cages

Polyetheretherketone (PEEK) cages have become a popular interbody graft material that can be used for anterior cervical interbody fusion (Fig. 17-12). For corpectomy, variable height is addressed with stackable cage designs using PEEK, carbon-fiber reinforced PEEK (CFRP), or other materials, including titanium. The plastic and carbon-fiber cages try to emulate the modulus of elasticity that is close to that of bone. In theory, this allows the tensile and compressive forces to be transmitted to the bone within and surrounding the cage and avoids stress shielding of the bone. The strength of CFRP is twice that of PEEK. Both types of cages can be filled with bone graft to promote fusion, and they are often radiolucent.

Expandable Cages

Expandable titanium cages are the latest construct for vertebral body replacement after a cervical corpectomy (Figs. 17-13 and 17-14). They allow vertebral height adjustment in situ; hence the sizing is easier compared with a mesh cage. A disadvantage is their smaller caliber for packing bone versus a simpler cage, yet studies indicate high fusion rates.[13] These cages provide excellent structural support but also allow for greater end plate compressive forces, and they can help correct cervical kyphosis with restoration of height and sagittal alignment simultaneously; they have a wide footprint that helps distribute forces evenly. Expandable titanium cages can be used with good results in settings of vertebral osteomyelitis, and they have a low rate of infection recurrence even in combination with allograft.[14]

Cage subsidence is a known problem with all titanium cages and is found to be higher in multilevel corpectomies with no posterior fusion; in patients with malignant spinal involvement and rigorous preparation of end plates; and in those with osteoporotic bones and overdistraction with the expandable cage.[15,16] Overall cage placement is much easier with expandable cages and results in less end plate damage from intraoperative placement.[17] Newer expandable cages come with an integrated plate that obviates the need for any additional anterior plating, and it prevents graft migration (Fig. 17-15).

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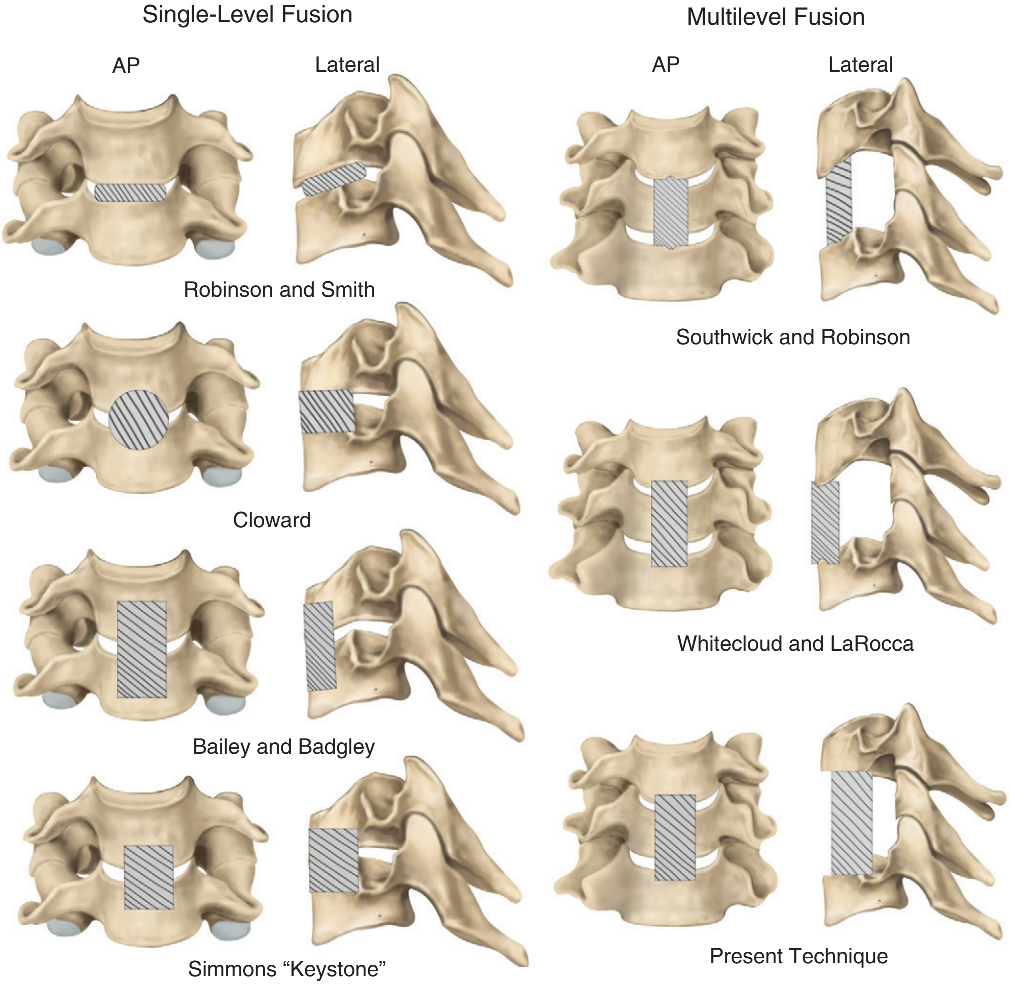

Figure 17-9 Evolution of cervical fusion techniques. The first column shows examples of single-level fusion. Note that the Robinson-Smith technique is the most commonly used technique for anterior cervical fusion. The second column shows multilevel fusions: two types of notching techniques can be used to hold a bony autograft or allograft after a cervical corpectomy. AP, anteroposterior.

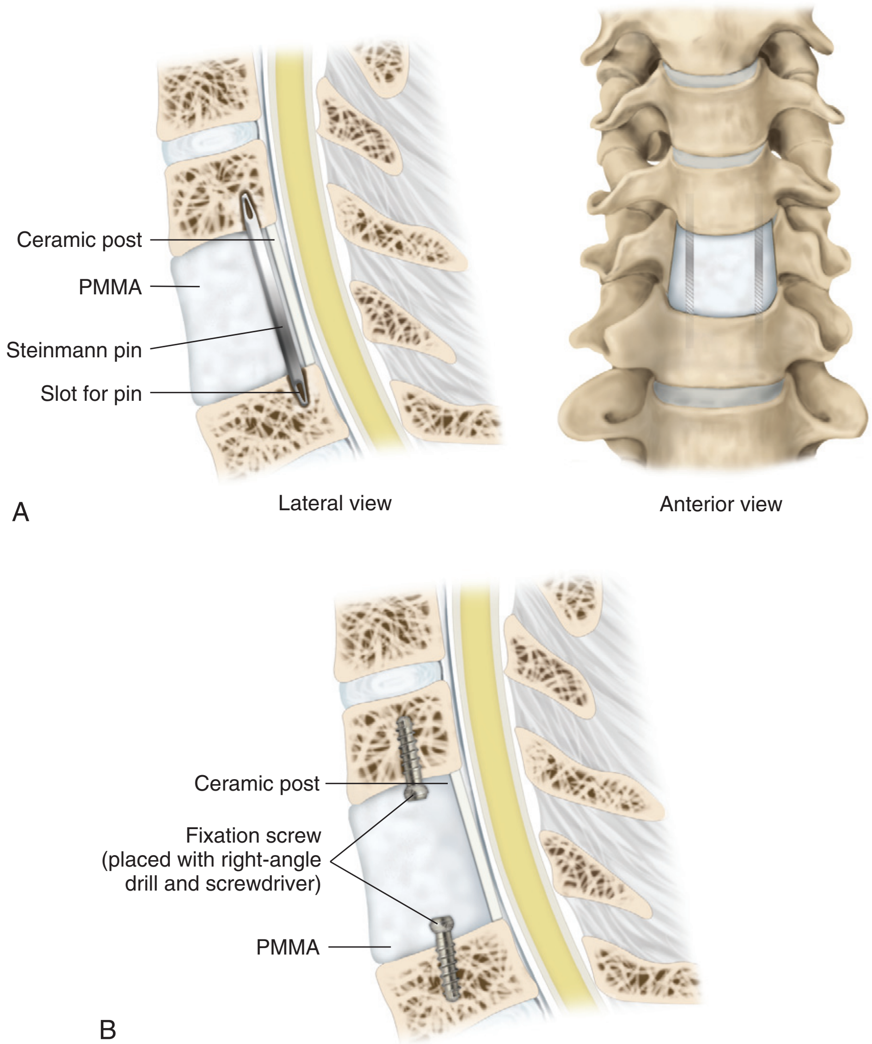

Figure 17-10 Techniques of vertebral body reconstruction using polymethylmethacrylate (PMMA). **A,** Using a Steinmann pin. **B,** Using a fixation screw.

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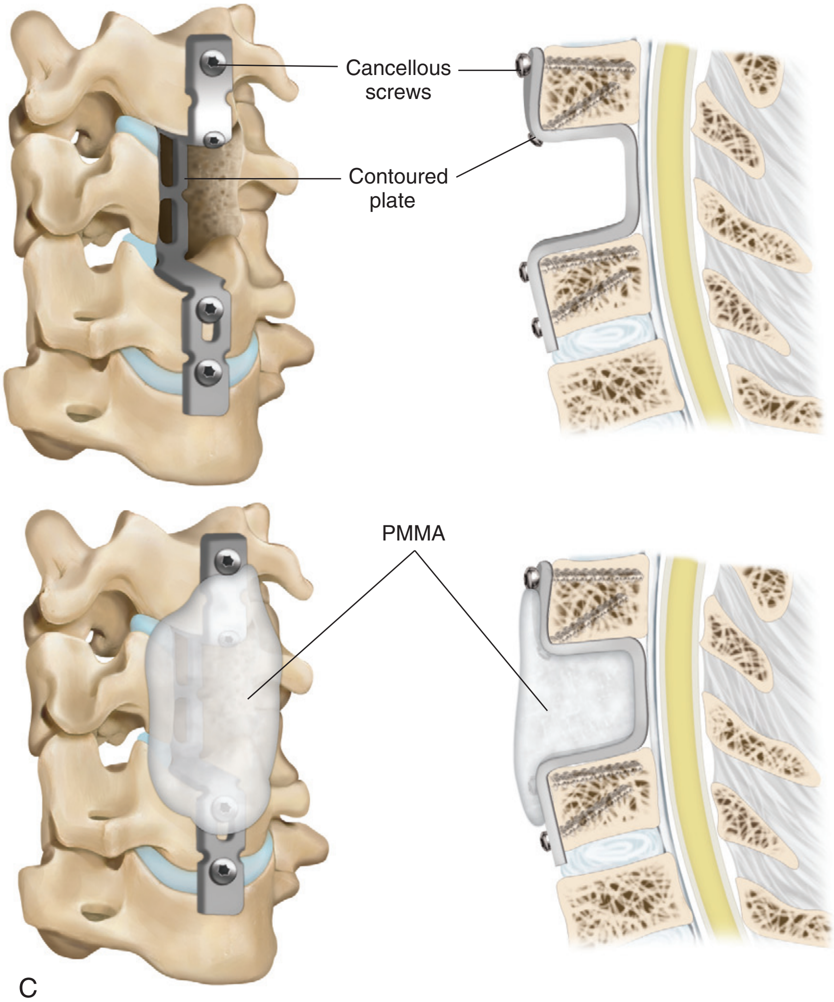

Figure 17-10, cont'd **C,** Using a contoured plate.

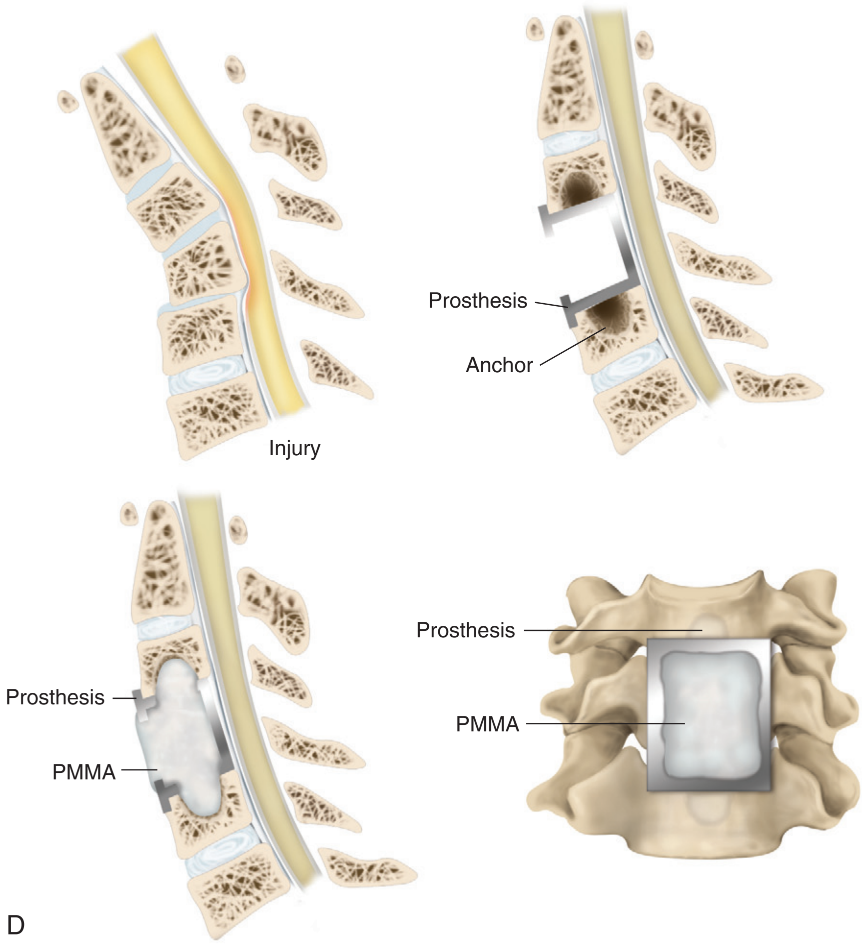

Figure 17-10, cont'd **D,** Using an anchoring plate.

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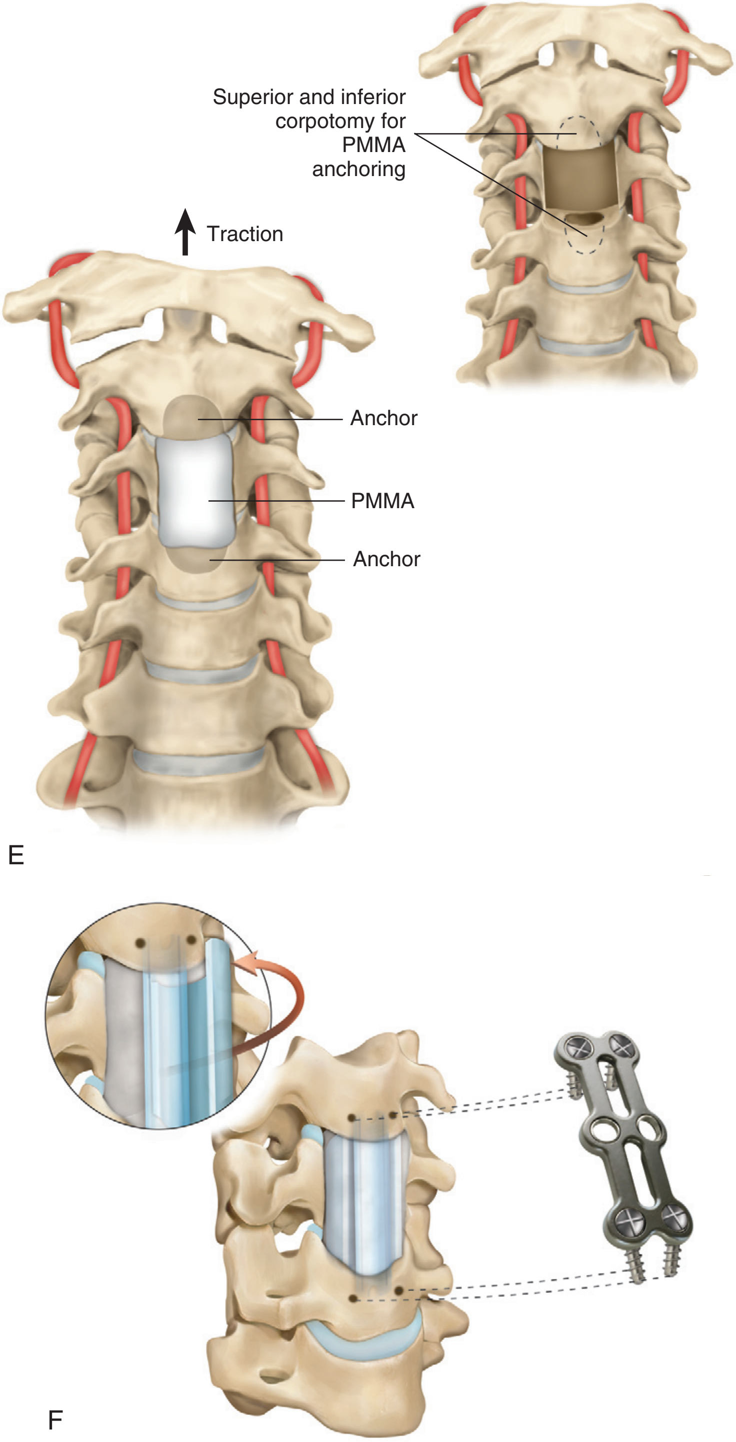

Figure 17-10, cont'd **E,** Using an anchoring notch. Gelfoam is used to prevent thermal injury to the dura while the PMMA is setting. **F,** Using the coaxial double-lumen method for placing PMMA.

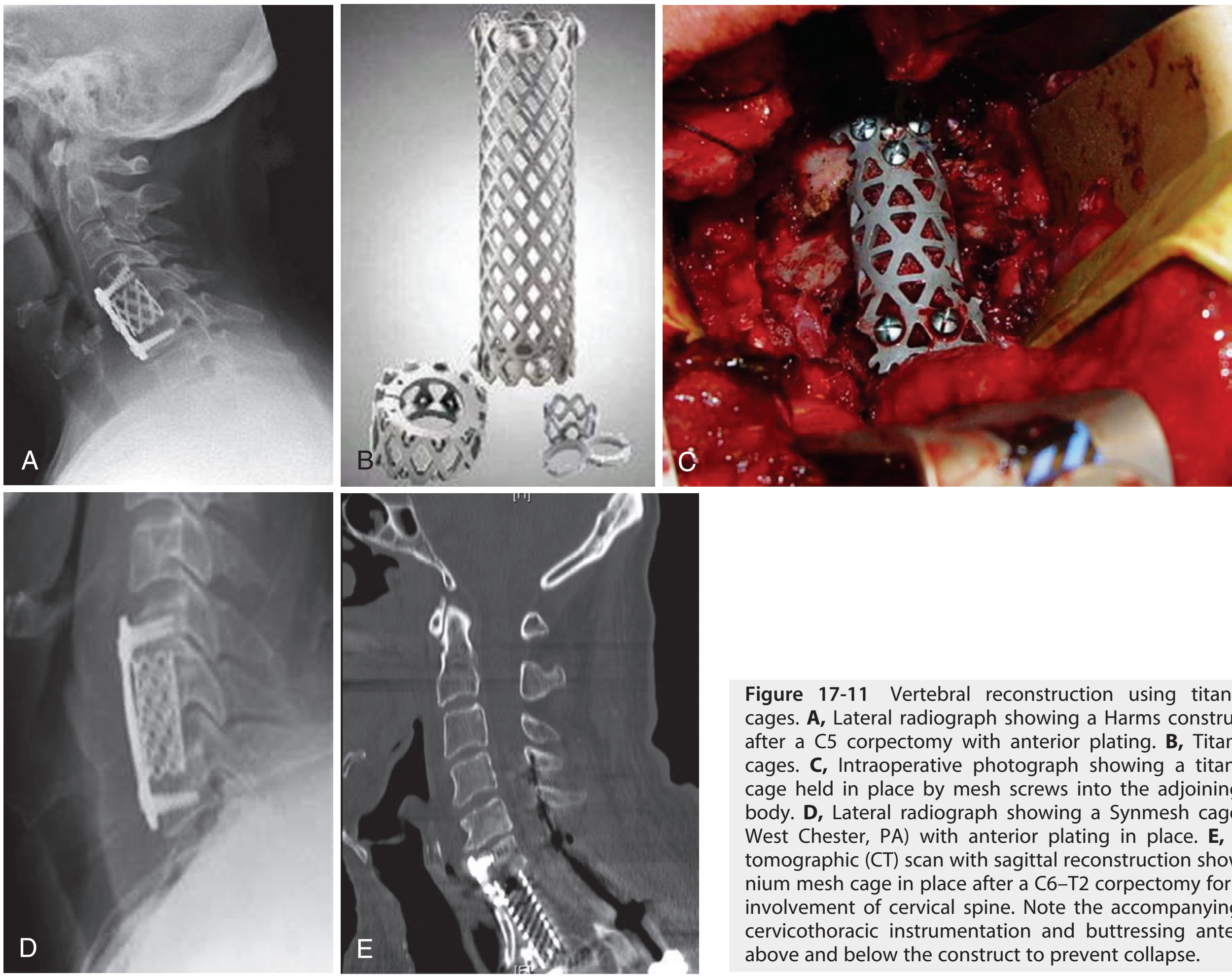

Figure 17-11 Vertebral reconstruction using titanium mesh cages. **A,** Lateral radiograph showing a Harms construct in place after a C5 corpectomy with anterior plating. **B,** Titanium mesh cages. **C,** Intraoperative photograph showing a titanium mesh cage held in place by mesh screws into the adjoining vertebral body. **D,** Lateral radiograph showing a Synmesh cage (Synthes, West Chester, PA) with anterior plating in place. **E,** Computed tomographic (CT) scan with sagittal reconstruction showing a titanium mesh cage in place after a C6–T2 corpectomy for metastatic involvement of cervical spine. Note the accompanying posterior cervicothoracic instrumentation and buttressing anterior plates above and below the construct to prevent collapse.

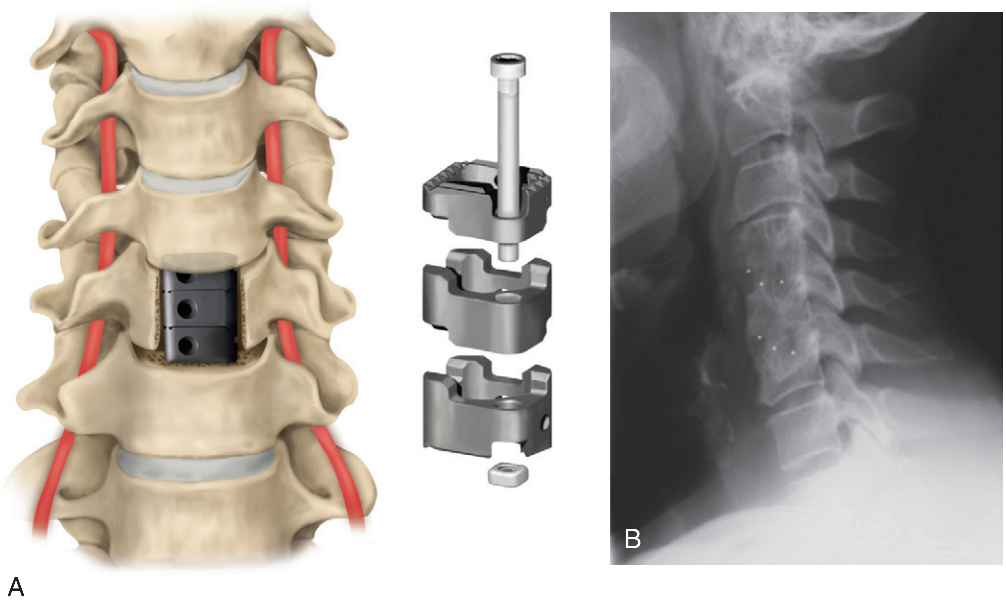

Figure 17-12 **A,** Modular cervical cages made of carbon-fiber–reinforced polymer can be used for fusion after corpectomy and may be stacked to achieve the necessary height (Bengal; DePuy Spine, Raynham, MA). **B,** Lateral cervical radiographs show carbon-fiber–reinforced polyetheretherketone cages in place; these radiolucent cages can help appreciate postoperative fusion easily. (From Ryu SI, Mitchell M, Kim DH: A prospective randomized study comparing a cervical carbon fiber cage to the Smith-Robinson technique with allograft and plating: up to 24 months follow-up. *Eur Spine* J 2006;15:157–164.)

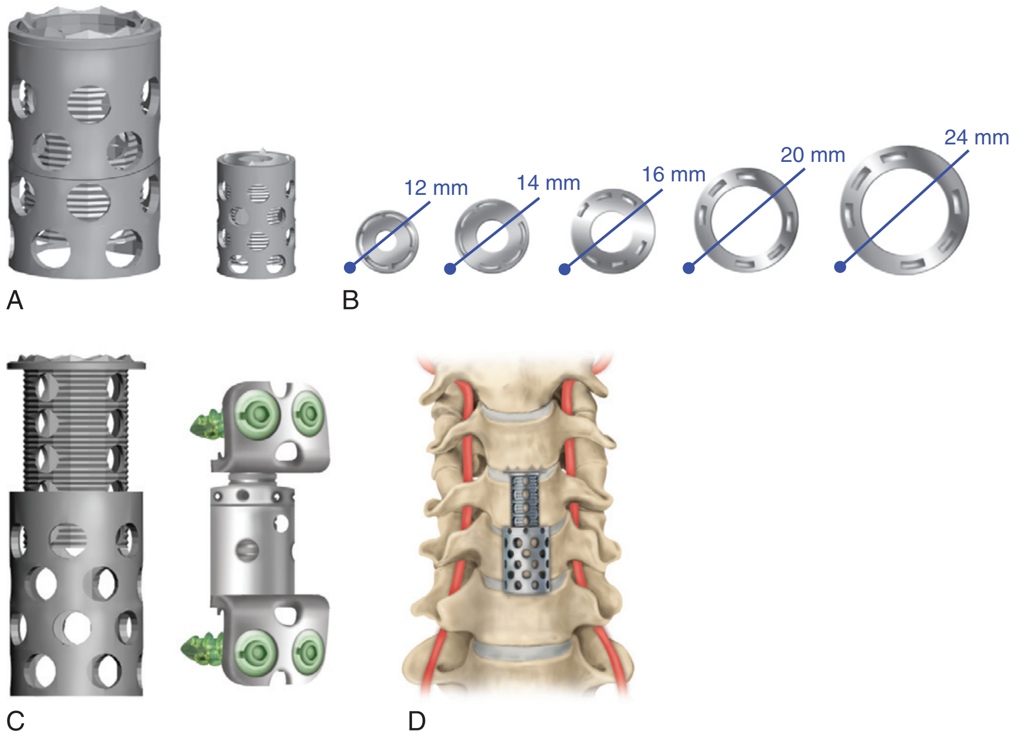

Figure 17-13 Expandable cages available for cervical vertebral restoration. **A,** Anterior distraction device and vertebral body replacement cages (Ulrich Medical, Ulm, Germany). **B,** Various sizes are available from 12 to 24 mm. **C,** Expanded VBR cage and an expandable cage-plate construct. **D,** Expandable cervical cage in place following a bilevel corpectomy.

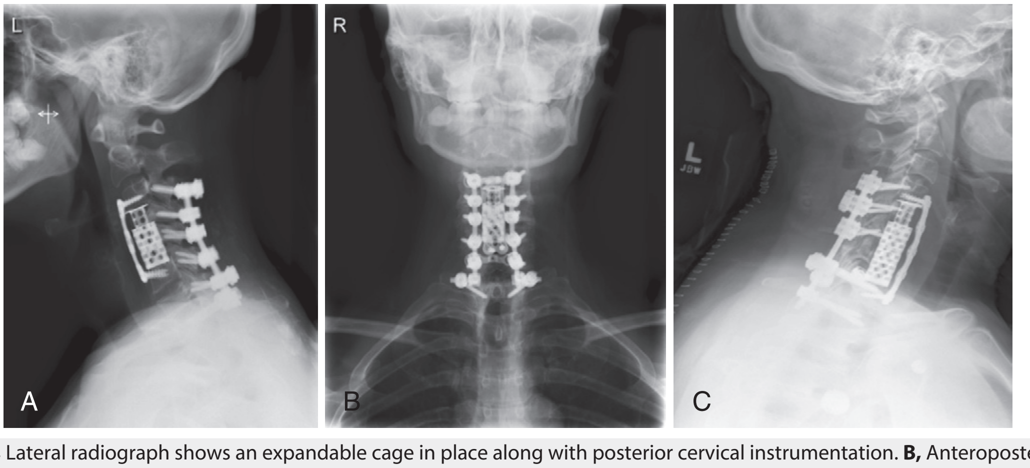

Figure 17-14 **A,** Lateral radiograph shows an expandable cage in place along with posterior cervical instrumentation. **B,** Anteroposterior radiograph shows an expandable cage in good position in midline and spanning the posterior cervical instrumentation construct. **C,** Expandable cage in place after a C5–T1 corpectomy and posterior cervicothoracic instrumentation. Note the correction of cervical deformity and mechanical support provided by the expandable cage construct.

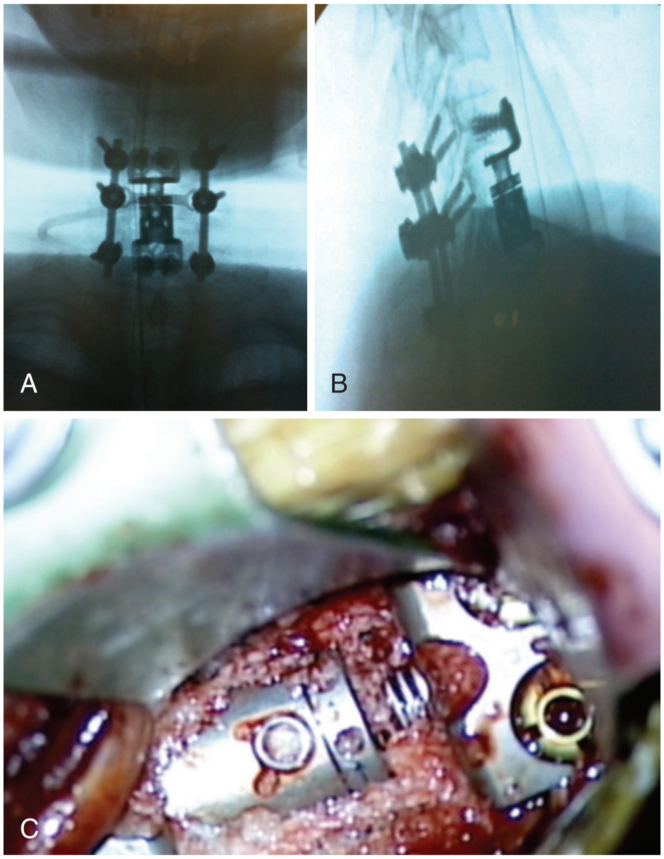

Figure 17-15 **A,** Anteroposterior radiograph showing an expandable cage-plate construct in place (ADD; Ulrich Medical, Ulm, Germany). **B,** Lateral radiograph demonstrates the same construct. **C,** Intraoperative photograph shows an expandable cage-plate construct in place after a cervical corpectomy. Note the bony allograft placed in and around the cage to allow improved fusion.

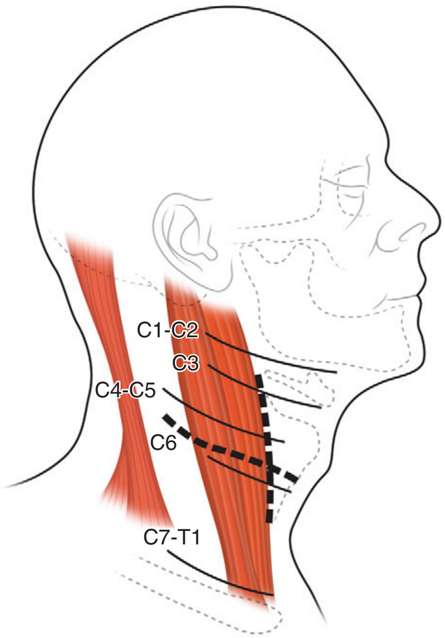

Figure 17-16 Incision lines in relation to the anatomic structures. The hyoid bone overlies at C3, thyroid cartilage at C5, cricoid ring at C6; the supraclavicular level is accessed for the C7–T1 region. Note that a horizontal or vertical incision may be used depending on intended extent of the corpectomy.

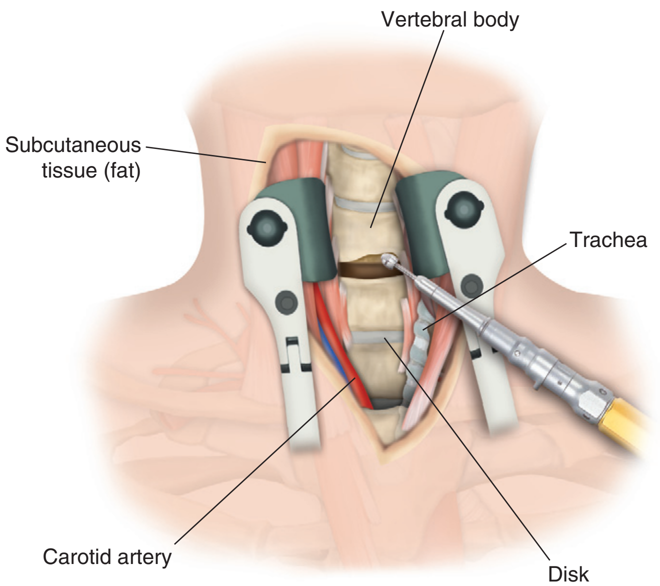

Figure 17-17 Anatomic relationships in the anterior neck during a corpectomy. Note that the trachea and esophagus are retracted medially and the carotid artery is retracted laterally for the approach.

PREOPERATIVE CONSIDERATIONS

Patient Positioning

- The patient is positioned supine, neck midline with a gel donut, and in slight extension with a shoulder roll, if needed.
- An incision is marked along a skin crease that extends from the anterior border of the SCM to slightly across the midline or along the medial aspect of the SCM.
- Preoperative verification of fluoroscopy images is very useful.

APPROACH (Figs. 17-16 and 17-17)

- A horizontal incision works for single-level or bilevel corpectomy, whereas a longitudinal incision for multilevel corpectomy may be better.
- The anterior cervical spine is exposed by a routine anterior approach, described earlier.
- A spinal needle is used to localize the correct level and adjoining disk spaces.
- The longus colli muscles are undermined on each side, and retractors are placed.
- Caspar pins are placed in the vertebral bodies above and below the level of planned corpectomy; predrilled pilot holes minimize screw placement trauma.
- Caspar distractors are placed, and gradual distraction is applied.

DISKECTOMY (Fig. 17-18)

- A #15 blade is used to make an annulotomy in the adjoining disk spaces.
- Disk material is removed, and end plates are identified in standard fashion.

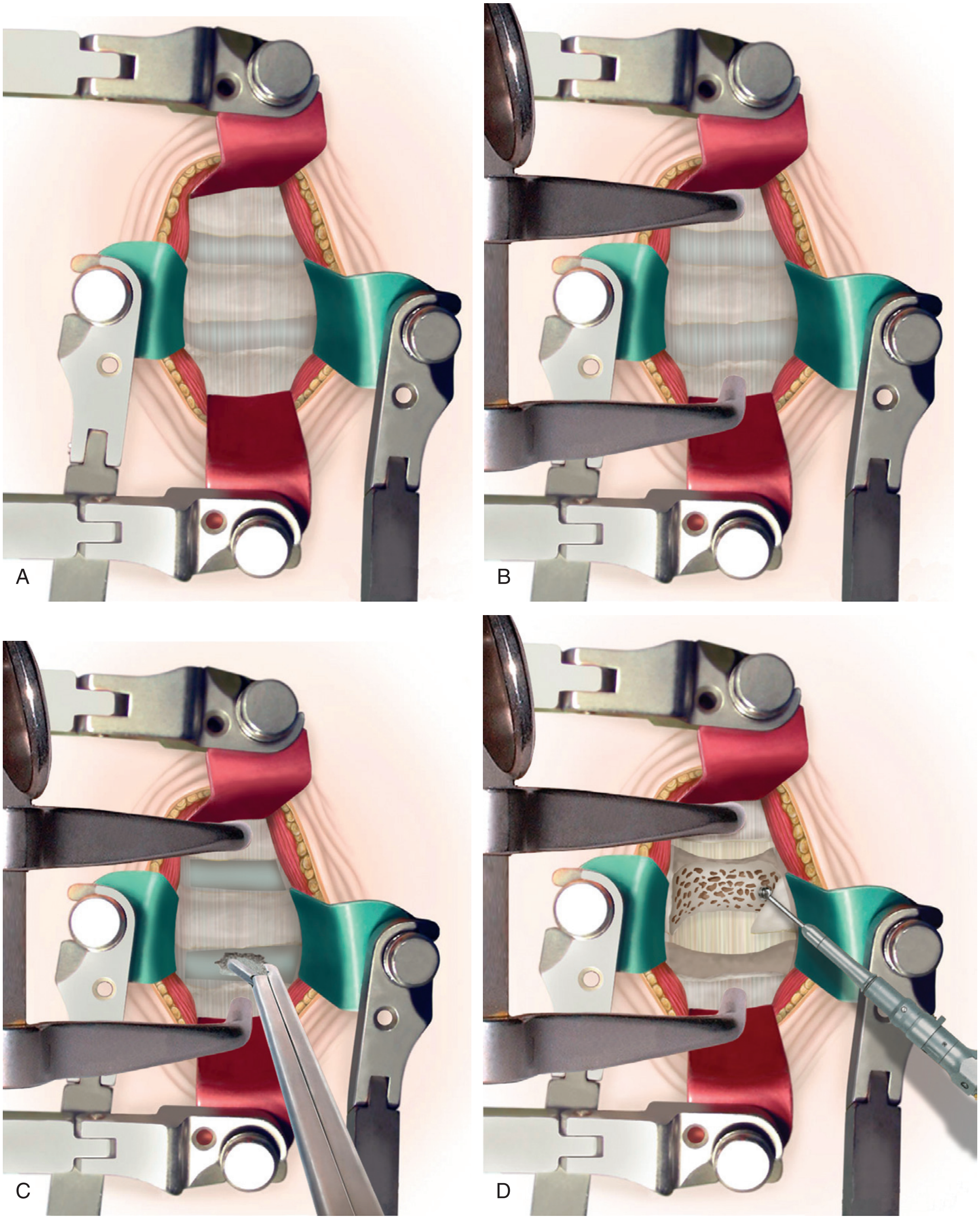

Figure 17-18 Technique for cervical corpectomy. **A,** Exposure of vertebral bodies with retractors in place. **B,** Caspar posts and distractors placed to provide gradual distraction. **C,** Diskectomies completed above and below the level of corpectomy. Curettes and pituitary forceps are used to clear the disk material. **D,** Extent of corpectomy is defined and vertebral body is resected using a high-speed drill and Leksell rongeurs.

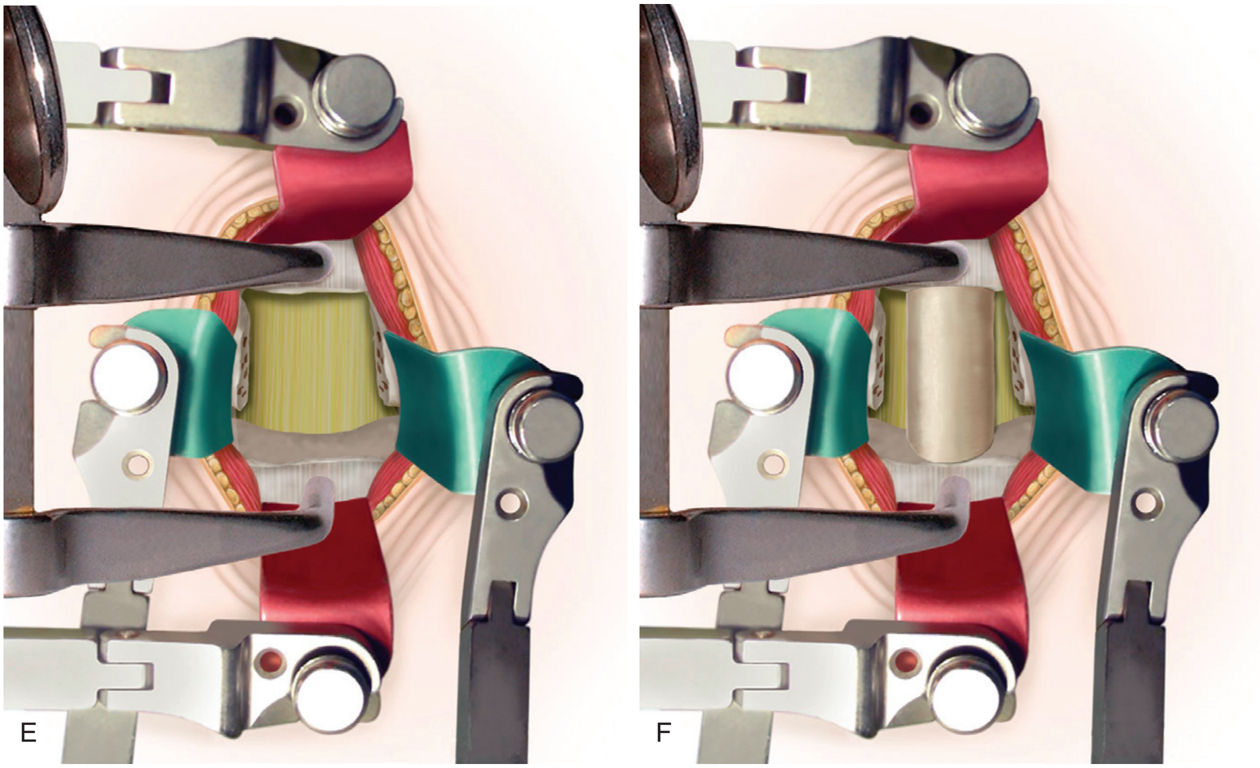

Figure 17-18, cont'd E, Once the vertebral body is removed and the posterior cortex is thinned to an eggshell, nerve hooks and up-biting curettes are used to remove the posterior longitudinal ligament (PLL). **F,** Completion of cervical corpectomy with exposure of glistening dural surface after removal of the PLL.

- A high-speed drill with a matchstick burr is used to gently drill end plates.

CORPECTOMY

- The midline of the vertebral body is defined carefully using sternal notch landmarks and the uncovertebral joints on each side.
- The width of the corpectomy should not be more than 15 mm across at first; often a small (half inch) cottonoid can be used to get an approximate estimate of the extent of bone to be removed.
- Troughs are drilled on each side of the identified area with a matchstick burr.
- Bleeding is controlled with bone wax packed into the troughs during this process.
- A small rongeur or an upgoing curette can be used to remove bone that may be used as an autograft.
- Any residual posterior cortex can be thinned with a cutting or diamond burr, until the PLL is clearly identified. Alternately, a thinned posterior cortex can be removed using up-angled curettes. It is often useful to limit the lateral trough depth until this is thinned out to prevent a floating bone mass.
- Once the posterior cortex is burred down along the lateral channels/troughs, the central portion of the body will float away from the spinal canal.
- A wide corpectomy will put the vertebral artery at risk, so dissection should not be more lateral than the uncovertebral joints on each side unless necessary.
- Foraminal decompression can be completed with Kerrison rongeurs while using a nerve hook to feel for adequate decompression.
- The bony removal may be done in an "Erlenmeyer flask" configuration that is wider posteriorly (Fig. 17-19).

END PLATE PREPARATION

- A high-speed drill is used to prepare end plate surfaces that are partly decorticated to allow better fusion.
- Curettes may also be used for a similar purpose to remove any disk material and prepare end plates.
- A variety of techniques may be used to prevent graft from being dislodged at this time. A 2 mm posterior shelf of bone is either created or is left on the end plate of the inferior vertebral body to prevent migration of the graft.

REMOVAL OF POSTERIOR LONGITUDINAL LIGAMENT

- Once the posterior cortical bone is removed, the PLL is visualized; it could be a number of layers and may be fused to the dura.
- It is crucial to identify the plane between the PLL and dura. This can be done using a small nerve hook laterally at the neural foramen to get under the PLL and define the plane, using Kerrison rongeurs for the resection.
- Dura can appear as a smooth, shiny, pulsating layer.
- Bipolar electrocautery can be used for hemostasis along the edges of the PLL and from epidural veins.

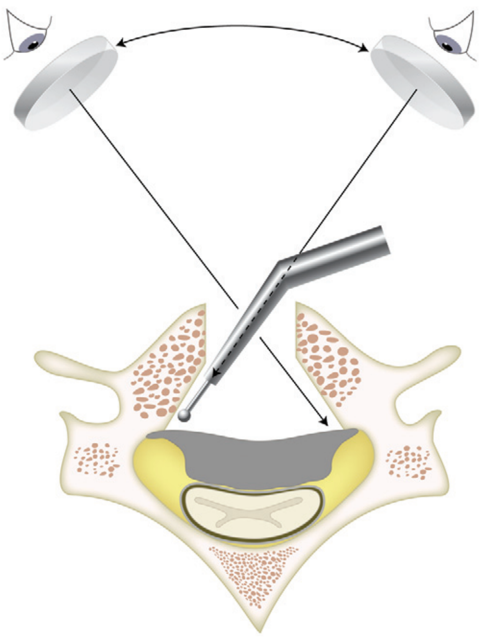

Figure 17-19 Erlenmeyer flask configuration of bony removal during a typical corpectomy. This is especially useful in ossified posterior longitudinal ligament cases, in which drilling is done laterally to minimize the risk of spinal cord damage.

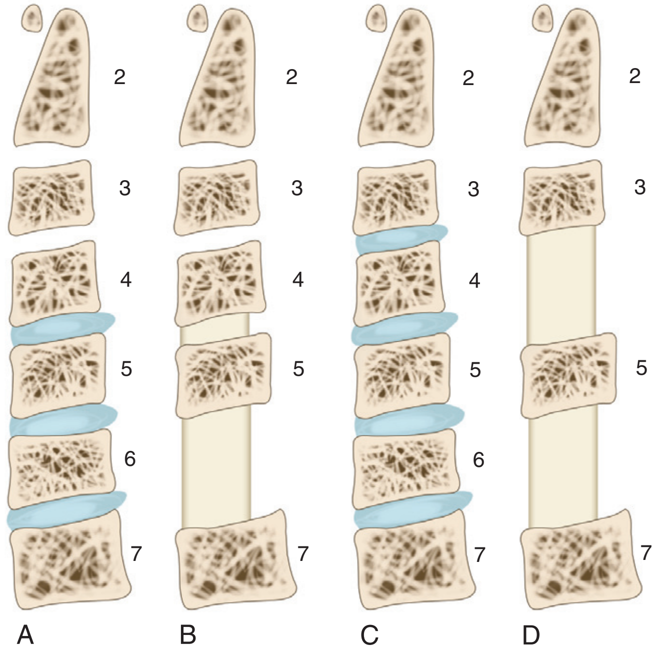

Figure 17-20 Examples of corpectomy constructs in multilevel degenerative disk disease. **A** and **B,** Single-level corpectomy at C6 with diskectomies at C5–C6 and C6–C7. **C** and **D,** Two-level skip corpectomy at C4 and C6 and diskectomies at C3–C4, C4–C5, C5–C6, and C6–C7 with C5 vertebral body left intact.

- Gelfoam and FloSeal hemostatics can be used to control epidural bleeding.

VETEBRAL REPLACEMENT PREPARATION

Bone Graft (Fig. 17-20)

- Tricortical iliac crest is harvested with osteotomes and sized for the vertebrectomy defect. Alternatively, fibular autograft or allograft may also be used.
- The bone graft is placed under distraction with the anterior surface of the graft flush with the anterior surface of the vertebral body.
- Distraction is then removed to allow a snug fit for the bone graft. Fluoroscopy is useful here.
- A radiograph is obtained to confirm graft position and to check for any impingement of the spinal canal. A nerve can be used to feel space dorsal to the graft. To remove the graft, distraction is applied, and an up-angled curette is used to dislodge the graft.
- The interspaces and slit between the graft and vertebral bodies are amply filled with previously harvested bone chips.

Polymethylmethacrylate (see Fig. 17-10)

- PMMA can be used in a variety of ways as discussed above, either with a Steinmann pin or using a coaxial double-lumen reconstruction with chest tubes.
- Care is taken to protect dura from thermal injury while the PMMA is setting by using a layer of Gelfoam over the dural surface.

Titanium Nonexpandable Cages (see Fig. 17-11)

- A caliper is used to measure the height of the vertebrectomy defect, and an appropriate cage is selected and sized accordingly.
- The cage is packed with bone graft before placement under distraction. The cage may be shaped to introduce a slight lordosis before placement.
- End rings are also available to provide angulation and to prevent graft subsidence.

Modular Cages (see Fig. 17-12)

- PEEK and CFRP cages come in predetermined heights and can be stacked to achieve needed height; cages of other materials may be precut to various heights.
- The central space of the spacer can be filled with bone graft before placement under distraction.
- Radiopaque markers on the device help visualize depth during placement.

Expandable Cages (see Fig. 17-13)

- A caliper is used to find the appropriate size range for the cage and diameter.
- The cage is packed with graft and is placed in the space and gently distracted.
- Fluorosocopy is very useful to ensure no overdistraction or migration.
- The cage is then locked in place with the locking mechanism.
- Bone graft is placed around the cage to assist in fusion.

SUPPLEMENTAL INSTRUMENTATION

Anterior Plating (Figs. 17-21 and 17-22)

- Anterior cervical plates are routinely placed after an anterior cervical corpectomy to prevent graft migration.

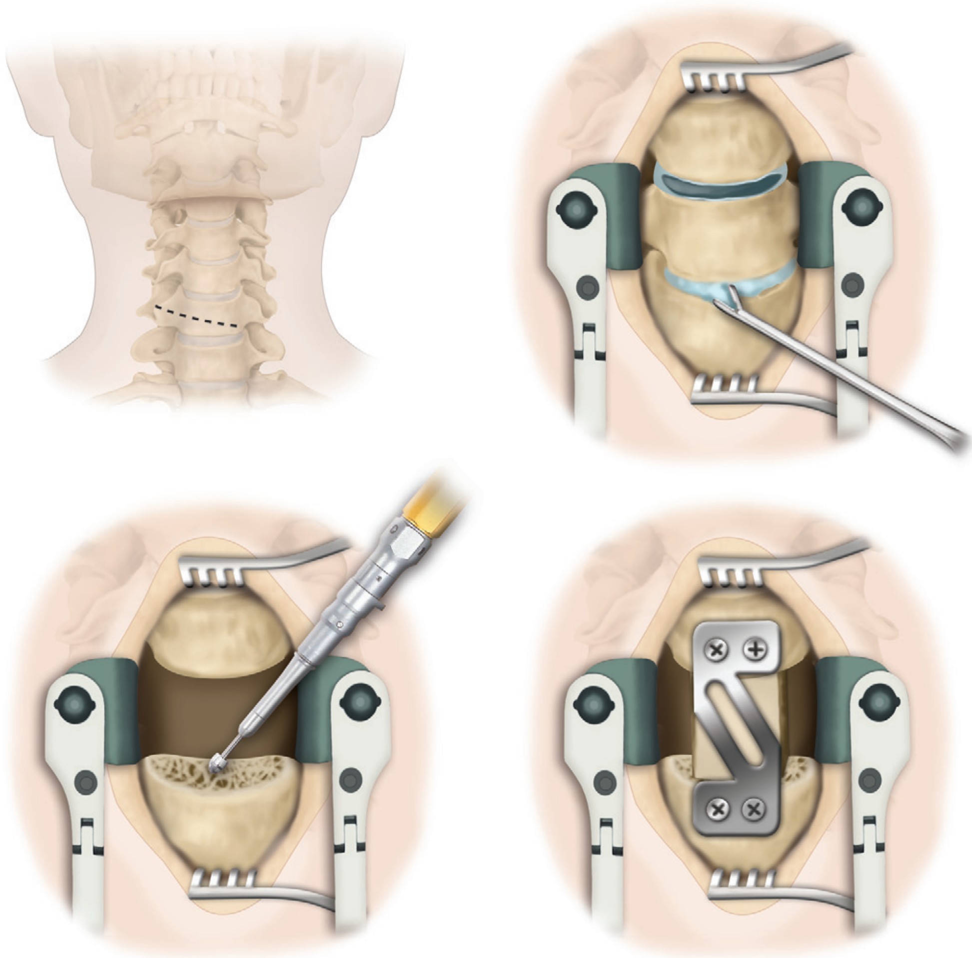

Figure 17-21 Anterior plating after a single-level corpectomy.

- Anterior plating leads to increased fusion rate, decreased time to fusion, diminished use of postoperative bracing, faster return to activities, and restored cervical sagittal balance.[1]
- Ample “gardening” of osteophytes should be done before plate application to allow the plate to sit flat.
- The plate can be bent slightly in the sagittal plane to achieve lordosis as needed.

Adjunct Posterior Instrumentation

- Posterior cervical stabilization in the setting of a multilevel corpectomy can prevent graft subsidence, improve sagittal correction, and improve fusion rates.
- Decisions must be made on a case-by-case basis.

CLOSURE

- The wound is closed in layers, starting with closure of the platysma with 3-0 vicryl sutures.
- The subcutaneous layer is closed with 3-0 vicryl sutures.
- 4-0 Monocryl may used for a subcuticular closure.
- Steri-Strips or Dermabond is used to close the skin surface.
- Drain stitches are placed as needed.

Postoperative Care

- Most patients can be extubated, unless a concern for airway swelling is present, and they can be sent to the medical/surgical floor.
- In extensive corpectomies, it is prudent to leave patients intubated in the intensive care unit.
- Steroids are given to reduce airway and soft-tissue swelling.
- Antibiotics are continued while drains are in place.
- Cervical hard-collar external immobilization is routine.
- Patients are started on a clear liquid diet and are advanced as tolerated; slow advancement is prudent.
- Postoperative anteroposterior and lateral radiographs are obtained for instrumentation and baseline imaging.

Complications

SOFT TISSUE

- Complications of soft tissue are most commonly the result of inadequate release of fascial tissue planes with damage to the esophagus and trachea.
- Injury may be minimized by taking time to release tissue planes, particularly superficially, before proceeding

deeper and by releasing retractors intermittently during operation.

VASCULAR

- Carotid injury is uncommon but possible during exposure, especially in patients with malignant involvement and prior irradiation.
- Vertebral artery injury can occur during the corpectomy when the defect is too lateral or the trajectory is too oblique.

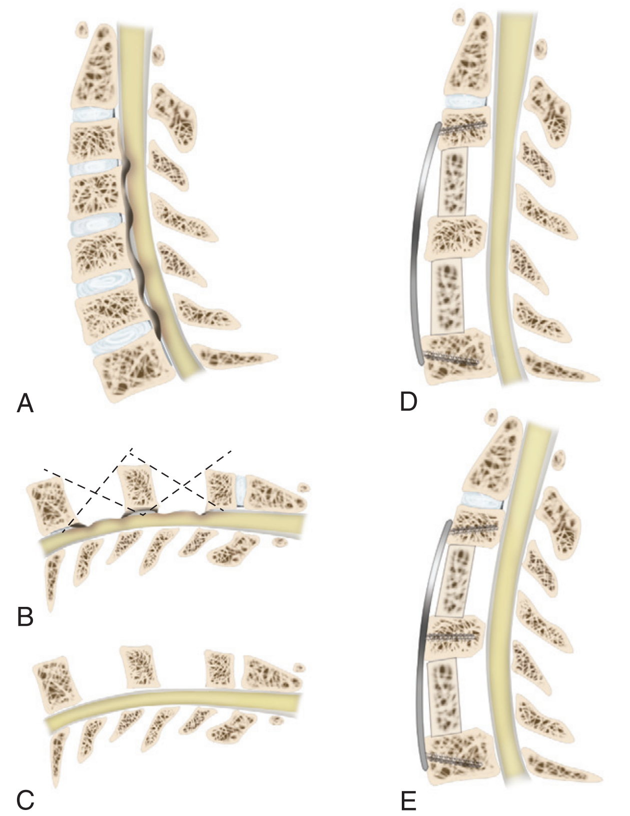

Figure 17-22 Technique of corpectomy, decompression, and vertebral reconstruction in ossified posterolateral ligament.

- Complications can be minimized by studying preoperative scans to note any anomalies of vertebral artery anatomy, such as the artery being too medial or having anomalous entry levels.

NEUROLOGIC

- Recurrent laryngeal nerve may be injured during exposure and prolonged retraction. Deflating and reinflating the endotracheal tube cuff after retractor placement may minimize this.
- The risk of recurrent laryngeal nerve injury is theoretically less with a left-sided approach.
- Superior laryngeal nerve injury can lead to aspiration risk.
- Spinal cord injury should be prevented in areas of severe stenosis by (1) avoiding the use of larger rongeurs and (2) using a high-speed burr to eggshell the bone.
- A cerebrospinal fluid leak can sometimes occur, especially with ossified PLL; repair may involve only dural substitute, fibrin glue, and lumbar drainage.
- Sympathetic chain injury can occur if exposure extends laterally over the surface of the longus colli, which can lead to ipsilateral Horner syndrome.
- C5 transient neuropathy can occur after any cervical decompression.
- Postoperative hematoma can cause rapid postoperative neurologic deterioration; drain when in doubt.

OTOLARYNGOLOGIC

- Malignant swelling of the trachea, larynx, and pharynx. Transient swallowing difficulty is the norm.
- Swallowing difficulty may be severe to the extent that it requires a temporary or permanent feeding tube.
- Speech difficulty may result from swelling or laryngeal nerve injury.

GRAFT COMPLICATIONS (Fig. 17-23)

- Pseudarthrosis occurs more with allograft than with autograft, and it occurs more with less bony surface area.

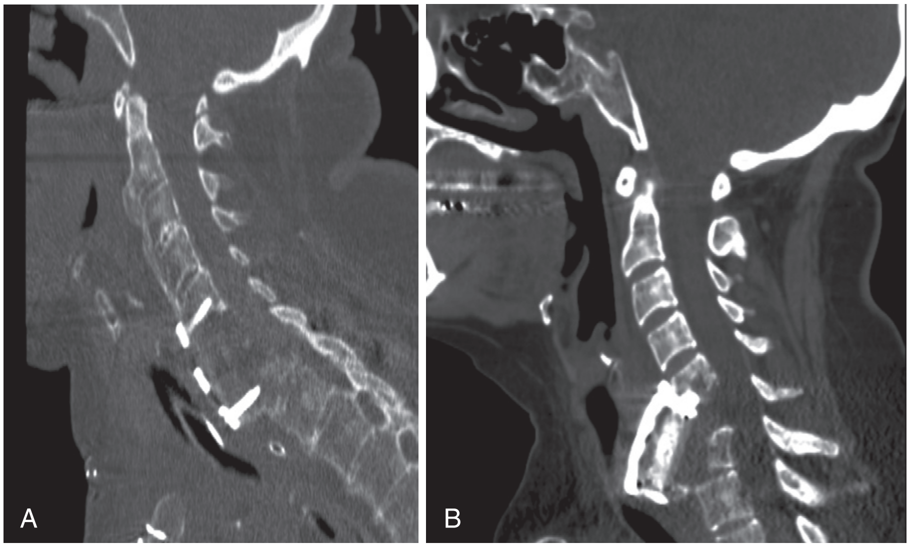

Figure 17-23 Computed tomography scans with sagittal reformats show complications after cervical corpectomy. **A,** Graft dislodgment and screw pullout inferiorly. **B,** Complete failure of the fusion construct with anterior kickout of the graft and plate.

- Dislodgment is possible; the longer the strut graft, the greater the leverage placed on the graft, particularly at the caudal end during cervical extension. Cages with teeth help mitigate this.
- Consider instrumentation and external immobilization to prevent graft migration.
- Settling and bone collapse may occur. Graft is stronger than bone, and it telescopes or settles into the bone; stress shielding can cause the graft to be protected such that it will not fuse.

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18 Anterior Cervical Instrumentation Techniques

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Overview

Although intense discussions persist in regard to which approach should prevail in treating pathology of the cervical spine, anterior approaches have become vastly more common and accepted over the last few decades. The anterior approach affords the surgeon the most direct route to ventral compressive pathology, and it is achieved through a small incision, without excessive blood loss, while providing ready access from C2–C3 to T1.[1] Surgical techniques have been variable since the initial reports from Cloward and Smith and Robinson. Regardless of individual preferences, anterior fusions have become an indispensable tool in the armamentarium of spine surgeons for dealing with a wide range of pathologies.

Anatomy Review

Surface anatomy may help localize levels of vertebrae. The most superior bony prominence below the mandible is the hyoid bone, and it commonly demarcates C3; the hyoid bone can be palpated at the angle of the mandible. The thyroid cartilage is typically over C4–C5, and the cricoid cartilage marks C5–C6.[1] With heightened attention to avoiding wrong-level surgery, the use of anatomic landmarks alone is discouraged. The authors use fluoroscopy with an endotracheal tube stylet as a radiopaque marker to localize the targeted levels and plan a skin incision. Transverse and longitudinal incisions[2] and both left- and right-sided approaches have been described.[1] The variable course of the recurrent laryngeal nerve on the right and its vulnerability to injury gives reason for some to advocate a left-sided approach; however, the thoracic duct is on the left side, and chylothorax is a serious complication that can be avoided with the right-sided approach.

No side of approach to the anterior cervical spine is undisputed, and surgeon handedness plays an important role in deciding which side to access.[1] We have found success even for multiple levels of decompression with a short transverse incision that just crosses the midline and spares more lateral exposure. We have successfully reached C2 to T2 with transverse incisions and mobilization above and below the platysma, and we seldom perform an incision along the sternocleidomastoid (SCM) unless a high anterior retropharyngeal approach is required to reach C1 (Figs. 18-1 and 18-2).

Indications

- Cervical spondylosis with myelopathy or radiculopathy
- Herniated nucleus pulposus with myelopathy or radiculopathy
- Trauma
- Infection
- Pseudarthrosis
- Ventral intradural pathology

Relative Contraindications

- Prior neck radiation
- Limitation by mandible superiorly and sternum inferiorly
- No absolute contraindication

Equipment

- Radiolucent operating table (helpful but not mandatory)
- Fluoroscopy
- Optical loupes
- Monopolar and bipolar cautery
- Cloward retractors
- Kittner dissector
- Black Belt self-retaining retractor
- 1- to 3-mm Kerrison punches
- High-speed drill (we prefer a 13-mm M-32 cutting burr)
- Up-angled curette
- Pointed nerve microhook
- Operating microscope
- Bone graft
- Cage
- Anterior plate and screws

Operative Technique

POSITIONING

- Adequate exposure is essential to optimal instrumentation and is contingent on sound positioning.
- A roll is placed between the shoulder blades to create gentle extension, provided this is not neurologically detrimental.

Figure 18-1 Lateral view of positioning of cervical spine. A donut, an intravenous infusion bag under the thoracic spine, and taping of the shoulders downward are used for adequate access to the cervical spine and optimal lordosis.

Figure 18-2 Use of a neck crease for incision planning.

- Keep the neck straight, although some have advocated slight rotation away from the proposed incision.[3]
- A donut is generally placed under the occiput, sometimes on top of towels, to avoid hyperextension and in conjunction with rolls above to obtain lordosis. The primary goal is to prevent rotation of the head after draping of the patient.
- The patient's arms are tucked, and the body is wrapped with care to pad bony prominences, particularly the elbows and wrists, to prevent a peripheral nerve injury. Gentle caudal retraction of the shoulders can facilitate lateral radiographic images.
- A lateral fluoroscopic image is acquired to assess degree of preoperative lordosis.
- A C-arm is draped in the field at the head of the bed. Although cranial tongs have in the past been advocated, we do not routinely use them.
- A Foley catheter is placed to avoid bladder distension and excess pressure on the inferior vena cava, reducing venous oozing from the bone and epidural plexus.
- Thromboembolic deterrent hose and sequential compression boots for deep vein thrombosis prophylaxis.
- Consider nasotracheal intubation for levels at or above C2–C3 (and C3–C4 disk space, depending on anatomy).[4]
- Other helpful devices used by some surgeons include a chin strap and Caspar head rest,[5] which help extend the neck and provide close juxtaposition to the patient, respectively. Some advocate the lounge position, with knees and back slightly flexed, to avoid stretch injury and pressure points and to offer a more direct view of the disk space.[5]

INCISION

- A fluoroscopic image is acquired with a radiopaque marker in the surgical field.
- When rostral-caudal self-retaining retractors are used in lieu of distraction pins, the exposure tends to shift caudally once the retractors are inserted. Planning for a slightly more rostral incision obviates this difficulty.
- The incision starts 2 to 5 mm to the left of the midline and is carried to the right approximately 4 to 6 cm in the lines of Langer.

TECHNIQUE FOR APPROACHING THE CERVICAL SPINE

- After skin incision, a self-containing retractor is placed, and the platysma is transected with monopolar cautery transversely. However, some authors prefer an anatomic splitting of the platysma, particularly for a single-level surgery.[5] Medial approaches with release and lateral reflection of the platysma have also been used.
- The platysma is then undermined rostrally and caudally, with the extent of each direction based on whether more exposure is needed inferiorly or superiorly.
- Superficial fascia investing the SCM is released, and the omohyoid is palpated. Although blunt dissection and retraction are often enough to release and obtain adequate exposure, this occasionally requires transection at the middle.
- The middle layer of the deep cervical fascia contains the omohyoid, trachea, and esophagus. The trachea and esophagus are retracted medially. The carotid artery may be palpated laterally, and the spine may be palpated medially and deep to the exposure.
- A handheld retractor is used with the nondominant hand to expose the spine, and the retractor can be given to the assistant when firmly on the spine and retracting midline structures away.
- A Kittner dissector is used to bluntly develop the plane of the prevertebral fascia, and bipolar cautery or a sheathed Bovie can be used to free the medial edges of the longus colli muscles, the center of which can be used to identify the midline.
- With the carotid sheath swept laterally, a Black Belt retractor system is placed using all four blades, although some choose only the lateral blades or defer placement until the appropriate level is confirmed.

- An 18-gauge spinal needle is bent twice to create a right angle at the distal end to prevent inadvertent advancement toward the spinal cord. Intraoperative fluoroscopy is used to place the needle in the intervertebral disk space.
- Once any levels of interest have been confirmed, the disk space is marked with either a skin marker or the Bovie, and the longus collus muscle is reflected further laterally if needed. Initial exposure is made with attention to avoiding disruption of the annulus of any disk that is not intended to be treated.
- The superior half of the most caudal vertebral segment to be included in the fusion is cleared of soft tissue as is the inferior half of the most rostral body.
- Care is taken not to disrupt the disk space of the level above or the level below the fusion construct.
- The dissection is carried out laterally to the uncovertebral joints.

TECHNIQUE FOR APPROACHING THE UPPER CERVICAL SPINE

An anterior approach to the basiocciput and upper cervical spine is complicated by the internal carotid artery, vagus, and hypoglossal nerves, all of which may be injured if retracted significantly. The approaches include dislocation of the temporomandibular joint, osteotomy of the mandible, transoral approach, and anterior retropharyngeal approaches.[4]

One effective extraoral approach, described by DeAndrade and MacNab, is via an oblique incision parallel to the anterior border of the SCM, which grants access to the retropharyngeal space anterior to the SCM and carotid sheath.[3] Unfortunately, this approach requires retraction or division of the laryngeal or pharyngeal nerves, which creates a minor but lasting hoarseness.[2] In any case, this anteromedial retropharyngeal approach is an extension of the Smith-Robinson approach to the lower spine, in which the neck is hyperextended, and the chin is turned to the opposite side.[4]

- Care is taken not to hyperextend the neck, because this may result in spinal canal diameter restriction because of buckling of the ligamentum flavum. The incision is made along the anterior aspect of the SCM and is curved toward the mastoid process.
- The platysma and superficial layer of the deep cervical fascia are divided along the incision to expose the anterior border of the SCM.
- The muscle is retracted anteriorly, and the carotid is retracted laterally.
- While the superior thyroid artery and lingual vessels are ligated, the facial artery must be identified at the rostral portion of the incision as a landmark for the hypoglossal nerve, which is adjacent to the digastric muscle. This nerve must be retracted carefully to avoid injury, as must the superior laryngeal nerve, which is in close proximity to the superior thyroid artery.
- Another retropharyngeal anterior exposure described by McAfee involves a right-sided submandibular transverse incision and division of the platysma,[3] leading to the SCM and deep cervical fascia.
- Nerves can be identified with a nerve stimulator, and the retromandibular vein is ligated during the initial exposure.
- The anterior border of the SCM is mobilized, and the submandibular salivary gland and digastric lymph nodes are resected with care to suture the duct in the gland to prevent a salivary fistula.
- The digastric tendon is split and tagged for future repair, and the hypoglossal nerve is identified and mobilized.
- To move the carotid contents laterally, the carotid sheath is opened, and arterial and venous branches are ligated.
- A stimulator is also used to identify the superior laryngeal nerve.
- Prevertebral fasciae are dissected longitudinally to expose and dissect the longus colli.[4]

Yet another anterolateral retropharyngeal approach described by Whitesides and Kelley provides exposure to the upper cervical spine but not to the basiocciput.[1] This approach uses an incision made from the mastoid along the anterior aspect of the SCM with dissection anterior to the SCM and posterior to the carotid sheath.

- Effort is made to spare the greater auricular nerve, and the jugular vein is ligated.
- The splenius capitis and SCM are dissected off the mastoid, and cranial nerve (CN) XI must be recognized and protected.
- After the carotid is retracted anteriorly and the SCM is retracted posteriorly, blunt dissection leads to the transverse processes and anterior aspect of C1–C3. Caveats to this approach include possible injuries to CN XI, the vertebral artery, and sympathetic ganglion.[4]

An alternate means of approaching the basiocciput is a transpharyngeal approach with division of the soft and hard palates. Although this approach involves some difficulty, a small working space, and contamination by pharyngeal organisms, it may be appropriate when instrumentation is not required and durotomy is not anticipated.[3]

DISKECTOMY

- An annulotomy is made with a #11 blade, and disk material is removed with a pituitary rongeur.
- The anterior inferior osteophyte lip is removed from the vertebral segment above using the Kerrison rongeur to better visualize the disk space. Proud ventral osteophytes are also removed with rongeurs, allowing the eventual plate to sit flush with the ventral surface of the vertebral bodies. This bone is saved for use in the interbody cage.
- The end plates are then scraped with an up-angled curette to delineate the superior and inferior margins of the disk space.
- Next, the high-speed drill is used to drill the end plates, taking care to stay parallel to them. The removal of bone is carried out laterally to the uncovertebral joints.
- The posterior longitudinal ligament is opened using a pointed nerve hook and fine Kerrison punches (Fig. 18-3).
- Remaining ligament and disk material is removed using Kerrison rongeurs, and meticulous hemostasis is achieved using thrombin-soaked Gelfoam and irrigation with a 50% hydrogen peroxide–saline solution.

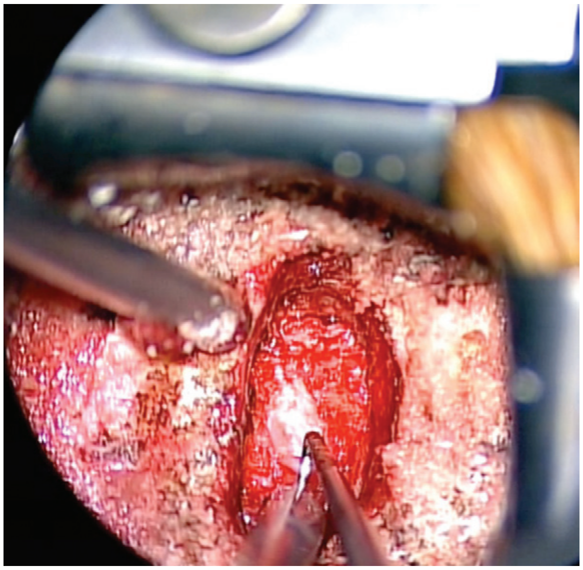

Figure 18-3 Opening of posterior longitudinal ligament after diskectomy.

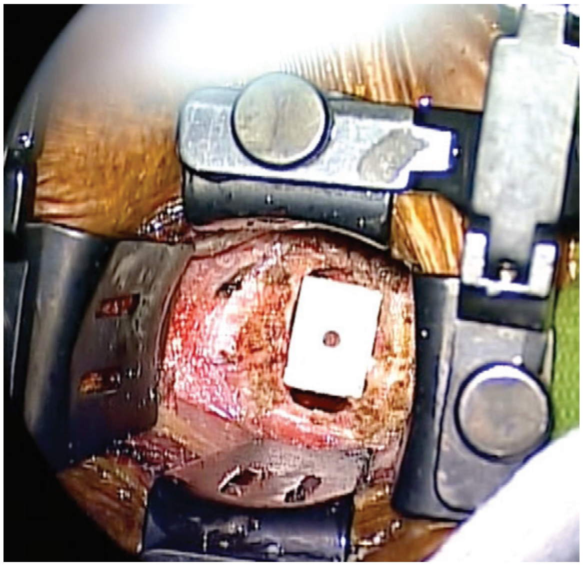

Figure 18-4 Position of interbody cage after end plate preparation.

CAGE PLACEMENT AND INSTRUMENTATION

- After diskectomy, a trial cage is placed in the disk space to determine the appropriate cage size. After corpectomy, a caliper is used to measure the distance between the end plates. If restoration of cervical lordosis is desired, a cage slightly larger than the decompressed segment is selected, and the head is distracted by an assistant during cage placement.
- Prior to placement of the cage, the cage is packed with bone graft obtained during the procedure. Following vertebral corpectomy, the amount of local autograft is typically ample. Other options include iliac crest autograft, cadaveric allograft, and other supplements.
- A tamp is used to position the interbody cage so that it is flush with the anterior aspect of the vertebral body. Any remaining anterior osteophytes are taken down using the Leksell rongeur to allow for plate placement (Fig. 18-4).
- The anterior plate is secured with screws. At the rostral level, screws are aimed medially and superiorly relative to the disk space. At the caudal level, screws are directed medially and inferiorly.
- As in a multilevel diskectomy, screws at levels between the top and bottom are placed parallel to the disk space; if restoration of lordosis is desired, these screws are placed last to allow the intervening segments to be pulled up into the lordosis of the plate during screw placement.
- Anteroposterior and lateral fluoroscopic images are acquired to verify satisfactory hardware position (Figs. 18-5 and 18-6; see also Fig. 18-4).

CLOSURE

- The wound is copiously irrigated with a 50% hydrogen peroxide–saline solution and antibiotic solution to promote hemostasis and reduce infection risk.

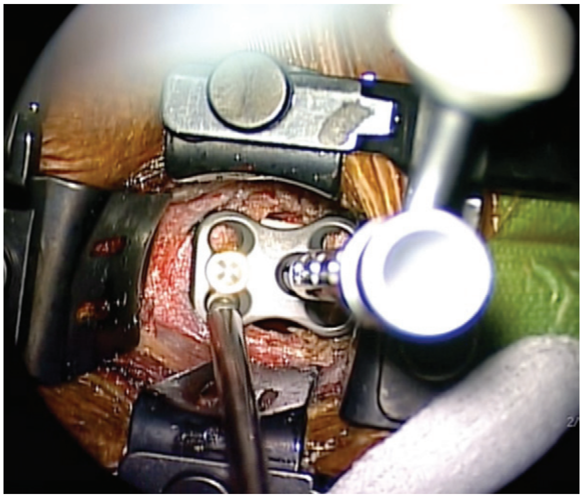

Figure 18-5 Placement of a screw through the cervical vertebral body for bony purchase and plate fixation.

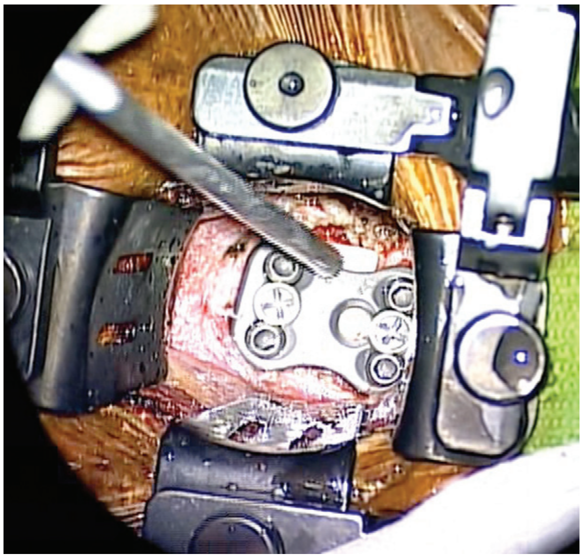

Figure 18-6 Completion of instrumentation of anterior cervical plate.

- A #10 flat Jackson-Pratt surgical drain is routinely left in place.
- Meticulous hemostasis is achieved.
- The platysma is closed in an interrupted fashion using 3-0 Vicryl suture.
- The dermis is closed in an interrupted fashion using inverted 3-0 Vicryl suture.
- The incision is covered with Dermabond skin adhesive and dressed. (Some surgeons opt for a running subcuticular stitch with monocryl, or they place Steri-Strips to the wound; cosmesis is usually satisfactory.)
- The patient may be placed in a padded cervical collar.

Complications

- Hoarseness may occur. The variable course of the recurrent laryngeal nerve on the right and its vulnerability to injury gives reason for some to advocate a left-sided approach.
- Injury to CNs IX, X, XI, and XII may occur with high cervical approaches.
- Dysphagia may result from esophageal or hypopharyngeal retraction.
- Esophageal and/or tracheal injury may occur.
- Great vessel and verterbral artery injury may occur.
- The thoracic duct is on the left side, and chylothorax is a serious complication that can be avoided with the right-sided approach.
- C5 palsy may occur, associated with decompression wider than 20 mm at C4–C5.
- Lymph node dissection may occur.
- There is no undisputed side from which to approach the anterior cervical spine, and surgeon handedness and comfort will play an important role in deciding which side to access.[1]

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19 Cervical Disk Arthroplasty Techniques

DO HEUM YOON and SEONG YI

Overview

Anterior cervical diskectomy and fusion is a well-established, commonly performed surgical procedure for cervical spondylosis. Since its introduction in the 1950s by Robinson and Smith and also Cloward, excellent clinical results have been reported in the treatment of degenerative disorders of the cervical spine.[1-4] The primary disadvantage of the procedure is that interbody fusion converts a functionally mobile, mechanically stable spinal unit into a fixed, nonfunctional unit. Analysis of the strain distribution of intervertebral disks after anterior cervical disk fusion has shown an increase in longitudinal strain, most frequently at the levels immediately adjacent to the fused segment.[5] The resulting increase in stress on adjacent disks is thought to lead to accelerated disk degeneration and mechanical instability.[6] Radiographic changes consistent with spondylosis and instability at levels above and below cervical fusions have been described by several authors,[3,6-10] but these changes have not always manifested as clinical symptoms.

Recently, cervical arthroplasty performed with artificial cervical disks has gained attention as an alternative to traditional arthrodesis, and this can be used to restore and maintain mobility and function of the involved cervical spinal segments.[11-14] The theoretical advantages of disk arthroplasty include maintenance of range of motion (ROM), avoidance of adjacent-segment degeneration, reconstitution of disk height and spinal alignment, and greater maintenance of maneuverability. Furthermore, the procedure shows decreased surgical morbidity and avoidance of complications from instrumentation or postoperative immobilization, and it allows an earlier return to the previous level of function.[14]

Indications and Contraindications

The indications for cervical artificial disk replacement (C-ADR) are single-level or multilevel disk herniations between C3–C4 and C6–C7 with radiculopathy, myelopathy, or both with minimal spondylosis and no substantial adjacent-level degeneration. The indications for cervical disk replacement are similar to those for anterior cervical diskectomy and fusion (ACDF). These are patients who present with a neural compressive lesion causing upper extremity weakness, paresthesias, and pain, with or without lower extremity hyperreflexia, who are refractory to conservative treatment. Diagnoses may include spondylotic radiculopathy, spondylotic myelopathy, disk herniation with myelopathy, and soft-tissue disk herniation with radiculopathy. Patients with predominantly anterior compression of the cervical spinal cord or nerve roots are good candidates. The radiologically documented presence of motion at the level for which the procedure is proposed is a prerequisite for arthroplasty.

As more experience with cervical arthroplasty accrues, the inclusion criteria may expand. At the beginning of the arthroplasty era, cervical spondylotic myelopathy and spondylotic radiculopathy were not included in the surgical indications. Only young patients under age 50 without spondylotic changes were accepted for this procedure. Since that time, inclusion criteria have evolved to include cervical spondylotic radiculopathy without progressive myelopathy.[15] For example, reconstitution of disk height by C-ADR could be beneficial to some patients with narrowed disk height caused by spondylotic change resulting in foraminal stenosis and nerve root entrapment. The indications could be further expanded to include patients with diskogenic axial neck pain. Interestingly, the indication for lumbar total disk replacement (TDR) is primarily diskogenic axial low back pain. In contrast to the indications for C-ADR, neural compressive lesions such as spinal canal stenosis or herniated nucleus pulposus are considered contraindications to lumbar TDR.[16] Limited data indicate that patients with refractory axial neck pain and degenerative disk disease limited to one or two levels can benefit from ACDF, and these same patients may benefit from C-ADR.[17,18] Contraindications for C-ADR include axial neck pain related to facet arthropathy, cervical myelopathy caused primarily by posterior compression, deformity (cervical scoliosis, postlaminectomy kyphosis), potential for C-ADR instability as posterior element insufficiency, potential for inadequate end plate integrity (osteoporosis, metabolic bone disease), infection or inflammatory disease (prior infection, ossification of the posterior longitudinal ligament, ankylosing spondylitis, rheumatoid arthritis), insufficient cervical motion at the indexed level or bridging osteophytes, and intervertebral disk space collapse greater than 50% of the normal height.[19]

One of benefits of C-ADR expected in the near future includes its usefulness in the treatment of adjacent-segment disease after ACDF. Revision fusion for adjacent disease is challenging because of high rates of pseudarthrosis and postoperative dysphagia.[8,20,21] The difficulty in achieving fusion adjacent to a prior fusion may be due to an unfavorable biologic milieu and a substantial difference in stiffness between the fusion and the adjacent open disk space. With C-ADR, the need for fusion is eliminated, although bony ingrowth is still necessary. C-ADR may also decrease the potential for disease progression to the next adjacent level. With revision fusion for adjacent disease, the index plate is removed to provide space for a new plate to be extended to the additional level. The multilevel dissection required to remove the index plate likely contributes to a higher incidence of postoperative dysphagia and respiratory compromise.[22-24] If C-ADR is used, there is no need to remove the previously operated plate, and multilevel dissection can be avoided.

Potential Disadvantages of Cervical Artificial Disk Replacement

Several potential disadvantages of cervical disk arthroplasty exist. It is important to realize that symptomatic radiculopathy and myelopathy are caused by combined static and dynamic neural compression.[25-28] Because motion at the diseased level is retained with C-ADR, there may be greater potential for failure to relieve symptoms at the same level. With ACDF, the static and dynamic component can be eliminated by fusion. With C-ADR, dynamic neural compression will remain unless a more aggressive decompression is performed. More aggressive decompression may mean greater blood loss and a higher risk of neural or vascular injury. Contrary to these contentions, short-term results of randomized trials suggest the clinical outcomes of ACDF and C-ADR are equivalent. However, these trials are being conducted by surgeons with vast experience in performing anterior cervical decompression. Wider use of these implants in the general population may decrease the predictability of good results. With ACDF, the room for error in performing a decompression is high. In fact, it has been shown that equally good outcomes can be achieved regardless of whether direct uncovertebral joint decompression is performed.[29] With C-ADR, performing a decompression may be more critical in achieving successful short-term outcomes. Reports of C-ADR revisions for inadequate decompression have already begun to surface.[15,30,31]

In the long term, successful ACDF also eliminates motion and thus halts the progression of spondylotic spurs. Fusion often leads to spur resorption. However, with motion preserved in C-ADR, spondylotic spurs may recur and lead to late symptom recurrence at the same level.[32] Heterotopic ossification or osteophyte growth at the operated level during long-term follow-up after arthroplasty indicates the role of motion preservation in the progression of spondylotic change. Further follow-up may reveal that we have traded a relatively low incidence of adjacent-segment disease for a higher incidence of same-level disease.

Other potential disadvantages of C-ADRs include increased cost, neurologic injury as a result of posterior implant dislodgment, implant failure, and need for revision. Fortunately, the approach and potential need for corpectomy in revision C-ADR are known to most spine surgeons.[19]

Preoperative Radiologic Evaluation

- C-spine plain radiographs should include anteroposterior (AP), lateral (neutral, flexion, extension), and bilateral oblique views.
- Visibility must be checked on a C-arm lateral view preoperatively: short neck, high shoulder, C6–C7 level.
- Assess preexisting spondylosis (anterior or posterior osteophytes, ossification of ligaments).
- Proper disk height for arthroplasty must be ensured.
- A prerequisite for arthroplasty is identification of motion in operation segments.
- Biomechanical properties must be checked.
- Sagittal balance, whole cervical (C2–C7) ROM, and segmental motion (functional spinal unit, FSU) must be evaluated.
- Cervical spine computed tomography (CT) and magnetic resonance imaging (MRI) are essential and used to identify both pathology and surrounding structures.

Equipment

- Radiolucent operating table
- C-arm fluoroscopy (essential) or intraoperative radiograph
- Operating microscope
- Bipolar electrocautery
- Cervical retractor system
- High-speed drill system
- Caspar distraction pins, 12 to 14 mm
- Straight and angled curettes
- 1- to 3-mm Kerrison punches

Operating Room Setup

Proper setup of the operating room is essential and is the most important step before operation. The difference compared with conventional cervical diskectomy surgery is the use of C-arm fluoroscopy in real time during surgery. Special considerations for arrangement are required to avoid improper C-arm imaging, unexpected contamination, and anesthesia difficulty during surgery. Additional considerations include sufficient space for the surgeon, assistants, scrub nurse, and other medical personnel to participate in the surgery (Fig. 19-1).

- The C-arm fluoroscope is initially located on the cranial side, separated from the patient with a drape, and it is only used during the arthroplasty procedure after microscopic diskectomy. The C-arm fluoroscope base is located on the ipsilateral side of the operator.
- The breathing circuit and electrical lines for patient monitoring connected to the anesthesia machine are arranged such that they do not interfere with the caudal location of the C-arm fluoroscope with respect to the patient's cervical spine. An extension tube for the breathing circuit is commonly required.
- The anesthesia machine is located on the lateral side of the operating table opposite the surgeon.

Figure 19-1 Operating room setup for artificial disk replacement. Special considerations for arrangement are required to avoid improper C-arm imaging, unexpected contamination, and anesthesia difficulty during surgery. Additional considerations include sufficient space for the surgeon, assistants, scrub nurse, and other medical personnel to participate in the surgery.

- The assistant stands on the opposite side of the operating table as the surgeon during the diskectomy procedure and stands aside to make way for the C-arm fluoroscope. The scrub nurse is positioned below the iliac crest.

Patient Positioning

The patient is placed in a supine position, and general endotracheal anesthesia is used. The patient is asked to extend his or her neck to the point of pain or onset of radicular or myelopathic symptoms before the induction of anesthesia. A neck roll to facilitate neck support is used in most cases.

The head is placed in a foam cradle headrest, and the arms are tucked to the sides. The patient's neck is positioned neutrally, not in hyperlordosis, which is routinely used for anterior fusion techniques. Positioning of the patient's neck in hyperlordosis can result in inappropriate positioning of the prosthesis, because intraoperatively, the alignment of the prosthesis and the spinal segment may appear correct. However, as soon as the spine returns to a neutral position, the segment and prosthesis can fall into a kyphotic position.

Before the patient is draped, C-arm fluoroscopic examination is required to gain a true AP lateral view and to visualize the upper and lower end plate at the operation segment. Because the inserted artificial disk should be properly centered and placed at the appropriate biomechanical depth and height, the position of the patient, operating table, or C-arm fluoroscope should be modified to achieve perpendicular alignment for arthroplasty before draping. If the target segment is not visible because of the lower cervical level (C6–C7), a short neck, high shoulders, and shoulder traction in the caudal direction using tape is required. The patient is covered with a warm-air blanket to maintain body temperature (Fig. 19-2).

Figure 19-2 Patient positioning. **A,** The patient's neck is positioned neutrally. **B,** Before the patient is draped, C-arm fluoroscopic examination is required to gain a true anteroposterior lateral view and to visualize the upper and lower end plate at the operation segment.

Operative Technique

INCISION LOCATION

The identical incision technique is used as with cervical disketomy and fusion. Sometimes, a slightly longer incision is needed for instrumental insertion in a specific artificial disk system. Fluoroscopy can help with incision planning.

- At C3–C4, the incision is made 1 cm above the thyroid cartilage.
- At C4–C5, the incision is made at the thyroid cartilage.
- At C5–C6, the incision is placed between the thyroid cartilage and the cricoid cartilage, about two thirds of a point from the lower end of the thyroid cartilage. A prominent bony tubercle on the C6 transverse process can be palpated to help guide incision placement.
- At C6–C7, the incision is made at the level of the cricoid cartilage, generally two fingerbreadths above the sternal notch.
- To expose the C7–Tl level, a transverse incision is made as low as possible above the clavicle.

Incision, Soft Tissue Dissection, and Exposure of the Vertebra

A local anesthetic is injected subcutaneously at the incision site, and a transverse skin incision is made from the midline to the lateral edge of the sternocleidomastoid (SCM) muscle (Fig. 19-3, *A*).

SEQUENTIAL IDENTIFICATION AND DISSECTION OF IMPORTANT ANATOMIC STRUCTURES

- The subcutaneous layer, platysma muscle, subplatysmal areolar layer, medial border of the SCM muscle, anterior cervical fascia on the medial border of the SCM muscle, areolar plane between the SCM muscle, and the omohyoid and sternothyroid muscles are identified (see Fig. 19-3, *B* through *D*).
- The carotid artery pulse is palpated, and the artery is freed from the surrounding connective tissue medially by blunt dissection and is then retracted laterally (see Fig. 19-3, *E*).
- The omohyoid and sternothyroid muscles are then retracted medially along with the trachea and esophagus (see Fig. 19-3, *F*).

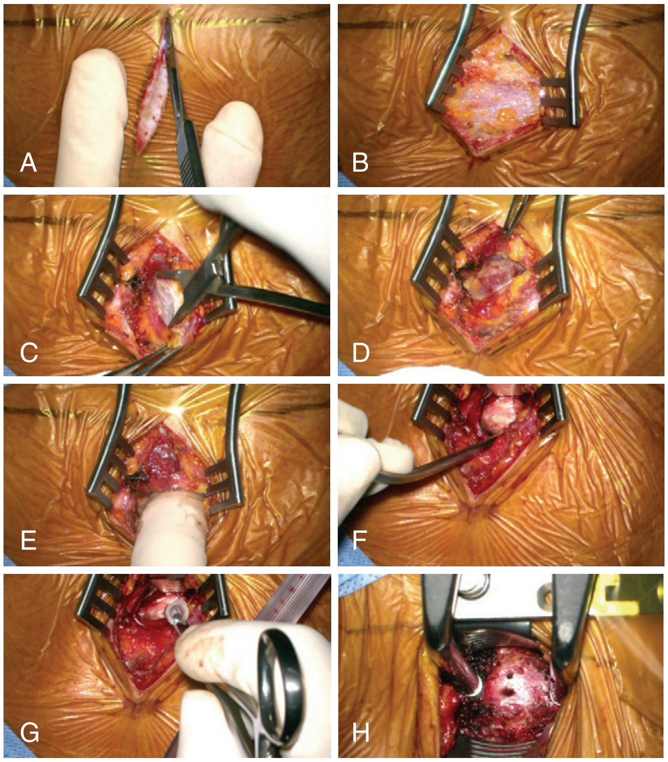

Figure 19-3 Operative technique. **A,** Transverse skin incision is made from the midline to the lateral edge of the sternocleidomastoid (SCM) muscle after local anesthesia subcutaneous injection. **B** through **D,** The subcutaneous layer, platysma muscle, subplatysmal areolar layer, medial border of the SCM muscle, anterior cervical fascia on the medial border of the SCM muscle, and the areolar plane between the SCM muscle and the omohyoid and sternothyroid muscles. **E,** The carotid artery pulse is palpated, and the artery is freed from the surrounding connective tissue medially by blunt dissection, and it is retracted laterally. **F** and **G,** Exposure of the vertebra and needle insertion to localize the desired level. **H,** Self-retaining retractor placement.

EXPOSURE OF THE VERTEBRA

- With blunt dissection using a finger or cottonoid, the prevertebral fascial layer is exposed and incised in the midline to reveal the longus colli muscles.
- An 18-gauge needle is inserted into the selected intervertebral disk space, and fluoroscopy is used to localize the desired level (see Fig. 19-3, *G*).
- The longus colli muscles are elevated from their medial attachments to the anterior longitudinal ligament. Only electrocautery dissection should be performed beneath these muscles to prevent injury to the esophagus, trachea, and neurovascular structures; sufficient dissection underneath will also facilitate self-retaining retractor placement (see Fig. 19-3, *H*).

RETRACTOR PLACEMENT

- Attention to the midline is important during longus colli muscle dissection and is guided by the contour of the vertebral bodies and the original sites of attachment of the longus colli muscles.
- Various techniques can be used to identify the midline based on the position of the artificial disk.
- The inferior thyroid vein and artery may also be encountered, especially if the dissection is extended toward C4–C5. If necessary, they may be ligated.
- The superior laryngeal nerve near the C3–C4 and C4–C5 spaces can be identified coursing inferomedially from the region of the carotid sheath toward the thyroid cartilage; it should be preserved.
- A self-retaining retractor system is then positioned and secured, and blade teeth are inserted beneath the longus colli muscles.
- A vertical line of sight to the vertebral column and midline must be firmly established to avoid an asymmetric approach to the posterior portion of the disk and the vertebral osteophytes and to minimize the potential for vertebral artery injury.
- If required, a second retractor with longer, smooth-tipped blades is positioned longitudinally to complete the exposure.
- Caspar distraction pins (12 to 14 mm) are placed into the midportions of the vertebral bodies above and below the operative disk space at a cephalad angle.
- Various distractor pins can be used in these steps depending on the artificial disk being used.
- The disk space is distracted with distractor pins (see Fig. 19-3, *H*).

ANTERIOR CERVICAL DISKECTOMY

- A rectangular opening wide enough to secure the uncovertebral joints is created by incising the anterior longitudinal ligament and annulus at the desired level under the operating microscope (Fig. 19-4, *A* and *B*).
- To maintain midline positioning during microscopic surgery, the microscope should be aligned perpendicular to the anterior surface of the spinal column.
- The end plate is prepared for artificial disk insertion.
- Special considerations and various procedures are required according to the device being used.

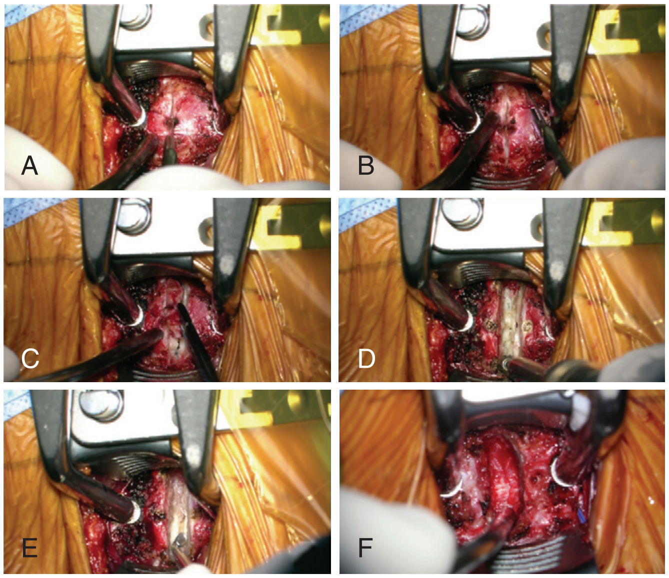

Figure 19-4 Anterior cervical diskectomy. **A** and **B,** A rectangular opening is made wide enough to secure the uncovertebral joints. **C** through **E,** Power drill, curettes, and rongeurs are used to remove the fibrocartilage of the annulus and disk. **F,** The anterior vertebral body "lips" and marginal osteophytes that usually overhang the disk space should be removed.

- Preservation of the curved surfaces of the cartilaginous plates of the upper and lower vertebral bodies is recommended to ensure optimal placement of the artificial disk.
- An end plate milling step for the Bryan disk (Fig. 19-5, *A*) and keel formation on the end plate of the ProDisc-C (Synthes, Inc., West Chester, PA, USA) or Prestige devices (all Medtronic Sofamor Danek, Memphis, TN) may be required (see Fig. 19-5, *B*).
- Curettes and rongeurs are used to remove the fibrocartilage of the annulus and disk (see Fig. 19-4, *C* and *E*).
- The anterior vertebral body lips and marginal osteophytes that usually overhang the disk space should be removed (see Fig. 19-4, *F*).
- A power drill is used to remove the posterior vertebral body lip and the attached osteophyte (see Fig. 19-4, *D*).
- Posteriorly and inferiorly, complete osteophyte removal should be performed by undercutting with a drill and Kerrison rongeurs.
- If complete decompression is uncertain, the posterior longitudinal ligament should be opened, and the epidural space should be inspected.
- Palpating the floor of the neural canal and foramina with a blunt hook can help confirm the completeness of the decompression.
- All ruptured disk particles should be removed with cautious palpation into the neural foramen along the nerve root. Usually a ruptured disk is multifragmented and completely removed after thorough inspection.
- Complete removal of disk material, redundant tissue, or partially torn end plates should be confirmed before inserting the implant. Because of the implant width, implant insertion can push the remaining materials into the foramen or epidural space, resulting in incomplete relief of symptoms.

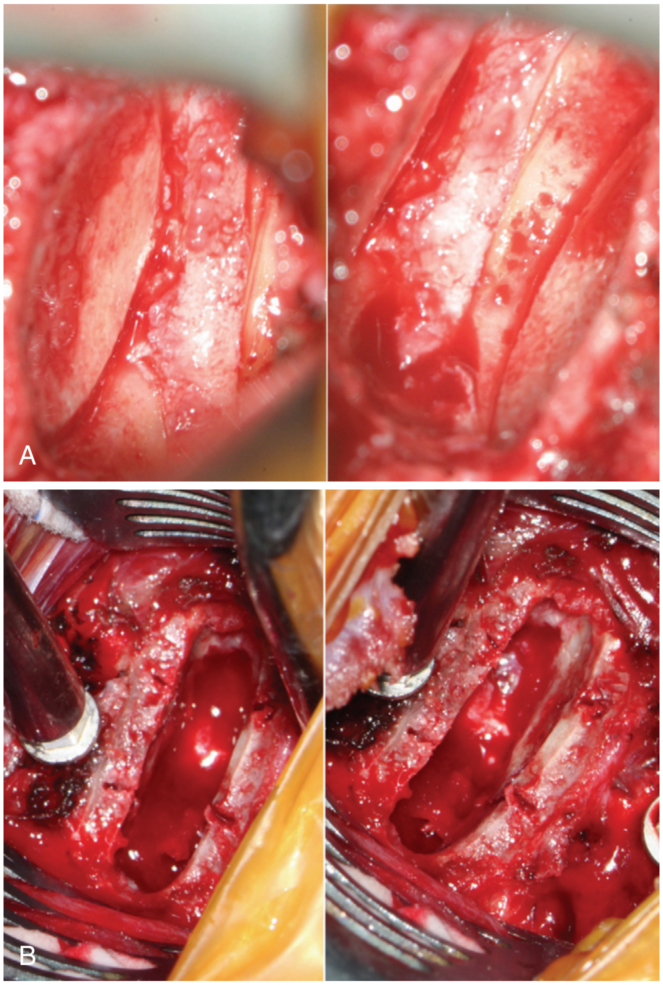

Figure 19-5 An end plate milling step for the Bryan disk (**A**) and keel formation on the end plate of the Prodisc or Prestige device (**B**) may be required.

ARTIFICIAL DISK REPLACEMENT

- Various surgical techniques can be used to insert an artificial disk. Follow the specific surgical technique suggested by each artificial disk manufacturer. The technique of Mobi-C disk prosthesis (LDR Medical, Troyes, France) is shown in Figure 19-6, and the Prestige LP is shown in Figure 19-7.
- Follow the universal description of the surgical technique for artificial disk placement.
- The cervical distraction pins are placed after determination of the midline based on anatomic landmarks, a width gauge, or C-arm fluoroscopic verification. Distraction pins are placed at the center of the upper and lower vertebral bodies parallel to both end plates, and their positions are verified under C-arm fluoroscopy.
- An intersomatic distractor is inserted to achieve parallel distraction in the AP and bilateral directions. The distraction is created gradually in a parallel fashion. Step-by-step distraction allows relaxation of the surrounding ligaments. The target disk space height should be compared with that of adjacent disks to avoid overdistraction of the segment. Careful observation of appropriate joint fissure enlargement can be helpful.

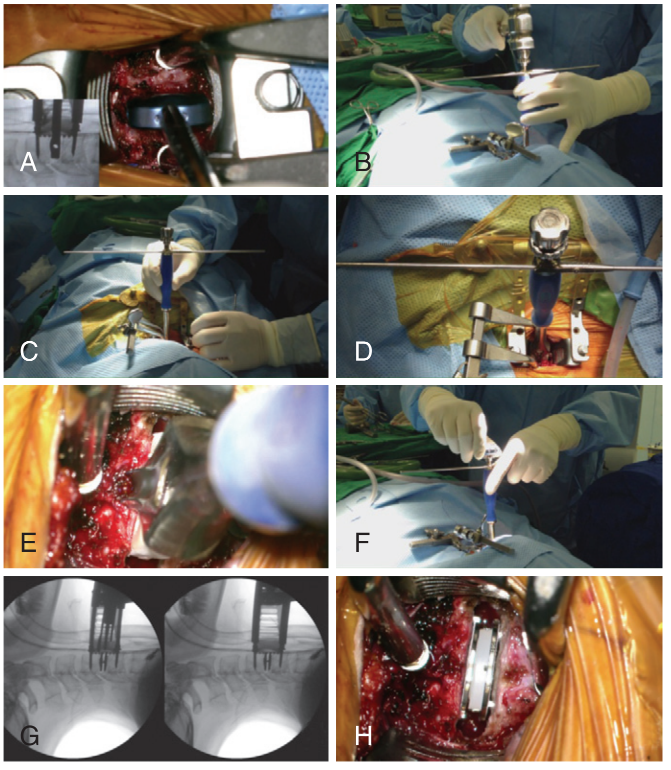

Figure 19-6 The technique of placing the Mobi-C disk prosthesis (LDR Medical, Troyes, France). **A,** Cervical distraction pin placement and insertion of a trial implant into the disk space to determine implant size, width, depth, and height under C-arm fluoroscopy. **B,** The device is slowly inserted with a mallet along the prepared end plate. **C** and **D,** The implant holder must be located in the disk axis on the horizontal plane; this can be confirmed by an outer inspection of the patient performed by a surgical assistant. **E** and **F,** The millimetric adjustment of the stop allows repositioning of the prosthesis depth. **G,** Anteroposterior and lateral C-arm control is carried out to confirm that the device is positioned correctly; the implant holder is then dislodged and removed. **H,** The stability of the implant is confirmed by direct inspection and an attempt to mobilize the implant from the end plate.

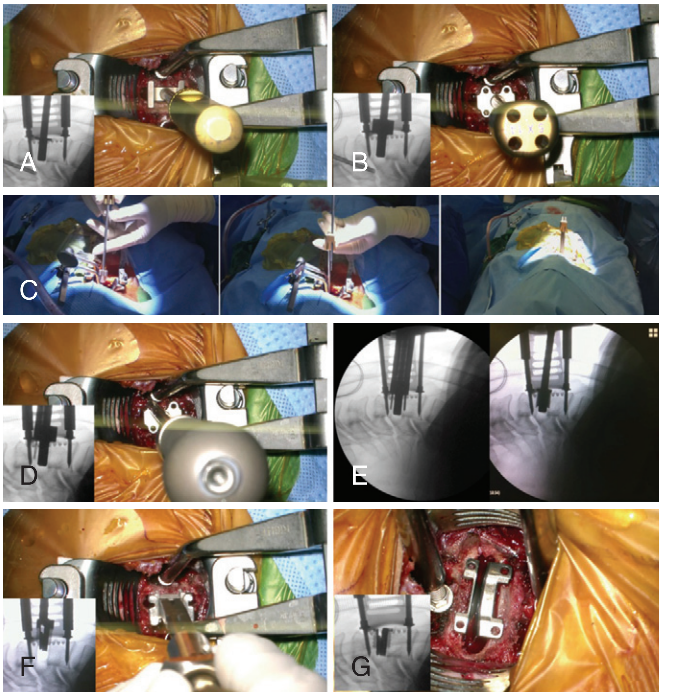

Figure 19-7 The technique of placing the Prestige LP (Medtronic Sofamor Danek, Memphis, TN). **A,** The sizing trial insertion into the disk space. **B** through **D,** Channels are created in the end plates to accommodate the rails of the device. Four holes are drilled using a trial with a captured drill guide. **E,** Keeling procedure using a channel cutter. **F** and **G,** The device is slowly inserted with a mallet along the prepared end plate under C-arm fluoroscopy.

- The appropriate implant size is determined by inserting a trial implant into the disk space and assessing the width, depth, and height under C-arm fluoroscopy (see Fig. 19-6, *A*).
- The appropriate-sized device will have the shortest height and largest footprint possible. Height should not exceed the height of the healthy adjacent disks.
- The implant should be assembled following the protocol supplied by the manufacturer.
- The artificial disk is inserted into the disk space with verification under C-arm fluoroscopy.
- The artificial disk is positioned at the entrance of the target disk space before inserting the device.
- The implant holder must be located in the disk axis on the horizontal plane; this can be confirmed by an outer inspection of the patient performed by a surgical assistant (see Fig. 19-6, *B* through *D*).
- The device is slowly inserted with a mallet along the prepared end plate (slight upward direction).
- The millimetric adjustment of the stop allows repositioning of the prosthesis depth (see Fig. 19-6, *E* and *F*).
- The distraction is relaxed to verify the size of the implant.
- Anteroposterior and lateral C-arm control is carried out to confirm that the artificial disk is positioned correctly (see Fig. 19-6, *G*).
- The implant holder is dislodged and removed.
- Finally, the stability of the implant is confirmed by direct inspection and an attempt to mobilize the implant from the end plate (see Fig. 19-6, *H*).
- An implant and reasonable disk space maintenance are implemented even if subsidence occurs.
- If the implant does not start to enter the intervertebral space, it should be removed and inspected for oversized surfaces or protruding points that need to be trimmed.
- Once the distraction is released, it should not be possible to move the implant with reasonable force.
- Palpation of the posterior margin of the implant with a blunt nerve hook should verify a lack of dural compression.

CLOSURE

- The distraction pins and retractors are removed.
- Hemostasis is carefully achieved, and the esophagus should be checked for injury that may have resulted during retraction.
- A subplatysmal drain should be placed if epidural and bony oozing is significant.
- The platysma layer is closed separately with fine, absorbable sutures.
- Fine, interrupted, subcuticular stitches are used to cosmetically reapproximate the skin.

Postoperative Care

- Postoperative orders are written for monitoring of the airway and monitoring for signs of neurologic deterioration.
- Early ambulation (1 day after operation) is encouraged.
- The diet can be advanced as tolerated, depending on the presence of esophageal edema and swallowing difficulties.
- Paratracheal edema can cause a sensation of upper airway tightness and hoarseness; it can be distinguished from recurrent laryngeal nerve injury if the hoarseness lasts 3 days after the operation and by vocal cord examination.
- Head elevation can reduce cervical edema.
- Oral pain control is usually sufficient but can be patient dependent.
- Posterior cervical and shoulder pain can be an initial response to ligamentous and facet capsule stretching during surgery.
- Postoperative cervical radiographs should be obtained to confirm proper device positioning and to assess postoperative prevertebral edema and unexpected hematoma.
- Postoperative cervical radiographs can be obtained before discharge to verify maintenance of spinal alignment and device positioning and to provide a baseline for follow-up visits.

POSTOPERATIVE RADIOLOGIC ASSESSMENT

- C-spine plain radiographs should include AP and lateral (neutral, flexion, extension) views.
- Proper device positioning is verified.
- Device displacement, dislodgment of device components, and fusion at the end plate–device contact surface are observed.
- Biomechanical properties are evaluated.
- Sagittal balance of the whole cervical spine (C2–C7) is assessed.
- Maintenance of motion should include the entire cervical ROM and segmental motion FSU of the operated segment and adjacent segment (Fig. 19-8).
- Maintenance or change in biomechanical properties should be compared with preoperative values.
- Adverse outcomes should be identified.
- The appearance of heterotopic ossification (HO) around the device should be identified. Cervical CT should be sufficiently accurate for this (Fig. 19-9).
- Cervical MRI is usually not required except in the case of recurrent symptoms, the possibility of other segment pathology, and so on. The proper choice of device with minimal metallic MR artifacts is needed preoperatively to achieve the lowest metallic artifact.

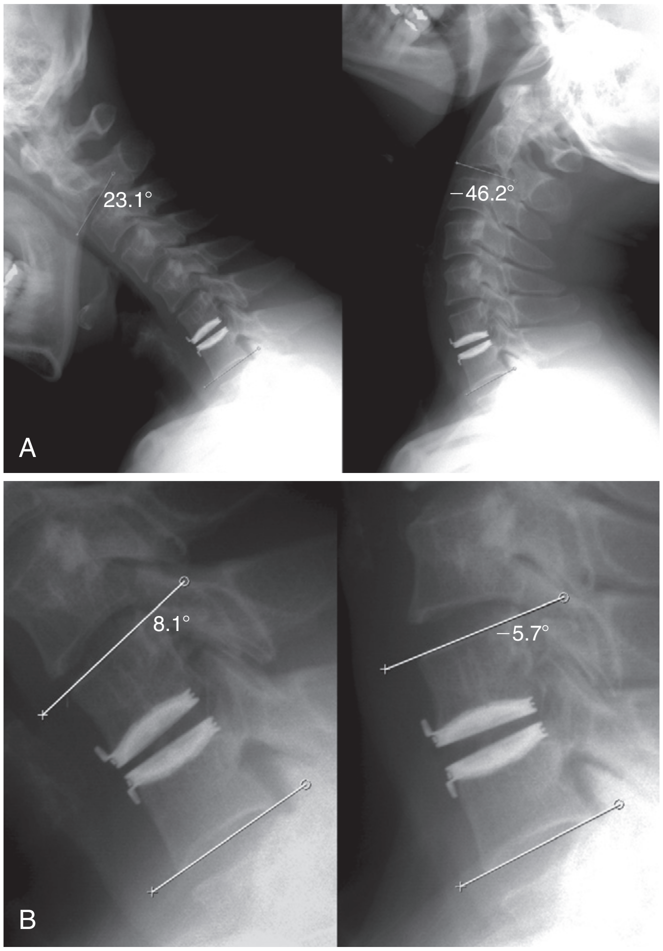

Figure 19-8 Postoperative radiologic assessment. **A,** The entire cervical (C2–C7) range of motion. **B,** Segmental motion (functional spinal unit, FSU) of the operated segment and adjacent segment.

Complications and Adverse Outcomes of Cervical Artificial Disk Replacement

GENERAL COMPLICATIONS

- New neurologic deficits may develop after recovery from anesthesia secondary to nerve root injury or edema, spinal cord concussion, or rapid release of chronic compression.
- Acute deficits may develop as a result of mechanical problems such as intervertebral subluxation, bone graft migration, residual compressive disk fragments, residual osteophytes, or an acute epidural hematoma, all of which should be surgically treated.
- Progressive deficits after the first week of surgery may indicate spinal instability or an epidural abscess.
- Infection is extremely rare—less than 1% with prophylactic antibiotic therapy.
- Severe cervical pain that occurs weeks or months after surgery may be secondary to vertebral osteomyelitis.
- Carotid thrombosis as a result of lateral retraction can be a risk factor in patients who have a history of transient ischemic attacks. These patients should be treated for significant carotid stenosis before undergoing anterior cervical fusion. Cerebral ischemia or infarction at the side of the surgical approach may develop because of thrombus migration in the carotid artery.
- Persistent postoperative hoarseness, dysphagia, or vocal cord paresis may occur as a result of injury of the recurrent laryngeal nerve.
- Violation of the adjacent disk space may also be noted.

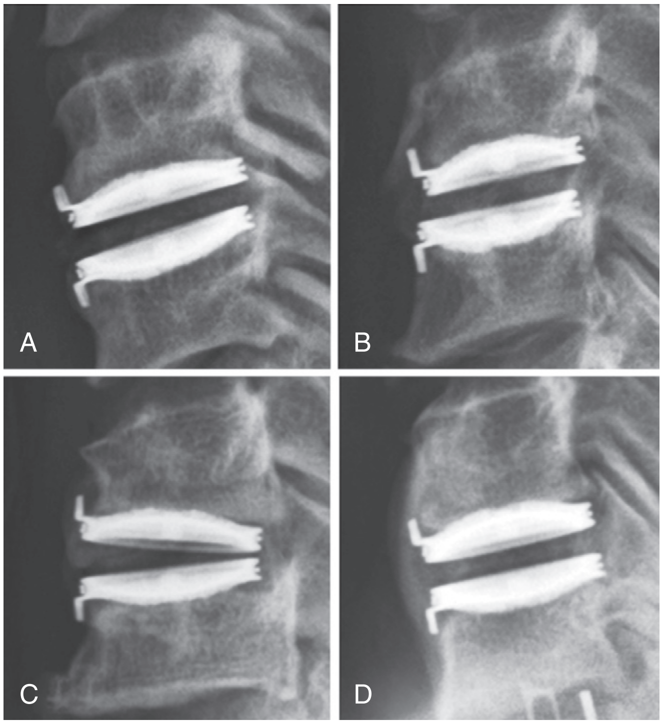

Figure 19-9 Identify the appearance of heterotopic ossification around the device.

In addition to the standard potential complications associated with surgery and general anesthesia—including incomplete pain relief as a result of inadequate decompression, nerve root or spinal cord injury, hematoma, and infection[33]—several unique complications associated with artificial disk replacement have recently emerged. HO,[34,35] delayed fusion around the cervical disk prosthesis,[36,37] and asymmetric end plate preparation resulting in postoperative kyphosis and reduction in caudal vertebral body height have all been reported in the literature.[38,39]

An unexpectedly high rate of HO was observed after 12 months of follow-up in the Bryan Disc Study performed by the European Consortium.[34] Sixteen (17.8%) of the 90 studied patients experienced HO, and 6 patients (6.7%) experienced grade 3 and 4 HO according to the McAfee classification (see Fig. 19-9).[40] Ten (62%) of these 16 patients had less than 2 degrees of motion at the operated level. Fusion has been noted more frequently in older patients and in male patients. Trauma to the longus colli muscle is thought to be one of the factors that facilitates the formation of paravertebral ossification. It is thought that perioperatively administered nonsteroidal antiinflammatory drugs, abundant intraoperative irrigation, and limited retraction to the muscles may help prevent this complication.[33,34] HO has been reported with most of the other designs as well.

No evidence suggests adverse clinical outcomes resulting from sagittal imbalance after arthroplasty. However, postoperative aggravation of kyphosis is a vital problem in terms of the fundamental goal of cervical arthroplasty, which is reconstruction to achieve normal cervical biomechanics. Because postoperative kyphosis can affect all arthroplasty patients, its significance is more substantial than any other complication. Preservation of segmental motion and aggravation of kyphosis after arthroplasty are known concerns, and hypotheses with regard to causative factors related to prosthesis design and operational processes have been previously discussed.[38,39]

Recently, several design limitations and factors contributing to postoperative kyphosis of the Bryan disk prosthesis were discussed in the literature.[41] Yi and colleagues reported that postoperative kyphosis was caused by several factors that included overmilling at the dorsal end plate, the angle of the Bryan disk insertion, structural absence of lordosis in the Bryan disk, the surgical procedure used to remove the entire posterior longitudinal ligament, and preexisting kyphosis.[38,41] The insertion angle had a significant negative correlation with postoperative shell angle. The insertion depth also showed a significant negative correlation with the shell angle and FSU angle and also showed an insignificant negative correlation with C2–C7 sagittal alignment. That study indicated the possibility of preventing sagittal imbalance in cervical arthroplasty using the Bryan disk via technique modifications, especially in terms of the insertion angle and depth, and also suggested the potential for new, unexpected paradoxical stress on the other cervical segments.[41] Fong and colleagues[39] reported that postoperative kyphosis, including FSU angle and end plate angle, resulted from a postoperative reduction in the posterior vertebral height of the caudal segment. This mechanism occurred secondary to asymmetrical end plate preparation. Asymmetrical milling occurred in the forced lordosis state, caused by hyperlordotic neck positioning or impaction of a wedge-shaped distractor.

ADJACENT-SEGMENT DISEASE AFTER CERVICAL ARTIFICIAL DISK REPLACEMENT

We already know that the fundamental goals of cervical arthroplasty are to maintain motion at the operated level and to decrease the strain in the adjacent segment to prevent adjacent-segment disease. Although many reports have supported this insistence that cervical arthroplasty is superior to ACDF in terms of preventing adjacent-segment disease in vitro or in vivo, whether it is independent of the natural degenerative process has still not been proven. At a recent forum, based on considerable literary support and clinical experience, some investigators questioned whether artificial disk replacements would have long-term success comparable with anterior interbody fusion.[42]

Although clinical and radiographic evidence suggests that arthrodesis is associated with an increased incidence of adjacent-segment disease, it is not true that no adjacent-segment degeneration occurs after cervical arthroplasty. A recent prospective study revealed that the prevalence of adjacent-segment degeneration was somewhat higher than expected. Robertson reported that the radiologic incidence of adjacent-segment degeneration after cervical arthroplasty was 17.5%, and the annual incidence of symptomatic adjacent-segment disease was 0.65% per year. In the arthrodesis group, 34.6% of patients showed radiologic adjacent-segment disease, and 13.9% had symptomatic adjacent-segment disease, a statistically higher incidence compared with that in the artificial disk group.[43] Yi and collegues[44] reported that the radiologic incidence of adjacent-segment degeneration after cervical arthroplasty was 12.5%, and the rate of coincidence with HO was 44.4%. These studies indicate that the incidence of adjacent-segment disease after arthroplasty is high enough that it should not be ignored clinically.

One feature supporting the recommendation of this procedure for successful artificial disk replacement is that it yields a lower incidence of adjacent-segment disease than arthrodesis and prosthetic treatment over the long term. However, we should keep in mind the similar potential for adjacent-segment degeneration to occur after cervical arthroplasty as after arthrodesis in the long term. Future studies should focus on determining whether iatrogenic production of a rigid motion segment after arthrodesis or the progression of the natural history of degenerative disease cause adjacent-segment degeneration.

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20 Cervical Microforaminotomy and Decompressive Laminectomy

JARED D. AMENT, HEUM DAI KWON, and KEE D. KIM

Overview

Disorders of the cervical spine can cause radiculopathy, myelopathy, or both. Compression of the neural elements occurs most commonly as a result of disk herniation and/or osteophyte formation but can also be caused by congenital deformities, facet joint hypertrophy, infection, and neoplasm. Conservative, nonoperative management is initially recommended for most patients with radiculopathty.

In patients refractory to nonoperative treatment, surgical intervention can often lead to significant long-term improvement in quality of life.[1,2] Depending on the etiology, posterior cervical microforaminotomy (PCMF) or decompressive laminectomy can offer several important benefits over an anterior cervical approach and fusion: better preserved neck motion, no complications associated with instrumentation, no risk of pseudarthrosis, and decreased costs associated with shorter operative times and lack of implants.[3,4] Posteriorly approached tandem foraminotomies have similar outcomes while maintaining superior neck motion when compared with anterior decompressions and fusions.[1] Multilevel disease, even with ventral spinal cord compression, may be adequately decompressed with cervical laminectomy. Reports have suggested that adjacent-segment disease and C5 nerve root palsy are also mitigated by the posterior approach.[5,6]

In patients with sagittal or coronal deformity or any signs concerning for instability, a concomitant fusion may be appropriate and unavoidable. Furthermore, if the majority of the disk or facet joints are removed, the posterior decompression itself can lead to instability.

Diagnosis

As is normally the case, patient anamnesis is critical for making the correct diagnosis and for surgical planning. Typically, patients come to medical attention with complaints of neck and radiating arm pain. This is often associated with numbness or tingling in the arms and fingers. In addition, they may indicate difficulties with specific tasks, such as opening a jar, playing a guitar, or turning a car key. It is similarly important to inquire about clumsiness and gait and balance issues, as these can be early signs of myelopathy.

Radiographic images—such as magnetic resonance imaging (MRI) scan or computed tomographic (CT) myelogram, the latter being useful in patients with previously instrumented fusion—should supplement, not replace, the patient history and exam (Fig. 20-1). Plain radiographic images including anteroposterior (AP), lateral, and flexion and extension views, should always be obtained to evaluate spinal curvature, alignment, and motion. Oblique views may be helpful in assessing foraminal stenosis. When the source of the pain is difficult to localize, selective nerve root blocks or electromyography with nerve conduction velocity testing may be considered.

The goal of surgery may dictate the approach taken and the number of cervical levels addressed. Surgery may be limited to address symptoms or may extend more broadly to address subtle signs and radiographic abnormalities. The patient must be included in the decision-making process and must be informed of all advantages and disadvantages associated with any given intervention.

Indications and Contraindications

POSTERIOR CERVICAL MICROFORAMINOTOMY

Indication

- Cervical radiculopathy at one or more levels caused by disk herniation and/or osteophyte formation

Relative Contraindications

- Cervical myelopathy
- Midline disk herniation
- Cervical instability at the pathologic level
- Preoperative cervical kyphosis
- Vertebral body pathology
- Disk herniation with bilateral radiculopathy at the same level

LAMINECTOMY

Indications

- Multilevel cervical spondylotic myelopathy
- Cervical stenosis involving three or more levels
- Ossified posterior longitudinal ligament (OPLL) at multiple levels

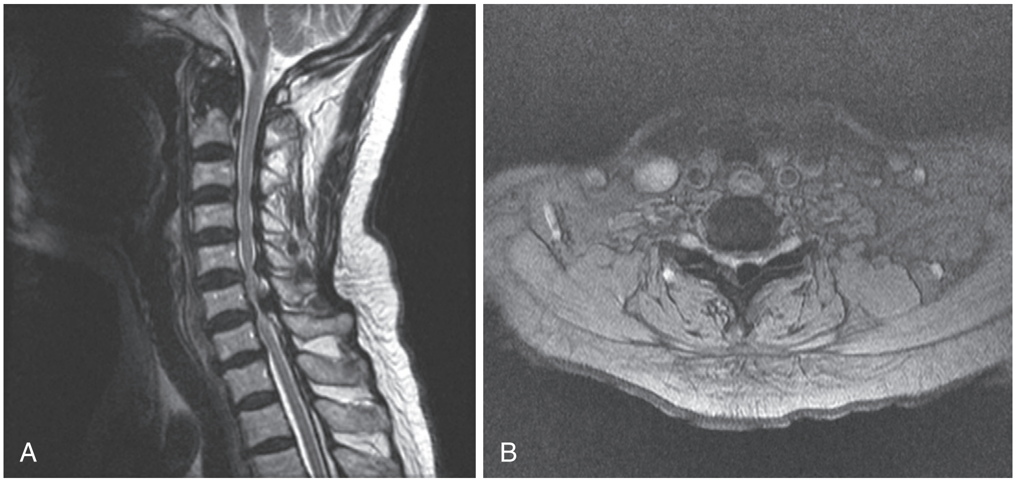

Figure 20-1 T2-weighted (**A**) sagittal and (**B**) C5–C6 axial magnetic resonance images illustrate the extent of the spinal cord compression. In addition to congenital spinal stenosis, this patient also had an ossified ligamentum flavum.

- To access an intradural pathology (e.g., extramedullary and intramedullary neoplasm)
- Structural difficulties with an anterior approach (previous anterior surgery, short neck, barrel chest, obesity)
- Failure of previous anterior decompressive surgery

Contraindications

- Kyphotic deformity
- Instability of the pathologic level
- Younger patients (high risk of developing kyphotic deformity)

Operative Technique

EQUIPMENT

The Mayfield head clamp is recommended over a horseshoe headrest to avoid pressure on the central retinal artery. Excessive and extended pressure on the orbits and central retinal artery can lead to blindness.

PATIENT POSITIONING

PCMF or decompressive laminectomy is best approached with the patient in a prone position. The sitting position may reduce blood loss secondary to collapse of the epidural vessels but requires greater preoperative preparation and intraoperative vigilance for detection of air emboli. The embolic risk in prone position is relatively small and can be further reduced by proper positioning. The patient's knees should be positioned higher than the heart, and bilateral compression stockings should be the standard of care. The authors prefer and recommend the prone position with the patient's chin flexed approximately 45 degrees to reduce cervical venous pressure and to increase the interlaminar space. With the patient secured, the reverse Trendelenburg position is often used so that the cervical spine is roughly parallel to the floor (Fig. 20-2).

Figure 20-2 The patient is positioned in slight flexion to facilitate surgical exposure. The neck is maintained parallel to the floor to decrease epidural bleeding and risk of air embolism. The patient's eyes should be free from direct pressure, especially when using the horseshoe headrest.

MINIMALLY INVASIVE APPROACH

With the minimally invasive approach to PCMF, a spinal needle is inserted approximately 1 to 2 cm off midline at the pertinent level. The target, the junction of the medial facet joint and two laminae, should then be confirmed with intraoperative fluoroscopy. A 12- to 14-mm stablike incision is made over the needle puncture site and is followed by removal of the spinal needle and insertion of a guidewire or a small dilator. The dilator is preferred over the guidewire to avoid penetration of the ligamentum flavum and creation of an inadvertent durotomy.

The dilator should be advanced and docked on the corresponding lateral mass. This can be confirmed by intraoperative fluoroscopy. Gentle soft-tissue dissection is carried out with subsequent dilators until the appropriate sized tubular retractor can be inserted. The location should again be confirmed by intraoperative fluoroscopy (Fig. 20-3). The

Figure 20-3 Anteroposterior fluoroscopic view shows tubular retractor setup for left C6–C7 posterior cervical microforaminotomy, lateral mass instrumented fusion for pseudarthrosis, and residual foraminal stenosis after previous anterior C5–C6 and C6–C7 surgery.

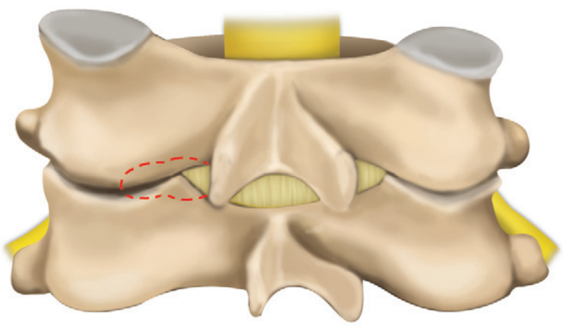

Figure 20-4 The operative boundary for posterior cervical microforaminotomy. The "keyhole" (*red dotted line*) is made up of the lateral portion of the superior and inferior laminae and the medial one third of the facet joint. (All schematic drawings by Phillip Lee.)

operative microscope is then brought over the surgical field to allow for direct visualization of the corresponding laminae and facet joint. The subsequent steps, whether done via a minimally invasive approach or by open PCMF, are identical and are described below.

CERVICAL MICROFORAMINOTOMY

Once the initial soft-tissue exposure is complete, the Bovie is used for subperiosteal dissection. Adequate hemostasis and unobstructed visualization are required before using the high-speed drill. The drill should be fitted with a 3 mm burr, which is then used to thin the laminae and expose the thecal sac. Continue the exposure laterally, thinning both the superior and inferior laminae up to the medial third of the facet joint (Fig. 20-4). While drilling, the hard outer cortical layer, the softer middle cancellous layer, and the inner cortical layer should be appreciated. We recommend using both hands on the drill for better control. Intermittent saline irrigation by an assistant is important in preventing thermal injury.

The bone is drilled until only a thin inner osseous layer remains. This layer is carefully removed with a curette from an anterior-posterior direction to reduce the risk of injury to the underlying spinal cord and nerve root. The ligamentum flavum is identified medially and incised with a scalpel or a microcurette. The goal is to create an anatomic plane between the ligamentum flavum and the dura to facilitate resection of the ligamentum flavum and exposure of the thecal sac and exiting nerve root. An epidural venous plexus commonly overlies the nerve root, and if necessary, it may be coagulated with bipolar cautery. Surgifoam (absorbable gelatin powder) mixed with thrombin administered via a syringe tip also works well to achieve hemostasis.

For lateral decompression to be sufficient, 5 mm of nerve root exposure is generally required (Fig. 20-5). A thin dental probe can be passed laterally along the foramen, tracing the path of the nerve root to assess the decompression. Pedicle-to-pedicle and more lateral facet joint resection may be performed for maximal bony decompression.

DISKECTOMY

For most soft-disk herniations, PCMF results in adequate nerve root decompression. However, in patients with noticeably diminished nerve root mobility following PCMF, the vascular cuff enveloping the nerve root should be removed to allow further exploration of both the nerve root and disk. The nerve root should always be manipulated in a controlled fashion to avoid injury (Fig. 20-6). When the herniated disk is below the nerve root, gentle rostral retraction should be applied. Similarly, gentle caudal retraction should be applied for a herniated disk above the nerve root.

Free disk fragments are carefully removed with a small pituitary ronguer. Depending on the location of the disk herniation, the annulus may be approached over the nerve root shoulder or from beneath the axilla. First, make an incision into the annulus; this initial incision can often yield substantial disk material; however, in the case of degenerative disk disease, more aggressive resection, often with a small pituitary rongeur, is normally required. To avoid manipulating the dura, use a small nerve hook to retrieve any loose disk fragments.

OSTEOPHYTECTOMY

The surgeon is sometimes presented with hard disk pathology or degenerative spurs. In these patients, the adequacy of the decompression needs to be further assessed. Pass a small Penfield probe around the shoulder, axilla, and foramen of the nerve root in question. If any resistance is felt, the foraminotomy should be extended. The pedicle below the exiting nerve may be palpated with a small dissector for anatomic orientation. Anterior osteophytes may be drilled away from the nerve root with a 2-mm diamond-tipped burr. This should only be attempted when there is observable deformation or compression of the nerve after unroofing the foramen.

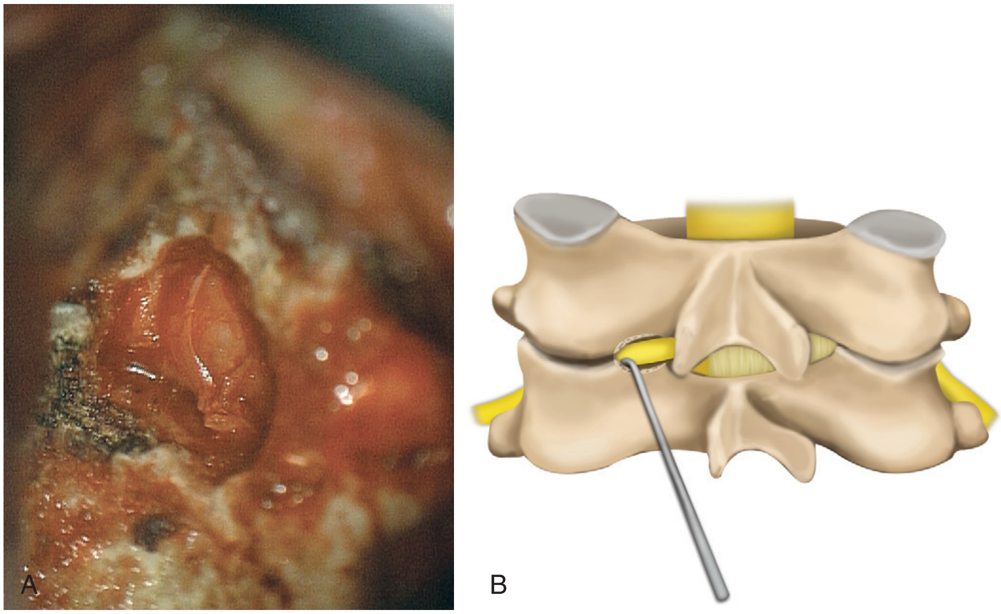

Figure 20-5 Intraoperative photograph (**A**) and schematic drawing (**B**) of a left C5–C6 posterior cervical microforaminotomy demonstrates a decompressed nerve root.

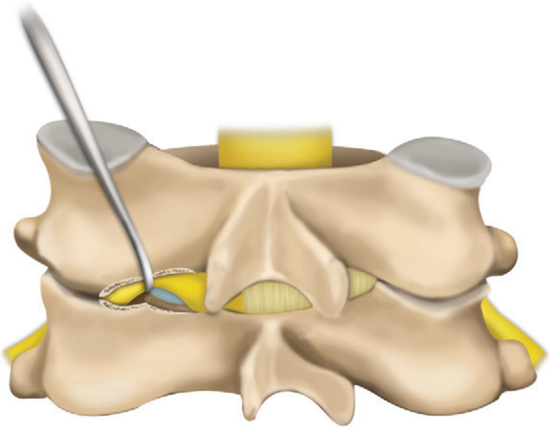

Figure 20-6 The nerve root is gently mobilized and retracted upward to expose the herniated portion of the disk.

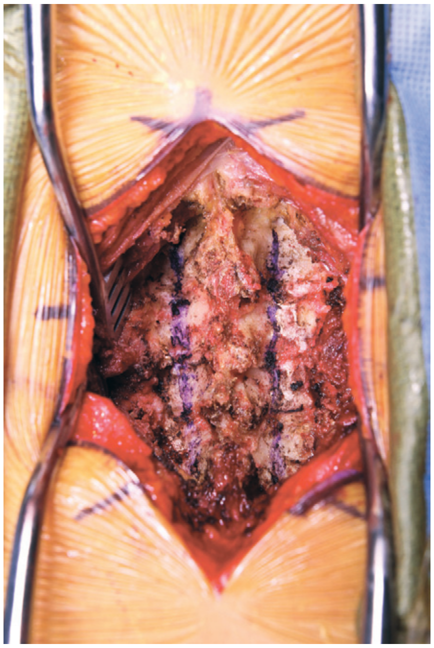

Figure 20-7 Operative view after subperiosteal exposure for a cervical laminectomy. A blue surgical marker demarcates bilateral troughs to be created just medial to the laminofacet junction.

DECOMPRESSIVE LAMINECTOMY

After prepping and draping in the normal sterile fashion, make a midline skin incision that is appropriate in length for the procedure and required exposure. Dissect down to the fascia, and identify midline structures to avoid transecting through the paraspinous muscle. Expose the spinous processes of the involved levels using a scalpel and/or Bovie cautery. Subperiosteal dissection is important to limit the amount of blood loss during the exposure. If at any point in the procedure the targeted anatomic level is unclear, an intraoperative radiograph should be obtained.

Cerebellar retractors adequately maintain the exposure; however, tension should be intermittently released to avoid ischemic injury to the paraspinal muscles and skin. Continue the subperiosteal dissection over to the lateral masses bilaterally while being cognizant of, and not disrupting, the facet joint capsule (Fig. 20-7). If the C1 posterior arch needs to be removed, electrocautery should not be used more than 1.5 cm from the midline to avoid injury to the vertebral arteries.

After completing the subperiosteal dissection, the authors recommend an en bloc resection of the involved laminae. Bilateral troughs are created with a 3-mm cutting burr just medial to the facet joint (Fig. 20-8). With intermittent irrigation, the troughs are created down to the ligamentum flavum. Drilling should proceed in a controlled and careful manner to avoid contact with the dura or underlying nerve root. Another, arguably safer option is to drill down to the

Figure 20-8 The trough is created using a 3-mm burr just medial to the laminofacet junction. A high-speed drill may be used to create the trough down to the ligamentum flavum, or partially down to the inner cortex, followed by use of a Kerrison rongeur.

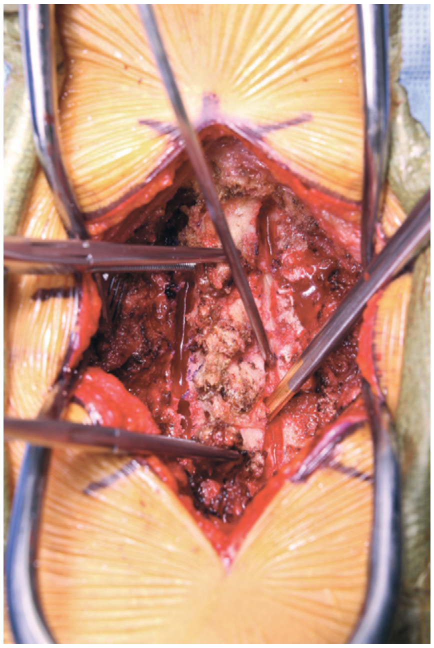

Figure 20-9 A small Kerrison rongeur is used to reduce the ligamentum flavum to complete the en bloc laminectomy. Kocher forceps are used to grasp the cranial and caudal spinous processes to distract the lamina to allow safe completion of laminectomy.

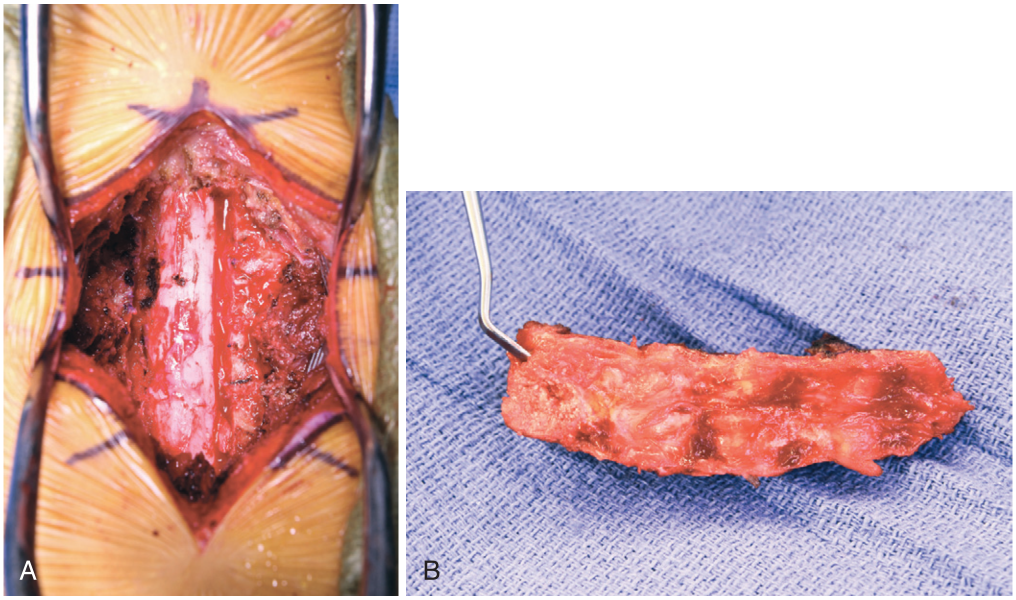

Figure 20-10 En bloc C3–C6 laminectomy with undercutting of C2 and C7 laminae. The lateral margins of the dura are visualized with the facet joints intact (**A**). Intraoperative photograph shows the undersurface of C3 to C6 en bloc laminae of the patient (**B**). Note the yellowish hue of the ossified ligamentum flavum.

inner cortex and complete the trough using a 1 or 2 mm Kerrison rongeur.

Upon completing the bilateral troughs, Kocher clamps are used to grasp the most cephalad and caudad spinous processes to gently distract the en bloc laminae away from the spinal canal (Fig. 20-9). Gently pull the Kocher clamps to one side, and expose the ligamentum flavum from below the contralateral trough. Without disrupting any epidural veins, use a small Kerrison rongeur to ensure separation of the ligamentum flavum from the dura. Repeat these steps along the contralateral trough. To prevent injury to the spinal cord, it is critical that the laminae and ligamentum flavum be removed outward and in a controlled manner, especially because areas of the dura may still be adherent to the laminae.

When the en bloc laminectomy is properly carried out, the lateral margins of the dura with intact facet joints are visible (Fig. 20-10). Use a Kerrison rongeur or a curette to remove any bony spicules and, if desired, to perform a foraminotomy. The foramen should first be palpated with a small nerve hook or a dental probe to ensure adequate decompression.

Postoperative Care

Postoperatively, a cervical collar does not need to be routinely provided. Patients often request a collar for comfort; however, it is preferable that its use be limited. Laminectomy patients benefit from exercises and muscle strengthening after adequate time is given for recovery. Collars can directly inhibit this, resulting in weak paraspinal muscles and increased susceptibility for developing a delayed cervical kyphotic deformity.

Complications

Among the possible complications of PCMF and cervical laminectomy, C5 nerve palsy, postsurgical instability, and kyphotic deformity deserve special attention.

C5 nerve palsy affects approximately 5% to 7% of patients, making it the most common motor palsy following cervical spine surgery.[6] Despite this, its pathogenesis remains unclear. A number of etiologies have been proposed, including direct nerve root injury, cord tethering, reperfusion injury, progressive malalignment, and iatrogenic foraminal stenosis. Interestingly, the C5 root is shorter than other nerve roots, and the angle it exits from the cord is more obtuse than at any other level. It also seems to occur irrespective of the procedure type, surgical technique, or initial pathology.[7] Radiographic differences among postoperative patients with and without C5 palsies have also been demonstrated. In affected patients, computed tomography and magnetic resonance imaging scans demonstrate narrowing of the intervertebral foramen, larger superior articular processes, and significantly greater posterior shift of the spinal cord.[7]

Efforts have been made to better understand and prevent C5 palsies. Some authors have suggested raising the mean arterial pressure during surgery or limiting reperfusion injury with free radical scavengers. Others have been proponents of multimodal intraoperative monitoring. Although the results appear to be highly sensitive and specific, the level of evidence that an intraoperative response to a neuromonitoring alert reduces the rate of perioperative deterioration remains low.[8] However, the most compelling evidence suggests that a prophylactic foraminotomy in patients undergoing laminectomies or laminoplasties significantly reduces the incidence of C5 palsy.[9]

Unlike C5 nerve root palsy, postsurgical instability is much better described. Zdeblick and colleagues[10] applied physiologic loads to human cadaveric cervical spines following resection of 25%, 50%, 75%, and 100% of the facet joint and capsule, unilaterally. They reported a statistically significant increase in the displacement observed during flexion after 75% or 100% capsular resection. Hence, when decompression involves greater than 50% of the facet joint, a concomitant fusion may be necessary. Novel surgical techniques have subsequently been described in an effort to preserve the facet joint. For example, Chang and colleagues[11] described a posterior cervical inclinatory foraminotomy with substantial facet preservation and reported excellent biomechanical and clinical results.

Cervical spine deformity and axial neck pain have also been reported following cervical laminectomy. This has been attributed to muscle disruption, primarily at the C2 and C7 spinous processes.[12,13] We strongly advise against resection of the C2 and C7 soft-tissue attachments to avoid this complication and to better maintain cervical lordosis. We prefer a C3–C6 decompressive laminectomy combined with undercutting of the C2 and C7 laminae. If a C7 laminectomy is necessary, cervicothoracic instrumentation is recommended.

Postlaminectomy kyphosis is a disabling problem that may be avoided by careful preoperative evaluation. Although this deformity can occur at any age, it occurs most frequently in children.[14] In adults with cervical spondylotic myelopathy, Kaptain and colleagues[10] reported a 21% incidence of postlaminectomy kyphosis.[15] Kyphosis has also been shown to be directly correlated with facet disruption and preoperative deformity and malalignment.

Conclusions

For the appropriate indications, posterior laminectomy and PCMF are safe and effective decompressive surgical modalities. There is also some evidence to suggest that the incidence of C5 motor root palsy is decreased in patients who undergo PCMF in addition to decompressive laminectomy. Cervical laminectomy, however, is associated with a higher incidence of delayed cervical deformity. Risk factors such as age, the cervical levels requiring decompression, and preoperative cervical alignment and motion must be carefully considered to avoid this complication.

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21 Cervical Laminoplasty

NEIL BADLANI and HOWARD AN

Overview

Cervical laminoplasty is a surgical treatment for cervical spondylotic myelopathy and ossification of the posterior longitudinal ligament (PLL) that increases the area of the spinal canal while preserving the posterior elements, therefore eliminating the need for fusion. The procedure has several variations, but all involve decompression of the spinal canal by expanding, but not removing, the posterior arch, usually from C3 to C7; this allows the dural sac to drift posteriorly, away from compressing anterior structures.[1] By preserving the laminae, the paraspinal muscle attachments are not compromised, minimizing the chance of postoperative instability.

Laminoplasty was first described in Japan by Hattori and colleagues[2] in 1973, primarily as a treatment for ossification of the PLL. It has since been modified by many authors and has come to gain acceptance in North America as an alternative to laminectomy or multilevel anterior decompression, because it does not have some of their limitations. Laminoplasty seems to avoid some of the complications and morbidity associated with laminectomy, such as neurologic deterioration from postoperative segmental instability, sagittal malalignment, and perineural scarring.[3-6] Laminoplasty is relatively simple and completely avoids the approach-related complications of anterior decompression and fusion, which can be particularly morbid if three or more levels are involved.[7-10] Because fusion is not necessary, laminoplasty is a motion-sparing procedure that allows for earlier and more aggressive rehabilitation, theoretically decreasing the incidence of adjacent-segment disease.[11] It also has a lower implant-associated cost than posterior or anterior instrumented fusion procedures.

Types of Laminoplasty

Hattori's original description of laminoplasty involved a Z-plasty done by thinning the lamina laterally, making a Z-shaped cut between adjacent lamina, and then securing them together with suture. Because of the complexity and time required to successfully complete the procedure, this specific technique did not catch on. However, it was this concept that originated the development of laminoplasty.[2]

Current laminoplasty techniques tend to fall into one of two categories, *open-door* or *French door* procedures. Neither procedure has been shown to be clinically superior, and each has advantages and disadvantages, surgeon preference being the main factor in determining their application.

Hirabayashi first described the *open-door laminoplasty* technique in 1978.[12] In this procedure, a trough is created on one side of the lamina and a hinge on the other, allowing for lifting up of the entire lamina without removal of the posterior bony arch. Because of its simplicity and long-term results, this technique has become increasingly popular, and it will be described primarily in this chapter.[13-15] Open-door laminoplasty is likely safer than the French door technique, because the burr is used more lateral to the midline, but it does risk injuring the dorsal venous plexus.

Kurokawa[16] described the alternative *French door laminoplasty* or *spinous process splitting technique* in 1982. In this procedure, bilateral hinges are created at the lateral aspect of the lamina, and a complete midline osteotomy allows for opening of each hemilamina to enlarge the space available for the spinal cord. Advantages of this approach include a more symmetric, and possibly greater, expansion of the spinal canal. Although the procedure may involve less bleeding than the open-door procedure from the venous plexus, it does involve a riskier midline osteotomy, and additional time is required to make a second hinge (Fig. 21-1).

Anatomy Review

- Relevant anatomy includes the osseous and ligamentous structures of the subaxial cervical spine (Fig. 21-2).
- Careful attention should be paid to the muscular and ligamentous attachments of the C2 spinous process.
- The junction of the lamina and lateral mass should be carefully identified, because it is the landmark for creation of the troughs, and the facet capsules should be recognized and protected.

Indications and Contraindications

INDICATIONS

- Cervical spondylotic myelopathy involving three or more levels, including multiple disk lesions or congenital stenosis[14,17]
- Ossification of the PLL with resultant multilevel cord compression[13]
- Myelopathy as a result of posterior pathology, such as ligamentum flavum hypertrophy or calcification
- Spinal cord mass

CONTRAINDICATIONS

- Cervical kyphosis: If the cervical spine is kyphotic, laminoplasty is strictly contraindicated, because the spinal

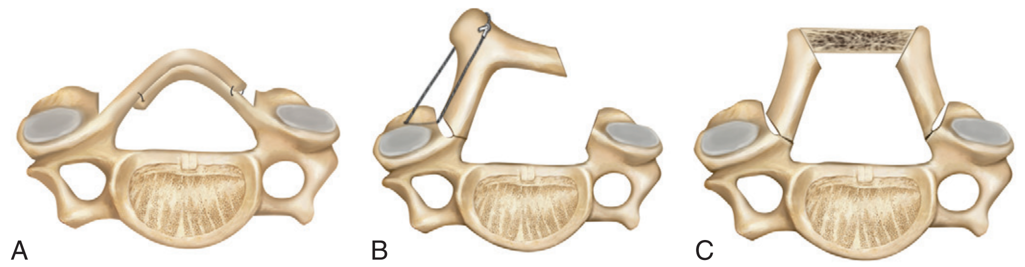

Figure 21-1 **A,** *Hittori Z-plasty*: The spinous processes are removed, the laminae are thinned, troughs are drilled laterally, a Z-cut is made between adjacent laminae, and the laminae are secured by sutures. **B,** *Hirabayashi expansive laminoplasty*: The spinous processes are removed, and bilateral troughs are made in the laminofacet junction. On one side, the laminae are separated, while the other side is hinged open and secured to the facets using sutures. **C,** *Kurokawa French door laminoplasty:* The spinous processes are split, and troughs are made on both sides of the laminofacet junction; the spinous processes are split in midline and stabilized.

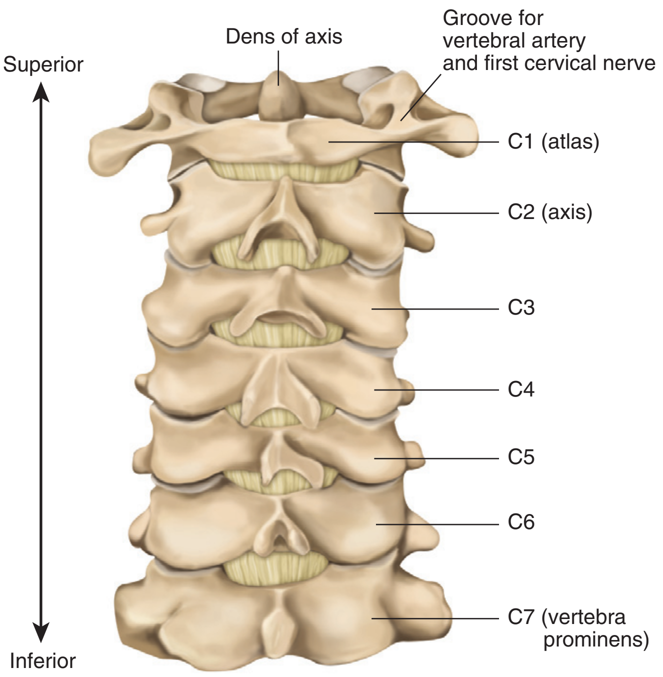

Figure 21-2 Bony anatomy of the cervical spine.

cord will continue to stay draped along the compressing anterior structures, even when the posterior arch is removed or widened. Laminoplasty may in fact worsen postoperative kyphosis.[18-20]

- Instability: Laminoplasty should be supplemented with arthrodesis if instability is present, or an alternative fusion procedure should be performed.
- Rheumatoid arthritis is a relative contraindication, because such patients may be a higher risk for postoperative instability.[21]

Advantages and Disadvantages

ADVANTAGES

- Laminoplasty does not require fusion, and although range of motion is diminished, it is therefore still somewhat preserved when compared with fusion techniques; this may decrease adjacent-level degeneration.[11,13,17,19,22,23]
- The spinal cord is decompressed without significantly compromising stability; this decreases the chance of postoperative kyphosis or listhesis.[24-27]
- The procedure maintains a bony "roof" over the spinal cord, which prevents the formation of scar tissue directly on the dura. Therefore if revision is necessary, it is easier and safer to reexpose the cervical spine.
- Laminoplasty can be combined with posterior foraminotomy for concomitant radiculopathy, or it may be combined with posterior lateral mass fusion if more stability is necessary.[28,29]
- Completely avoids all of the approach-related complications of anterior decompression, which can be particularly challenging when multiple levels are involved, and it can be accomplished more quickly than a multilevel anterior decompression, which decreases morbidity, particularly in the elderly.[7-10,30]

DISADVANTAGES

- Range of motion is reduced after laminoplasty, up to 30% to 50%, particularly in extension, lateral bending, and rotation.[23,31]
- Axial neck pain is common after laminoplasty, and it occurs in up to 25% of patients.[32] Some may consider preoperative neck pain a relative contraindication, and it is reasonable to consider a posterior fusion combined with laminoplasty in these patients.

Operative Technique

EQUIPMENT

- Regular operating room (OR) table with Mayfield tongs
- Headlights and surgical loupes
- Portable fluoroscopy for localization
- Retractors (cerebellar, Adson-Beckman)
- M-8 or 3-mm cutting burr with round tip
- Saw blade
- Kerrison rongeurs (1, 2, and 3 mm)
- Fresh-frozen or freeze-dried allograft, or "mini" laminoplasty plates
- Hemostatic agents (FloSeal, thrombin gel)

POSITIONING

- General anesthesia is performed without significant manipulation to the neck to avoid spinal cord injury in the face of myelopathy. Fiberoptic intubation is therefore preferred.
- Neuromonitoring electrodes should be placed before placing the patient prone, and baseline somatosensory evoked potentials and motor-evoked potentials can be recorded.
- Mayfield tongs are applied. The single pin is centered just above the ear, and the double pins are placed at the same level on the opposite side. The frame is tightened until the pressure indicator reads 60. The tongs are stabilized to the table after the patient is placed prone (Fig. 21-3).
- The patient is log-rolled onto the OR table in the prone position; careful attention is given to neck stability during transfer to avoid spinal cord injury.
- Neck positioning is critical: the optimal position is slight flexion, which facilitates exposure and closure by tensioning skin folds, and it opens the interlaminar spaces (Fig. 21-4). This is the opposite of a posterior fusion procedure, in which slight neck extension is recommended.
- The arms are placed at the patient's side and are held in position with a draw sheet. The knees are flexed to prevent distal migration of the patient. Bony prominences should be well padded, and the shoulders can be taped down to improve radiographic visualization.
- The table is placed in reverse Trendelenburg position to facilitate venous drainage and decrease bleeding.

PREPPING AND DRAPING

- The bony landmarks are palpated. The spinous processes of C2 and C7 are most prominent and are easily identified (Fig. 21-5).

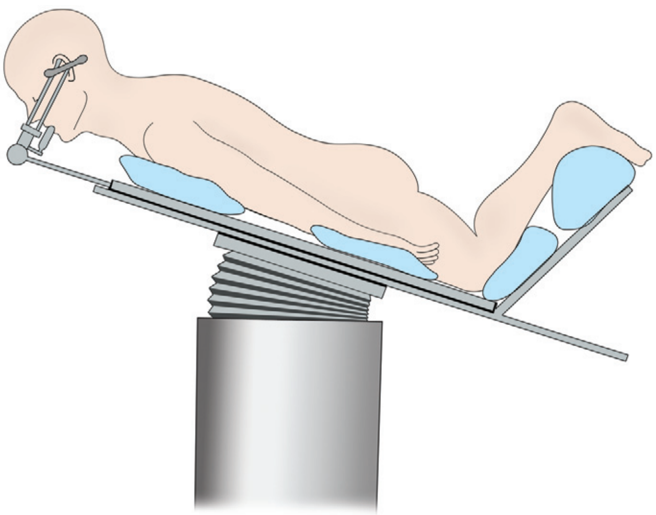

Figure 21-3 The patient is positioned prone with the head and neck extending over the edge of table. The head is stabilized with Mayfield tongs in a neutral position, and all bony prominences are padded. The knee is bent to prevent the patient's sliding while the table is placed in reverse Trendelenburg position to decrease venous bleeding.

- The neck is shaved superiorly to the level of the occipital protuberance.
- The field is prepped and draped in a sterile fashion using towels and Ioban from the external occipital protuberance to the spinous process of approximately T3.

INCISION AND EXPOSURE

- Posterior longitudinal midline incision is made from C2 to C7. A long incision is necessary because of the tight ligamentum nuchae (Fig. 21-6).
- The ligamentum nuchae is divided; care is taken to stay in the midline, because developing this natural avascular

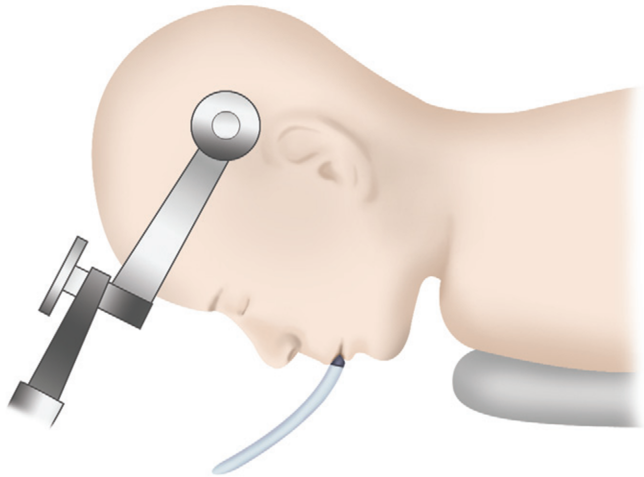

Figure 21-4 Slight cervical flexion is beneficial.

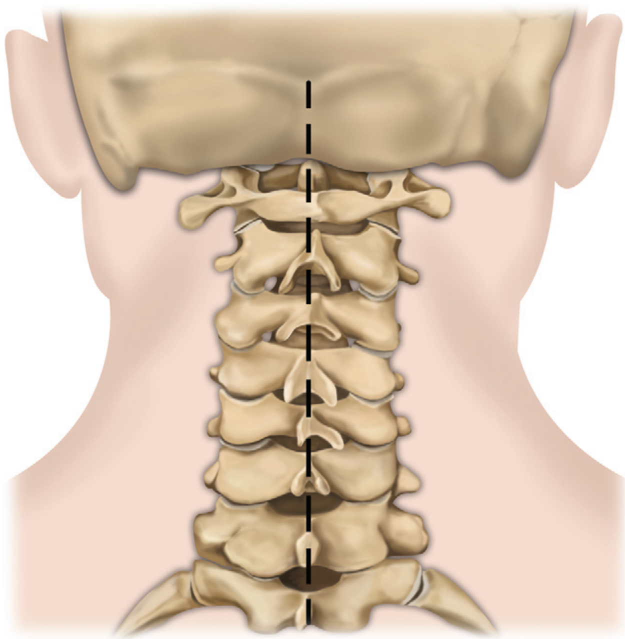

Figure 21-5 Bony prominences are palpated beneath the skin. The occipital protuberance and C2, C7, and T1 spinous processes are easily palpated. An incision is made from the inferior occipital protuberance to the T1 spinous process.

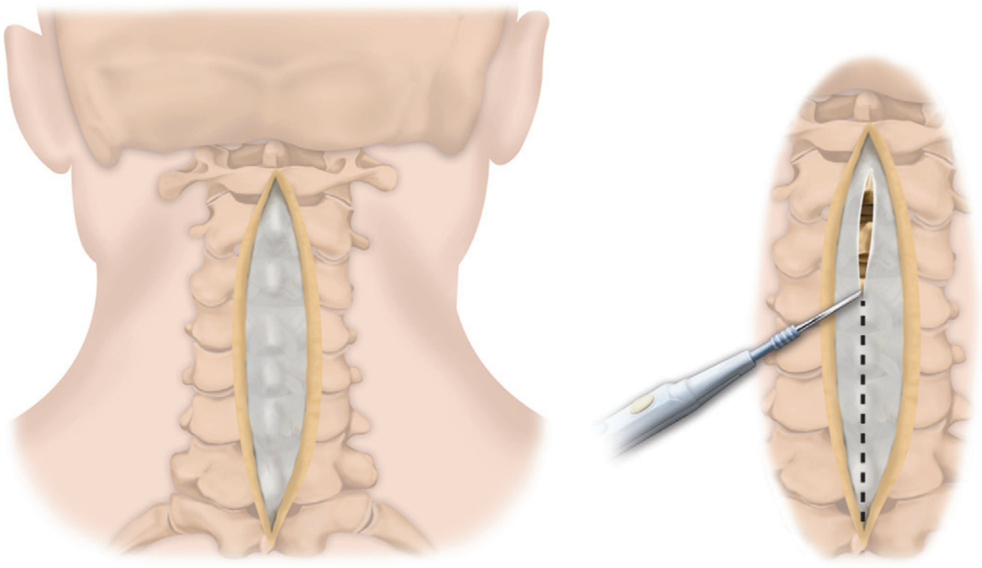

Figure 21-6 A midline longitudinal incision is made over the operative cervical levels. Dissection is carried down to the spinous processes, predominantly an avascular plane. Care is taken to ensure the intraspinous ligament is left intact and the posture tension band is undisturbed.

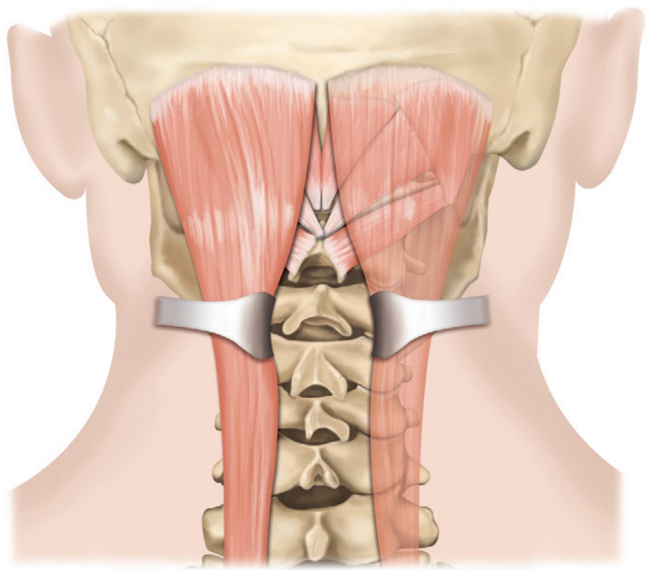

Figure 21-7 The ligamentum nuchae is incised in the midline, followed by subperiosteal dissection of the paravertebral muscles exposing the facet joints. The muscle attachments of C2 are not released.

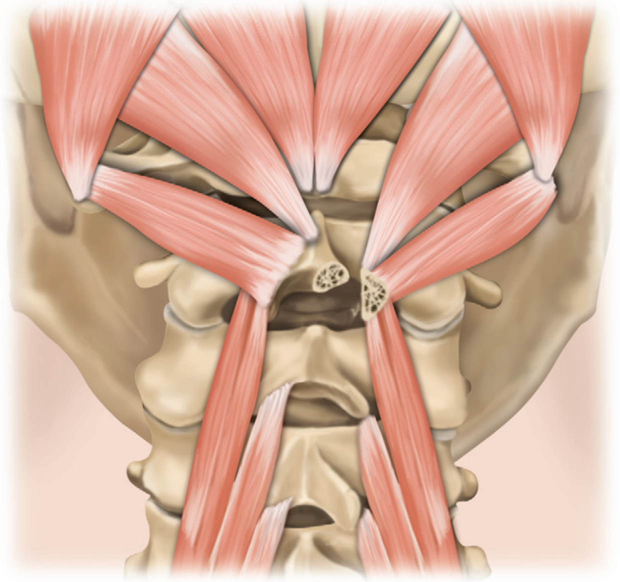

Figure 21-8 Alternatively, the C2 muscle attachments can be released as a sleeve, which can later be sutured back down to the C2 spinous process.

plane decreases bleeding significantly. Meticulous hemostasis with electrocautery should be maintained through the subcutaneous tissue.

- A subperiosteal dissection is carried out from C3 to C7, reflecting the paraspinal muscles laterally (Fig. 21-7). Care should be taken to prevent penetration of the widened interspinous spaces. The C2 and C7 spinous processes are also exposed, and care is taken to preserve the midline posterior ligamentous complex during the dissection.
- Laterally the dissection should extend to the middle of the lateral masses of C3 to C7 with preservation of the facet capsules. This can be facilitated with use of a lap sponge under the Cobb elevator to prevent injury to the capsules. If possible, the C7 spinous process should be preserved for muscle reattachment; the cephalad portion of C7 could be removed if stenosis is present at C6–C7.
- The muscular attachments to the C2 spinous process should be preserved to prevent instability. If they are taken down, the insertion should be repaired before

closure (Fig. 21-8). Wide exposure of the inferior surface of the C2 lamina can aid in visualization of the C3 lateral mass.

- Retraction is best facilitated by two deep cerebellar retractors.

TROUGH PREPARATION

- The spinous processes can be amputated to facilitate exposure and can provide bone graft to keep the lamina open. This also decreases tension on the soft tissues for wound closure.
- The open side of the lamina should be cut first to reduce blood loss. This side should be the one with more significant radiculopathy. Additional foraminotomy can be performed on this side as well.
- The trough is made with a nonaggressive 3-mm burr at the lamina–lateral mass junction (Fig. 21-9). A side-to-side sweeping manner without downward pressure minimizes the risk of canal injury. The surgeon can be more aggressive at the inferior aspect of the lamina because of the underlying ligamentum flavum, although the tendency is to not burr enough of the superior lamina, which is in fact thicker.
- The cut can be completed with a 1-mm Kerrison rongeur on the inner cortex, once it has been sufficiently thinned by the burr (Fig. 21-10). It is safest to start at the inferior aspect of C6 or C7, depending on the levels of laminoplasty, and to proceed cephalad. A small curette or Penfield #4 can be used to identify bony bridges and to carefully separate the ligamentum flavum below. The ligamentum must be released for the laminoplasty to open. Great care should be taken to avoid significant epidural bleeding at this time. Bipolar electrocautery, FloSeal, or Gelfoam can be used to achieve hemostasis.
- The hinge side is then burred on the opposite side at the same anatomic junction of the lamina and lateral mass. The outer cortex and inner cancellous bone must be removed, leaving only the inner cortex (Fig. 21-11). This can be done with incremental thinning to allow creep deformation. Bone wax can be used here for hemostasis.

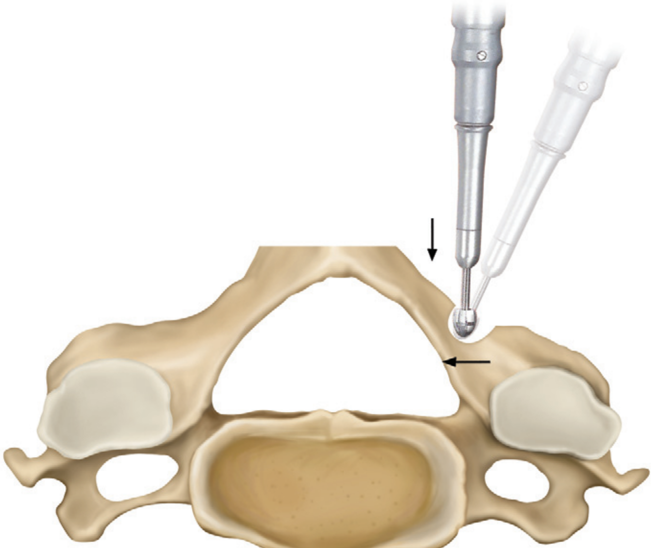

Figure 21-9 The trough is made at the lamina–lateral mass junction.

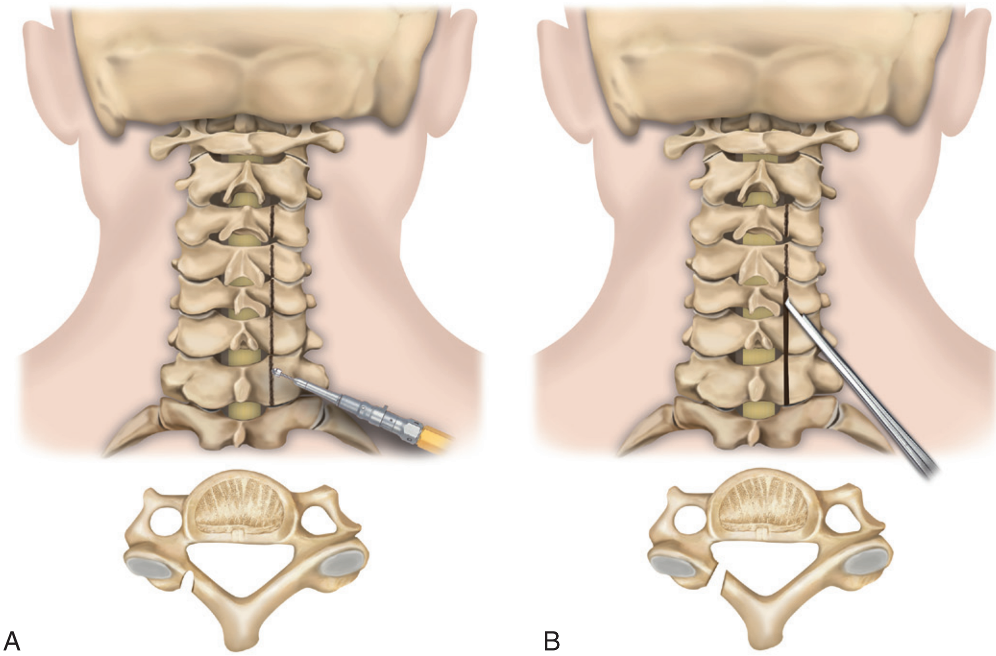

Figure 21-10 **A,** With the help of a 3-mm burr, a trough is made on the opening side of the lamina-facet junction. **B,** The lamina is detached from the facet using a 1-mm Kerrison punch.

The flexibility of the posterior elements and hinge is then continuously tested, with pressure on the corresponding spinous processes, until it is felt to be free and pliable (Fig. 21-12). If the hinge side is inadvertently fractured, laminectomy and fusion should be done instead.

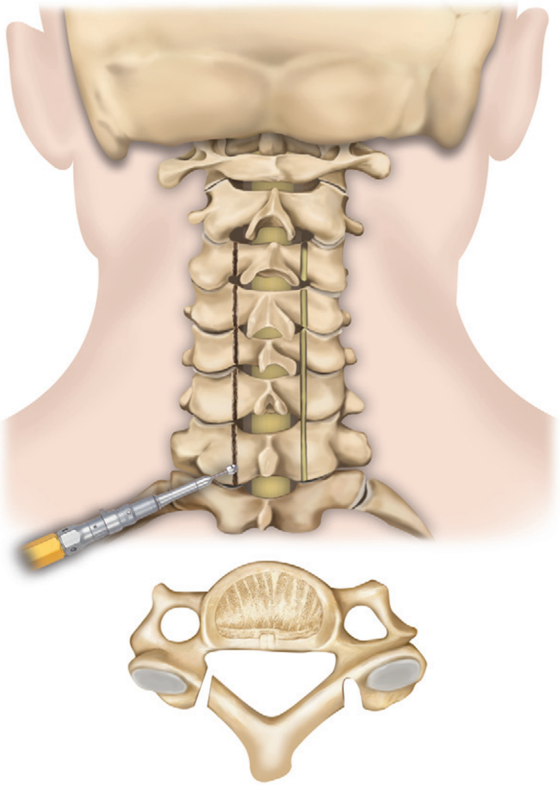

Figure 21-11 A trough is made in the hinged side of the lamina at the laminofacet junction. This trough needs to be wider than the opposite side to allow the lamina to hinge.

OPENING THE LAMINOPLASTY

- The interspinous ligaments at C2–C3 and C6–C7 are divided. Complete release of the ligamentum flavum at the open side of the lamina must be done. Adhesions can be gently released with a Woodson probe swept under the lamina (Fig. 21-13).
- The laminoplasty is then opened with gentle pressure on the spinous processes. Proceeding from caudal to cranial, pressure with a nerve hook on the open side can help facilitate the opening (Fig. 21-14).

POSTERIOR ARCH RECONSTRUCTION USING GRAFT OR PLATING

- The laminoplasty can be held open using a variety of techniques that include autograft, allograft, sutures, or plating.
- The options for autograft include the autogenous spinous processes; those of C6 and C7 are usually the appropriate size. Tricortical iliac crest pieces can also be taken. Three 4×15 mm pieces cut perpendicular to the ilium work well (Fig. 21-15).
- Allograft options are abundant and include freeze-dried or fresh-frozen tricortical iliac crest and rib grafts. Fresh-frozen grafts should be thawed slowly and washed with antibiotic irrigation before use. Freeze-dried grafts should be placed in saline for 10 minutes before use for rehydration.
- Troughs should be fashioned on either side of the grafts, and one side should be slightly deeper than the other to prevent dislodgment into the canal. We prefer to place the grafts at the C3, C5, and C7 laminae; the C5 graft should be slightly larger than the others because this level is at the center of the decompression and has the greatest stress. The troughs are then wedged into place; beveling allows them to fit appropriately with minimal need for any other fixation, although it may be necessary to reshape the grafts to obtain the optimal fit (Fig. 21-16).

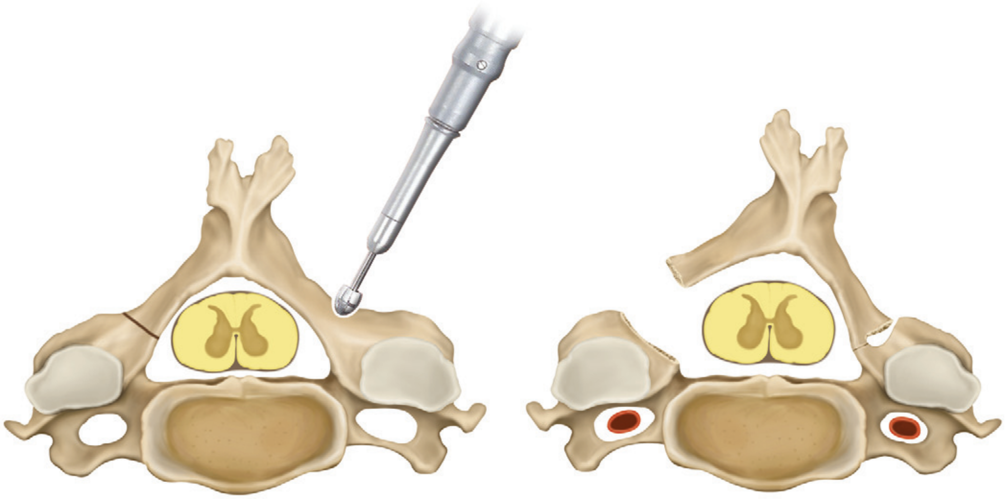

Figure 21-12 The flexibility of the posterior elements and hinge is then continuously tested with pressure on the corresponding spinous processes until it is felt to be free and pliable.

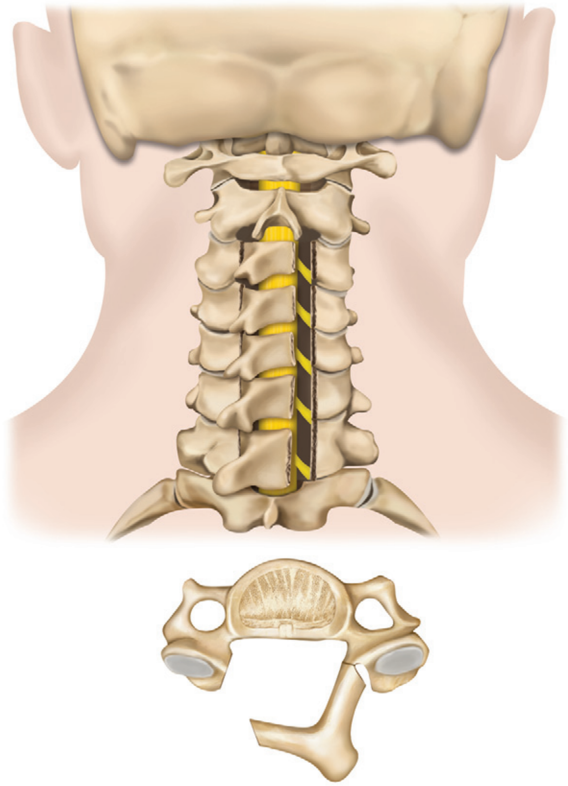

Figure 21-13 Once the interspinous ligaments at C2–C3 and at C7–T1 are released, the lamina is hinged open.

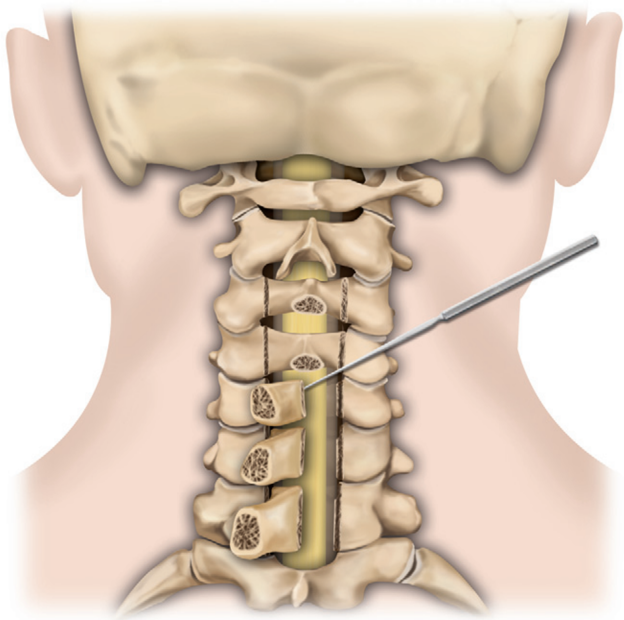

Figure 21-14 A nerve hook can be used to facilitate opening.

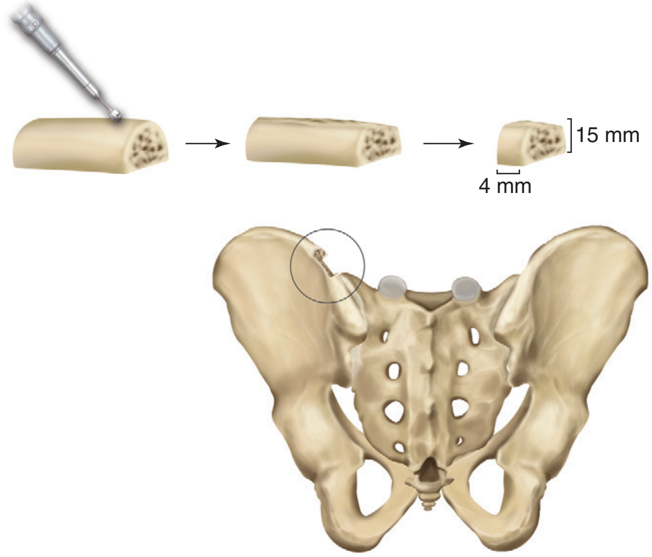

Figure 21-15 Three 4 × 15 mm segments are cut out of the anterior ileal crest using a sagittal saw.

- Suture can be used as an alternative. It can be passed through the facet capsule on the hinge side and tied to the spinous processes.
- Plates are becoming increasingly more popular. Specifically designed laminoplasty plates are available for this purpose (Fig. 21-17). All forms of fixation rely on bony healing of the hinge side to permanently hold the laminoplasty open.

FORAMINOTOMY TECHNIQUE

- Foraminotomies can be done on the open side of the laminoplasty if there is significant radiculopathy in addition to the myelopathy. Foraminotomies are performed before laminoplasty to avoid inadvertant injuries to dura.
- The medial third of the facet should be thinned using a cutting burr initially and then a diamond burr. The bony resection is completed with a 1 mm Kerrison rongeur to remove the foraminal roof and expose the nerve root. Care should be taken to protect the open dura (Fig. 21-18).
- A nerve hook is placed into the foramen to confirm that it is open and that the decompression is sufficient (Fig. 21-19).

ARTHRODESIS TECHNIQUE

- Concomitant arthrodesis can be performed in cases with severe axial neck pain or instability.
- Exposure is taken lateral to the facet capsules. Capsules at C3–C4, C4–C5, C5–C6, and C6–C7 can be sacrificed, but those of C2–C3 and C7–T1 must be preserved to decrease adjacent-level degeneration or instability.
- After completion of the laminoplasty, lateral mass screws are placed using standard technique. Our preference is to start these screws 1 mm medial to the midpoint of the

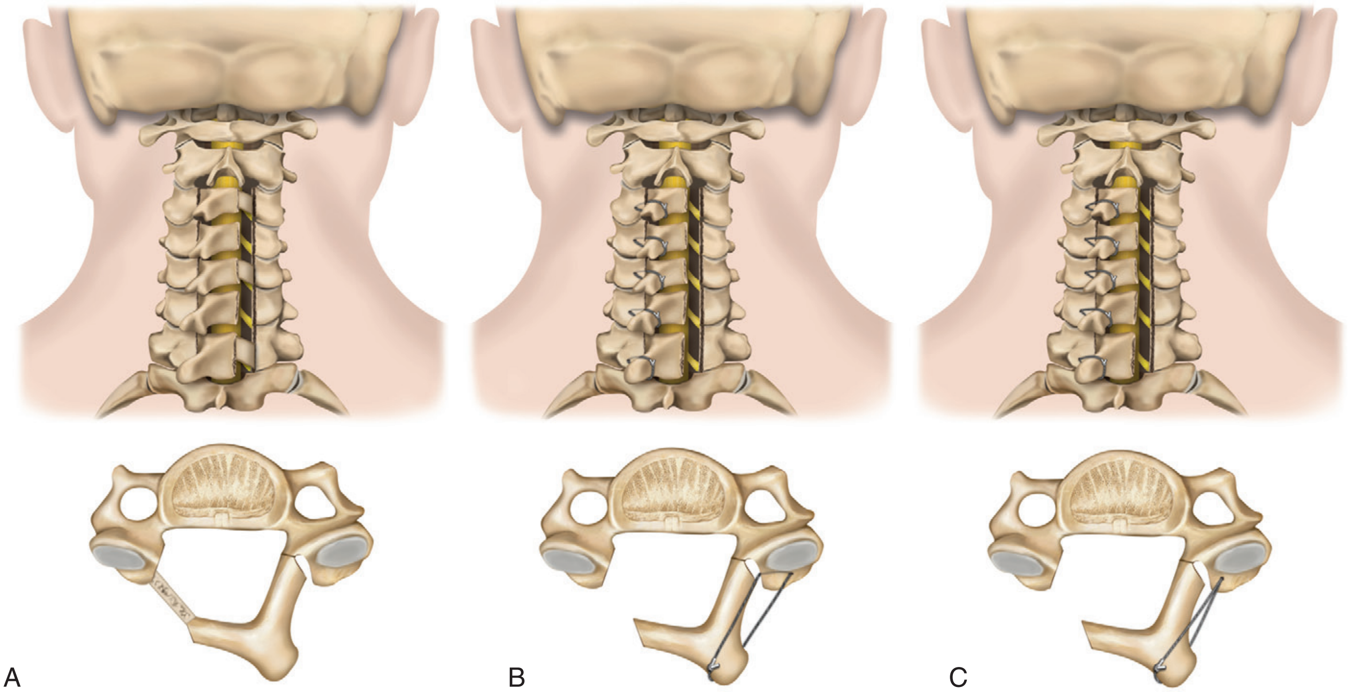

Figure 21-16 **A,** The prepared grafts are wedged into place at C3, C5, and C7 laminar openings. Some degree of work is needed to fashion the grafts into appropriate sizes that allow the tension of the laminae to hold them in place. The beveled edge prevents the graft from dislodging into the canal. The lamina may be stabilized with a suture through the facet capsule (**B**) or with a bone anchor placed in the lateral mass (**C**).

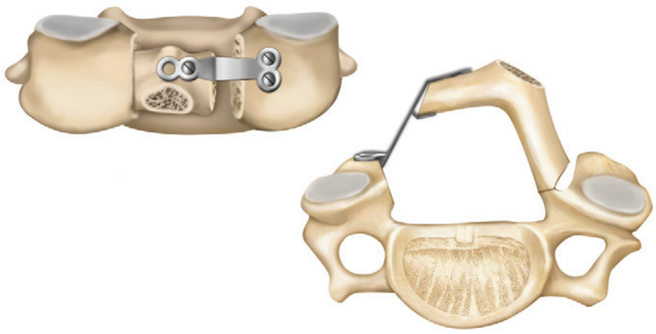

Figure 21-17 Plates specifically designed for cervical laminoplasty.

lateral mass and to aim 15 degrees cephalad and 30 degrees laterally.[33]

- After instrumentation the lateral masses are decorticated and packed with bone graft, autograft, or allograft.

FRENCH DOOR LAMINOPLASTY

- The "French door" technique is an alternative in which a complete midline osteotomy is performed and hinged bilaterally.
- After exposure, a low-aggression burr is used midline over the spinous processes and laminae to create a complete division. This can be finished delicately with a 1-mm Kerrison rongeur.
- Identical bilateral hinges are made as described above at the lamina–lateral mass junctions.
- The French door can be held open by similar methods as described above. Appropriate bone graft is used with suture or plate fixation.

WOUND CLOSURE

- A deep drain is placed to decrease postoperative hematoma formation.
- The paravertebral muscle layer is reapproximated with a running #1 Vicryl suture to reduce dead space and decrease tension on the fascial closure.
- The ligamentum nuchae is also closed with #1 Vicryl using figure-eight sutures. A watertight closure is critical.
- Standard subcutaneous and skin closure is then performed. We prefer a subcuticular skin closure.

Postoperative Care

- We prefer to use a hard cervical collar initially (Aspen, Philadephia, or Miami-J), for 2 to 4 weeks, and then the patient is transitioned briefly to a soft collar. Neck range of motion and strengthening is begun at this time and is advanced with physical therapy guidance.
- We prefer to keep the head of the bed at 30 to 45 degrees during the first day to decrease venous bleeding. The early postoperative course is standard, pain medication is used as needed, and the drain is removed after 24 to 48 hours.

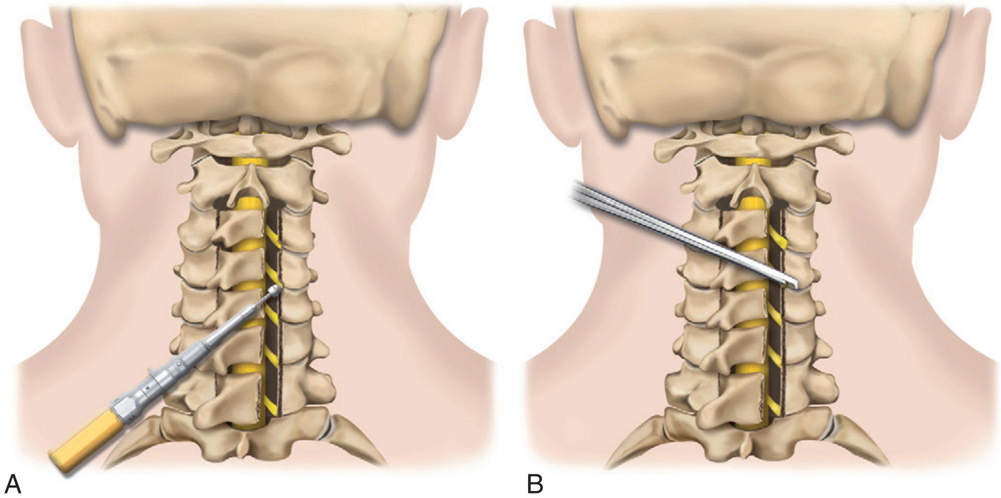

Figure 21-18 The foraminotomy can be performed on the opening side of the laminoplasty. This is accomplished by thinning out the medial third of the facet with a burr followed by use of a 1 mm Kerrison punch.

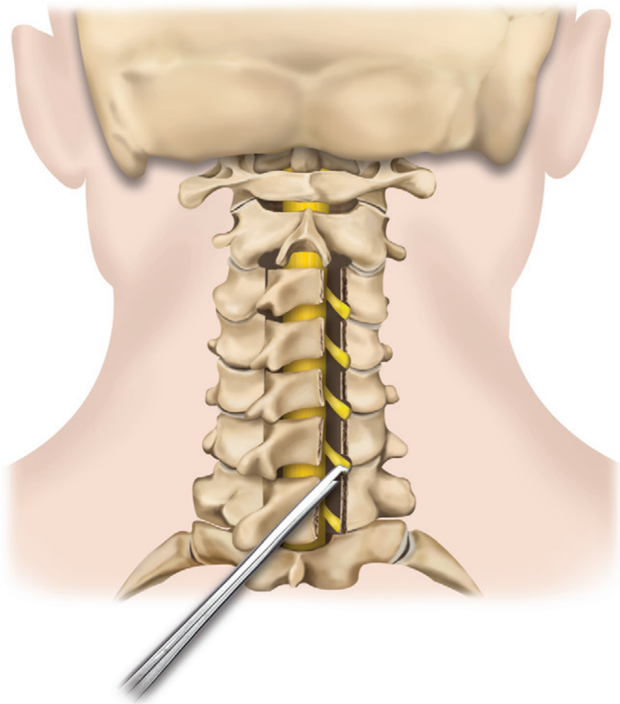

Figure 21-19 The adequacy of the foraminotomy can be measured by passing a nerve hook through the foramen.

Inpatient physical therapy is used to help the patient mobilize. Length of stay is 2 to 4 days after surgery.

Complications

- Wound infection and wound dehiscence can be minimized with good soft tissue technique, meticulous hemostasis, watertight fascial closure, and appropriate wound care.
- The most common complication following laminoplasty is axial neck pain, which can be a new symptom or an exacerbation of a previous condition. This is present in anywhere from 5% to 50% of patients, depending on the literature, but most studies report less than 25%.[23,31,32,34-37] This complication is best mitigated by appropriate patient selection.
- A well-known postoperative complication of both laminectomy and laminoplasty is C5 palsy. It has been reported in approximately 5% to 14% of cases.[23,31,38-43] It is felt to be due to a traction phenomenon of the relatively shorter and more tethered C5 root, with dorsal translation of the cord. It usually appears in the first 24 to 48 hours, and most cases improve within 24 months. A recent large series found a smaller incidence of only 2% and found a correlation with decreased preoperative size of the C5 intervertebral foramen.[44]
- Range of motion can also be reduced after laminoplasty, as much as 30% to 50%, particularly in extension, lateral bending, and rotation.[23, 31]

ILLUSTRATIVE CASE

The patient is a 58-year-old woman who came to medical attention with early signs and symptoms of myelopathy that included decreased coordination in her hands and radiculopathy in the right arm in the C6 and C7 distributions. Preoperative cervical spine radiographs show diffuse spondylosis at multiple levels with fair preservation of lordosis, and preoperative MRI shows multilevel spinal stenosis with cord compression (Fig. 21-20). The patient underwent C3 to C7 laminoplasty with right-sided C5–C6 and C6–C7 foraminotomies without complication. Clinically, the patient had significant improvement in her symptoms, and her postoperative cervical spine radiographs demonstrate an increase in the size of the canal, with the laminoplasty held open by specially designed plates (Fig. 21-21).

Figure 21-20 A 58-year-old woman with myelopathy. Preoperative cervical spine radiographs show diffuse spondylosis at multiple levels with fair preservation of lordosis. Preoperative magnetic resonance image (T2-weighted sagittal view) shows multilevel spinal stenosis with cord compression.

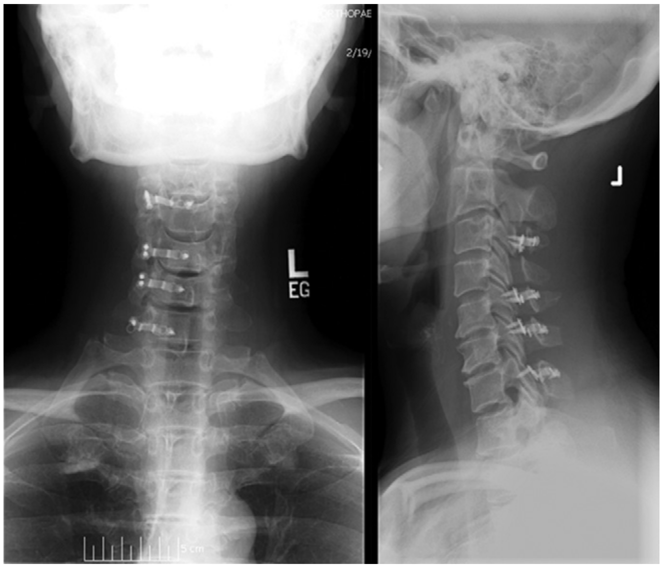

Figure 21-21 The patient underwent C3 to C7 laminoplasty with significant improvement in her symptoms. Postoperative cervical spine radiographs demonstrate an increase in the size of the canal with the laminoplasty held open by specially designed plates.

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22 Posterior Cervical Stabilization Techniques: Cervical Pedicle Screw Fixation, Lateral Mass Screw Fixation, and Wiring

DO HEUM YOON, YOON HA, and JAE KEUN OH

Overview

A variety of techniques have been developed to internally stabilize the subaxial cervical spine using a posterior approach. These include interspinous wiring with bone grafts, interlaminar clamps, hook plates, lateral mass screw and plates or rod and pedicle screw, and rod constructs. Before the advent of lateral mass screw fixation, intraspinous wiring was commonly used for multilevel subaxial cervical stabilization. For cases requiring laminectomy with removal of the spinous process, various facet wiring techniques were developed, with and without bone grafting, for stabilization purposes.

In the late 1970s, Roy-Camille presented a technique for posterior cervical fixation in which plates were secured to the lateral masses using screws, a technique proven by biomechanical test results to be significantly stronger than previous constructs. Application of this technique in cervical trauma cases resulted in fusion rates greater than 95% when autogenous bone grafting was combined. Because lateral mass screws at C7 often achieve inadequate purchase, pedicle fixation of the lower cervical spine and upper thoracic vertebrae has been proposed. Transpedicular screws have been shown to have more fixation stability than other subaxial cervical spine reconstruction systems. However, because pedicle screw fixation has the potential to seriously injure the spinal cord, nerve roots, or vertebral arteries, it is generally considered a high-risk procedure. Nevertheless, if the safety of the procedure can be ensured, cervical pedicle screw fixation is an effective procedure for reconstructing the cervical spine.

In this chapter, we introduce the posterior cervical stabilization techniques of cervical pedicle screw fixation, lateral mass screw fixation, and wiring for the treatment of an unstable cervical spine, and we describe indications, procedural steps, intraoperative imaging techniques, technical pitfalls, and postoperative courses in detail.

Cervical Pedicle Screw Fixation

Cervical pedicle screw fixations have more fixation stability than other subaxial cervical spine reconstruction systems. Therefore this procedure is especially beneficial in settings where laminae or lateral masses may be inadequate because of postsurgical disturbances or marked osteoporosis. Preoperative evaluation of the vertebral artery and pedicle is critically important for cervical pedicle screw fixation; therefore preoperative computed tomographic angiography (CTA) or magnetic resonance angiography (MRA) is required.

INDICATIONS

- Cases that require powerful correction of cervical kyphosis
- Progressive symptomatic cervical myelopathy that requires surgical decompression and fusion
- Cervical instability—traumatic, iatrogenic, neoplastic, or inflammatory—with disruption or destruction of the posterior elements that precludes the use of standard fixation
- Fixation for C2 and C7
- Following a multiple-level anterior cervical decompression and fusion for added stability

CONTRAINDICATIONS

- Patients with insufficient pedicles (congenitally narrow pedicles <4.5 mm in diameter)
- Destruction of pedicles by trauma/tumor
- Ipsilateral to a single dominant vertebral artery with the contralateral side nonfunctional
- Ipsilateral to an anomalous vertebral artery

OPERATIVE TECHNIQUE

Patient Positioning and Incision

The patient is placed in a prone position with the skull fixed in a Mayfield three-point fixator and the cervical spine positioned parallel to the floor (Fig. 22-1). Both shoulders are pulled caudally and fixed by taping. A midline posterior approach is used, and longitudinal midline exposure through the ligamentum nuchae is performed. Monopolar electrocautery is used to dissect down to and through the ligamentum nuchae. Strict subperiosteal dissection makes

Figure 22-1 Positioning of the patient with the skull fixed in a Mayfield three-point fixator.

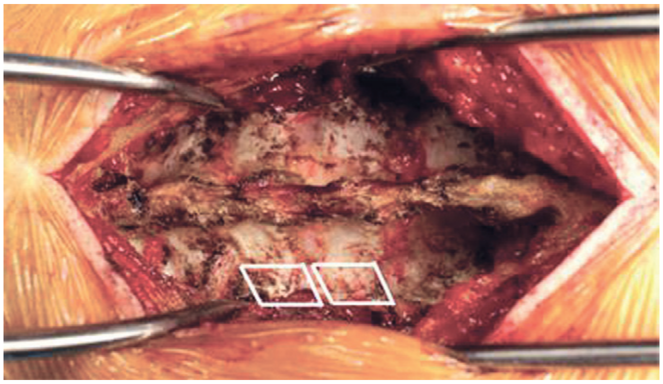

Figure 22-2 Adequate exposure of the lateral mass using a posterior midline approach. The white boxes show the lateral mass.

Figure 22-3 Pedicle axis view by fluoroscopy. Oblique radiography shows the shadows of the cortical circle of the cervical pedicle (*arrows*).

a bloodless operation field, and care should be taken not to disrupt the attachments of the semispinalis cervicis and capitis to C2, which can lead to increased risk of C2 on C3 kyphosis.

Adequate exposure of the lateral mass is crucial for accurate screw placement (Fig. 22-2). Care should be taken to avoid violating the facet capsules of levels not intended to be fused. Dissection lateral to the lateral aspect of the articular pillars can lead to excessive venous bleeding. If adequate exposure of the surgical field cannot be obtained, an additional small incision lateral to the main incision can be considered.

Subaxial Pedicle Screw Insertion

Accurate screw placement requires precise identification of the screw entry point matched with the trajectory angle. For that purpose, four techniques can be used: 1) the original technique described by Abumi and colleagues,[1] 2) pedicle axis view by fluoroscopy,[2] 3) the laminoforaminotomy technique,[3,4] and 4) computer-assisted navigation techniques (Figs. 22-3 and 22-4).[5,6] Computed tomography (CT) allows the assessment of pedicle morphology and dimensions and allows the surgeon to determine the appropriate screw diameter, length, and transverse plane trajectory.

The points of screw penetration for the C3 through C7 pedicles are slightly lateral to the center of the lateral mass and close to the inferior margin of the inferior articular process of the upper adjacent vertebra (Fig. 22-5). The lateral margin of the lateral mass of the cervical spine has a notch approximately below the lateral vertebral notch at C2 and C3–C6 and at or slightly above the notch at C7.

The drill is angled 45 degrees medially and is advanced in a vertical line parallel to the end plate (see Fig. 22-5). Alternatively, a line parallel to the contralateral lamina provides a 3-mm safe corridor for sagittal plane angulation.[7] Another option is removal of the lateral mass with a high-speed burr to provide a direct view of the pedicle introitus. The pedicle is probed and tapped, and a 3.5-mm cortical screw is inserted (see Fig. 22-5). Mean pullout strengths are similar.[8] Standard angulations and entry points may be dangerous, because pedicle anatomy and surface topography are highly variable between C4 and C6.[9]

Pedicle screw fixation safety can be improved by avoiding pedicles smaller than 45 mm, by performing a laminoforaminotomy to palpate the pedicle directly, and/or by using navigation assistance.[10] Violation of the upper facet capsules sometimes causes instability. Cervical roots run just above the pedicles, unlike in the lumbar spine. Cephalad malpositioning of pedicle screws is more likely to cause root injury than caudal malpositioning.

Intraoperative electromyography assessment may be helpful for posterior cervical screw placement. To reduce scatter, the screws should be tested before placing the connecting rod. Stimulation thresholds correlate with screw position, and values greater than 15 mA reliably predict acceptable screw positioning.[11]

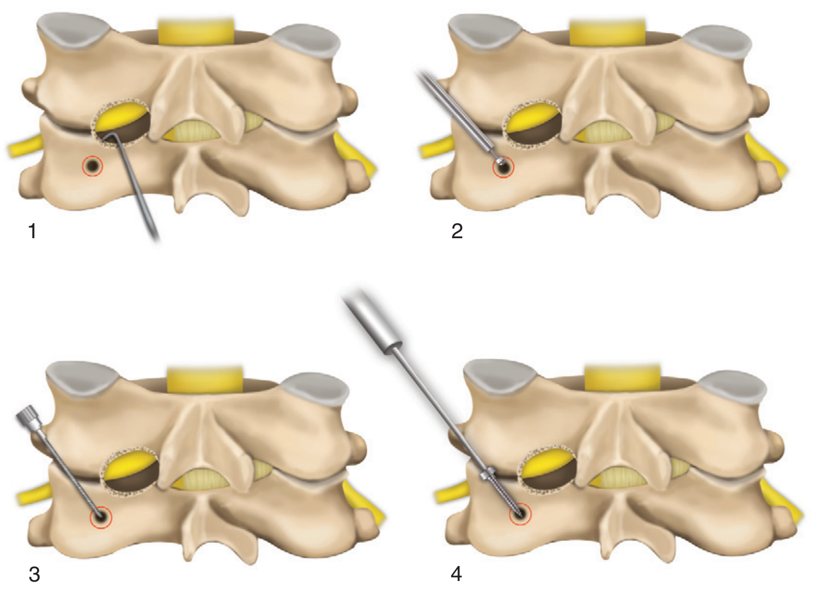

Figure 22-4 Laminoforaminotomy technique. Laminoforaminotomy of C3–C7 was performed at the level of the laminofacet junction to allow direct visualization of the medial wall of the pedicle from within the spinal canal.

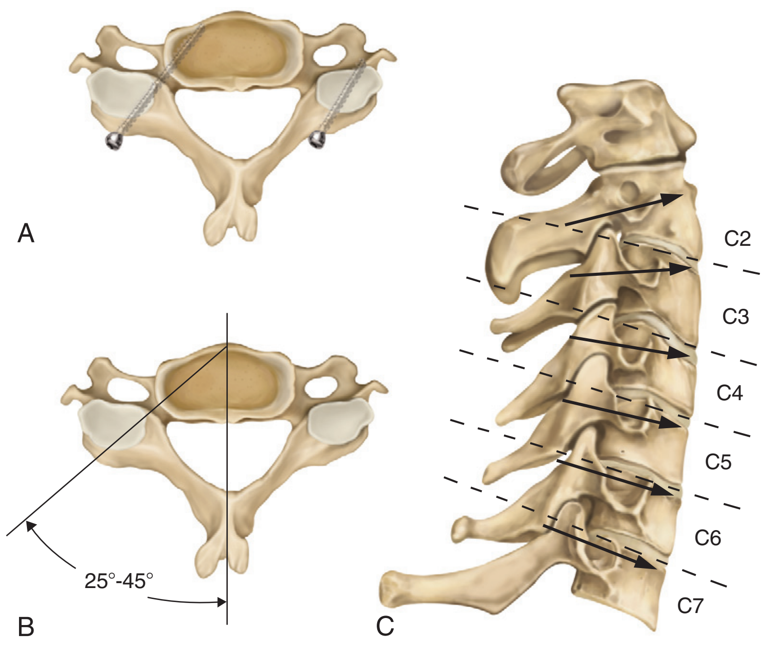

Figure 22-5 Screw insertion point and trajectories. **A,** The points of screw insertion for the C3 through C7 pedicles are slightly lateral to the center of the articular mass and close to the caudal margin of the inferior articular process of the cranial adjacent vertebra. **B,** The drill is angled 25 to 45 degrees medially and is advanced in a vertical line parallel to the end plate. **C,** After creating the insertion hole, a small pedicle probe, a tap, and screws are inserted into the pedicle with the help of lateral images to confirm the direction and insertion depth.

Fusion

Facets of the segments to be fused are drilled to remove joint material. Lateral mass bone is then decorticated with a high-speed cutting burr and irrigation, with care taken not to create thermal injury that will inhibit bone fusion. Morcellized autograft harvested from the posterior iliac crest is filled into the decorticated facet joints and is packed along the decorticated lateral mass bone. Local autograft from the cervical decompression with or without demineralized bone matrix may also be used.

Wound Closure

A suction drain is inserted, and the deep fascial sutures are tied down. Subcutaneous sutures are then used, followed by staples for the skin.

POSTOPERATIVE MANAGEMENT

Postoperative immobilization varies according to the number of fixed spinal segments, the patient's general condition, the stability of the inserted screws, the extent of osteoporosis, and other factors.

Generally, patients who required fixation of one to three motion segments are required to wear a short, soft neck collar postoperatively for 2 to 3 weeks. A Philadelphia collar should be worn for 2 to 3 months by patients with severe osteoporosis and those who underwent fixation of four or more motion segments. More rigid postoperative external supports, including halo–vest immobilization, are not typically used. All patients are permitted to ambulate or sit upright in bed the day after surgery unless contraindicated by their general condition. Patients with jobs that have low physical demands can return to their original jobs 3 to 6 weeks after surgery, before bony union is complete.

COMPLICATIONS

- Vertebral artery injury from a laterally perforated screw
- Penetration of the pedicle
- Radiculopathy as a result of nerve root injury from a cranially or caudally dislodged screw
- Dural injury or spinal cord injury from a screw that strays out medially

Surgeons must bear in mind that cervical pedicle screw placement is limited by anatomic variation of the pedicle and the vertebral artery. Complications can be minimized by sufficient preoperative imaging studies of the pedicles, thorough knowledge of local anatomy, and strict control of intraoperative maneuvers for screw placement.

Lateral Mass Screw Fixation

Since the early 1990s, the emphasis in the literature has been directed toward providing more immediate rigid stabilization through the use of plates and screws implanted into the articular masses of the cervical spine.

INDICATIONS

- Progressive symptomatic cervical myelopathy that requires surgical decompression and fusion
- Cervical instability demonstrated on preoperative flexion–extension cervical spine radiography or when adequate decompression requires stabilization of the posterior spinal elements
- Cervical instability—traumatic, iatrogenic, neoplastic, or inflammatory—with lateral mass preservation

CONTRAINDICATIONS

- Cervical instability with destruction of the lateral mass

OPERATIVE TECHNIQUE

Lateral mass screws are used for the third to sixth cervical vertebrae, and pedicle screws are used for the second and seventh cervical vertebrae. Pedicle screw fixation is preferred at C7 because of the thin anatomy of the associated lateral mass.

Surgical Approach

A midline skin incision is made in the posterior cervical spine, and dissection is carried down to the fascia. The fascia and ligamentum nuchae in the midline are identified, and the superficial soft tissues are stripped off the fascia a short distance from the midline bilaterally. The fascia is incised over the prominence of the spinous process using electrocautery, and further dissection is carried along the spinous process and laminae in a subperiosteal fashion. Care should be taken to preserve the soft tissues over the facet joints until the entire central exposure is performed, and the required levels of decompression and fusion are identified; this helps preserve stability, and it decreases adjacent-level degeneration at levels not included in the screw fixation and fusion. Meticulous dissection and soft tissue stripping of bone are essential to delineate landmarks required for placement of instrumentation and to provide sufficient surface area for fusion.

Fusion bed preparation is essential to create adequate bone fusion, and this will strongly influence the surgical results. Facet joint cartilage and soft tissue should be resected and the posterior bony surfaces decorticated; this can be performed with a 3-mm high-speed burr or with a curette. Identification of the screw entry point and determination of the trajectory and placement of the implants are easier when the bony morphology is intact.

Insertion Point and Trajectory

Adequate exposure of the posterior surface of the lateral mass is essential for safe and appropriate placement of lateral mass screws. The quadrilateral lateral mass is defined superiorly and inferiorly by the articulations above and below. The medial border is a faint groove at the junction of the lamina and lateral mass; the lateral border can be palpated. Once the four borders have been identified, screw placement is performed.

Several techniques have been described to determine the insertion points and trajectories of lateral mass screws in an effort to decrease the risks of iatrogenic nerve root or vertebral artery injuries (Fig. 22-6). In the *Roy-Camille approach*[12] the starting point is the apex of the posterior lateral mass or the midpoint of the quadrant created by the medial/lateral and cephalad/caudal lateral mass borders. The trajectory is perpendicular to the lateral mass in the sagittal plane and is 10 degrees lateral in the axial plane. As discussed previously, a potential advantage of the Roy-Camille technique is less risk to the spinal nerve, although this comes at an increased risk of vertebral artery injury and violation of the inferior facet joint. For those who prefer the Roy-Camille technique, avoiding it at the caudal level is warranted to circumvent the infraadjacent facet.

In the *Magerl technique*[13] the starting point is 1 mm medial and 1 to 2 mm cephalad to the midpoint of the lateral mass, with a sagittal plane trajectory parallel to the superior articular facet (approximately 30 degrees) and 25 degrees lateral. Although this poses less risk to the vertebral artery and the inferior facet, it increases the risk of spinal nerve injury with bicortical purchase. An and associates[14] proposed a technique, with the advantages of both the Roy-Camille and the Magerl techniques, that they based on an anatomic study that found that the safest place for bicortical purchase was superolateral, avoiding the spinal nerve. These authors proposed that the starting point be 1 mm medial to the lateral mass midpoint with a trajectory 15 degrees cephalad and 30 degrees lateral.

Anderson[15] recommended starting 1 mm medial to the lateral mass midpoint with a lateral trajectory of 10 degrees and a cephalad trajectory of 30 to 40 degrees. The *Anderson technique* is similar to the Magerl technique except the starting point is less medial, and the trajectory is less caudal/lateral; this makes it an easily obtainable trajectory intraoperatively when limited by surrounding soft tissue and adjacent spinous processes.

Technique	Starting point from the center of lateral mass	Axial trajectory	Sagittal trajectory
Roy-Camille	Center	10° lateral	Perpendicular to lateral mass
Magerl	1 mm medial and 1-2 mm cephalad	25° lateral	Parallel to the superior articular facet (30°)
An	1 mm medial	30° lateral	15° cephalad
Anderson	1 mm medial	10° lateral	30°-40° cephalad

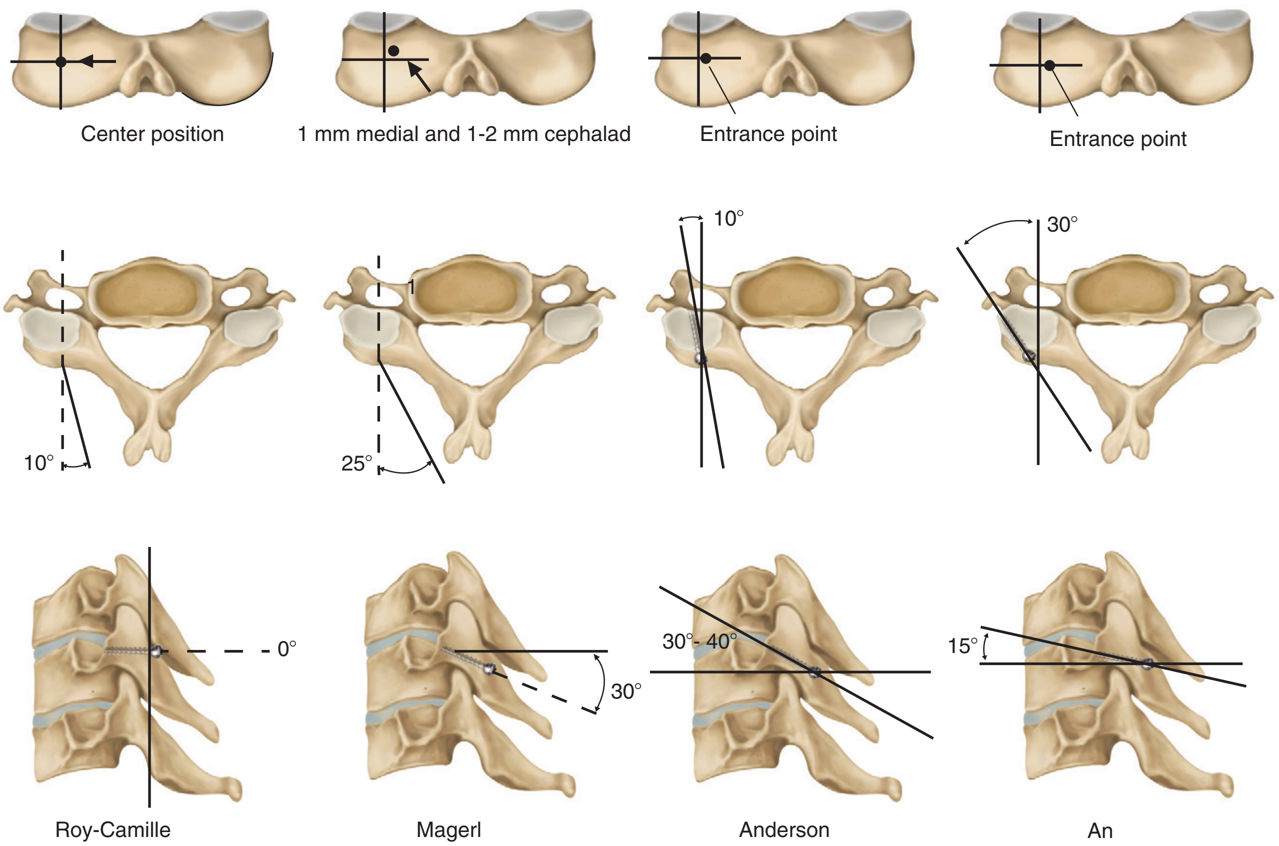

Figure 22-6 Illustration of various screw insertion techniques.

Drilling and Screw Placement

The center of the lateral mass is then marked. A 3-mm burr is used to make a pilot hole 1 mm medial to the marked center of the lateral mass. A drill with the stop set at 12 mm is then used. Using this trajectory, most patients are able to accommodate a 12- to 14-mm screw from C4 to C6. For C3 and C7 lateral mass screws, the drill stop is set to a depth of 10 mm. Our preference is unicortical fixation to decrease the risk of nerve root irritation; however, bicortical penetration improves failure resistance by 20%, but it increases the risk of nerve root injury. Bicortical screws should be considered in osteoporotic bones, in spines with few acceptable anchor points, in unstable spines, and particularly in spines with anterior column collapse and decreased axial load-bearing capability. To place a bicortical screw, the drill's set depth is gradually increased, and the opposite cortex is palpated. To avoid stripping the threads, the full screw depth needs to be tapped.

Use of polyaxial top-loading screws will allow for small variations in screw placement and makes rod contouring easier. The most proximal and distal screws should be placed first, followed by intervening screws. This allows better alignment of all screws and facilitates placement of the rod.

Vertebral Artery

The vertebral artery originates from the subclavian artery, enters the transverse foramen of the sixth cervical vertebra, and courses upward through the foramina above. On the transverse plane, the vertebral artery lies in front of the lateral mass but is separated from it by the spinal nerve (Fig. 22-7). The vertebral artery is not at risk of injury as long as the screw is directed lateral to the sagittal plane.

Wound Closure

One or two deep drains are placed on the lamina or on the exposed nerve tissue. Subcutaneous suturing of layers and ordinary skin closure are then performed.

COMPLICATIONS

- Fracture of lateral mass
- Nerve root injury as a result of improper placement of excessively long screws
- Vertebral artery injury (rare)
- Pseudarthrosis
- Screw loosening, pullout, or failure

To avoid complications, preoperative planning and meticulous intraoperative surgical skills are required. Bleeding can be controlled by careful dissection, use of bipolar coagulation, and liberal application of bone wax. Adequate removal of soft tissues from the bony surfaces to be fused and removal of articular cartilage from the facet joint are the strongest determinants of successful formation of a solid fusion mass and absence of pseudarthrosis. Implants are best placed before decompressive laminectomy, because the morphology of the posterior elements is more obvious before laminectomy.

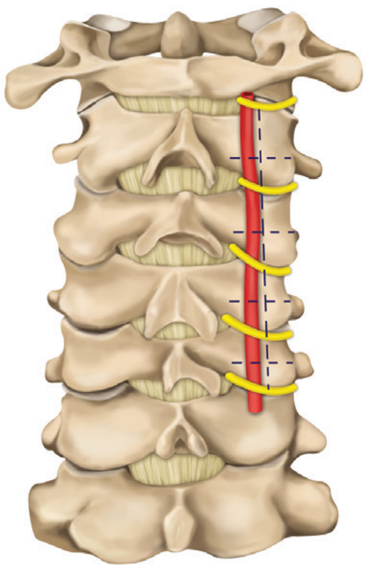

Figure 22-7 Relative location of the vertebral artery and nerve root with lateral mass. The vertebral artery lies in front of the lateral mass and is separated from it by the spinal nerve.

Posterior Wiring of the Subaxial Spine

Over the past few decades, several methods have been developed to stabilize the subaxial cervical spine both posteriorly and anteriorly. Methods of posterior stabilization have progressed from interspinous wiring through facet wiring and sublaminar wiring to lateral mass screw fixation with plates and rods. In general, wiring techniques are effective at blocking flexion, but they are not very effective at blocking extension or rotation. Facet wiring can be used when the laminae or spinous processes of the adjacent rostral segments are missing.

INDICATIONS

- Ligamentous instability of the lower cervical spine (lateral mass, pedicle screw, wiring)
- Pure interspinous ligament disruption (wiring)
- Flexion-distraction injury with facet subluxation/dislocation
- Following a multilevel anterior cervical decompression and fusion for added stability
- Adjunct to rigid fixations, including screws, rods, and plates

CONTRAINDICATIONS

- Loss of structural integrity of the posterior cervical lamina (previous laminectomy)
- Absence of a spinous process
- A lone procedure in the setting of three-column instability
- Osteoporotic posterior elements

OPERATIVE TECHNIQUE

Positioning and Incision

The intraoperative setup and exposure for wiring techniques are the same as those used for posterior cervical screw fixation. The skin and subcutaneous tissue are dissected down to the midline fascia. Subperiosteal dissection is completed to expose the spinous processes, laminae, and facet joints at the involved levels. To prevent inadvertent extension of the fusion, dissection should be limited to the intended levels, and the adjacent facet capsules should be protected.

Procedures and Wiring Techniques

Interspinous Wiring (Bohlman's Triple-Wire Technique). This technique is the most stable biomechanical method of wiring stabilization of the subaxial spine. However, this method is still considered a semirigid stabili-

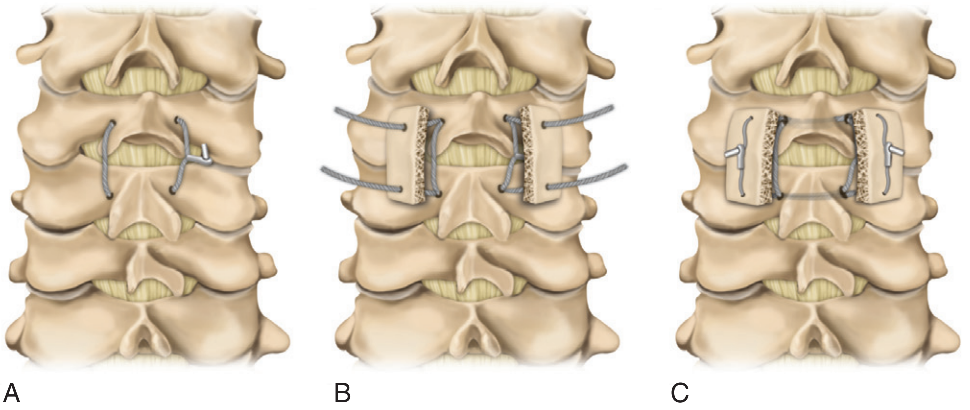

Figure 22-8 Illustration of the triple-wire technique. **A,** A wire is passed from the superior spinous process to the inferior spinous process. **B,** The second and third wires are passed through the superior and inferior holes in the bases of the spinous processes. After decortication of the lamina and facets, corticocancellous bone grafts from the outer table of the iliac crest are placed. **C,** Wires are tightened over the grafts, and additional cancellous chips are laid down on the exposed laminae or facets.

zation and may not be adequate alone in significant three-column instability.

The triple-wire technique is biomechanically superior to other wiring techniques. The starting hole is made on either side of the spinous process base by drilling a 3-mm burr hole. The holes are aimed toward the proximal aspect of the cephalic spinous process and distal aspect of the caudal spine. A nerve hook should be run along the interior lamina border to identify the canal; low holes may injure the dura or posterior cord.

To create a tunnel for the wires, a towel clip is passed gently through the holes. Extreme care should be taken not to apply dorsal force while using the towel clip, as this can lead to a fracture of the spinous process. One 18- or 20-gauge wire is then passed through both sets of burr holes and is tightened on one side (Fig. 22-8, *A*). The burr is then used to decorticate the lamina and facets, and a second wire is placed through the superior spinous process and through holes in a corticocancellous autograft (see Fig. 22-8, *B*). A third wire is then placed through the inferior spinous process holes and is passed through the corticocancellous autograft (see Fig. 22-8, *C*). In a single-level fusion, this wire can be tensioned and tightened. When fusing more than one level, intervening spinous processes should be incorporated with a figure-eight wiring pattern.

Facet Wiring Technique (Fig. 22-9**).** For patients who have had a prior laminectomy or rotational instability caused by unilateral facet subluxation or dislocation, interfacet wiring can be used. This technique provides increased rotational stability in combination with interspinous wiring method.

This technique uses a flat, blunt dissector that is placed in the facet joint, initially to distract the joint. Next, a small burr hole is made that angles inferiorly through the facet. A 20-gauge wire is then passed through the burr hole and around the inferior spinous process and is tightened. Autologous graft is placed over the lamina and in the facet joint to facilitate fusion. Care must be taken to obtain an adequate reduction at the time of wire tightening without causing wire pullout.

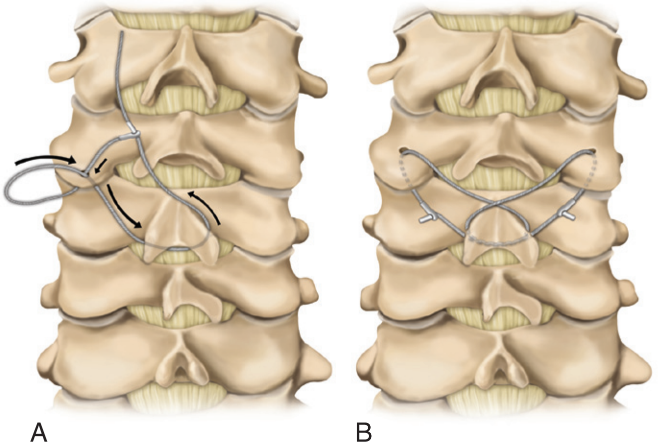

Figure 22-9 Illustration of facet wiring technique. **A,** Wires are placed through a hole made in the superior articular facet and wrapped around the caudal spinous process. **B,** The same steps are repeated on the contralateral side.

Wound Closure

Wound closure for wiring techniques involves the same methods used for posterior cervical screw fixation. Wound closure is performed in layers, with approximation of the paraspinal muscles and tight closure of the fascial layer, followed by subcutaneous and skin closure.

POSTOPERATIVE CARE

The patient is usually kept in a rigid neck collar for approximately 2 to 3 months to allow for bony healing. Early after surgery, the patient is encouraged to carry out general isometric neck muscle exercises.

COMPLICATIONS

- Overtightening of midline wires can theoretically cause narrowing of the foramen and radiculopathy.

- Failure or breakage of the spinous process or articular process during wire cable placement or tightening may occur.
- Facet wire pullout or loss of fixation may lead to loss of cervical alignment and late deformity.
- These complications are directly influenced by bone quality, the surgeon's techniques, and postoperative external orthosis.

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23 Facet Dislocation Injuries and Surgical Management

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Overview

Traumatic injuries to the cervical spine represent a common and potentially devastating collection of injuries with significant clinical impact and a high rate of neurologic injury.[1,2] The subaxial spine is affected in as many as 65% of all cervical spine fractures and more than 75% of all fracture-dislocations.[3] In fact, the cervical spine is the most vulnerable and most frequently injured portion of the spine following high-velocity trauma.[4,5] The most common causes of injury to the cervical spine include motor vehicle accidents (MVAs); diving into shallow water; and sporting-related injuries, especially from playing football and rugby.[6] Facet dislocations account for as many as half of all cervical injuries.[7] In particular, this chapter will focus on fracture or dislocation of the cervical facet joint or facet complex.

The three types of subaxial injury morphology described by Vaccaro and colleagues and the Spine Trauma Study Group (STSG)[3] give insight into the complexity and degree of instability created by either a unilateral or bilateral facet disruption or dislocation. For example, distraction injuries, which demonstrate anatomic disruption of the either the bony elements and/or diskoligamentous complex, are often the result of a significant force. The bony and ligamentous components of the facet joint are considered the determinants of posterior stability.[3,8] Thus disruption of the facet can lead to a tremendous amount of instability of the spinal column and carries the potential for neurologic injury.

A unilateral facet dislocation is the result of the inferior facet being forced anteriorly and thus ventral to the superior facet of the caudal adjacent level; the inferior facet may remain there in a perched or "locked" position (Fig. 23-1). Unilateral facet dislocations are often the result of flexion with some component of distraction and rotation.[1,2,9-11] Typically, the unilateral facet dislocation occurs on the side opposite the rotation.[9] Often, a unilateral facet dislocation is associated with a facet fracture (Fig. 23-2).[9,11-13] Unilateral facet dislocation without a fracture is associated with a higher incidence of neurologic injury and may be more difficult to reduce (Figs. 23-3 and 23-4).[2,9-11,13] In fact, unilateral facet dislocation with or without fracture is associated with damage to the facet capsule, interspinous ligament, posterior longitudinal ligament (PLL), and vertebral artery and with disruption or herniation of the intervertebral disk.[2,11,14,15] Bilateral injury to the facet joints or ligamentous facet capsules can lead to translation of the spinal column itself, with even greater potential for neurologic injury. Such an injury also implies disruption of the PLL (Fig. 23-5).[16,17] Facet injury or disruption can result in spinal instability and neurologic injury that necessitates prompt reduction and stabilization.

Clinical Presentation

Cervical spine injuries should be suspected in those who have sustained head injuries, patients who have been involved in a high-speed MVA, or those who complain of neck pain after a traumatic event. Initial evaluation and treatment should follow the guidelines established by the American College of Surgeons (ACS) through the Advanced Trauma Life Support (ATLS) protocol, whereby the initial priority is given to establishing the airway, breathing, and circulation.[18]

Establishing a competent airway may be complicated in any patient with a suspected cervical spine injury. Cervical spine "in-line" stabilization and immobilization must be maintained throughout the ATLS evaluation. Thus chin-lift and jaw-thrust techniques should be avoided in the setting of potential cervical spine instability, because such maneuvers may reduce the amount of space available for the spinal cord.[6] Obtaining a complete history from the patient and from other in-field medical care providers may also help to guide clinical suspicion for a cervical spine injury. Throughout the primary and secondary survey, a complete physical exam that includes a detailed neurologic exam should be completed, taking note of external signs of trauma such as lacerations, abrasions, and hematomas. In addition, assessment of midline tenderness with palpation, bony step-offs, or movement of the cervical spine should be undertaken. Likewise, the complete neurologic exam should include evaluation of the mentation, manual motor strength, sensation, and deep tendon reflexes. Digital rectal exam is mandatory in all cases of suspected spinal cord injury as is assessment of the bulbocavernosus reflex to assess for spinal shock.[18]

The more severe the injury to the subaxial spine, the greater the likelihood of spinal cord or nerve root injury. Moreover, a more significant neurologic injury suggests a greater force of impact and thus a greater potential for cervical spine instability.[3] Complete versus incomplete spinal cord injuries will present with different neurologic signs. Likewise, injuries to the spinal cord itself portend a much different mechanism and predicted outcome than injury to a spinal nerve root. Spinal cord injuries are classified via the American Spinal Injury Association (ASIA) scale. For example, complete spinal cord injury results in complete

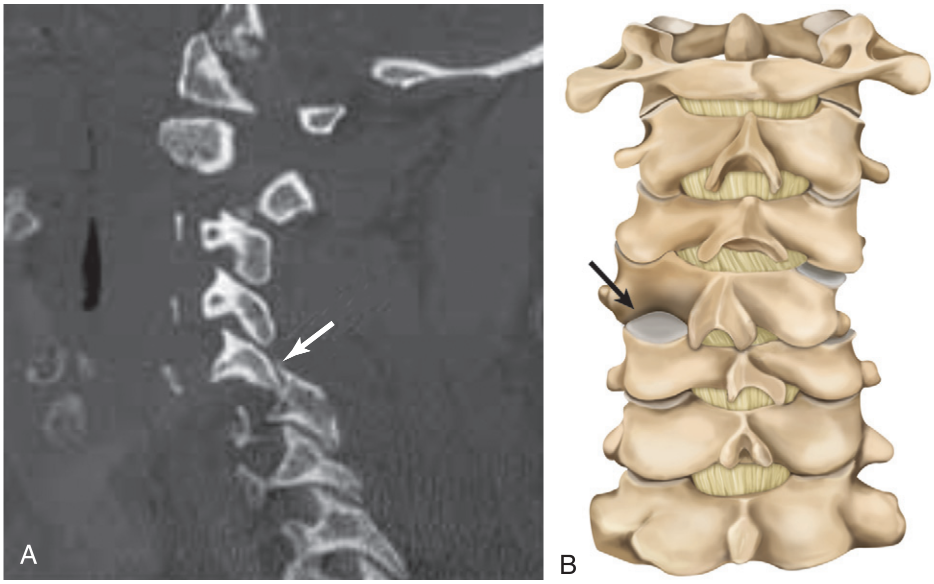

Figure 23-1 **A,** Sagittal computed tomography demonstrates a jumped or "locked" facet (*arrow*). Note: The inferior facet is ventral to the superior facet of caudal level. **B,** Schematic drawing demonstrates a dorsal view of cervical spine with a unilateral jumped facet.

Figure 23-2 Sagittal computed tomography demonstrates unilateral fracture (*arrow*) of the C7 superior facet.

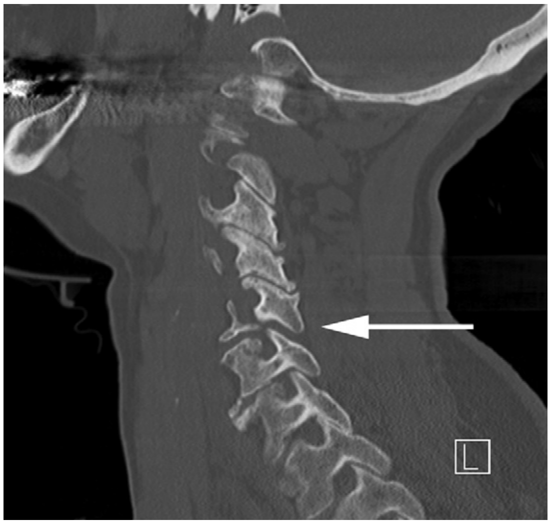

Figure 23-3 Sagittal computed tomography demonstrates splayed facet complex (*arrow*) at the level of C5–C6.

loss of motor and sensory function below the level of injury without evidence of sacral sparing. Incomplete spinal cord injury may result in partial weakness with sensory sparing. Likewise, injury to a nerve root will demonstrate loss of motor strength and/or sensation in a particular dermatomal distribution.

In the setting of a unilateral facet dislocation, approximately 25% will present with a nerve root injury, and about 25% will present with an incomplete spinal cord injury; the remaining 50% tend to be neurologically intact.[19] However, in the setting of a bilateral facet injury, two thirds of patients will come to medical attention with a complete spinal cord injury, and one third will be seen with a combination of incomplete spinal cord injury and nerve root injury.

Radiographic Evaluation

Radiographic evaluation in the setting of potential injury to the spinal cord and/or column must accurately depict the spinal axis in a rapid and safe fashion to guide acute management. Radiographic evaluation of suspected injury to the cervical spine begins with radiographs that include anteroposterior (AP), lateral, and open-mouth odontoid views. The radiographs should include the occiput through T1 to completely evaluate the cervical spine (Fig. 23-6). Often the patient's shoulders can obscure the view of lower cervical spine, thus traction on the patient's arms, or a swimmer's view, may be required to fully visualize the lower cervical spine. This is an important point, because most missed cervical dislocations and fractures are in the lower cervical spine.[20,21] With that in mind, despite the best technique and optimized conditions, plain-film radiographs underestimate the extent of traumatic spine injury.[22] It has been estimated that only 60% to 80% of fractures in the cervical spine can be visualized, even when all three views are obtained.[22,23] Woodring and Lee's study[24] that compared radiography (three cervical views) and computed tomography (CT) demonstrated that radiography missed 61% of fractures and 36% of subluxations and dislocations. On radiographs, 23% of the spines were classified as normal, when half of the so-called normal group in fact had an unstable injury.

Figure 23-4 A short T1 inversion recovery (STIR) sequence sagittal MRI demonstrates increased STIR signal intensity in the facet capsule itself (*arrow*) as a result of a unilateral dislocation. The image also demonstrates a herniated C5–C6 intervertebral disk and evidence of increased signal intensity within the spinal cord itself.

Given the increased access to CT and the increased efficiency with which CT images and corresponding three-dimensional (3D) reconstructions can be obtained, the use of CT in the setting of cervical trauma evaluation has grown tremendously. CT imaging has been shown to detect as many as 97% to 100% of all fractures in the cervical spine, and it maintains a higher sensitivity and specificity than plain radiographs.[22,23,25-27] Given the ease of use and increased visualization provided by CT, any patient with a suspected cervical spine injury should undergo CT evaluation. In particular, when evaluating for potential facet dislocation, the axial view can be especially helpful. Daffner and colleagues[28] have described the "hamburger bun sign." When the cervical facets are aligned normally, they resemble the shape of the two parts of a hamburger bun facing each other. However, in the setting of facet dislocation or jumped facets, the two halves of the hamburger bun are reversed (Fig. 23-7).

The biggest limitation of CT imaging is the inability to fully assess the integrity of the ligamentous anatomy. Magnetic resonance imaging (MRI) is the preferred imaging modality for assessing soft tissue such as ligaments, the spinal cord, and/or nerve roots.[29] Goradia and colleagues[30] have demonstrated that the use of MRI in the setting of cervical spine trauma maintains high sensitivity for injury to the intervertebral disk (93%), PLL (93%), and the interspinous soft tissue (100%). Increased signal intensity or short T1 inversion recovery (STIR) sequence signal abnormality on MRI can also demonstrate laxity or movement

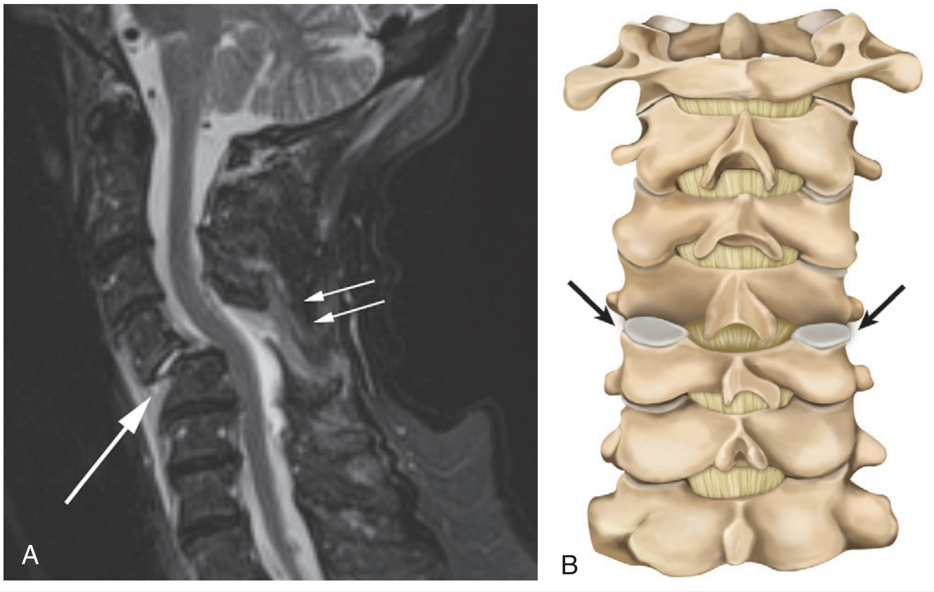

Figure 23-5 **A,** Sagittal magnetic resonance short tau inversion recovery sequence demonstrates bilateral facet dislocations (*double white arrows*) with ruptured intervertebral disk and posterior longitudinal ligament (*long arrow*). **B,** Schematic drawing demonstrates a dorsal view of the cervical spine with bilateral facet dislocations (*arrows*).

Figure 23-6 Lateral radiograph of the cervical spine, which includes the occiput through T1. Radiographs to evaluate the cervical spine must include all cervical levels to avoid missing an injury in the lower cervical spine.

Figure 23-8 Lateral radiograph of the cervical spine demonstrates bilateral jumped facets with disruption of the intervertebral disk and translocation of the C4 vertebral body onto C5.

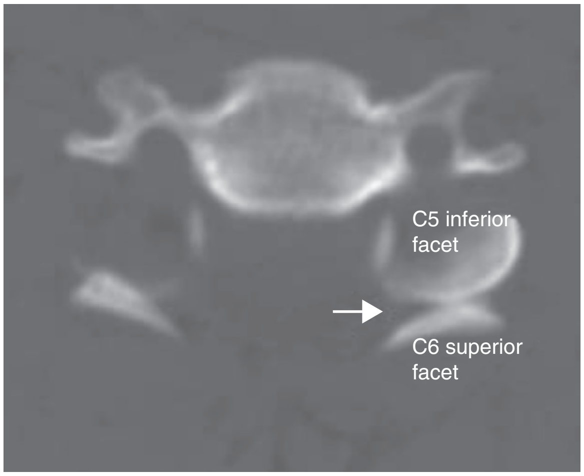

Figure 23-7 Axial computed tomography of the cervical spine demonstrates facet dislocation or a "jumped" facet. The "hamburger bun" sign is seen when the inferior facet has moved ventral to the superior facet.

within a facet capsule, suggesting some degree of movement or potential instability (see Fig. 23-4).

Initial Management

Patients with suspected cervical spine injury should remain immobilized in a rigid cervical collar until definitive evidence of injury has been determined. Patients with potential spinal cord injury or cervical spine instability should be monitored in an intensive care setting with full cardiac, hemodynamic, and respiratory capabilities. Furthermore, for those patients who have suffered definite spinal cord injuries, the mean arterial pressure should be maintained at 85 to 90 mm Hg for the first 7 days after the injury to maximize spinal cord perfusion.[31]

Once the patient has been fully evaluated, and a unilateral or bilateral facet dislocation has been diagnosed, reduction of the dislocation and realignment of the column should be undertaken. A variety of methods may be used for performing closed reduction. The basic principle, which was described in 1933,[32-34] includes the application of weighted in-line axial traction to reduce the facet dislocation. Crutchfield tongs, Gardner-Wells tongs, or a halo-ring orthosis with a traction bar have been described as effective means of applying traction for closed reduction (Figs. 23-8 and 23-9).

A great deal of controversy surrounds the timing of closed reduction in the setting of either unilateral or bilateral facet dislocation. Lee and colleagues[35] concluded that the decision to perform closed reduction is largely dependent on the ability to safely and successfully perform the reduction. The safety profile is determined by the ability to monitor the patient's neurologic status during application of traction and manipulation and by the risk of further cord injury in the setting of an anterior compressive lesion, such as a disk herniation or hematoma.

A consensus statement of the American Association of Neurological Surgeons (AANS)/Congress of Neurological Surgeons Joint Spine Section states that the overall rate of successful reduction restoring anatomic alignment is about 80%, with a reported rate of neurologic complication less than 1.0%.[32] Although evidence is insufficient to support definitive treatment guidelines or standards, expert opinion stressed the importance of restoration of anatomic alignment and also maintained that for those patients unable to follow the neurologic exam, MRI should be performed before reduction. Likewise, patients with injury rostral to

Figure 23-9 Lateral radiograph with the patient in halo–ring traction demonstrates complete closed reduction and reestablishment of normal alignment.

the level of dislocation should not undergo closed reduction, because further injury could result. Closed reduction in awake patients has been shown to be safe in multiple studies.[35-38] Although prereduction MRI can demonstrate evidence of a disrupted or herniated disk in as many as 33% to 50% of patients with facet subluxation, this has not been shown to influence outcome following closed reduction in awake patients.[32]

Surgical Management

Following evaluation and medical stabilization of a patient with a cervical facet injury, the need for surgical intervention must be determined. The goals of surgery are decompression of the neural elements and stabilization of the spinal column. A great deal of variability exists among surgeons in determining the stability of the spine in the setting of a cervical facet injury and thus the need for surgery.[35,39]

The STSG conducted a survey of its members in regard to cervical facet dislocation, treatment, and surgical approach. In that study, Nassr and colleagues[40] showed little agreement in the treatment algorithm for neurologically intact patient scenarios ($\kappa = 0.094$) and only slightly more agreement on the appropriate treatment for incomplete spinal cord injury scenarios ($\kappa = 0.133$) or for complete spinal cord injury scenarios ($\kappa = 0.15$). Vaccaro and colleagues[3] devised the Subaxial Cervical Injury Classification System based on the injury morphology, clinical neurologic status, and integrity of the diskoligamentous complex (intervertebral disk, anterior longitudinal ligament [ALL], PLL, ligamentum flavum, interspinous ligament, supraspinous ligament, and facet capsules). Based on the score, the overall severity of the injury can be rated to guide potential intervention. Higher scores are awarded for incomplete neurologic status and greater diskoligamentous disruption, suggesting a greater degree of instability and need for surgical intervention. In fact, all injuries with a score of 5 or more were treated surgically, and all injuries with a score of 3 or less were treated nonsurgically, whereas scores of 4 were considered equivocal.[3,41]

The AANS/CNS consensus statement regarding management of subaxial cervical facet dislocation injuries states that 26% of cervical facet dislocation injuries cannot be reduced using craniocervical traction. In addition, 28% of patients in whom anatomic reduction is achieved are unable to maintain reduction with external immobilization alone,[42] thus necessitating surgical stabilization. It is recognized that prolonged bed rest with maintained cervical traction for 12 to 16 weeks' duration is associated with the highest rate of mortality of all treatment strategies.[42,43] The authors note that certain factors such as vertebral subluxation, ligamentous or bony facet injury, and a locked/perched facet on initial imaging have been associated with failure of nonoperative management.[4,12,42,44-46] Although facet dislocation with facet fracture may preclude successful closed reduction, for those in whom reduction can be achieved, a high rate of arthrodesis has been shown with external immobilization alone.[4,42,46] Injury or disruption of the ligamentous complex in the setting of facet dislocation without facet fracture has been associated with a higher rate of failure when managed with external orthosis alone, and the presence of a laminar fracture in combination with a facet dislocation has led to increased rates of delayed kyphosis following surgical intervention.[4,42,45,47]

Despite successful closed reduction, surgical intervention is often required; options include anterior, posterior, or combined anteroposterior approaches. The choice of approach is dependent on several factors that include surgeon training and preference, but more specifically it often revolves around whether a facet dislocation can be effectively reduced from an anterior-only approach, and whether evidence suggests intervertebral disk herniation.[42] In a survey of the STSG, the anterior approach was preferred in the setting of intact neurologic status, and a combined approach was preferred in the presence of evidence of bilateral facet dislocation.[35,40] However, a great deal of differing opinion centers around the interpretation of the MRI. Dvorak and colleagues[41] recommend an anterior approach when MRI shows evidence of disk herniation that extends posterior to the posterior vertebral body wall at the caudal level (Fig. 23-10).[48-51] They argue that the spinal cord can be decompressed by performing the diskectomy; facet dislocation can be reduced by placing the neck in extension and applying axial reduction followed by placement of an interbody graft and anterior plate.[48-50,52] When the disk is intact, the surgeon can use either an anterior or posterior approach for unilateral facet dislocations. In the setting of bilateral facet dislocation, an increased rate of delayed kyphosis has been shown with posterior stabilization alone.[41,50,53] It is postulated that the mechanism of injury, namely distraction, also disrupts the disk and leads to progressive disk collapse that the posterior instrumentation cannot overcome.[41]

As always, the surgeon must select a familiar surgical approach that accomplishes the goals of surgical intervention while minimizing risk to the patient. Although both anterior and posterior approaches can produce excellent results, each approach has its own set of advantages and

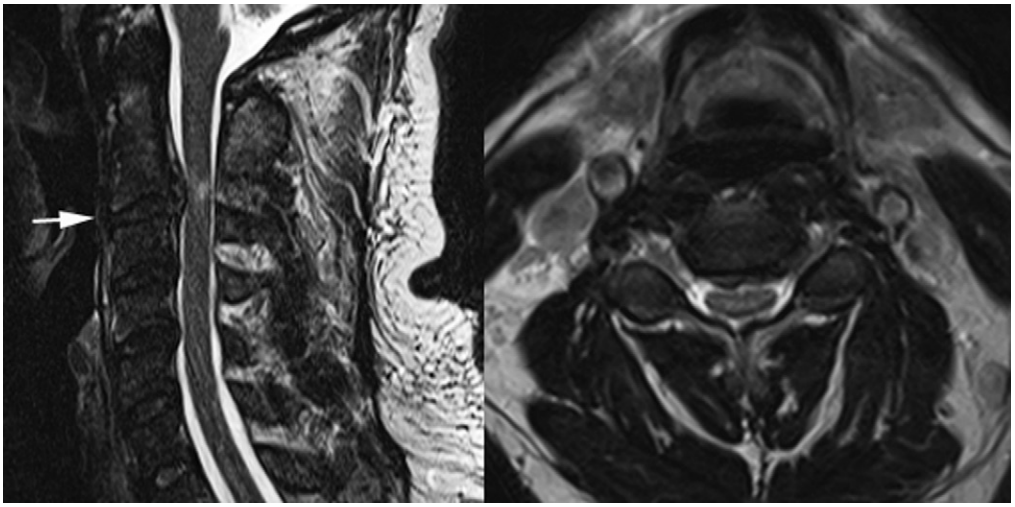

Figure 23-10 Sagittal (*left*) and axial (*right*) T2-weighted magnetic resonance imaging of the cervical spine. Intervertebral disk herniation (*arrow*) is shown at the level of C3–C4 with evidence of T2 hyperintensity within the spinal cord.

disadvantages. Dvorak and colleagues[41] comment that the posterior approach is often preferred because of its familiarity to surgeons, biomechanical strength in stabilizing posterior element disruption, and ability to directly reduce dislocated posterior elements.[53-59] However, the disadvantages of a posterior approach include a higher infection rate, a higher degree of postoperative pain, and a higher rate of delayed segmental kyphosis.[41,50] The anterior approach is often preferred for several reasons: 1) the patient does not need to be turned into the prone position, 2) the spinal canal can be directly decompressed via diskectomy, 3) the fusion rate is high using an anterior interbody graft, 4) segmental lordosis can be maintained, and 5) the infection rate is relatively low.[48-51] Disadvantages of the anterior approach, as Dvorak and colleagues[41] point out, include the inferior biomechanical strength compared with a posterior construct,[60,61] early radiographic failure in the setting of vertebral body compression fracture or large facet fracture fragments,[41,52] and approach-related complications such as dysphagia and hoarseness.

Surgical Technique

ANTERIOR APPROACH

The patient is positioned supine on a radiolucent operating table, and it should be ensured that C-arm fluoroscopy can be positioned appropriately. It is often helpful to place the neck in slight extension. If traction is required, Gardner-Wells tongs or a halo-ring with a traction bar can be used. The amount of weight required to achieve reduction is determined during closed reduction before surgery, when the awake patient's neurologic status can be followed. Oftentimes, the amount of weight required during surgery is significantly less because of the neuromuscular laxity produced by general anesthesia. The use of neuromonitoring, both somatosensory-evoked potentials and transcortical motor-evoked potentials, is recommended for both anterior and posterior approaches. Fluoroscopy is used before incision to localize the level of injury; the patient's shoulders may need to be positioned in traction toward the feet to visualize the appropriate level on fluoroscopy.

Once the appropriate level has been identified, a standard anterior cervical approach is used. Either the left or right side can be used, depending on the surgeon's preference, keeping in mind the anatomy and location of the recurrent laryngeal nerve.[62] Once the spinal column is identified, the appropriate level is again verified using fluoroscopy before annulotomy. By releasing the ALL and the anterior annulus, the spine becomes more mobile for reduction. Various techniques have been described for reducing facet dislocations from an anterior approach. The use of distraction (Caspar) pins placed in a divergent manner can aid in distraction of the disk space and in gradual reduction of the dislocated facet. Likewise, a vertebral or laminar spreader can be inserted in the disk space and distracted, or external traction can be applied.

Once the dislocation has been realigned, and the disk space is appropriately prepped, an interbody graft is placed to maintain lordosis and achieve arthrodesis. Surgeon preference influences the type of graft material used. Interbody graft options include polyetheretherketone, iliac crest, titanium, or other allograft materials. Once the graft has been seated appropriately, an anterior cervical plate is placed and secured by means of screws. The use of an anterior cervical plate is essential, because the rate of delayed instability and/or kyphosis is significantly increased without the use of a plate (Fig. 23-11).[42] Fluoroscopy is used to verify the position of the graft, plate, and screws. In the event that the facet dislocation cannot be reduced using an anterior approach, the patient may require an additional posterior procedure to facilitate open reduction and stabilization.

POSTERIOR TECHNIQUE

The patient is placed in the prone position using either an open Jackson table (Mizuho OSI, Union City, CA) or chest rolls on a standard operating table. A Mayfield head holder, Gardner-Wells tongs, or a halo-ring orthosis with a traction

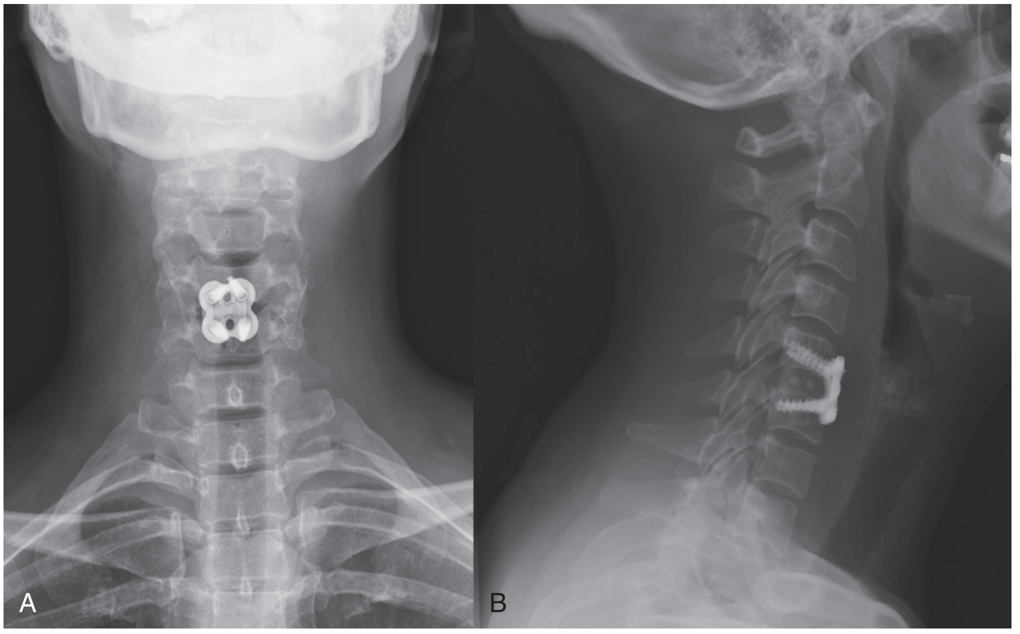

Figure 23-11 Anteroposterior **(A)** and lateral **(B)** radiographs of the cervical spine following C5–C6 anterior cervical diskectomy and fusion with cadaveric interbody allograft and anterior plating.

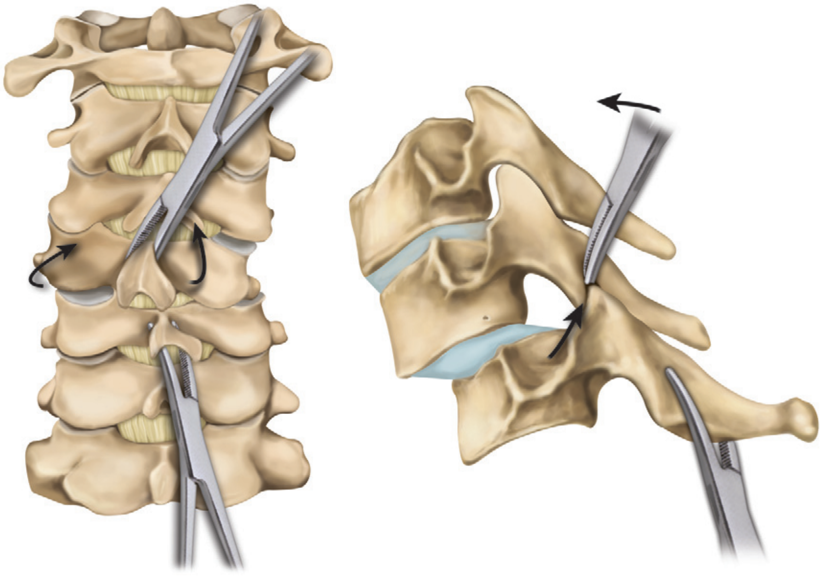

Figure 23-12 Towel clips and hemostats are used to manually reduce the facet dislocation by placing the penetrating towel clips on adjacent spinous processes and manipulating the spine. A Penfield #4 dissector placed in the facet complex (*not shown*) can assist in reduction with the application of distraction.

bar can be applied depending on the need for traction and the status of the facet dislocation. Fluoroscopy is used to identify the appropriate level. The shoulders may need to be placed in traction toward the feet to visualize the lower cervical spine. A standard midline dorsal approach is used; subperiosteal dissection of the paraspinal musculature while remaining in the midline avascular cervical raphe will minimize blood loss.

Once the spine is identified, a localizing radiograph should be obtained. In the setting of failure of closed reduction, the superior facet from the level caudal to the dislocation can be drilled off using a high-speed burr, or a rongeur can be used, and the bone can be used later as autograft during arthrodesis. Another technique for facet reduction involves placing instruments, such as penetrating towel clips or hemostats, on the spinous processes of the adjacent dislocated levels (Fig. 23-12). A curette or Penfield #4 dissector placed in the dislocated facet complex itself can also aid in reduction. The dislocated levels can then be manually manipulated and distracted to facilitate reduction. The instrument placed in the facet complex can help release the dislocated facet and move it back into the appropriate position. Once the facet has been realigned, and central decompression has been achieved when necessary, stabilization with the placement of instrumentation can begin.

A variety of techniques may be used for instrumented stabilization of the posterior cervical spine. Although facet wiring,[63] interspinous wiring,[64,65] and laminar clamps have

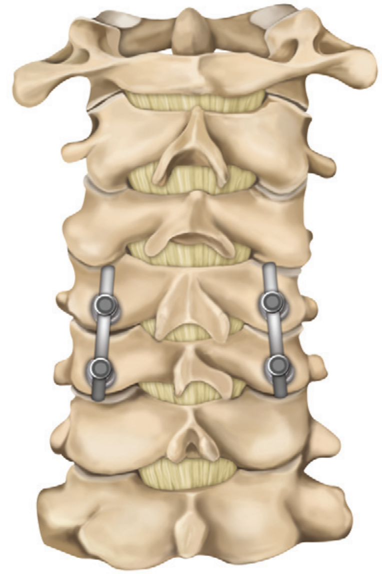

Figure 23-13 Lateral mass screw-and-rod construct for posterior cervical spine instrumented stabilization.

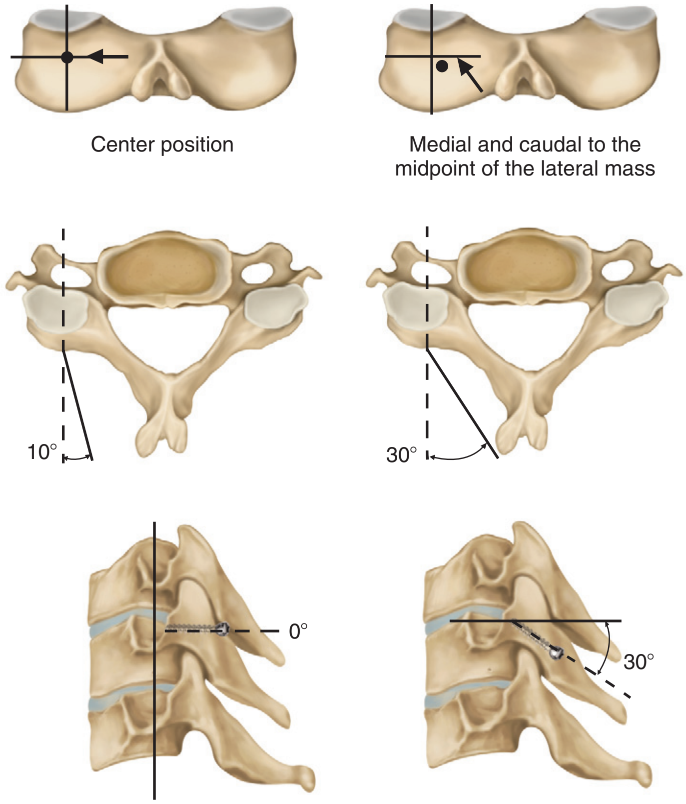

Figure 23-14 Schematic demonstrates the approximate trajectory for lateral mass screw placement.

all been described in the literature, often the safest and most biomechanically robust technique in the subaxial spine involves the use of lateral mass screws and rods (Fig. 23-13). The early description of the technique for the placement of lateral mass screws by Roy-Camille and colleagues[66] used a starting point at the midpoint of the lateral mass itself. The trajectory of the screw is perpendicular to the lateral mass and 10 degrees in the lateral direction. Although such a trajectory may minimize the risk to the vertebral artery or the exiting nerve root, it does not allow for much bony purchase of the screw itself. Magerl and colleagues[67] described a similar technique for the placement of lateral mass screws that utilizes a more medial starting point and takes a more rostral and more lateral trajectory. By using such a trajectory, more bony anatomy can be purchased while minimizing risk to the surrounding neurovascular structures. It can often be helpful to fully visualize the facet complex completely when placing lateral mass screws. Likewise, care must be taken to avoid exposing the facet complex rostral to the highest instrumented level to minimize instability above the construct and thereby minimize the risk for proximal junctional kyphosis.

Once the lateral mass has been fully exposed and the facet is fully visualized, a pilot hole is drilled 1 to 2 mm medial and inferior to the midpoint of the lateral mass. A handheld drill with an appropriately sized depth guard attached is used to drill the trajectory of the screw. In the subaxial spine the typical rule of thumb with regard to trajectory for the screw is 30 degrees lateral and rostral (Fig. 23-14). As an extra verification of the appropriate trajectory, the drill itself will abut the spinous process of the level immediately caudal. The key to finding the appropriate trajectory is to visualize the superior facet. The screw should be placed in the trajectory of the superior facet to optimize length and safety. If the inferior facet from the level above obscures the view, it can be partially drilled away.

Once the appropriate trajectory has been drilled, the screw tract must be palpated for evidence of breach; this puts either the vertebral artery or exiting nerve root at risk, depending on the location of the breach. If the trajectory shows no evidence of bony breach, the tract can be prepped using a tap. Typically the tract is prepped using a tap 0.5 to 1.0 mm in diameter smaller than the intended screw size. Before placing the screw, the facet complex and articular surfaces can be decorticated for appropriate arthrodesis. Often the screw heads prevent the surgeon from getting a comfortable angle into the facet complex once the screw is in place.

The final step involves placing the screw down the screw tract in the appropriate trajectory to maximize screw size and length. The rods are then contoured to the appropriate length, keeping in mind the normal lordosis of the cervical spine. The rod is fixed in place using top-loading set screws. A cross-link can be used, based on surgeon preference, to minimize the risk of rotational instability (Fig. 23-15).

Other considerations when planning a posterior cervical instrumented fusion include the use of osteobiologics and when to cross the cervical-thoracic junction. Although both of these are important issues, they are beyond the scope of this chapter.

Postoperative Management

Typically, patients who have undergone single-level anterior cervical diskectomy and fusion do not require a cervical collar, because studies have shown no benefit in fusion rate

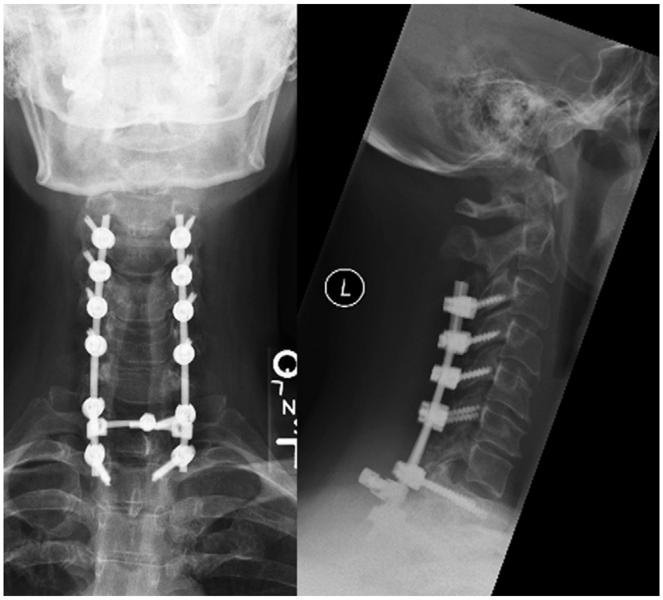

Figure 23-15 Anteroposterior (*left*) and lateral (*right*) radiographs demonstrate cervical lateral mass screw and thoracic pedicle screw placement in a C3–T2 construct.

or clinical outcome in patients with radiculopathy or myelopathy.[68] However, in the setting of facet injury or dislocation, patients who have undergone either anterior, posterior, or combined procedures are kept in a rigid cervical collar for 6 to 12 weeks. Upright radiographs are obtained before discharge from the hospital and at 6 weeks, 3 months, 6 months, 1 year, and then annually.

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24 Ossification of the Posterior Longitudinal Ligament

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Overview

Ossification of the posterior longitudinal ligament (OPLL) can manifest as myelopathy, radiculopathy, or myeloradiculopathy. Calcification and thickening of the posterior longitudinal ligament (PLL) in this disease leads to reduction in cross-sectional area of the spinal canal and subsequent compression of the neural elements.

Reported first in 1838, OPLL was only recognized as a pathologic condition in the 1960s.[1] Recent advances in radiographic techniques, particularly computed tomography (CT) and magnetic resonance imaging (MRI), have made it easier to diagnose. Several surgical options for the treatment of OPLL have been developed over the past two decades. In this chapter, we will review the disease process, details of available surgical techniques, and their current predicted outcomes.

Epidemiology

Individuals in Asian populations are most commonly affected by OPLL, with an incidence that ranges from 1.9% to 4.3%.[2-5] Other ethnic groups demonstrated much lower rates: for instance, North American Caucasians have a reported incidence of 0.01% to 1.7%.[1,2,5,6] Despite the relatively low incidence, OPLL may account for up to 20% to 25% of cervical myelopathy seen in the United States and 27% of that observed in Japan.[7] OPLL is twice as common in men and typically shows up during the fifth decade of life.[8,9] The primary site of OPLL is in the cervical spine in 70% to 95% of patients, with the remainder divided between the midthoracic and upper lumbar spine.[7,10,11] The spinal levels most often affected are C4–C6, T4–T7, and L1–L2.[1]

Pathophysiology

Although the exact cause of OPLL remains uncertain, evidence is mounting that genetic susceptibility plays the most significant role in disease development.[6,12-14] Early familial studies show the disease in more than 25% of first-degree relatives of affected individuals.[15] Recently, more sophisticated in vitro and in vivo studies have identified potential candidate genes responsible for gene transmission.[16-18] This increased understanding of the genetic susceptibility suggests that OPLL is probably transmitted in a complex multifactorial inheritance pattern.[14] Clinical associations have also been reported between OPLL and other disorders, including diffuse idiopathic skeletal hyperostosis, ankylosing spondylitis, obesity, diabetes, acromegaly, and hyperparathyroidism.[1,10,19,20]

Although it is clear OPLL is a multifactorial process, several genetic targets and key gene products have recently emerged as potential targets. One of the most studied genes is *COL11A2*, which encodes for the α-2 chain of type XI collagen. Multiple authors have demonstrated a clear link between several single-nucleotide polymorphisms and a susceptibility to OPLL development.[16,21-26] Tumor growth factor β (TGFβ) has also been linked to OPLL because of its known role in regulating mesenchymal stem cells.[23,27] Several authors have demonstrated both radiographic and clinical findings that link OPLL and several specific genetic polymorphisms.[22,28-33] Another potential target is nucleotide pyrophosphatase, a known inhibitor of calcification, which in knockout mice has been shown to cause spontaneous development of OPLL.[21,23,34-40] Although current treatment strategies continue to rely on surgical intervention, as our knowledge of genetic links to OPLL evolves, targeted gene therapy may ultimately prove to be an effective prophylactic.

In an early and commonly used classification system developed by Hirabayashi,[41,42] four types of OPLL were identified: 1) *continuous,* with the ossified mass extending over several levels; 2) *segmental,* with ossification only behind each vertebral body; 3) *mixed,* a combination of the above; and 4) *localized,* which may present as anterior or circumferential ossification and stenosis (Fig. 24-1). In a study of Japanese patients, these types of OPLL were found in 39%, 27%, 29%, and 7.5% of patients, respectively.[1]

Clinical Presentation and Natural Course

Although presentation varies widely depending on levels and degree of involvement, myelopathy, radiculopathy, and neck pain are the most common symptoms of OPLL. In a meta-analysis of six series that compiled data from 120 patients, including 51 of her own, Epstein[7] reported that 84% presented with myelopathy that caused severe neurologic dysfunction in Ranawat classes IIIA and IIIB. Radiculopathy with dysesthesias was seen in 47%, and neck pain was reported in 42%. These symptoms were present an average of 13.3 months (range, 7.5 to 22 months) at the time of presentation.

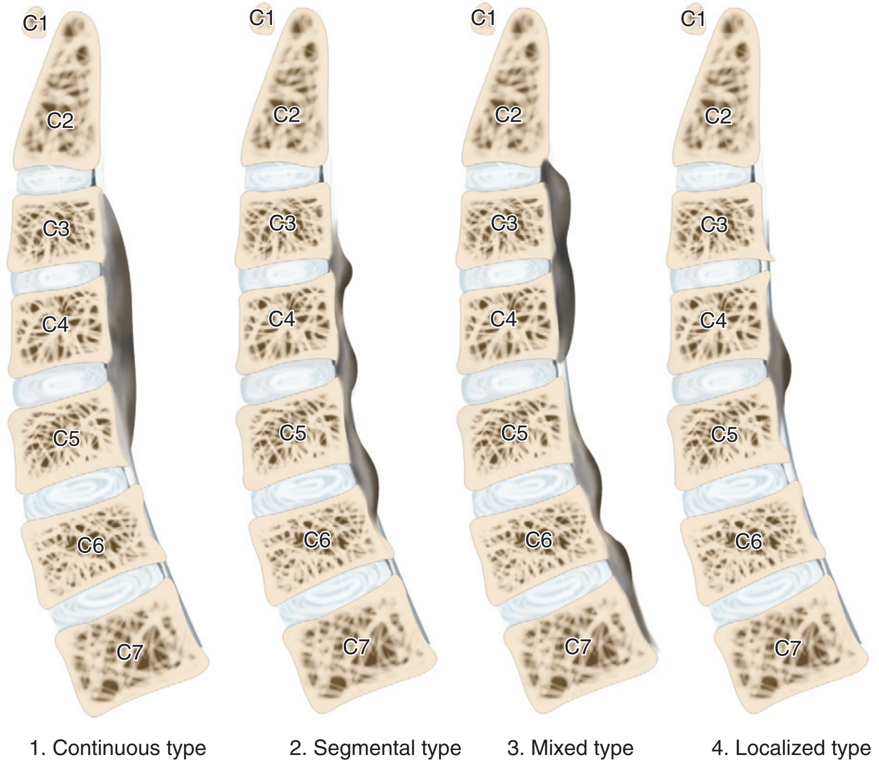

Figure 24-1 Classification of the four types of ossification of the posterior longitudinal ligament.

The majority of patients with OPLL (70% to 85%) report a gradual onset of symptoms.[1] Another subset (15% to 30%) come to medical attention with sudden deterioration of neurologic function, often after only minor cervical trauma.[7,43] While following 207 patients, Matsanuga and colleagues[43] found that of those who presented with myelopathy, 37% experienced worsening of symptoms during a 10-year observation period. In 170 patients who were initially free of myelopathy, only 16% developed myelopathy over the same time course. In multiple reports, duration of symptoms correlated inversely with recovery.[44,45]

Diagnostics and Radiographic Findings

Before the advent of CT, diagnosis of OPLL was based on findings observed on true lateral spinal radiographs. Dynamic lateral cervical spine radiographs remain a critical part of the evaluation of stability in the workup of OPLL, with instability defined by more than 3.5 mm of subluxation, 20 degrees of angulation, or 2 mm of motion between adjacent spinous processes.[46]

High-resolution CT with sagittal reconstructions represents the definitive diagnostic tool for OPLL (Fig. 24-2). CT also permits calculation of canal diameter and transverse area of the spinal cord, factors that may predict recovery after surgery.[44] Preoperative CT has been shown to have a predictive value for OPLL incorporation or penetration of the dura and for risk stratification for postoperative cerebral spinal fluid (CSF) leakage.[47,48] Additionally, CT myelography allows more detailed evaluation of the level and location of compression on neural elements.

Figure 24-2 Sagittal reconstruction of cervical OPLL.

The use of MRI contributes significantly to the evaluation of patients with OPLL by delineating the amount of cord compression and spinal cord edema, which when present on T2-weighted sequences have been shown to correlate with worse outcomes (Fig. 24-3).[7,49] The ossified

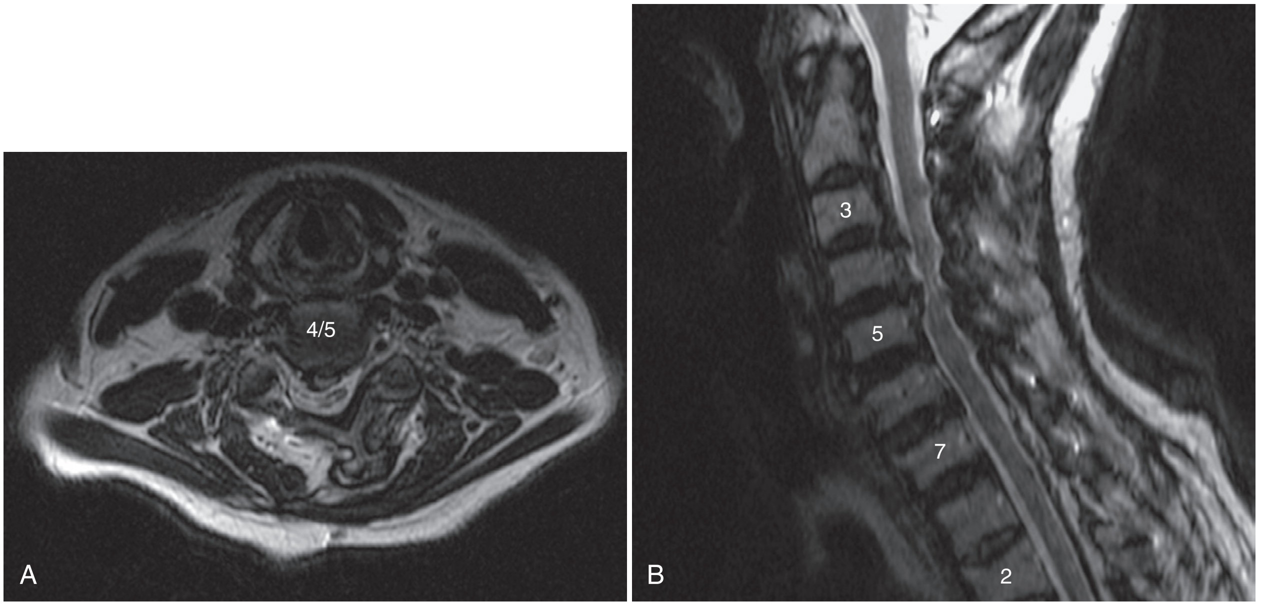

Figure 24-3 Axial (**A**) and sagittal (**B**) T2-weighted magnetic resonance imaging sequences of cervical ossification of the posterior longitudinal ligament.

ligament usually appears as an area of low signal intensity in the anterior aspect of the canal on both T1- and T2-weighted images. Flexion and extension MRI can also be obtained to evaluate the dynamic changes in canal diameter and cord compression.

Surgical Options and Outcomes

In those patients whose symptoms progress despite conservative therapy, surgical options include laminectomy, laminectomy plus fusion, laminoplasty, or anterior decompression and fusion. The decision is complex as to which surgical approach is the most appropriate, and no data are currently available to define a standard. Multiple factors must be considered in each case, including the patient's age, anatomy of the lesion, degree of stenosis, extent of lordosis or kyphosis, and symptomatology.

LAMINECTOMY

Laminectomy provides a relatively safe and simple approach to decompression of the neural elements when normal cervical lordosis is preserved.[46,50] Posterior decompression in a lordotic spine allows the spinal cord to settle away from the compressive mass of the calcified PLL; however, the same procedure in a kyphotic spine will provide little relief, because the cord remains draped over the anterior elements. In addition, 30% to 40% of patients risk progression of the kyphotic deformity after elimination of the posterior tension band.[45,51] Kato and colleagues[52] reported a series of 52 patients who were treated with laminectomy alone. Patients initially had a 44.2% rate of neurologic recovery, yet long-term follow-up demonstrated a progression of kyphotic deformity in 47% of patients and radiographic progression of OPLL in 70% of patients.

Laminectomy alone is best reserved for older patients with multisegmental disease, preserved lordosis, limited cervical range of motion, and continuous OPLL. The details of laminectomy have been described in another chapter.

LAMINECTOMY PLUS FUSION

The addition of posterior instrumentation and fusion after decompressive laminectomy should be considered in cases of segmental instability, cervical kyphosis, or decompression extending across the cervicothoracic junction.[46] The addition of a fusion construct produces similar clinical improvement to laminectomy alone, but it decreases the risk of subsequent kyphotic deformity and progression of spinal instability.[53] The addition of lateral mass or cervical pedicle screws does carry the risk of potential vascular injury, nerve root injury, hardware failure, and adjacent segment disease and subsequent nonunion. Techniques for placement of lateral mass screws and those for posterior cervical fusion have been described elsewhere in this text.

ANTERIOR APPROACHES

Anterior decompression of the spinal canal by partial or complete vertebrectomy and subsequent grafting and fusion represent an alternative to posterior approaches.[51,54,55] Anterior corpectomy and fusion may help prevent progressive kyphotic deformity and allows for direct decompression of the calcified ligament. The anterior approach has several significant potential drawbacks, such as increased intraoperative blood loss, significant risk of durotomy, continued neurologic deterioration as a result of insufficient decompression, and high pseudarthrosis rates in fusions that involve more than three levels.[56-59] In a recent systematic review by Li and Dai,[59] the authors reported the surgical complications of anterior versus posterior approaches in the treatment of cervical OPLL and identified 27 studies that included more than 1500 patients. Although the overall incidence of surgical complications varied widely among studies (5.2% to 57.6%), interestingly, the overall incidence of complications was not significantly different in anterior surgery (24.3%) compared with posterior surgery (25.4%).

When an anterior approach is planned, several modifications should be considered. Preoperative placement of a lumbar drain and preparation for dural repair or grafting are recommended. The use of a small diamond burr with the high-speed drill and an operative microscope aids in minimizing dural and spinal cord injury. Although some surgeons advocate removal of all calcified elements, this increases the risk of dural violation. An alternative technique that may provide adequate decompression is the generation of a floating segment of bone.[54] This can be achieved by thinning the posterior vertebral body and ossified PLL and then drilling small troughs at the lateral aspects of the canal (Fig. 24-4). The midline bone is then free to "float" ventrally, away from the spinal canal.

COMBINED ANTERIOR AND POSTERIOR APPROACHES

In cases of multisegmental OPLL in younger patients, Epstein advocated using circumferential surgery.[46] She reported 25 successful fusions in 26 patients with multilevel anterior corpectomy with fusion followed by

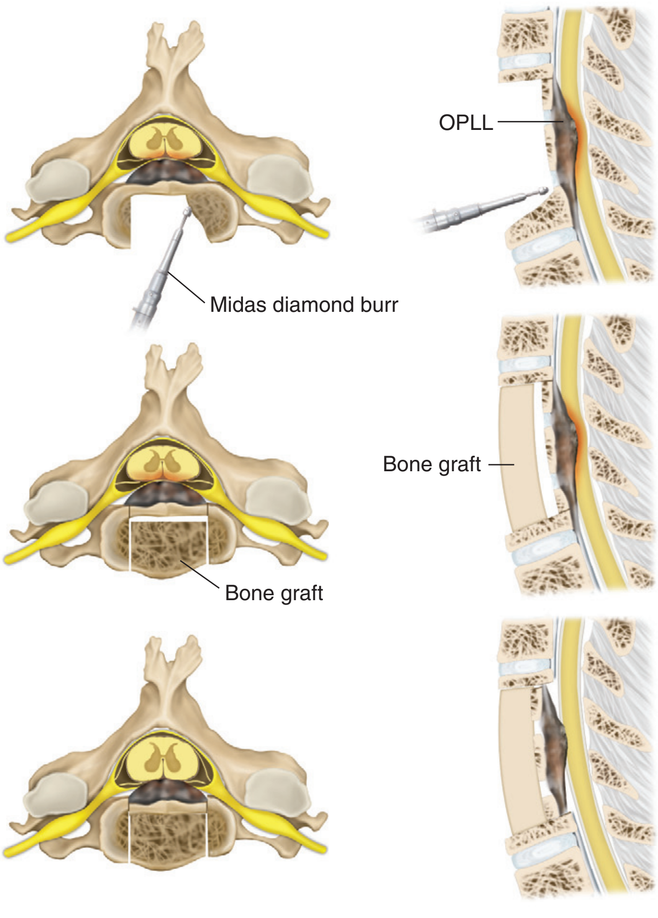

Figure 24-4 Anterior "floating segment" approach. OPLL, ossified posterior longitudinal ligament.

decompressive laminectomies and posterior fusion. Improvements of more than 3 Nurick grades were noted, with most patients rated at Nurick grades 0 or 1 at follow-up. This promising report must be weighed against the cumulative risks of combined procedures, and, as always, the approaches must be tailored to individual cases.

LAMINOPLASTY

In an effort to prevent postlaminectomy kyphosis and repeat compression from postlaminectomy membranes, laminoplasty was developed as an alternative. In a recent meta-analysis of the laminoplasty data, Ratliff and Cooper[60] attempted to evaluate the benefits of laminoplasty using the Japanese Orthopedic Association (JOA) scale for assessing myelopathy. They found wide-ranging results, with recovery rates of 20% to 80% with an average of 55%. These data were compared with those of laminectomy, which had a similar recovery rate of 54% in the immediate period and 48% at 5 years. Matz and colleagues[61] recently reported the results of a meta-analysis, in which they concluded that class III evidence supports the use of laminoplasty as a treatment option for cervical OPLL. The authors reported a 55% to 60% improvement in JOA scores compared with those achieved with conservative therapy.

Other findings in the review by Ratliff and Cooper included a 10% rate of postlaminoplasty kyphosis and a 35% rate of worsening cervical alignment,[60] although these data were not defined as loss of lordosis or progression of present kyphotic deformity. A 50% reduction in cervical range of motion and a 40% restenosis rate were also seen. Rates of postoperative axial neck pain were noted to range from 6% to 60%, and no evidence was found to indicate a slowing of posterior cervical muscle atrophy with laminoplasty versus laminectomy. As much as a 70% reduction in cross-sectional area of cervical musculature has been noted after laminoplasty, with no correlation between the degree of atrophy and spinal curvature. Similarly, it is unclear to what degree preservation of the posterior tension band preserves range of motion. From their review the authors concluded that the literature has yet to support the benefits of laminoplasty as a standard in all patients with OPLL. As with other procedures, laminoplasty must be applied and tailored to the individual patient and pathologic condition.

The incidence of postoperative C5 nerve paresis after cervical decompression for OPLL ranges from 4.6% to 16.3%.[59,62,63] Although this a well-known complication after cervical decompression, the relative incidence of C5 palsy after surgery for OPLL seems to be higher than in degenerative cervical spondylosis.[59,64] Although the exact pathogenesis of C5 palsy remains controversial, most authors report a good spontaneous functional recovery with conservative therapy.[59,62,65]

Laminoplasty Techniques

Laminoplasty techniques were first popularized by Hirabayashi in the late 1970s.[41,42] Since that time, many variations have been offered to lower the rates of postlaminectomy kyphosis.[41,66-68] Many modifications of the original laminoplasty technique have subsequently been described in the literature and are schematically represented here (Fig. 24-5).

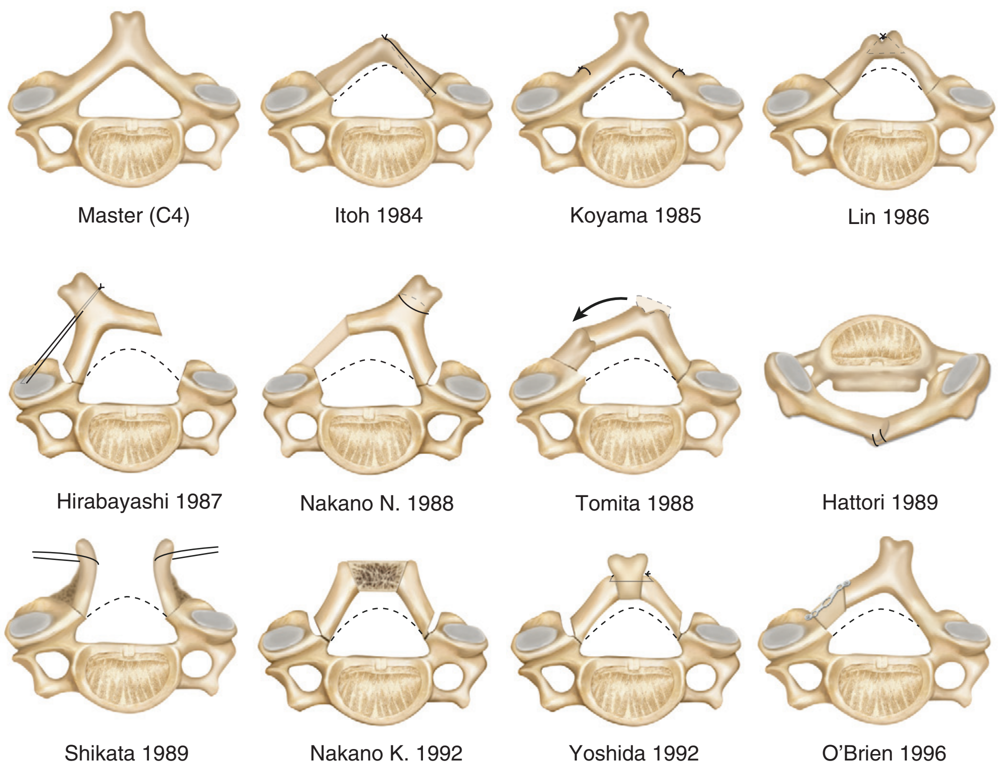

Figure 24-5 Laminoplasty techniques and the year they were pioneered.

Development of these earlier methods, in many cases, was driven by the lack of appropriate implantable stabilization hardware. The recent availability of allograft bone spacers and small titanium plating systems allows for a simple and effective fixation. Open-door laminoplasty using titanium miniplates avoids the use of stainless steel implants and allows for improved visualization on postoperative MRI. Precut allograft eliminates the morbidity of autograft. The detailed procedure for open-door laminoplasty using grafts and a plating system is outlined below. It should be kept in mind that outcomes of any type of laminoplasty may be more a function of the surgeon's experience with a given technique than of anything else.

Indications and Contraindications for Laminoplasty

Indications

- Myelopathy
- Progressive or recurrent cervical radiculopathy
- Minimum of 10 degrees of cervical lordosis from C2 to C7[46,50]
- Less than 7 mm of ventral OPLL[69]
- Less than 50% canal stenosis[69]
- Multilevel disease
- Younger patients (age <60 years)[50]
- Preserved cervical mobility

Relative Contraindications

- Cervical kyphosis[46,69]
- Single- or short-segment disease
- Segmental instability
- Older patients with other comorbidities

Operative Technique: Open-Door Laminoplasty

Equipment

- Radiograph-compatible operating table
- C-arm fluoroscopy
- Somatosensory-evoked potential and motor-evoked potential monitoring
- Headlight system
- Self-retaining retractors
- High-speed drill with fine-cutting and diamond burrs
- Straight and angled curettes: 3-0, 4-0, and 5-0 sizes
- 1- to 3-mm Kerrison punches
- Bone graft source
- Autograft (spinous process, rib, iliac crest)
- Allograft (precut and presized fibula)
- Titanium laminar plating system

Patient Positioning and Intubation

- General endotracheal anesthesia is used. The use of awake, nasotracheal, or fiberoptic-aided intubation is preferred to minimize cervical extension and potential spinal cord injury.
- Baseline spinal cord monitoring is performed before turning the patient to the prone position.
- Mayfield three-pin head holder is placed.
- The patient is placed in the prone position, and the Mayfield head holder is attached to the bed, taking particular care to maintain neutral positioning of the neck.
- The shoulders are gently taped down to maximize visualization under fluoroscopy.
- Spinal cord monitoring is repeated to confirm maintenance of signals.

- If autograft harvesting is anticipated, the site is appropriately selected and prepped.

Location of Incision

- The C-arm is moved into position for verification of appropriate cervical positioning and marking of the appropriate surgical level.
- A midline incision is marked from one spinous process above to one spinous process below the planned levels of laminoplasty.

Preparation and Draping

- The incision is marked, and the cervical skin area is sterilely prepared.
- Draping is carried out in the usual manner.
- If autograft is to be used, a harvest site is draped separately.
- The anesthesiologist is at the head of the table, and the scrub nurse stands at the lower half of the table.
- The headlight and microscope are based on the side of the primary surgeon.
- Fluoroscopy is based on the side contralateral to the primary surgeon.

Incision and Soft Tissue Dissection

- Local anesthetic is injected subcutaneously at the incision site.
- A midline skin incision is made at the appropriate levels.
- Monopolar electrocautery is used to carry the dissection through the midline raphe to the spinous processes (Fig. 24-6, *A*).
- The paraspinous musculature is dissected off the spinous processes and laminae in a subperiosteal fashion. Care is taken to preserve the intraspinous ligaments.
- Particular care should be taken to avoid damage to the facets, which can lead to instability and kyphosis.[46]
- Fluoroscopy-guided confirmation of the level of exposure is made by applying towel clips to the uppermost and lowermost exposed spinous processes.
- Two self-retaining retractors are placed in the cranial and caudal aspects of the wound to spread the paraspinous musculature laterally.
- Unilateral muscle dissection can be used to preserve the posterior tension band and may reduce the incidence of postoperative kyphosis.[70,71]
- When possible, care should be taken to preserve muscle and ligamentous attachments to the C2 and C7 spinous processes to reduce postoperative axial pain.[72-74]

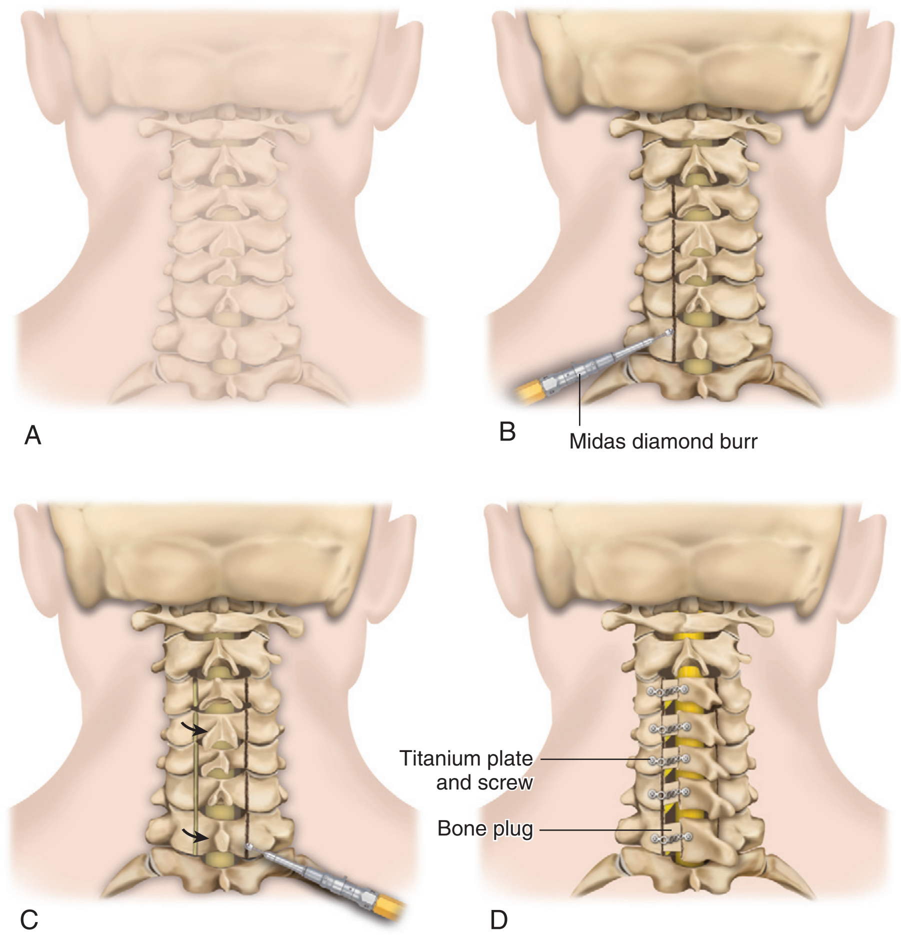

Figure 24-6 **A,** Incision and approach. **B,** Drilling troughs. **C,** Spreading of the lamina. **D,** Placement of bone plugs, plates, and screws.

Laminoplasty

- A high-speed drill with a fine cutting burr is used to generate troughs bilaterally at the junctions of the laminae and lateral masses. The ventral cortex should not be penetrated. Unintentional entry into the canal can be prevented by creating a small shelf on the medial aspect of the lateral mass to a depth that exposes the ventral cortex of the lamina (see Fig. 24-6, *B*).
- Right- or left-sided opening of the laminoplasty should be dictated by eccentricity of the bony pathology and radiculopathy (see Fig. 24-6, *C*).
- The remaining bone is preferentially removed with careful drilling or with a 1 mm Kerrison rongeur and up-angled curettes.
- The unicortical trough on the "hinge" side of the lamina is then thinned to a point that allows posterior rotation of the released bony mass.
- The intraspinous ligaments and ligamenta flava are partially released at the cranial and caudal extent of the laminoplasty.
- The posterior elements are rotated posteriorly using the lamina spreader in an en bloc fashion, keeping the interspinous ligaments and ligamenta flava intact. Care should be taken not to fracture the ventral cortex on the hinge side of the lamina.
- Epidural adhesions and the venous plexus should be freed at this time; this may result in significant bleeding, which is best treated with powdered Gelfoam and bipolar electrocautery.

Bone Graft and Instrumentation

- Bone wax should be avoided because it may interfere with the fusion process.
- Allograft spacers or appropriately cut autografts are then placed at each exposed level to maintain the open position of the lamina.
- Miniplates are secured to the lamina, graft, and lateral mass using screws. Screws should be directed into the lateral mass at an angle to avoid penetration of the facets (Figs. 24-7 and 24-8; see also Fig. 24-6, *D*).

Closure

- Careful hemostasis is achieved.
- A drain should be placed and tunneled out a few centimeters caudal to the inferior aspect of the incision.
- The muscle layer is gently apposed using 0 Vicryl suture.
- A secure fascial closure is achieved with interrupted 0 Vicryl suture.
- The deep dermal layer is approximated using interrupted 2-0 Vicryl suture.
- The skin is closed with a 4-0 Monocryl absorbable suture in a running subcuticular fashion.

Postoperative Care

- Cervical radiographs are obtained in the recovery room to confirm cervical alignment, verify graft and hardware position, and obtain a baseline for follow-up (Fig. 24-9).
- Early ambulation and pulmonary toilet are encouraged.
- Oral pain control is usually supplemented with a short course of intravenous narcotics and muscle relaxants.

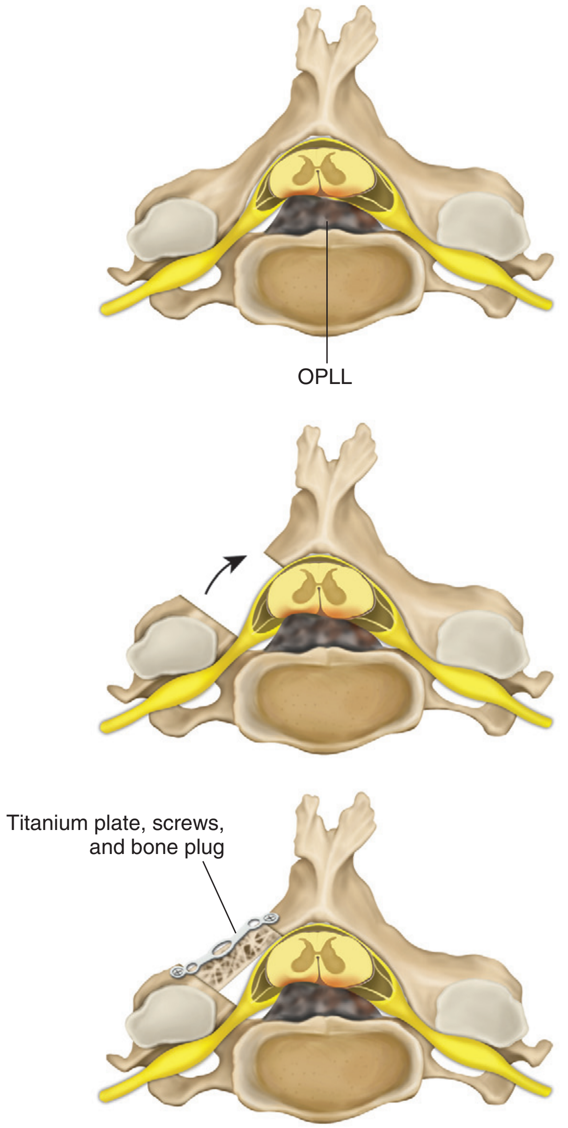

Figure 24-7 Axial views of laminoplasty technique.

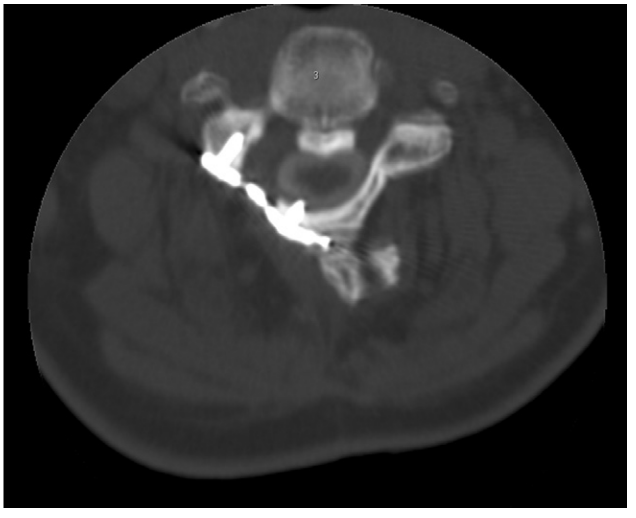

Figure 24-8 Axial computed tomography of postlaminoplasty cervical spine myelogram.

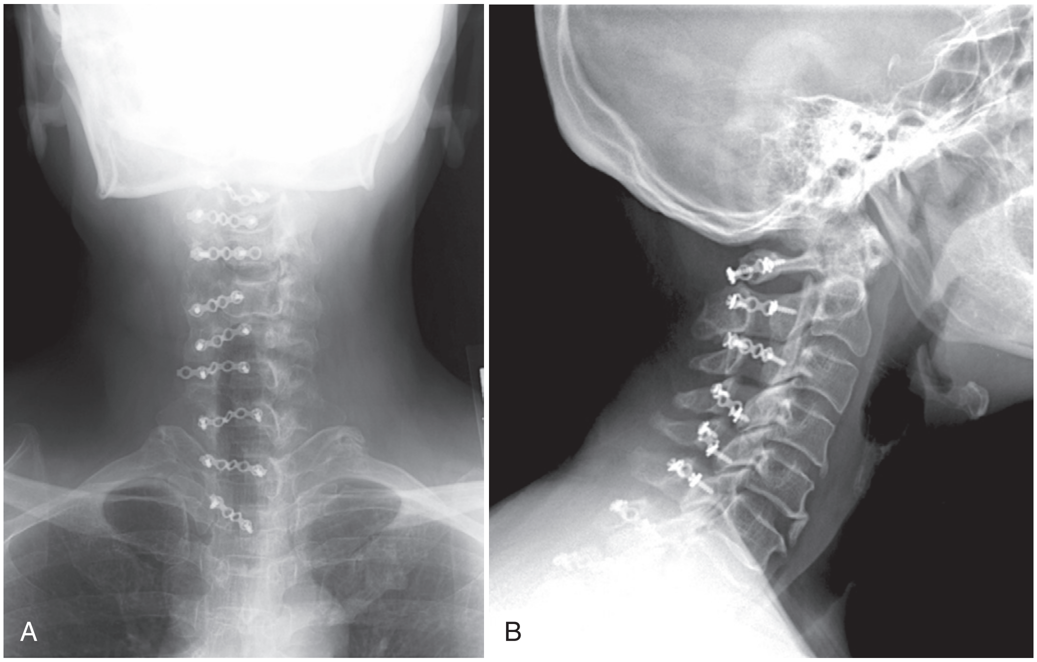

Figure 24-9 Anteroposterior (**A**) and lateral (**B**) cervical spine radiographs after laminoplasty.

- To confirm stability, upright cervical spine x-rays are obtained after the patient has been walking.
- Patients are usually discharged from the hospital in 2 or 3 days if there are no complications.

Complications

- Complications may present as a new neurologic deficit after recovery from anesthesia; this occurs secondary to nerve root injury or edema, spinal cord concussion, or rapid release of chronic compression.
- Acute deficits from mechanical causes such as intervertebral subluxation, migrated bone graft, or an acute epidural hematoma should be surgically treated.
- Early delayed deficits, including C5 root symptoms, are usually due to postoperative edema or stretch and have a good prognosis for recovery.[62]
- Postoperative axial symptoms of neck and shoulder pain may be seen in as many as 60% of laminoplasty patients.[54,75]
- Progressive deficit after the first week of surgery may indicate spinal instability or an infection.

Conclusions

As a general guideline, older patients with multisegment OPLL, preserved cervical lordosis, and no obvious instability are candidates for laminectomy. Fusion or laminoplasty may be used in younger patients and in cases where preservation of a posterior tension band would prove beneficial. Anterior decompression should be reserved for short-segment disease and often must be accompanied by a posterior decompression and fusion.

The variety of options available for the surgical treatment of OPLL is a testament to the challenges presented by this difficult disease. As with most pathologic conditions, the therapy must be directed at the individual patient. Careful consideration of the patient's symptoms, anatomy, disease, and comorbidities should direct the approach rather than strict criteria and routines.

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SECTION C

Cervicothoracic Junction and Thoracic Spine

25 Surgical Anatomy and Biomechanics in the Cervicothoracic Junction and Thoracic Spine

SAMUEL K. CHO

Overview

The cervicothoracic junction (CTJ) is the transition zone that connects the lower cervical spine to the proximal thoracic spine; it includes the lower brachial plexus, thoracic outlet, and superior mediastinum. Gaining access to this region can be rather challenging because of the presence of vital structures that surround the spine. Proper and safe surgical treatment of spinal pathology that arises in the CTJ is predicated on thorough knowledge of and familiarity with the pertinent anatomy.

The thoracic spine differs from the cervical and lumbar spines because of its complex osseoligamentous articulation with the ribs. The transition from the mobile and lordotic cervical spine to the relatively rigid and kyphotic thoracic spine also has biomechanical implications, because the CTJ can be the point of undue stress; for example, when fusion stops either at C7 or T1 and does not span this transition zone, it leads to early degeneration of the adjacent segment.

Pathologic processes that arise in this region are relatively uncommon. The most common disease that affects the CTJ is spinal metastases. Others include infections, pathologic fractures, primary bone or meningeal tumors, vascular anomalies, congenital musculoskeletal diseases, trauma, and thoracic disk herniations.

Surgical Anatomy

ANTERIOR APPROACHES

Anterior approaches to the CTJ allow direct access to the vertebral bodies and intervertebral disks. These range from supraclavicular approaches that do not require any bony procedures to transmanubrial, transternal, and transclavicular approaches that include osteotomy of the manubrium, sternum, or clavicle, respectively, to allow better exposure of the upper thoracic vertebrae.[1]

The thoracic inlet is the first structure encountered during the anterior approach. The superior mediastinum is defined anteriorly by the manubrium. The T2–T3 level is typically at the suprasternal notch, and T4–T5 is at the sternal angle (Fig. 25-1). Sternohyoid muscle originates from the ventrocaudal hyoid bone and inserts on the dorsal surface of the manubrium (Fig. 25-2). It also attaches to the sternoclavicular joint capsule. Sternothyroid muscle attaches along the dorsal midline of the manubrium, and sternocleidomastoid (SCM) muscle arises on the mastoid process and superior nuchal line and attaches to the manubrioclavicular joint, whose nervous supply is from the accessory nerve. Arterial supply branches come from the superior thyroid artery. Removal of the manubrium and medial third of the clavicle reveals the pleural apices, which are covered by an extension of the transthoracic fascia, called the *Sibson fascia*.

The superior mediastinum contains several vascular and visceral compartments. In terms of fascial layers, the visceral fascia circumscribes the trachea, esophagus, and thyroid gland, defining a *visceral compartment.* Carotid sheath circumscribes the carotid artery, internal jugular vein, and vagus nerve, defining a *neurovascular compartment.* These adjacent compartments create a potential space, the *viscerocarotid space,* which extends from the base of the skull to C7 to T4, depending on the location of the fusion between the visceral and alar fascia (Fig. 25-3). Blunt dissection of the viscerocarotid space exposes the alar fascia and retropharyngeal space. The visceral compartment continues down to the bronchi, where the fascia fuses with the parietal and visceral pleurae. Carotid sheath extends down to the subclavian vessels, where it fuses into the axillary sheath. In the superior mediastinum, the vascular compartment is not circumscribed by its own well-defined fascial sheath but is defined secondarily by independent surrounding fascia. The prevertebral fascial extension, the transthoracic fascia, lies ventral, and the visceral fascia lies caudal. The parietal pleurae make up the lateral border, and the pericardium provides the inferior border.

In terms of veins, brachiocephalic veins with their branches descend from the neck into the superior mediastinum just posterior to the thymus gland. The right brachiocephalic vein is formed just posterior to the medial end of the right clavicle and descends vertically into the superior mediastinum. In contrast, the left brachiocephalic vein is formed just posterior to the medial end of the left clavicle and descends diagonally to join the right brachiocephalic vein just posterior to the right first costal cartilage to form the superior vena cava. In the superior mediastinum, the left brachiocephalic vein courses obliquely from left inferior to right superior. Tributaries that drain into the brachiocephalic veins include the vertebral and first posterior intercostal veins in the neck; the internal thoracic, thymic, and inferior thyroid veins in the superior mediastinum; and the superior intercostal vein, which drains the second and third intercostal spaces.

The aortic arch initially ascends posteriorly to the superior vena cava but also turns diagonally posterior, then it turns inferior just anterior and to the left of the vertebral

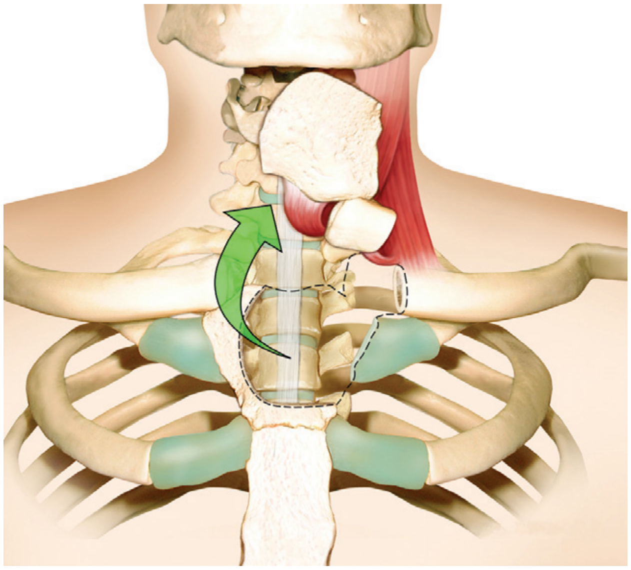


Figure 25-1 T2–T3 level at the suprasternal notch and T4–T5 level at the sternal angle.

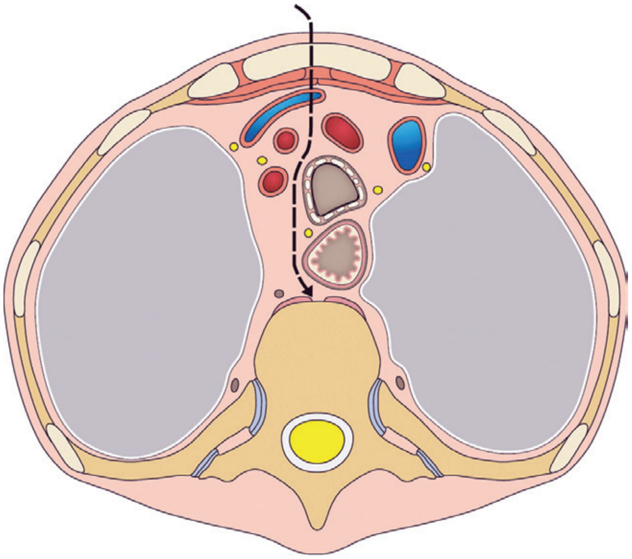


Figure 25-3 Dissection through the viscerocarotid space leads to the proximal thoracic prevertebral space.

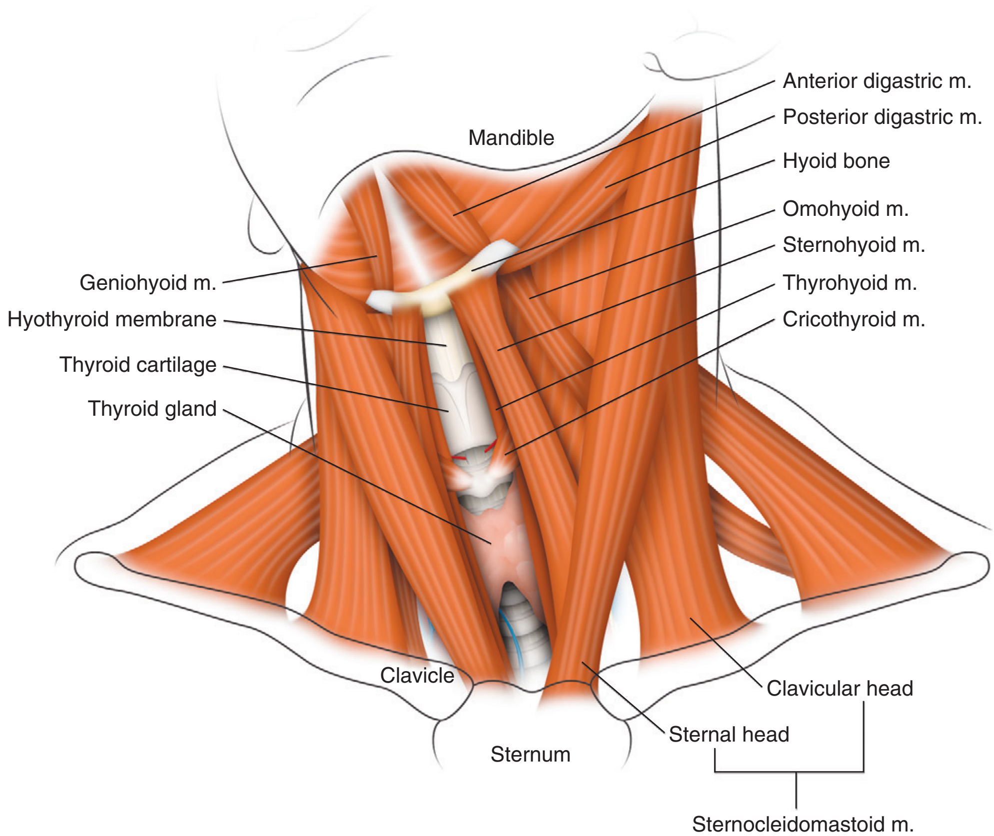


Figure 25-2 Superficial muscles of anterior neck.

column. A second concave turn occurs as the arch curves around the anterolateral visceral compartment to reach the vertebral column. Brachiocephalic artery is the first branch off the aortic arch, and it ascends vertically and slightly rightward to divide into the right common carotid and subclavian arteries posterior to the right sternoclavicular joint. The left common carotid artery arises next off the arch and ascends essentially vertically into the carotid sheath without branching in the superior mediastinum. The left subclavian artery is the third branch; it ascends superiorly and leftward to curve around the thoracic inlet and into the axillary sheath without divisions in the superior mediastinum.

By incising the alar and mediastinal fascia, the median compartment of the retromediastinal space can be entered. The prevertebral fascia covers the vertebral bodies and envelops the longus colli. Autonomic branches to the cardiopulmonary plexi may be seen in this region and can be sacrificed if necessary. Structures that may potentially cross the retropharyngeal and retromediastinal spaces include the right recurrent laryngeal nerve, which can cross the retropharyngeal or retromediastinal space anywhere from C7 to T3; the left recurrent laryngeal nerve, which loops around the ligamentum arteriosum and ascends within the visceral fascia between the esophagus and trachea; and lymphatics that terminate in the thoracic duct on the left side, course dorsal and to the left of the esophagus between the visceral and alar fascia in the superior mediastinum, and ascend to the C7 level. The lymphatics lie laterally in a plane dorsal to the carotid sheath and then run caudally and ventrally to the branches of the thyrocervical trunk and phrenic nerve. They terminate at the junction of the left internal jugular and subclavian veins. A lymphatic trunk located on the right side follows a course similar to that of the thoracic duct.

Anterolateral Transthoracic Approaches

The anterolateral transthoracic approaches allow direct access to the vertebral bodies in the proximal thoracic spine. These approaches often require mobilization of the scapula. Thus, careful dissection and subsequent repair of the parascapular musculature are essential to minimize surgical morbidity. Appreciation of the complex osseoligamentous relationship between the rib and its corresponding vertebrae, as well as thorough knowledge of vital structures found within the chest cavity, is also important.

Mobilization of the scapula for exposure of the proximal thoracic region will require detachment of the posterior musculature and associated tendinous attachments to the posterior, inferior, and medial scapular border (Fig. 25-4). Muscles detached during exposure include the serratus anterior anteroinferiorly, latissimus dorsi from the inferomedial border of the scapula, and trapezius and rhomboid major and minor from the medioposterior border.

The trapezius is one of the superficial muscles that originate along the superior nuchal line and external occipital protuberance and on each spinous process, via the ligamentum nuchae, from C1 through T12. It stabilizes and abducts the shoulder and is supplied by the spinal accessory nerve that arises from C1 to C5 and directly via the ventral rami of C3 and C4. The spinal accessory nerve lies deep to the trapezius but superficial to the levator scapulae. The arterial supply is from branches of the dorsal scapular artery.

Immediately deep to the trapezius are the rhomboid major and minor. The rhomboid major originates on the ligamentum nuchae of the spinous processes T1 through T4, whereas the rhomboid minor originates similarly on the

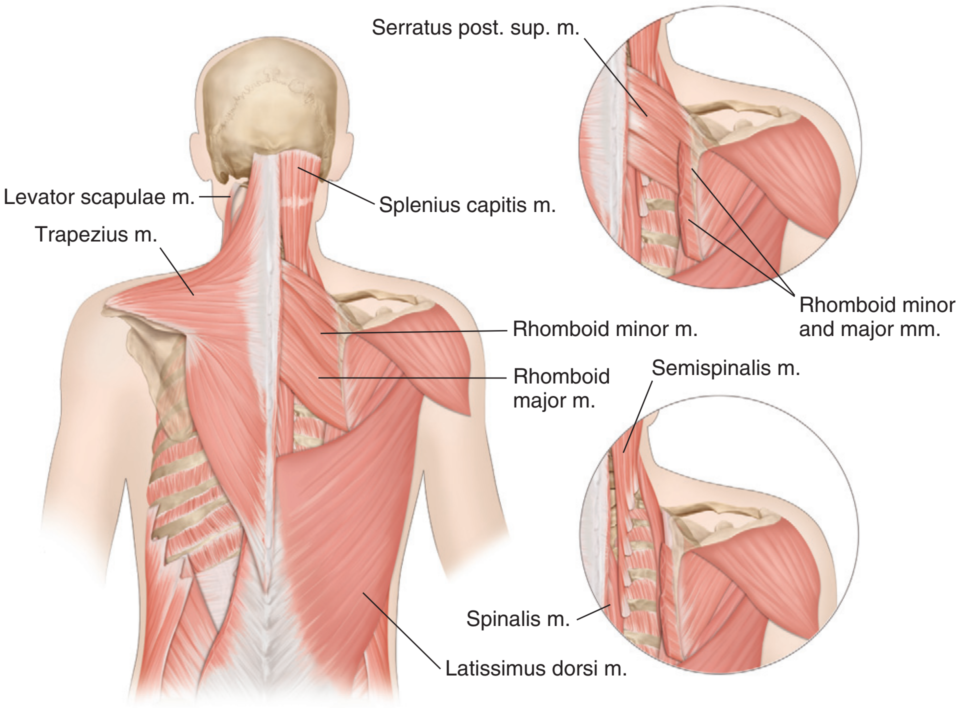


Figure 25-4 Parascapular musculature.

spinous processes of C6 and C7. These muscles insert into the scapular spine, rhomboid minor above and rhomboid major below. The nervous innervations and arterial supply are the dorsal scapular nerve and artery.

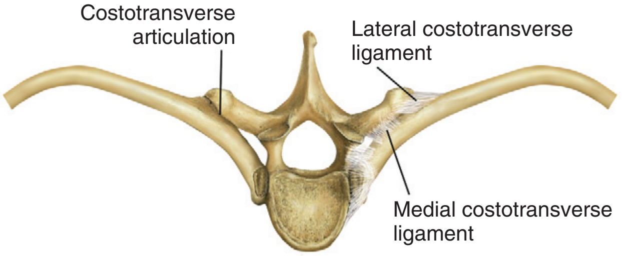
The levator scapulae are also immediately deep to the trapezius. They insert on the scapular spine above the rhomboid minor. Nervous supply is via branches from C3, C4, and C5; the dorsal scapular artery supplies the muscle. In a routine exposure, neither the dorsal scapular nerve nor the dorsal scapular artery or vein is directly exposed.

Following dissection of the superficial muscles—trapezius, rhomboid major, rhomboid minor, and levator scapulae—a group of intermediate muscles can be identified. The serratus posterior superior spans from C6 to approximately T2. The splenius capitis and splenius cervicis function to stabilize and rotate the skull. The splenius capitis inserts with the SCM on the superior nuchal line and mastoid process. The splenius cervicis joins the levator scapulae to insert on the transverse processes of C1 through C4.

The final group of muscles is found deep to the serratus posterior superior, splenius capitis, and splenius cervicis. The erector spinae (spinalis, longissimus, and iliocostalis) originate as a dense aponeurotic band from the sacrum and divide into three columns below the last rib. The iliocostalis is located most laterally and inserts on the angles of the ribs and into the cervical transverse processes from C4 through C6. The longissimus (thoracis, cervicis, and capitis) insert on the lumbar and thoracic transverse processes and nearby ribs between T2 and T12. Muscle bundles arising medial to these, from T1 to T4, are relayed to the cervical transverse processes from C2 through C6 and extend to attach to the mastoid process deep to the splenius capitis and SCM. The longissimus is the only erector spinae muscle to reach the skull. The spinalis is largely aponeurotic and extends from the upper lumbar to the lower cervical spinous processes.

The transversospinalis (semispinalis, multifidus, and rotatores) pass obliquely cephalad from the transverse processes to the spinous processes immediately deep to the erector spinae. The semispinalis arises near the tips of the transverse processes and inserts near the tips of the spinous processes approximately five vertebral levels cephalad. In the upper thoracic and lower cervical spine, most of this muscle is composed of the semispinalis capitis, which passes from the upper thoracic transverse processes and lower cervical articular processes (C4 to T4) to the occipital bone between the superior and inferior nuchal lines. The multifidus arises from the dense aponeurosis of the overlying erector spinae, and from all transverse processes up to C4, and it inserts into the lower border of each spinous process; this muscle generally spans about three levels. Rotators are small muscles that bridge one interspace. They pass from the root of one transverse process to the root of the spinous process immediately above. These muscles extend the vertebral column or, when acting individually on one side, bend and rotate the vertebrae.

The subscapular space is entered once the superficial muscles have been detached and the scapula is mobilized and retracted in a cephalad direction. The upper thoracic rib beds can be identified after division of the serratus anterior, and care should be taken to identify and preserve the long thoracic nerve. Once the scapula is retracted, identification of the third rib is possible. When counting ribs, the first rib is usually located inside the second rib and can be easily missed. Resection of the third rib will allow for greater intercostal spreading than would a second-rib resection.



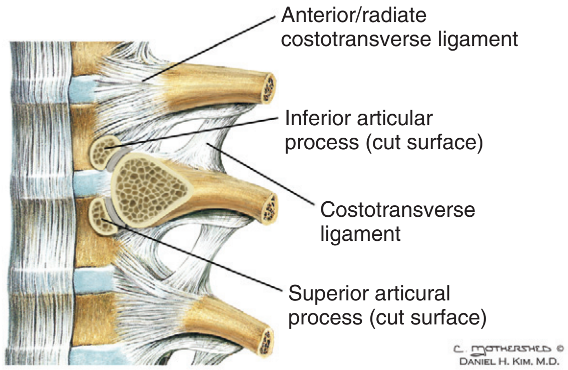


Figure 25-5 Osseoligamentous relationship between the rib and the vertebrae.

In general, each rib articulates with its own vertebral body, the vertebra above, and the intervertebral disk between them (Fig. 25-5). In the proximal thoracic spine, the only exception to this rule is the first rib, which articulates only with its own vertebral body. The tubercle of each rib also articulates with the transverse process of the respective vertebra. Each of these articulations forms a separate synovial joint, and these articulations are surrounded by a capsule and attached to the vertebral body anteriorly by the radiate ligament. Three important groups of ligaments articulate the rib with the corresponding vertebral body and transverse process and are disrupted for rib removal. The anterior and posterior superior costotransverse ligaments join the neck of the rib to the transverse process immediately above. The lateral and medial costotransverse ligaments attach the posterior neck of the rib to the transverse process. The anterior costovertebral (radiate) ligament secures the head of the rib to the vertebral body. The ribs are also attached to one another through the intercostal musculature, which originates medially on each superior rib and inserts laterally on its immediately inferior rib. The dorsal ramus of the spinal nerve and the dorsal branch of the intercostal artery run through the canal formed between the superior costotransverse ligament and the vertebral column.

The rib can be resected following blunt dissection of the surrounding intercostal muscles and ligaments. The isolated strip of intercostal musculature contains the intercostal nerve, artery, and vein as they pass laterally between the internal intercostal membrane and the pleura, then between the internal and innermost intercostal muscles.

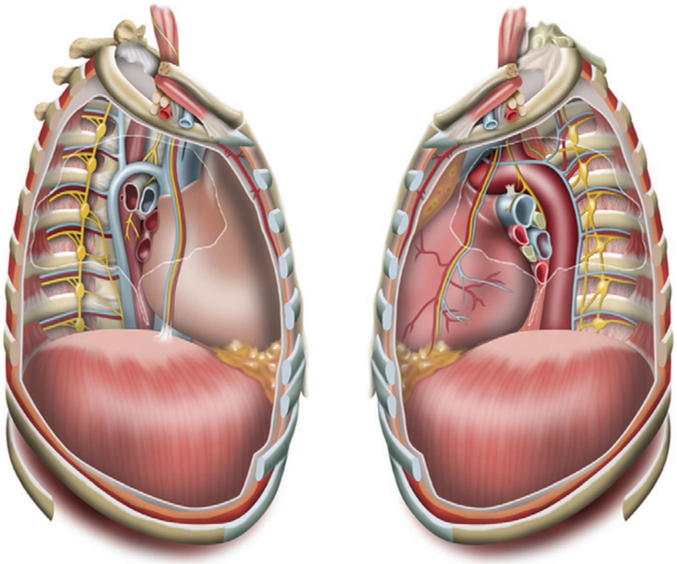


Figure 25-6 **A,** Right thoracic cavity. **B,** Left thoracic cavity.

The intercostal vein is typically cephalad to the artery, and the nerve is frequently found separate from the vasculature and is the most caudal structure of the three.

The parietal pleura covers the spinal column and vascular structures. It is removed to reveal the underlying structures (Fig. 25-6). In the proximal thoracic spine, disk spaces are large, white, prominent surfaces ("hills"). Intercostal vessels lie beneath the pleura and run over the concave midvertebral bodies ("valleys"). The sympathetic chain lies over the neck of the rib, close to the intervertebral disk space. The first thoracic ganglion can combine with the lower cervical ganglion to form the satellite (cervicothoracic) ganglion. Superior intercostal veins drain the proximal thoracic intercostal space and empty into the azygos venous system on the right side and above the accessory hemiazygos veins on the left side. They eventually drain into the left brachiocephalic vein, which also receives the thoracic duct. In terms of intercostal arteries, the superior (highest) artery supplies the first two intercostal spaces and branches off the costocervical trunk. The posterior (T3 to T11) artery branches off the aorta and ascends obliquely to reach intercostal spaces deep to the venous system. The ascending aorta and arch pass anterior to the trachea and esophagus to remain on the left side and then pass inferiorly on the left side of the T4 vertebra. The three branches from the arch are the brachiocephalic trunk, left common carotid artery, and left subclavian artery.

The esophagus is between the trachea and the vertebral column. It is anterior to the T1 to T4 vertebrae, medial and posterior to the aortic arch from the left side, and medial and posterior to the azygos vein and superior intercostal veins from the right side. The trachea is anterior and slightly right of the esophagus. The aortic arch is at first anterior to the trachea and then is on the left side. The brachiocephalic trunk and left common carotid arteries ascend to straddle the trachea and separate it from the brachiocephalic veins.

Posterolateral Approaches

The posterolateral approaches provide limited exposure of the low cervical spine but allow excellent exposure of the proximal thoracic spine. Similar to anterolateral approaches, they require dissection and mobilization of parascapular musculature. The extent of lateral dissection is dependent on the amount of exposure needed to reach the anterior and middle columns of the spine.

In the initial posterolateral dissection of the CTJ, the spinous process insertions of the trapezius, rhomboid, serratus posterior superior, splenius capitis, and splenius cervicis are taken down as a single group for lateral retraction. As these muscles are taken down, the scapula is released from its attachments to the spinous processes and rotates anterolaterally out of the operative field. Furthermore, the entire group of erector spinae and transversospinalis muscles can be dissected laterally as a single muscular mass. Control of the musculature in this way exposes all the vertebral elements, from the tips of the spinous processes to the tips of the transverse processes, as well as the costotransverse ligaments, joints, and ribs. This maneuver exposes the posterior and posterolateral rib cage for the remainder of the procedure.

After rib resection, pleura can be separated from the lateral vertebral elements. A layer of retropleural fat is often apparent anteromedially and can aid in the dissection plane. Tracing the intercostal neurovascular bundle medially will identify the neural foramen. Because the aortic arch does not reach the top of the thoracic cavity, the arterial supply to the chest wall has become specialized. The first two intercostal spaces are supplied by branches of the costocervical trunk through the highest intercostal artery. This artery descends anteriorly to the ventral rami of the eighth cervical and first thoracic nerves on the necks of the first two ribs. Remaining intercostal arteries arise from the posterior surface of the thoracic aorta. Each intercostal artery stretches obliquely across each vertebral body, from a caudad to cephalad direction, close to the vertebral body periosteum and is located deep to the azygos or hemiazygos vein, thoracic duct, and sympathetic trunk.

The ventral ramus of the first thoracic nerve passes cephalad across the neck of the first rib to join the eighth cervical nerve in the brachial plexus. A small intercostal branch runs across the inferior surface of the first rib to enter the first interspace close to the costal cartilage. Also, the ventral ramus of the second thoracic nerve usually sends a small branch to the brachial plexus. Although the intercostal nerves below T1 can usually be sacrificed to facilitate exposure, The T1 and C7 nerves, which are frequently exposed during this procedure, cannot be sacrificed without causing severe neurologic deficits in hand function.

Biomechanics

ANATOMIC CONSIDERATIONS

The CTJ serves as a transition zone between the mobile cervical spine and the relatively rigid thoracic spine. A change in sagittal alignment from cervical lordosis to

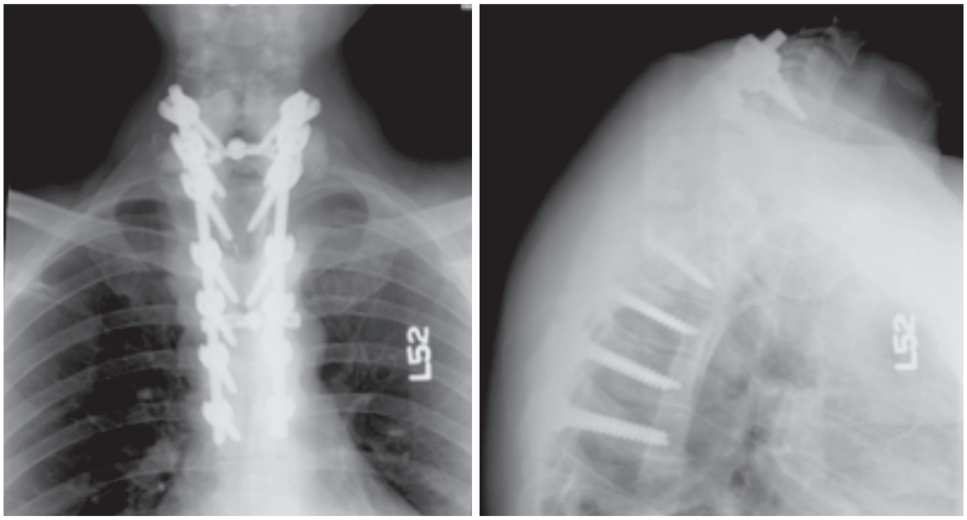


Figure 25-7 Posterior segmental instrumentation spanning the cervicothoracic junction (C7–T7) using C7 and thoracic pedicle screws, 5.5-mm rods, and two cross-links.

thoracic kyphosis also occurs. These anatomic features must be taken into consideration for proper preoperative planning and subsequent operative intervention to yield optimal outcome.

A unique anatomic feature found in the cervical spine is the attachments of functionally significant extensor muscles to the C2 and C7 spinous processes that behave like posts of a suspension bridge. When performing cervical laminoplasty, for example, preservation of the C7 spinous process to which the trapezius, rhomboid major, rhomboid minor, serratus posterior superior, splenius capitis, and splenius cervicis insert into the posterior CTJ is important to decrease the risk of developing postoperative neck pain and kyphosis.[2]

Disruption of the supraspinous ligament/interspinous ligament can result in destabilization of the supraadjacent CTJ following long thoracic constructs that stop at T1, which may manifest as proximal junctional kyphosis.[3] In contrast, facet capsule disruption, as might be encountered during T1 pedicle screw placement, does not seem to acutely destabilize the supraadjacent level because of the interaction of the C7–T1 facet joints with T1 instrumentation.

INSTRUMENTATION

Instrumentation across the CTJ requires several important considerations. Studies suggest posterior instrumentation is more stable than anterior plating.[4] Further, combined anterior and posterior instrumentation is even more stable than either anterior or posterior instrumentation alone.[5] Among posterior instrumentation techniques, screw-based systems (lateral mass screws in the cervical spine and pedicle screws in the thoracic spine) seem to provide the most robust fixation at the CTJ.[6]

The 3.5-mm rod-and-screw construct has been demonstrated to be biomechanically weaker than the dual-diameter rod (3.5 mm to 5.5 mm) and the solid domino connector extending between 3.5-mm and 5.5-mm rods as posterior fixation across the CTJ.[7] Addition of two cross-links may provide further stability.[8] C7 pedicle screw fixation affords the construct with the highest normalized stiffness for stabilizing the CTJ compared with lateral mass screws with or without spinous-process wiring (Fig. 25-7).[9]

Lastly, posterior segmental fixation alone may be inadequate to restore stability following a three-column injury at the CTJ, and additional anterior instrumentation may be needed.[10,11]

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26 Anterior Approaches to the Cervicothoracic Junction

ILSUP KIM and DANIEL H. KIM

Overview

The anterior approach to the cervicothoracic spine can be technically challenging and requires precise knowledge of cervicothoracic regional anatomy and careful preoperative planning. A standard low-cervical approach can often expose to the T1 level in most patients, and in those with long necks, it is possible to expose down to T2 with a standard low-cervical approach. However, for usual anterior exposure of T2–T4, more extensive approaches, such as the transmanubrial or transsternal approaches, will be necessary. The transsternal approach offers the best exposure of T3 and T4, but it carries the greatest morbidity of all the anterior approaches. Caudally the aortic arch and its branches limit access to the T3 and T4 vertebrae.

Anatomy

THORACIC INLET

- Superior mediastinum, defined anteriorly by the manubrium (Fig. 26-1)
- T2–T3 level at the suprasternal notch
- T4–T5 level at the sternal angle
- Sternohyoid muscle
- From the ventrocaudal hyoid bone to the dorsal surface of the manubrium
- Attaches to the sternoclavicular joint capsule
- Sternothyroid muscle
- Attaches along the dorsal midline of the manubrium
- Sternocleidomastoid muscle (SCM)
- Arises on the mastoid process and superior nuchal line and attaches to the manubrioclavicular joint
- Nervous supply is from the accessory nerve.
- Arterial supply branches from the superior thyroid artery.
- Removal of the manubrium and medial third of the clavicle reveals the pleural apices, which are covered by an extension of the transthoracic fascia, called *Sibson's fascia*.

VASCULAR AND VISCERAL COMPARTMENTS OF THE SUPERIOR MEDIASTINUM

Fascial Layers

- The visceral fascia circumscribes the trachea, esophagus, and thyroid gland, thus defining a visceral compartment.
- The carotid sheath circumscribes the carotid arterial system, internal jugular vein, and vagus nerve, thus defining a neurovascular compartment.
- These adjacent compartments create a potential space, the viscerocarotid space, which extends from the base of the skull to C7–T4, depending on the location of the fusion between the visceral and alar fascia.
- Blunt dissection of the viscerocarotid space exposes the alar fascia and the retropharyngeal space (Fig. 26-2).
- The visceral compartment continues down to the bronchi, where the fascia fuses with the parietal and visceral pleura.
- The carotid sheath extends down to the subclavian vessels, where it fuses into the axillary sheath.
- In the superior mediastinum, the vascular compartment is not circumscribed by its own well-defined fascial sheath but is defined secondarily by independent surrounding fascia.
- The prevertebral fascial extension, the transthoracic fascia, lies ventral.
- The visceral fascia lies caudal.
- Lateral are the parietal pleura.
- The pericardium lies inferiorly.

Venous Structures

- Brachiocephalic veins with their branches descend from the neck into the superior mediastinum just posterior to the thymus gland.
- The right brachiocephalic vein is formed just posterior to the medial end of the right clavicle and descends vertically into the superior mediastinum.
- The left brachiocephalic vein is formed just posterior to the medial end of the left clavicle and descends diagonally to join the right brachiocephalic vein just posterior to the right first costal cartilage to form the superior vena cava.
- In the superior mediastinum, the left brachiocephalic vein runs obliquely from left inferior to right superior.
- Tributaries drain into the brachiocephalic veins.
- The vertebral and first, posterior, and intercostal veins in the neck are included.
- The internal thoracic, thymic, and inferior thyroid veins lie in the superior mediastinum.
- On the left, the superior intercostal vein, which drains the second and third intercostal spaces, also drains into the left brachiocephalic vein.

Arterial Structures

- The aortic arch initially ascends posteriorly to the superior vena cava but also turns diagonally posterior then inferior just anterior and to the left of the vertebral column.

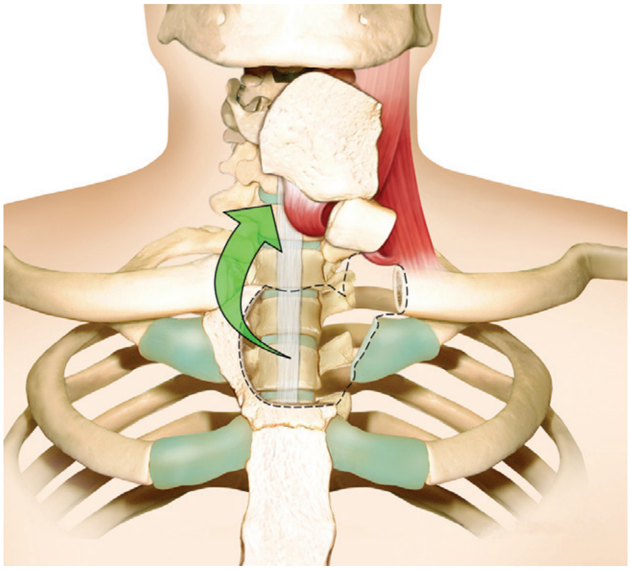


Figure 26-1 Surgical approach depends on the desired level of exposure. The suprasternal notch approximates the T2–T3 level, and the sternal angle approximates the T4–T5 level.

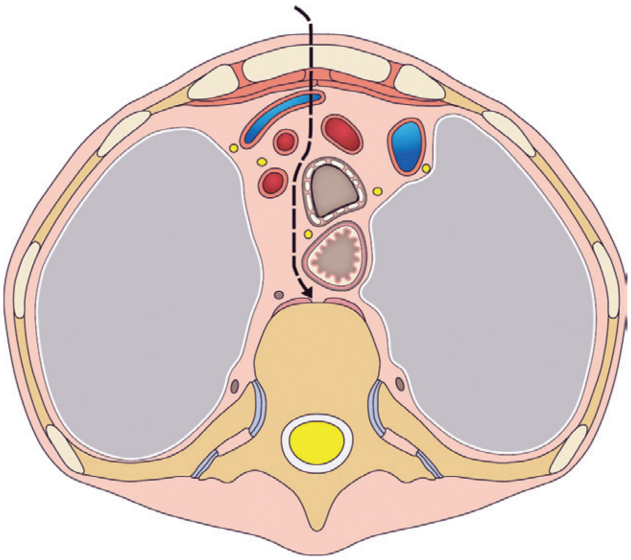


Figure 26-2 Dissection plane through the viscerocarotid space needed to reach the upper thoracic prevertebral space.

- A second concave turn occurs as the arch curves around the anterolateral visceral compartment to reach the vertebral column.
- The brachiocephalic artery is the first branch off the aortic arch; it ascends vertically and slightly rightward to branch into the right common carotid and subclavian arteries posterior to the right sternoclavicular joint.
- The left common carotid artery arises next off the arch and ascends essentially vertically into the carotid sheath without branching in the superior mediastinum.
- The left subclavian artery is the third branch; it ascends superiorly and leftward to curve around the thoracic inlet and into the axillary sheath without branches in the superior mediastinum.

RETROPHARYNGEAL AND RETROMEDIASTINAL SPACES

- By incising the alar and mediastinal fascia, the median compartment of the retromediastinal space is entered.
- The prevertebral fascia covers the vertebral bodies and envelops the longus colli muscles.
- Autonomic branches to the cardiopulmonary plexi may be seen in this region and can be sacrificed if necessary.
- Structures that may cross the retropharyngeal and retromediastinal spaces:
  - The right recurrent laryngeal nerve can cross the retropharyngeal or retromediastinal space anywhere from C7 to T3.
  - The left recurrent laryngeal nerve loops around the ligamentum arteriosum and ascends within the visceral fascia between the esophagus and trachea.
- Lymphatics that terminate in the thoracic duct (on the left side):
  - Run dorsal and to the left of the esophagus between the visceral and alar fascia in the superior mediastinum and ascend to the C7 level.
  - Lie laterally in a plane dorsal to the carotid sheath, then course caudally and ventrally to the branches of the thyrocervical trunk and phrenic nerve.
  - Terminate at the junction of the left internal jugular and subclavian veins.
  - A lymphatic trunk located on the right side follows a similar course to the thoracic duct.

Operative Techniques

LOW-CERVICAL APPROACH

- The low-cervical approach is the Smith-Robinson approach with possible caudal exposure to T1 or T2 in most patients. Technical description of this approach is similar to an approach used for anterior cervical diskectomy and fusion.
- Visualization of the posterior aspect of the disk is difficult and may require a resection of the lower aspect of the cranial vertebrae.
- Vertebrectomy may be easier than diskectomy.
- A right-sided approach should identify the recurrent laryngeal nerve.
- A left-sided approach should spare the thoracic duct.
- The inferior thyroid vein and artery may be encountered and ligated as necessary.
- Inferiorly, the brachiocephalic vein is anterior to the trachea at T3.

Retraction maneuvers include:

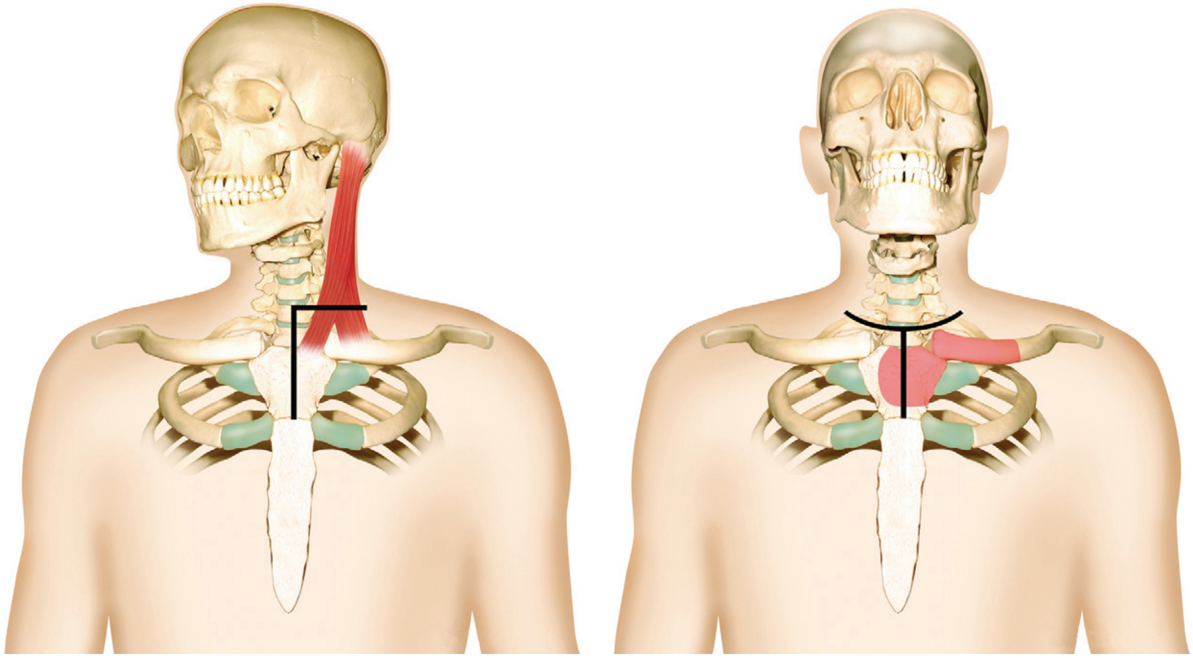
- Trachea and esophagus, medially
- Lung apex and innominate vessels, inferiorly
- Carotid sheath, laterally

SUPRACLAVICULAR APPROACH

- This approach uses incision above the clavicle with dissection posterior to the carotid sheath.
- The clavicular head of the SCM is divided.
- The subclavian artery and branches are exposed (thyrocervical, suprascapular, and transcervical; the last two can be ligated if necessary).
- The phrenic nerve on the anterior scalene muscle is identified. This muscle is divided with sparing of the phrenic nerve.
- Division of the anterior scalene will expose the Sibson fascia that covers the dome of the lung.
- Divide the Sibson fascia transversely to retract visceral pleura and lung inferiorly.
- A view into the thoracic inlet is now possible as is visualization of the posterior thorax, stellate ganglion, and upper thoracic vertebral bodies.
- Obese and muscular patients with short necks are poor candidates for the above two approaches but can be appropriate candidates for the approaches that follow.

TRANSMANUBRIAL-TRANSCLAVICULAR APPROACH

- This approach can be combined with a left-sided low-cervical approach.



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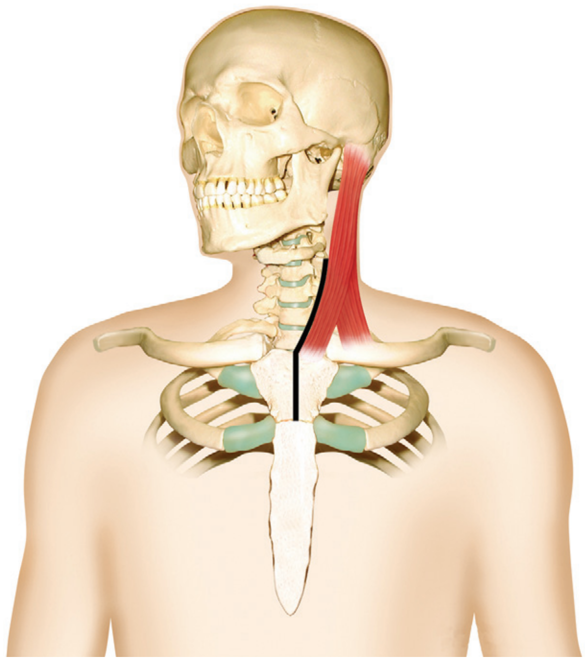
C



B

Figure 26-3 Possible incisions for the transmanubrial approach. **A,** Transverse cervical incision combined with midline sternal incision. **B,** Oblique cervical incision along the medial border of the sternocleidomastoid muscle and a midline sternal incision. **C,** T-shaped incision.

- Various hockey stick–type incisions can be used (Fig. 26-3).
- Platysma and deep cervical fascia are incised.
- Sternal and clavicular heads of the SCM are divided and retracted laterally.
- Sternohyoid and sternothyroid muscles are divided and retracted medially.
- Blunt dissection of the viscerocarotid plane is performed.
- The medial third of clavicle and manubrium are exposed periosteally.
- The clavicle at the junction of medial and middle thirds is divided.
- The medial end of the clavicle can be disarticulated from the sternoclavicular joint.
- The left side of the manubrium can be removed piecemeal along its posterior periosteum.
- Alternatively, the manubrium and sternoclavicular joint can be left intact and reflected with the sternal head of the SCM (Fig. 26-4).
- Dissection is carried deeper, until great vessels are identified (Fig. 26-5).
- Inferior thyroid vessels can be ligated.
- The left innominate vein should be identified and retracted caudally (Fig. 26-6).
- Identify the prevertebral fascia and incise to expose the vertebral bodies.
- Reconstruction of the clavicle and manubrium is optional but can be accomplished with wire or plating systems.

TRANSSTERNAL-TRANSTHORACIC APPROACH

- This approach provides the best exposure down to T4, especially in obese patients.
- Morbidity is higher with this approach than with other approaches.
- The transsternal-transthoracic approach can be combined with the low-cervical approach.
- Shoulder function is not affected.

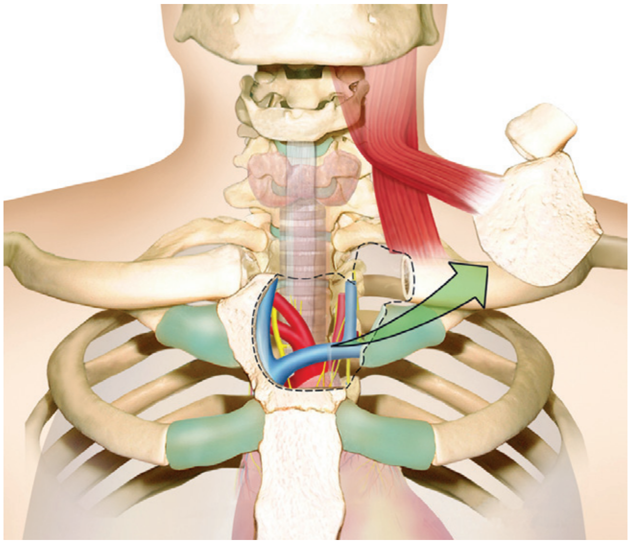


Figure 26-5 Great vessels should be identified after reflection of the manubrium and dissection through the retrosternal fat. Inferior thyroid vessels can be ligated as needed.

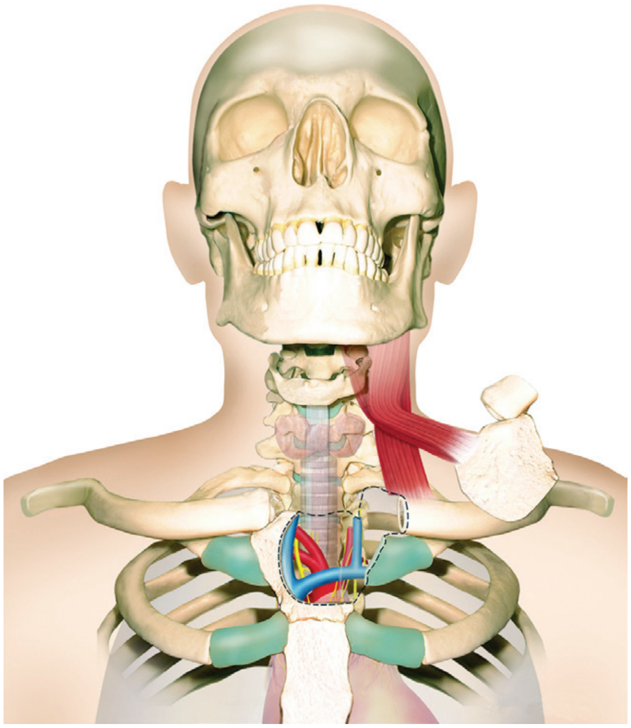


Figure 26-4 The sternoclavicular joint can be left intact by leaving the sternal head of the sternocleidomastoid muscle attached to the manubrium and reflecting it as one piece.

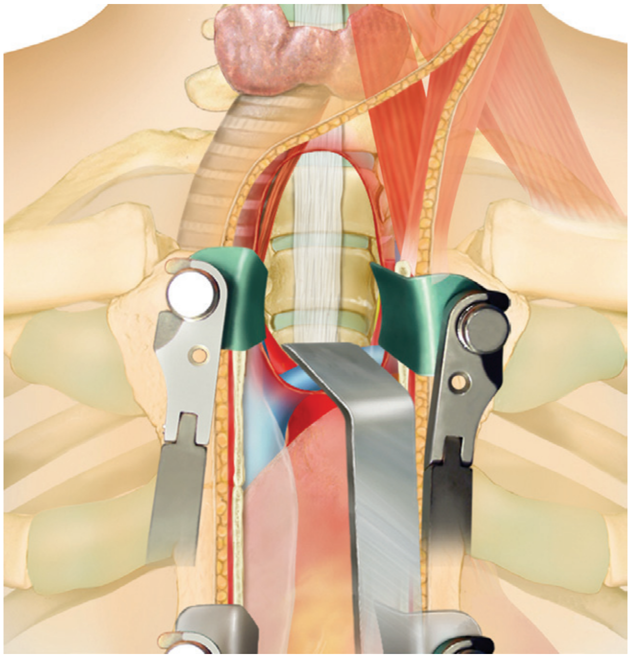


Figure 26-6 Retraction of the great vessels caudally, visceral structures medially, and carotid shealth laterally exposes the prevertebral space.

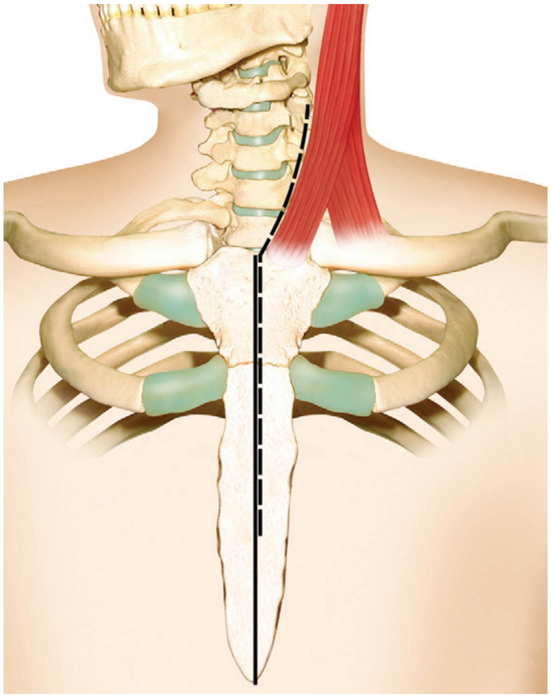


Figure 26-7 Incision used for a combined low-cervical sternotomy approach.

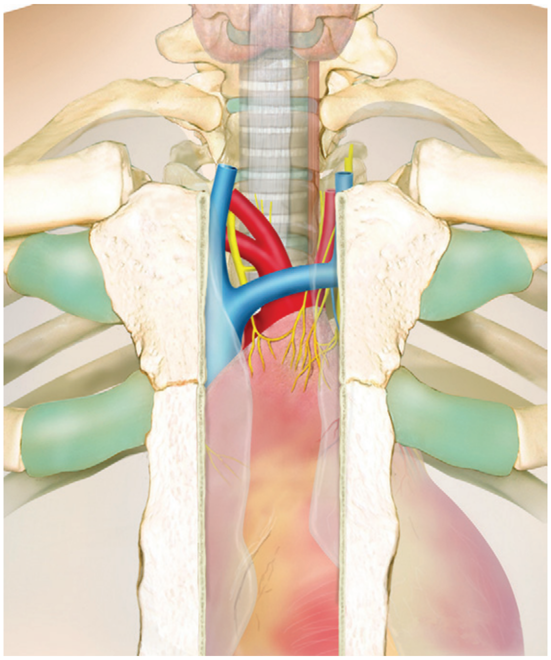


Figure 26-9 Close-up after median sternotomy. Recurrent laryngeal nerves can be identified with great vessels.

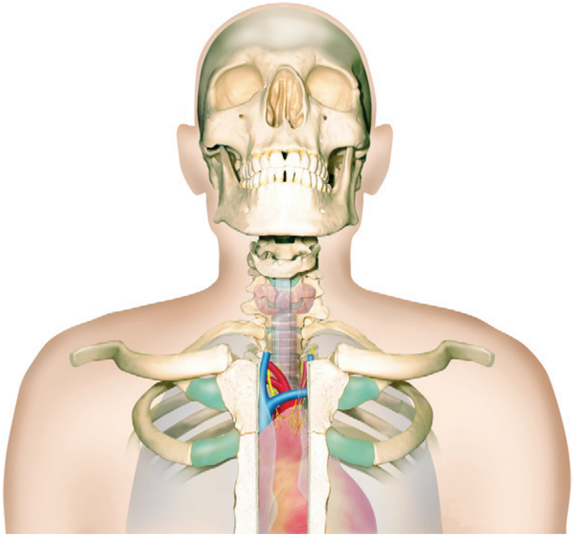


Figure 26-8 Exposure after a midline sternotomy. Stay midline to avoid injury to the pleura. Sternotomy should be done with utmost care so that underlying vessels are not injured.

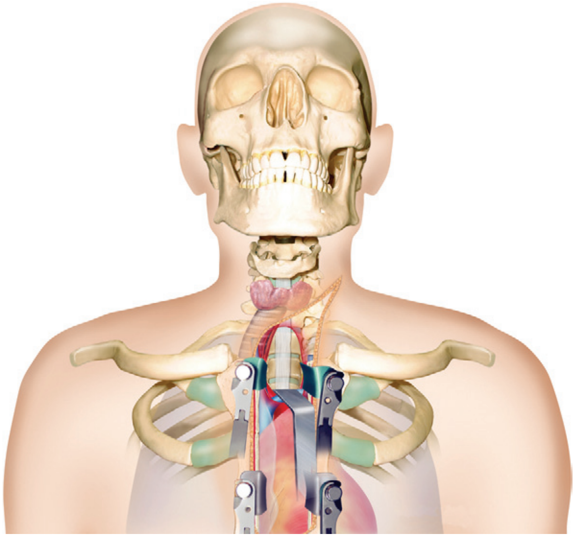


Figure 26-10 Exposure after retractors are placed for a sternotomy approach.

- Incision should be made medial to the anterior border of the SCM down the middle of the sternum to the xiphoid process (Fig. 26-7).
- Sternohyoid and sternothyroid muscles are divided.
- Retrosternal adipose and thymus tissues are retracted from the sternum.
- The sternum is exposed subperiosteally and divided in the middle with a sternal saw (Fig. 26-8).
- The inferior thyroid vessels can be ligated (Fig. 26-9).
- The left innominate vein is retracted caudally or ligated if necessary; the trachea and esophagus are retracted medially, and the carotid sheath is retracted laterally (Fig. 26-10).
- Identify the prevertebral fascia and incise to expose the vertebral bodies.
- Closure should be performed with standard wiring. A chest tube is not necessary except with pleural violation.

27 Posterolateral Approaches to the Cervicothoracic Junction: Transpedicular, Costotransversectomy, Lateral Extracavitary, and Parascapular Extrapleural Approaches

DONATO PACIONE, TAYLOR WILSON, NOEL PERIN, and ANTHONY FREMPONG-BOADU

Overview

The cervicothoracic junction (CTJ), from C7 to T4, presents a particularly challenging region for surgical approach secondary to the unique anatomy of the upper thoracic cage, the presence of the scapula, and the proximity of structures of the superior mediastinum. To avoid the morbidity and limitations associated with anterior approaches, a variety of posterior or posterolateral approaches have been developed. Each of the posterolateral techniques allows for different and more extensive views of the vertebral body. The major limitation of all of these approaches is the limited access to the C7 vertebral body as a result of the inability to sacrifice the T1 nerve root. However, for lesions from T1 through T4, these approaches allow for ventral neurologic decompression and the possibility of 360-degree stabilization with an overall lower morbidity compared with anterior or transthoracic approaches.[1-3]

Anatomy

The anatomy of the CTJ is complex, and knowledge of the multiple layers of muscle groups, costovertebral articulations, inferior contributions to the brachial plexus, and the nearby structures of the superior mediastinum is necessary for posterolateral approaches to the vertebral body.

MUSCLES OF THE SCAPULAR AND PARASCAPULAR REGION

The muscles of the scapular and parascapular region are divided into *superficial, intermediate,* and *deep* groups.

Superficial Muscle Group (Fig. 27-1)

Trapezius

- Originates at the medial third of the superior nuchal line and occipital protuberance, with attachments arising from the C7–T12 spinous processes
- Innervated by the spinal accessory nerve and the ventral rami of C3 and C4
- Responsible for elevating, retracting, and depressing the scapula

Rhomboid Major

- Arises from the spinous processes of T2–T5 and inserts into the medial surface of the scapula at the root of the spine to the inferior angle
- Innervated by the dorsal scapular nerve
- Responsible for retracting the scapula and fixing it to the thoracic wall

Rhomboid Minor

- Arises from the lower portion of the ligamentum nuchae and spinous processes of C7 and T1. Inserts into the medial scapula at the base of the root of the spine of the scapula
- Innervated by the dorsal scapular nerve
- Responsible for retracting the scapula and fixing it to the thoracic wall

Levator Scapulae

- Arise from posterior tubercles of the transverse processes of C1–C4 and inserts at the medial border of the scapula just superior to the rhomboid minor
- Innervated by the dorsal scapular nerve and the ventral rami of C3 and C4
- Responsible for elevating and rotating the scapula

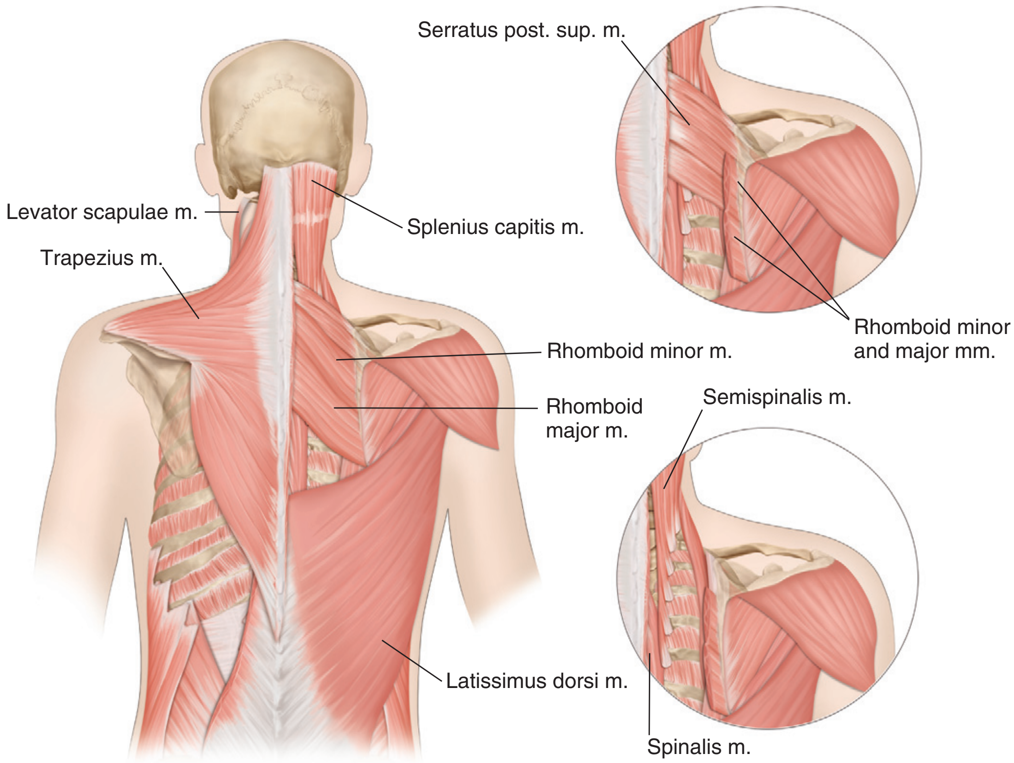


Figure 27-1 Dissection of the posteromedial shoulder musculature. These muscle groups can be divided into superficial, intermediate, and deep layer muscles.

Intermediate Muscle Group

Serratus Posterior

- Arises from the spinous processes of C6–T3 and inserts at the superior border of the second to fourth ribs
- Innervated by the second to fifth intercostal nerves
- Responsible for elevating the ribs

Splenius Capitis

- Arises from the lower half of the ligamentum nuchae and the spinous processes of C7–T3 and inserts at the mastoid process and lateral one third of the superior nuchal line
- Innervated by the posterior rami of cervical nerves
- Responsible for stabilization and rotation of the skull

Spenius Cervicis

- Arises from the spinous processes of the T3–T6 and inserts into the posterior tubercles of the transverse processes of C1–C4
- Innervated by the posterior rami of cervical nerves
- Responsible for stabilization and rotation of the skull

Deep Muscle Group

The deep muscle group is divided into the erector spinae and transversospinalis muscles.

Erector Spinae

- This group can be divided into three main columns: the *iliocostalis*, *longissimus*, and *spinalis* (Fig. 27-2).
- Each column is divided into *cervical*, *thoracic*, and *lumbar* regions.
- The erector spinae share a common aponeurotic band that attaches to the posterior part of iliac crest, the posterior aspect of the sacrum, and the sacroiliac ligaments.

Iliocostalis

- The most lateral column
- Originates from the angles of the ribs and inserts in the posterior tubercle of the transverse processes of C4–C6
- Innervated by the posterior rami of the spinal nerves
- Extends and laterally bends the vertebral column

Longissimus

- The intermediate column
- Originates from the transverse processes of thoracic vertebrae and inserts on superior transverse processes and articular processes of C2 through C6
- Innervated by the posterior rami of the spinal nerves
- Extends and laterally bends the vertebral column and extends the neck

Spinalis

- The medial column
- Originates from thoracic and lumbar spinous processes and inserts on lower cervical spinous processes
- Innervated by the posterior rami of the spinal nerves
- Extends vertebral column and extends the neck

Transversospinalis

- Made up of three groups of muscles that lie deep to the erector spinae

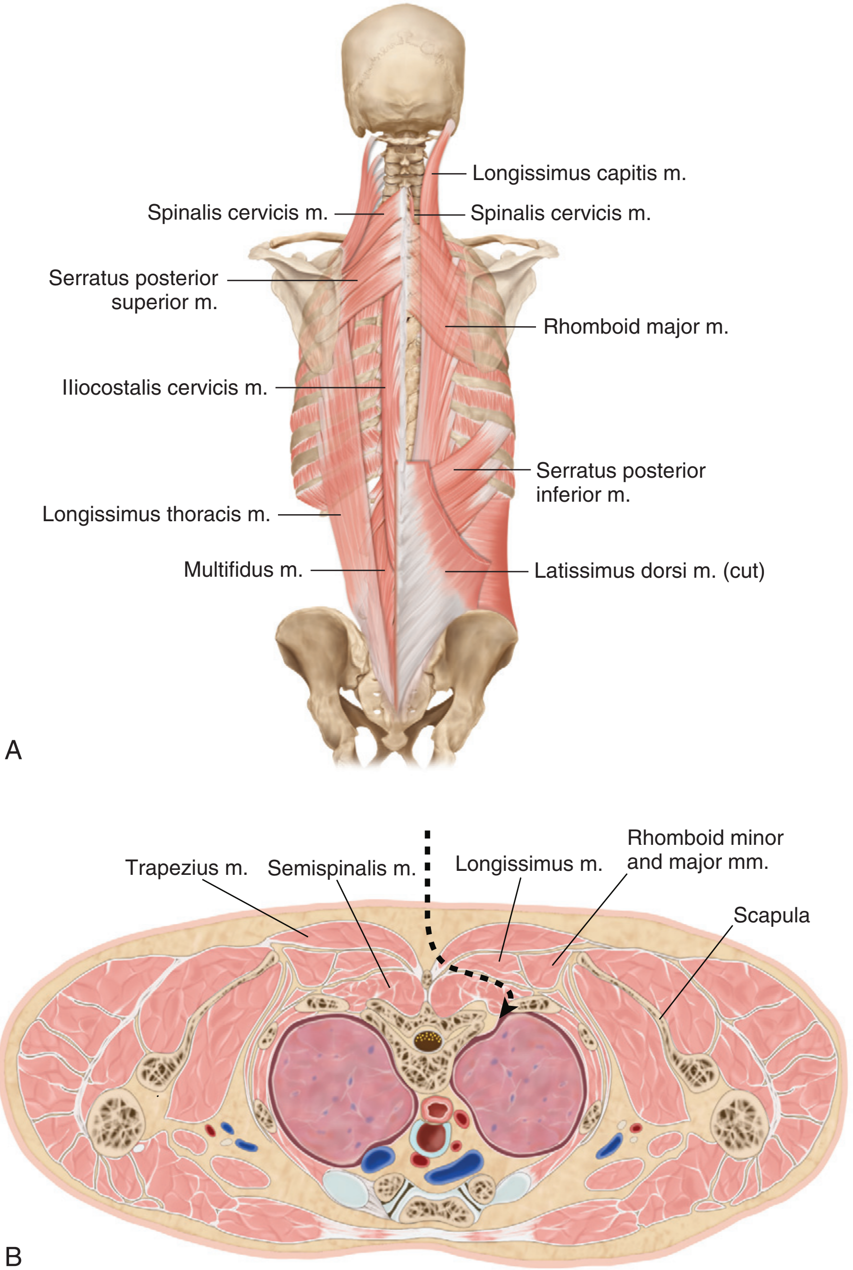


Figure 27-2 **A,** Dissection demonstrates deep muscle groups of the back. **B,** Cross-section demonstrates location of the superficial and deep muscle groups.

- Originate from transverse processes and insert at the spinous processes of superior vertebrae
- Innervated by the posterior rami of the spinal nerves
- Stabilizes vertebrae during local movements of the vertebral column

Semispinalis
- The most superficial group
- Divided into three regions: *capitis, cervicis,* and *thoracic*

Multifidus
- Deep to the semispinalis group
- Short triangular bundles

Rotares
- The deepest group
- Arise from the transverse process of one vertebra and insert into the root of the spinous process of the next superior vertebra

POSTERIOR THORACIC CAGE (Fig. 27-3)

Vertebral Body and Rib Articulation

- Thoracic vertebrae have costal facets on the superolateral aspect of the vertebral body where the rib head articulates.

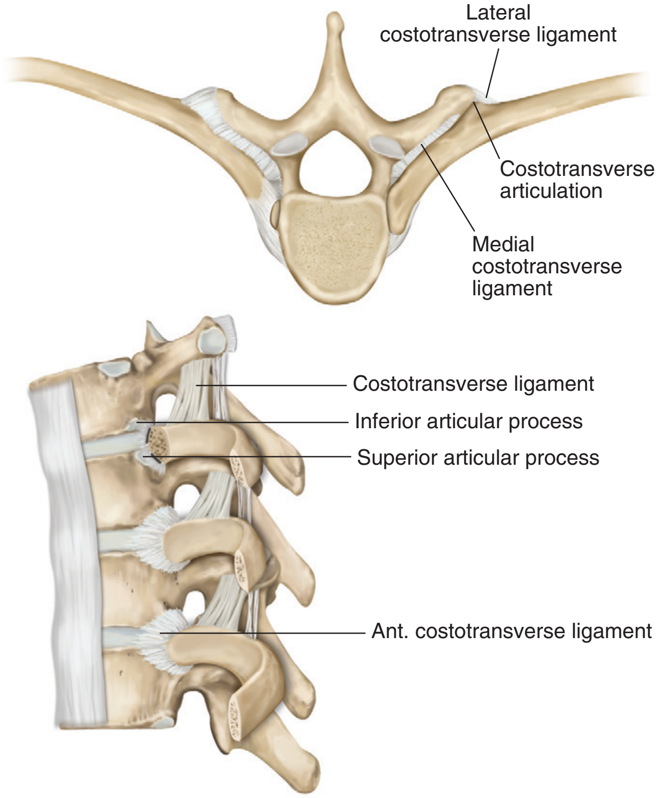


Figure 27-3 Three groups of ligaments articulate the rib with the corresponding vertebral body and transverse process. These are disrupted for rib removal: the anterior and posterior superior costotransverse ligaments, lateral and medial costotransverse ligaments, and anterior costovertebral (radial) ligament.

- Each rib head articulates with its own vertebral body, the inferior aspect of the vertebral body above, and the intervertebral disk space. The exception is the first rib, which articulates only with the T1 vertebral body.
- Thoracic transverse processes have a costal facet that articulates with the tubercle of the rib except for the inferior two to three ribs (i.e., T10–T12).

Ligaments of Rib Articulation

- Anterior and posterior superior costotransverse ligaments join the neck of the rib to the transverse process.
- Lateral and medial costotransverse ligaments attach the posterior neck of the rib to the transverse process.
- The anterior costovertebral ligament attaches the head of the rib to the vertebral body.

Rib Interconnection

- The intercostal musculature originates on the medial aspect of the superior rib and inserts laterally on the next inferior rib.
- The neurovascular bundle associated with each rib runs in a groove on the inferior aspect of the rib, with the vein being the most superior and the nerve inferior.

Retromediastinal Space

- Anterior to the rib is a layer of retropleural fat and the endothoracic fascia. This layer tracks anteromedially toward the ventral aspect of the vertebral body and may be used as a plane of dissection (Fig. 27-4).

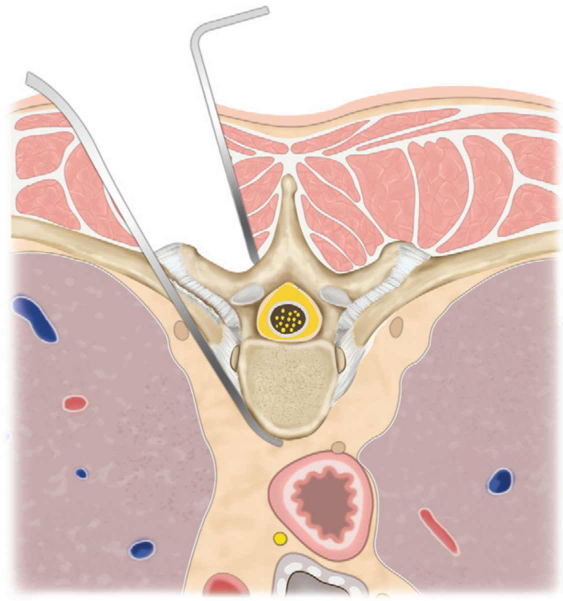


Figure 27-4 Anatomic illustration after costotransversectomy and retractor placement. Pleura can be separated from the lateral vertebral elements. A layer of retropleural fat is often apparent anteromedially and can aid in establishing the dissection plane.

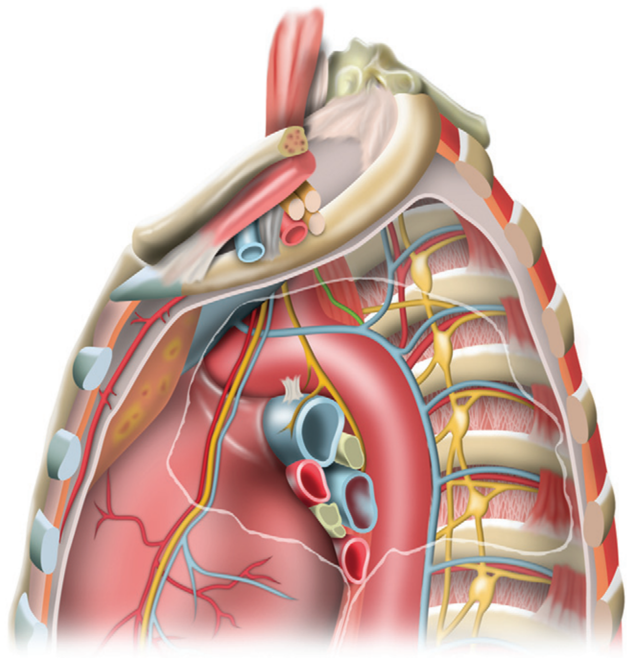


Figure 27-5 Lateral view of the mediastinum demonstrates the proximity of the aortic arch and esophagus to the vertebral bodies.

- The aortic arch ascends to the level of T3–T4 and lies anterolaterally to the left side of the vertebral bodies. It may obstruct the view of the vertebral bodies in posterolateral approaches to the vertebral body (Fig. 27-5).
- Intercostal arteries arise at T3 to T12 from the posterior aorta and travel across the ventral aspect of the vertebral body. The dorsal branch gives rise to the segmental arteries that supply the spinal canal and spinal cord. They

then become part of the neurovascular bundle, which runs along the inferior aspect of each rib.

- Because the aortic arch does not extend to the most superior aspect of the thoracic cage, it is instead supplied by a branch of the costocervical trunk (Fig. 27-6).
- The esophagus lies ventral to the vertebral body and is pushed slightly to the right side by the descending aorta.

Neural structures (Fig. 27-7):

- The upper portion of the CTJ contains nerves that form the inferior portion of the brachial plexus.
- The C8 nerve and the ventral ramus of the T1 nerve join the brachial plexus. There is also variable involvement of the ventral ramus of T2, which may contribute a small branch to the brachial plexus.
- The dorsal ramus of T1 runs along the inferior aspect of the first rib.
- Intercostal nerves below T1 may be sacrificed for increased exposure without causing significant neurologic compromise.

Surgical Approaches

LAMINECTOMY

Indications and Advantages

A standard posterior midline laminectomy approach to the CTJ may be used for any pathology that involves the dorsal aspect of the spinal cord or the posterior elements (Fig. 27-8). Specifically this approach is useful for relieving spinal cord compression secondary to ligamentous hypertrophy or tumor involving the posterior elements. It allows for complete posterior decompression without disruption of the anterior or middle column of the spine. As such, it does not

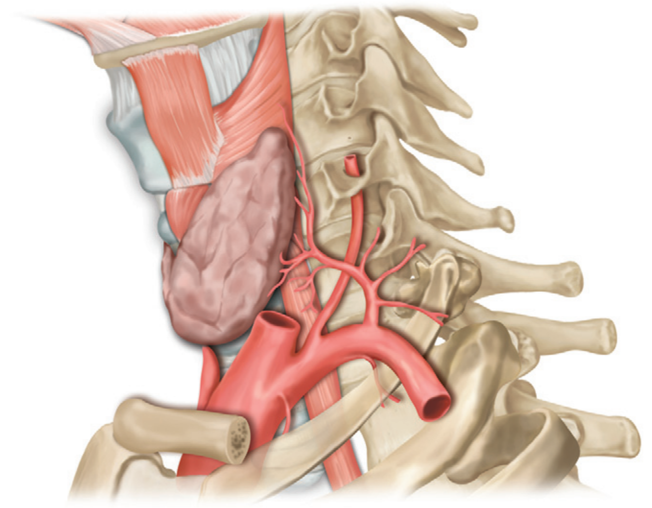


Figure 27-6 The vascular supply for the first two intercostal spaces is from the costocervical trunk. The first aortic intercostal artery supplies the third interspace.

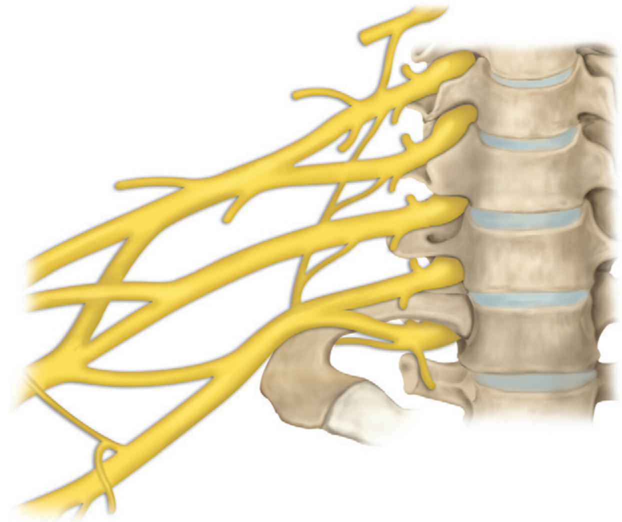


Figure 27-7 Brachial plexus anatomy demonstrates the significant contribution of the ventral ramus of T1 to the inferior trunk. A variable small contribution comes from the ventral ramus of T2.

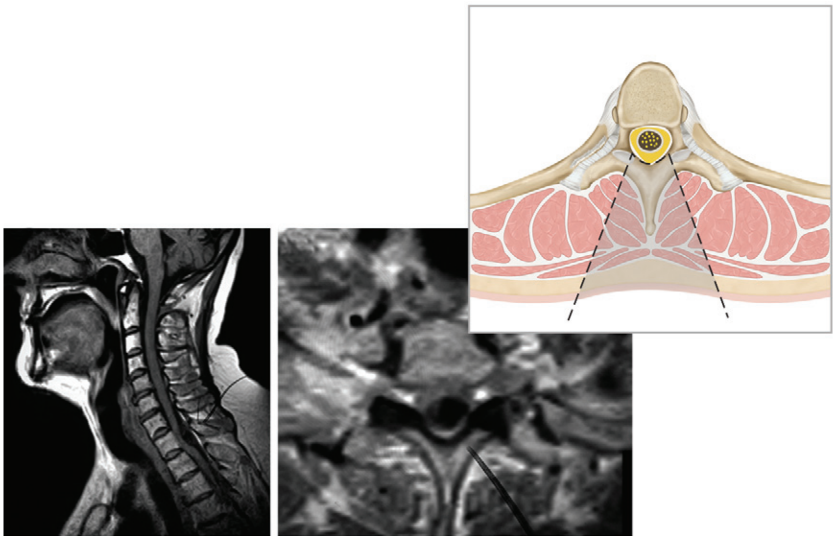


Figure 27-8 A laminectomy approach is ideal only for pathology located dorsally.

require stabilization with instrumentation and fusion. However, lesions that involve C7 and T1 may require stabilization, depending on the degree of resection or disruption of the facet joint, to avoid long-term junctional kyphosis. Because the exposure is limited, muscular dissection and disruptions are minimized.

Contraindications and Disadvantages

The major limitation of a midline approach is in addressing pathology anterior or lateral to the spinal cord. The viewing corridor involves the dorsal and dorsolateral aspect of the spinal cord. When the pathology causes significant anterior or anterolateral compression, a midline laminectomy approach should not be used. In the case of soft cervical or thoracic disk herniation and isolated, ventrally situated metastatic tumor, laminectomy alone may result in further neurologic compromise.[4-7] If the anterior and middle columns are disrupted, removal of the posterior elements will result in significant instability and a risk of further kyphosis.

Patient Positioning and Preparation (Fig. 27-9)

- Patients with significant spinal cord compression or instability at the CTJ should undergo either asleep or awake fiberoptic intubation for general anesthesia.
- Neurophysiologic monitoring should be performed, and baseline monitoring should be considered, before positioning in patients with significant cervicothoracic instability.[8]
- Position the patient prone with Mayfield three-point head-pin fixation on a table with gel rolls. The gel roll configuration may be placed with one horizontal roll across the chest and a second supporting the iliac crest. This allows the abdomen to hang free, and it decreases pressure on the inferior vena cava and therefore decreases overall venous pressure and bleeding tendency.
- The knees should be well padded and then flexed to prevent the patient from sliding down on the bed.
- The patient should be placed in a reverse Trendelenburg position, until the CTJ is parallel to the floor. This will decrease venous bleeding and allows the surgeon a more comfortable viewing angle.
- The patient's arms should be padded, specifically along the ulnar aspect of the arm, to prevent nerve injury.
- Taping the shoulders may open the cervicothoracic transitional region and may flatten the skin folds; this makes opening and closing simpler. Care must be taken not to place too much tension on the brachial plexus.
- The table should be radiolucent in the event that anteroposterior (AP) radiographs are necessary for localization. Lateral films are often difficult, especially below T1, because the shoulders, arms, and scapula obscure the vertebral anatomy.
- Before draping, check to ensure that excessive pressure is not being placed on pressure-sensitive areas such as the eyes, chin, elbows, knees, and genitals.
- Always prep and drape widely, in case the need arises for expansion of the operative site or for stabilization.

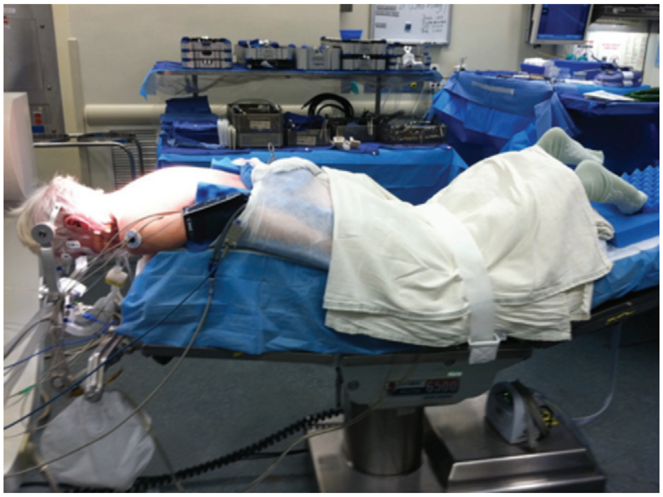


Figure 27-9 Standard positioning for posterior and posterolateral approaches to the cervicothoracic junction.

Operation

- Local anesthetic is injected into the surgical site.
- A midline incision is made over the length of the region of interest.
- Dissection is carried down through the subcutaneous tissue in the avascular midline nuchal plane.
- Before the dissection of the muscular layers, the use of paralytics will facilitate easier retraction and will decrease overall blood loss.
- A subperiosteal dissection is performed along the spinous process and lamina.
- The paraspinal musculature is taken down together and retracted laterally.
- Care must be taken when dissecting near the cervical interlaminar spaces, because they are wider than the thoracic spaces.
- Do not dissect anterior to the lateral mass, because this risks injury to the vertebral artery or nerve root.
- The extent of lateral exposure is the lateral mass of the cervical spine levels and the pars interarticularis for the thoracic levels.
- Do not dissect or disrupt the facet joints of the lateral masses and the thoracic levels to avoid destabilization.

Closure

- The muscular layer is first reapproximated.
- A tight fascial closure is obtained.
- Subcutaneous tissue and skin are closed in layers.

POSTEROLATERAL APPROACHES

The presence of significant anterior pathology may necessitate one of three posterolateral approaches to the CTJ. Each of the approaches allows for a varying degree of visualization and ease of vertebral body resection, reconstruction, and correction of kyphotic deformity.

Transpedicular Approach

Indications and Advantages. A transpedicular approach may be used to gain access to the lateral and limited anterior aspect of the spinal cord (Fig. 27-10). Pathology that involves ventral epidural compression (thoracic disk herniation, metastatic disease) or the anterior column may be

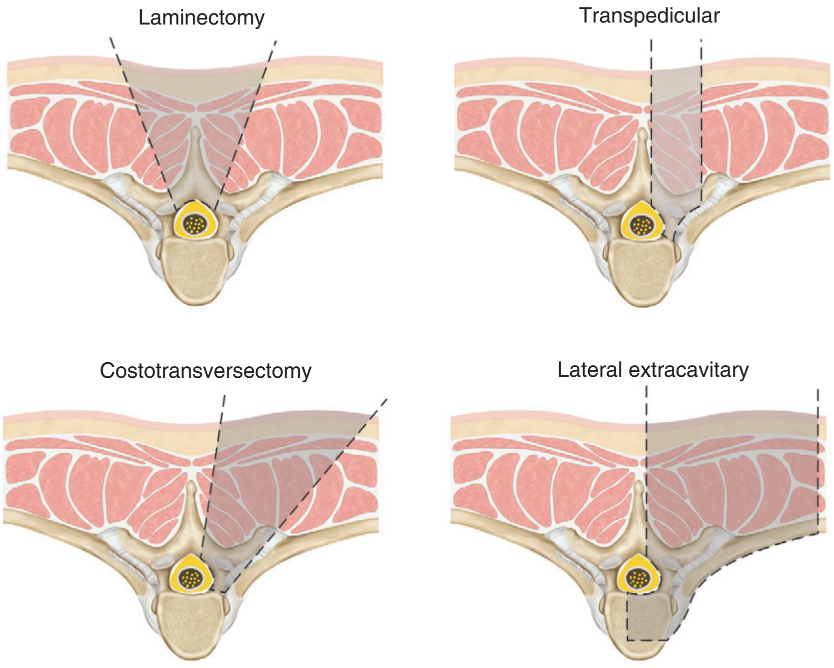


Figure 27-10 Viewing angle and extent of lateral exposure gained from each posterior approach.

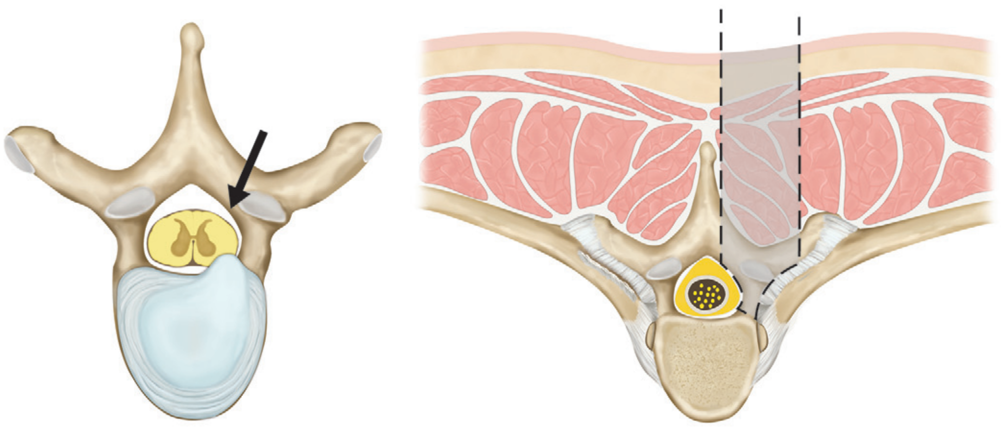


Figure 27-11 Transpedicular approach.

addressed (Fig. 27-11). In cases of lateral thoracic disk herniation, a unilateral transpedicular approach has proven effective without the need for stabilization.[9,10] This approach is used in patients with anterior column pathology who would not tolerate anterior or more extensive posterolateral dissections.[11] A bilateral transpedicular approach allows for improved visualization of the anterolateral aspect of the spinal cord, and it can be used for vertebral body resection with limited anterior column reconstruction.[11,12] A circumferential spinal cord decompression is achieved with the possibility of concurrent three-column stabilization.[12] This approach requires minimal lateral bone resection and avoids the risk of pleural violation and pneumothorax.

Contraindications and Disadvantages. Because of the limited viewing angle provided through this approach, ventral decompression is often performed without direct visualization, which increases the risk of neurologic injury. Firm, bony, or calcified ventral lesions may be difficult to address, because it is often necessary to curettage or push lesions into a cavity created in the vertebral body. This approach is also not recommended for a central thoracic disk herniation. The limited anterior column visualization precludes en bloc spondylectomy through the transpedicular approach. The anterior column may be resected in a piecemeal fashion, but reconstruction is often limited to the placement of Steinmann pins and polymethylmethacrylate (PMMA). When reconstructing the anterior column with PMMA, a partial vertebrectomy with maintenance of significant portion of the vertebral body may result in lower rates of PMMA dislodgment.[11,12] It may be possible to place a small expandable cage by using a trap-door rib osteotomy if the lesion is located at T2 or below (Fig. 27-12).[13] This is dependent on the individual anatomy and vertebral body size, as well as the degree of kyphotic deformity, because the entry corridor for any cage may be extremely limited.

Patient Positioning and Preparation. The patient is prepared and positioned the same as for a posterior midline approach.

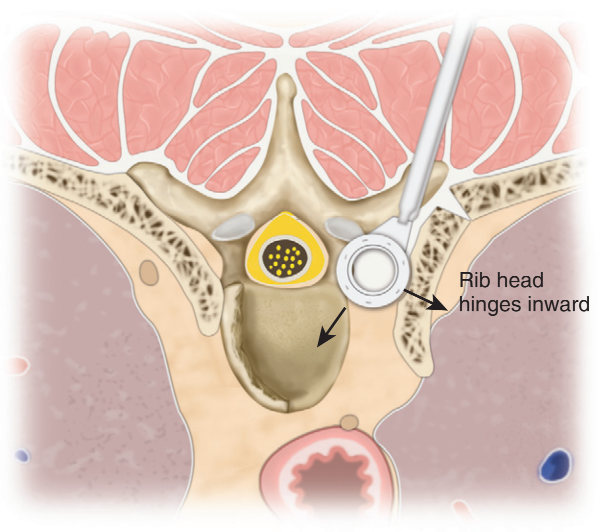


Figure 27-12 Trap-door osteotomy for placement of anterior cage in a transpedicular approach.

Operation

- All of the initial steps are the same as for a posterior midline laminectomy, except that the soft tissue is also dissected off the transverse processes.
- After performing the laminectomy, the appropriate pedicles may be identified and palpated.
- The pedicle is either drilled or resected using curettes and rongeurs.
- If significant anterior pathology exists, both pedicles are removed for additional access.
- In addition, nerve roots below T1 may be sacrificed proximal to the dorsal root ganglia to further facilitate visualization and ventral resection. Before sectioning the nerve root, a 0 silk tie should be applied to the proximal end to prevent a cerebrospinal fluid leak.
- Once the posterior aspect of the vertebral body is reached through the pedicle, a cavity is created within the vertebral body. Pathology ventral to the cord may be pushed away from the spinal cord into the cavity and subsequently removed.[11,12]
- If a significant portion of the anterior column is resected, pedicle screws should be placed above and below the region before vertebral body resection with placement of a temporary rod on the contralateral side while resection is taking place. This is done to prevent spinal cord injury secondary to destabilization and possible stretch injury during the resection.[3]
- With limited visualization, Steinmann pins and PMMA may be used for anterior column reconstruction.[11,12]
- For anterior reconstruction with an expandable cage, a small trap-door osteotomy may be performed on the lateral aspect of the rib to allow it to be pushed anteriorly. This requires no dissection anterior to the rib and thus avoids the risks associated with rib resection as with a costotransversectomy or lateral extracavitary approach.[13]
- Posterior stabilization may then be performed if necessary.

Closure. Closure is the same as for a posterior midline approach.

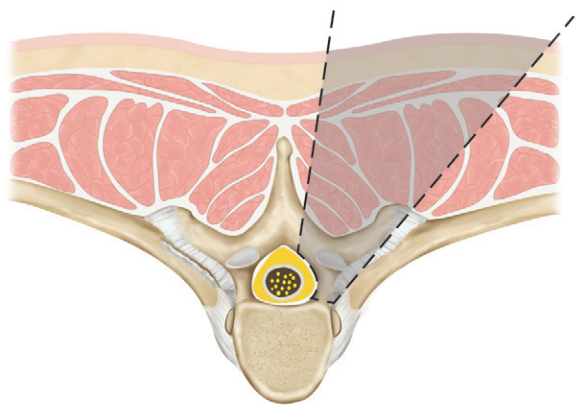


Figure 27-13 Costotransversectomy.

Costotransversectomy

Indications and Advantages. Initially described in 1894 by Menard for the treatment of Pott disease and later modified by Capener,[2] this procedure was developed as a means to access pathology in the posterolateral thoracic spine.[14,15] Hulme[16] later applied this approach in the treatment of thoracic disk herniation. This approach allows for access to ventral pathology that involves the anterior column and disk space (Fig. 27-13). It is more effective than a transpedicular approach for centrally located thoracic disk herniations. The costotransversectomy is also useful for the resection of metastatic disease that involves a significant anterior column component with ventral spinal cord compression. With a wider posterolateral view of the vertebral body, compared with a transpedicular approach, further resection of the vertebral body may be performed under direct visualization. If performed bilaterally, significant vertebral body resection can be achieved, and anterior column reconstruction with a cage is possible.[3,12] Because this approach involves proximal rib resection, the risk for pleural violation is lower than with a lateral extracavitary approach.

Contraindications and Disadvantages. This approach provides a limited view of midline ventral pathology that cannot be addressed through direct visualization. Centrally located bony compression may be difficult to treat through a costotransversectomy. Anterior column reconstruction often requires nerve root sectioning to provide a wider corridor for cage placement; thus it may be difficult to perform with a lesion at T1. This may limit the reconstruction at that level to the placement of Steinmann pins and PMMA. Below T1, the nerve roots may be sacrificed, and an expandable cage may be used for anterior column reconstruction. Regardless of the method of anterior reconstruction, this approach also requires posterolateral instrumentation and stabilization. When compared with a transpedicular approach, an increased risk of complication is associated with rib-head removal that includes pneumothorax, hemothorax, and injuries to the neurovascular bundle.[13,17] In general, the limitation with this approach at the CTJ is secondary to scapular obstruction, which limits the lateral vertebral body exposure and working corridor.

Patient Positioning and Preparation. The patient is prepared and positioned the same as for a posterior midline approach.

Operation

- All of the initial steps are the same as for a transpedicular approach, except that the soft tissue is also dissected laterally to expose the proximal rib head and the costotransverse joint.
- After the initial steps have been performed, dissect and incise the constotransverse joint.
- Remove the transverse process from lateral to medial, and eventually the pedicle will be exposed. A hemilaminotomy or laminectomy may be performed as well if posterior decompression is also necessary or to have a better visualization of the dura and spinal canal (Fig. 27-14).
- Identify the neurovascular bundle inferior to the rib and trace it to the neural foramen. The nerve root will enter in just below the pedicle.
- The anterior rib head and proximal rib should be carefully dissected in a subperiosteal fashion to avoid injury to the pleura. A layer of retropleural fat is often present along with endothoracic fascia, which should add a layer of protection. After dissection, the rib head is disarticulated and removed using a combination of Leksell and Kerrison rongeurs (Fig. 27-15).
- For further protection the rib may be alternatively drilled down, until there is only a thin cortical shell (Fig. 27-16).
- The extent of lateral rib removal may be tailored to the degree of ventral exposure necessary. The limit of lateral exposure is determined by the presence of the nearby scapula. Resected rib may be used later for graft material.
- The retropleural fat, endothoracic fascia, and pleura are retracted anteriorly to expose the lateral aspect of the vertebral body.
- Further access may be achieved by sacrificing the nerve root proximal to the dorsal root ganglia. This may be performed below T1.

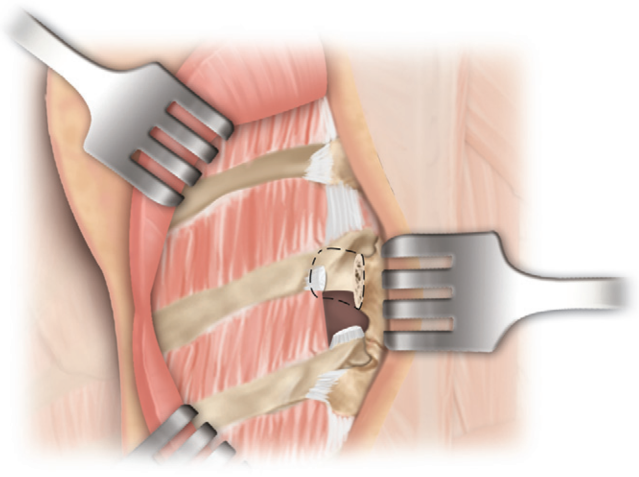


Figure 27-14 Costotransversectomy technique. Incise the costotransverse joint, and remove the transverse process back toward the pedicle and lamina.

- Similar to the bilateral transpedicular approach, if significant vertebral body resection is expected, a temporary rod should be placed to prevent spinal cord injury.[3]
- For extensive vertebral body resection, this approach can be performed bilaterally or unilaterally with a transpedicular approach on the contralateral side (Fig. 27-17).
- After the pathology has been addressed, it is necessary to provide posterior stabilization.
- The side of a unilateral approach is often determined by the position of the pathology. However, because of the left-sided position of the aortic arch at T3–T4, lesions at this level are better approached from the right side to avoid obstruction and possible injury.

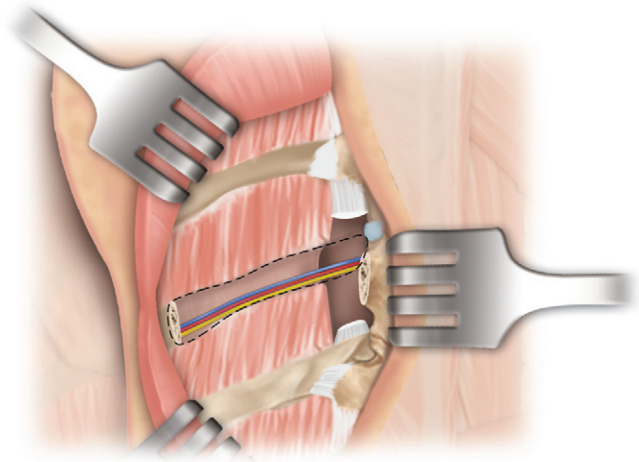


Figure 27-15 Costotransversectomy technique. The entire costovertebral articulation complex can be removed. Care should be taken during the dissection of the anterior periosteum not to injure the pleura. Laterally, this can be separated using a doyen.

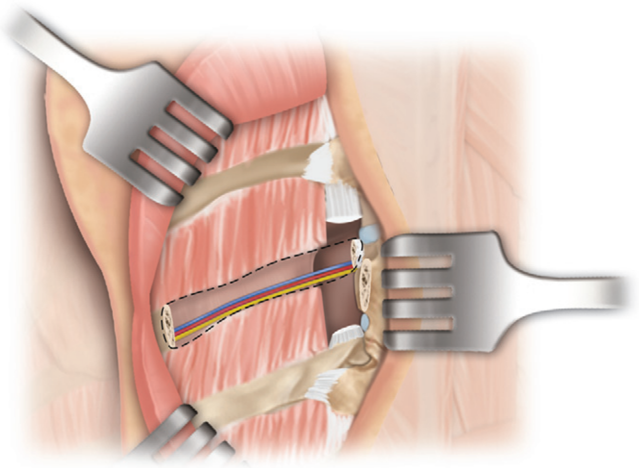


Figure 27-16 Costotransversectomy technique. To reduce injury to the pleura, a thin cortical shell of rib head can be left intact at the costovertebral junction with careful drilling. However, some protection can also be provided by the endothoracic fascia, periosteum, and retropleural fat. Avulsion of the rib from its costovertebral joint can cause significant bleeding. Microscopic dissection at this stage with a drill and Kerrison rongeur would be most prudent.

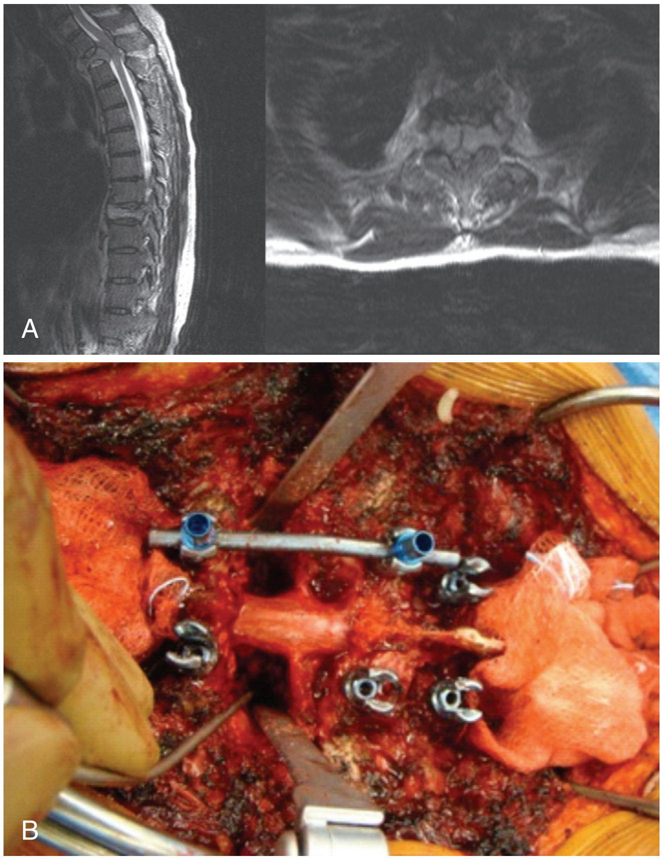


Figure 27-17 **A,** Pathologic compression fracture at T2. **B,** T2 pathologic fracture approach through bilateral costotransversectomy.

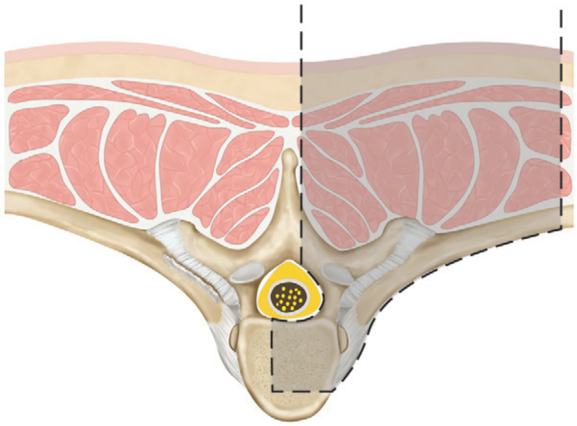


Figure 27-18 Adequate exposure of the vertebral body will often require sacrificing at least one thoracic nerve root; those at T2 and below are acceptable.

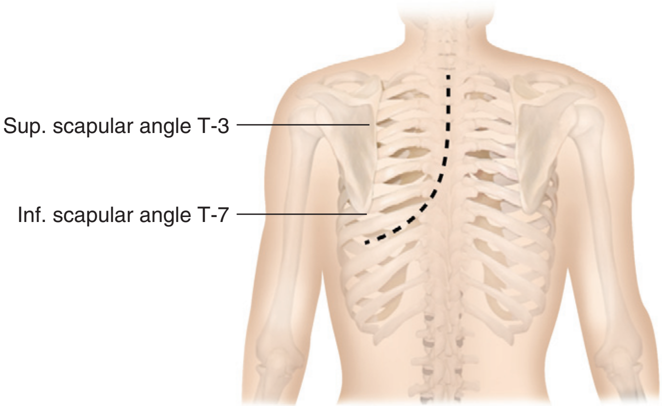


Figure 27-19 Incision for a lateral extracavitary parascapular extrapleural approach. Sup., superior; Inf., inferior.

Closure

- Before closure, the area is irrigated and observed for air bubbles during respiration to rule out a pneumothorax. If pleural violation is observed, a chest tube should be placed.
- The rest of the closure is similar to that described above for a transpedicular approach.

Lateral Extracavitary Parascapular Extrapleural Approach

Indications and Advantages. The lateral extracavitary approach (LECA) described by Larson[2] in 1976 evolved from the lateral rachiotomy described by Capener[14] to address midline ventral lesions from a posterior approach. In addition to providing posterolateral visualization, it is possible to view the ventral midline spinal dura. This allows for complete ventral decompression under direct visualization, and pathology may be moved away from the spinal cord to decrease the risk of neurologic complications. With the expanded ventral access, complete spondylectomy and maximum anterior column reconstruction is possible (Fig. 27-18).[2,15] The LECA was intended for use below T4 because of the limitations caused by scapular obstruction. To allow similar access rostral to T4, Fessler developed the lateral parascapular extrapleural approach.[1] Mobilization of the scapula in this approach provides an improved visualization of the vertebral body at the CTJ with a lower risk of postoperative shoulder injury.[1] This approach may be used with any pathology that involves the ventral aspect of the spinal cord or anterior column, and it is especially useful when a complete spondylectomy is desired in the presence of centrally located bony compression. Another advantage is that a formal 360-degree stabilization may be performed through a single incision.

Contraindication and Disadvantages. Given the complexity of this approach, the disadvantages are mostly associated with the possibility of injury to surrounding structures. Because of significant muscular dissection and bone resection, blood loss is often extensive during this procedure. Visualization of the segmental arteries is generally poor; if injured, these may be difficult to control. Similar to the costotransversectomy, pleural violation and associated pneumothorax or hemothorax is a risk.[1,3] A multitude of neurologic injuries are possible that include intercostalis nerve neuralgia, sympathectomy, Horner syndrome, and T1 nerve root injury.[1,3] Because of the extensive dissection, muscle atrophy often occurs, and significant recovery time is associated with the approach.

Patient Positioning and Preparation. The patient is prepared and positioned the same as for a posterior midline approach.

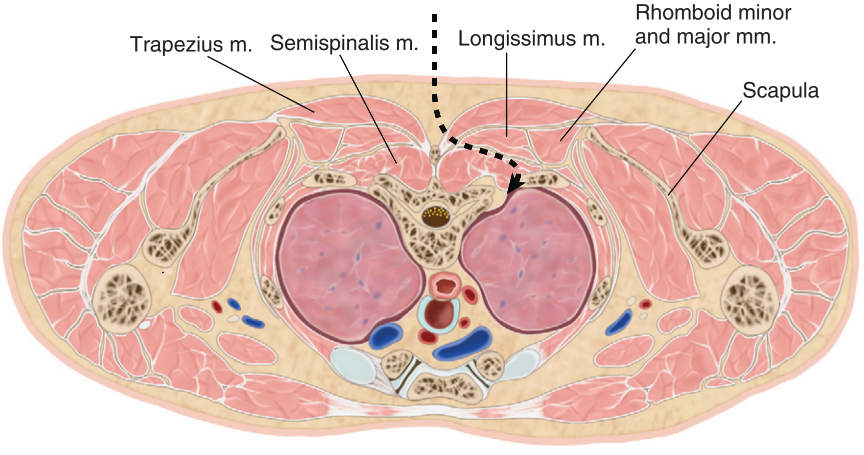


Figure 27-20 The lateral extracavitary approach will be lateral to the paraspinal musculature and medial to the longissimus muscle.

Operation

- A midline incision is made from approximately three spinous processes above to three spinous processes below and is curved to the scapular line on the same side of the approach (Fig. 27-19). This allows for reflection of the myocutaneous flap laterally.[1,2]
- The deep fascia is incised, and the attachments of the trapezius and rhomboid are dissected off of the spinous processes, until the plane of loose areolar tissue located between the superficial muscles and deep muscle group is encountered.[1,2]
- The plane of loose areolar tissue is dissected bluntly, and the skin, trapezius, and rhomboid are reflected toward the medial edge of the scapula (Fig. 27-20).[1,2]
- The inferior fibers of the trapezius muscle are transected to facilitate lateral retraction of the myocutaneous flap (Fig. 27-21). After mobilization of the flap, the medial border of the scapula falls laterally to expose the posterior thoracic cage.[1,2]
- Subperiosteal dissection of the erector spinae and transversospinalis is carried out to expose the posterior spinal elements (Fig. 27-22). This muscle mass is mobilized and retracted dorsomedially over the spinous processes.[1,2]
- Rib removal is similar to that performed in a costotransversectomy, except that the resection is carried out more laterally to the posterior bend of the rib. Two or three ribs may be removed to expose the vertebral body. The rib of the affected vertebral body and the rib below must be removed for adequate vertebral body exposure (Fig. 27-23).
- The resected rib may be used for graft or fusion material.
- Similar to the transpedicular and costotransversectomy approach, if significant anterior column resection is anticipated, a pedicle screw should be placed above and below the involved vertebral body before resection. A temporary rod should be placed contralateral to the side of approach.[3]
- As with the costotransversectomy, the retropleural fat, endothoracic fascia, and pleura are retracted anterolaterally to expose the lateral aspect of the vertebral artery.
- Nerve root sectioning is performed below T1 for expanded exposure of the vertebral body (Fig. 27-24).

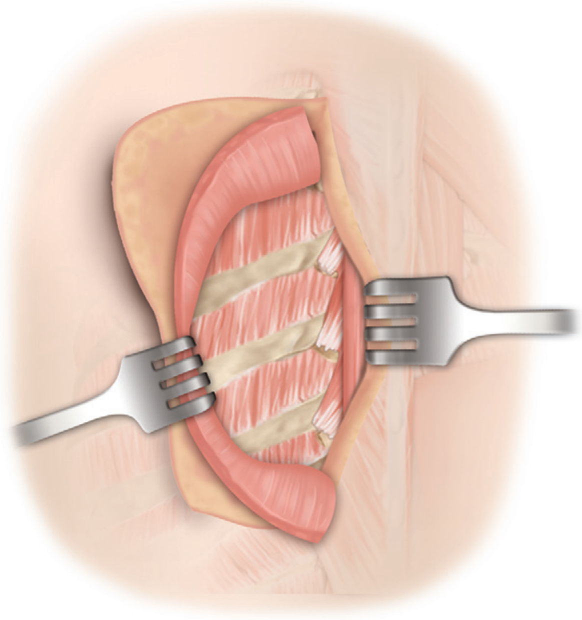


Figure 27-21 Lateral extracavitary approach. Retraction of the trapezius, rhomboid, and erector spinae muscles and medial border of the scapula laterally exposes the posterior thoracic cage.

- With subperiosteal dissection around the ventrolateral aspect of the vertebral body, the sympathetic chain may also be displaced anterolaterally. This may require sectioning of the rami communicantes and sacrifice of segmental vessels. Care must be taken with the sympathetic plexus, specifically when working near T1, because the stellate ganglia are at risk for injury.
- Vertebral body resection is performed under direct visualization.
- Because of the wide viewing angle and exposure, multiple options are available for anterior column reconstruction that include the placement of Steinmann pins, PMMA, titanium mesh cage, bone strut graft, or an expandable cage (Fig. 27-25).
- Posterior screw/hook-rod constructs are then applied for posterior stabilization.

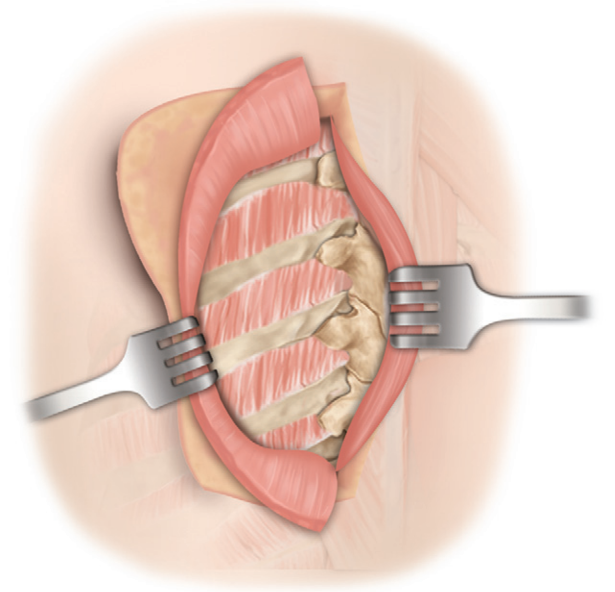


Figure 27-22 Lateral extracavitary approach. Transversospinalis muscles are dissected and retracted medially.

Figure 27-23 Axial computed tomograph demonstrates the amount of rib resection required in a lateral extracavitary approach.

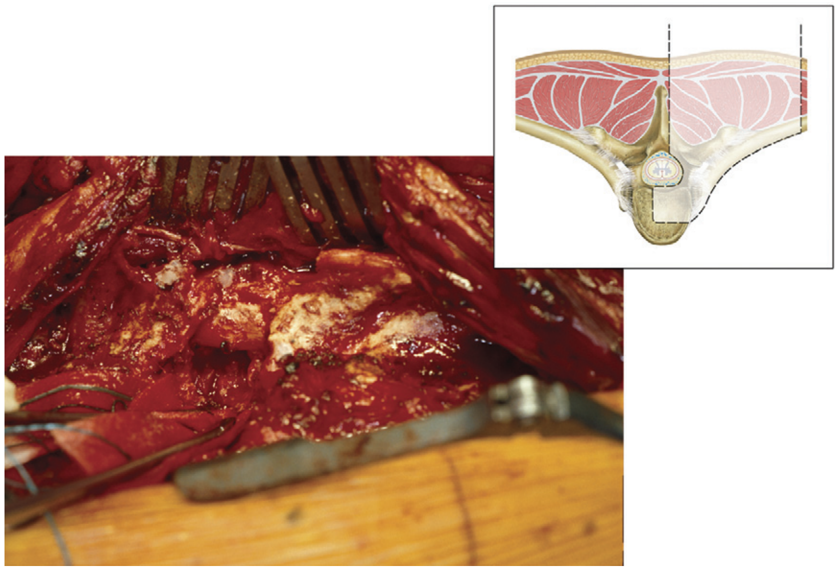


Figure 27-24 Adequate exposure of the vertebral body will often require sacrifice of at least one thoracic nerve root (T2 and below are acceptable). Intraoperative view after lateral extracavitary approach. Inset shows a lateral extracavitary approach decompression.

Figure 27-25 View after cage placement. Vertebral reconstruction and posterior stabilization can be performed without an additional anterior procedure.

Closure

- Before closure, the field is irrigated, and a Valsalva maneuver is performed to determine the presence of an air leak. If an air leak is detected, a small 22- or 24-Fr chest tube should be placed and tunneled posterolaterally to the inferior aspect of the incision.
- A multilayer closure is performed first to reapproximate the deep muscle group and close the deep fascial layer.
- The superficial muscle group is reapproximated with closure of the superficial fascia layer.
- The rest of the closure is the same as that described in the previous procedures.

Summary

Posterior and posterolateral approaches to the CTJ have evolved to avoid the difficulties and morbidity associated with anterior and transthoracic approaches to an anatomically complex and challenging region. The different approaches have developed to address a multitude of pathologic conditions. Most paracentral thoracic disk herniations may be addressed through a transpedicular approach, whereas central disk herniations may require a costotransversectomy. Metastatic lesions that involve the anterior column can be addressed with a bilateral transpedicular approach, which allows for a smaller incision, decreased muscle dissection, and less recovery time.[12,13] If necessary a combination approach may be used, with a unilateral costotransversectomy and a contralateral transpedicular approach. The lateral extracavitary extrapleural parascapular approach provides the most extensive ventral anterior column access and is generally used for extensive anterior column resection or en bloc spondylectomy. As the degree of lateral approach and ventral exposure increases concurrently, the amount of soft-tissue dissection and morbidity also increases. The choice of approach depends on the degree and type of ventral pathology, the necessity for anterior column reconstruction, and the ability of the patient to tolerate a more extensive surgery.

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28 Anterolateral Transthoracic Approaches to the Thoracic Spine

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Overview

Anterior lesions of the thoracic spine can present a challenging clinical scenario. Unlike the cervical spine, at which anterior approaches are commonplace, the generally unfamiliar surrounding anatomy can make thoracic anterior approaches seem daunting. Reaching the anterior column through a posterior approach, particularly to address central lesions, requires that the surgeon avoid manipulation of the thoracic cord to avoid potentially severe neurologic complications; this was shown by Love and Kiefer,[1] who found that over a third of patients undergoing laminectomy for thoracic disk herniation had either no improvement or experienced worsening of neurologic symptoms.

Knowing that the thoracic spinal cord is intolerant to manipulation, the spine surgeon may inadequately expose or undertreat an anterior compressive lesion from a posterior approach. Anterolateral thoracotomy has been in general use for more than a century, although its use in the spine was described more recently by Hodgson[2] in 1956 for débridement and fusion in the setting of Pott disease. Since that time, thoracotomy has been considered the "gold standard" for decompression of anterior spinal lesions. Although multiple alternative posterior and posterolateral approaches to the anterior column have been described elsewhere (transpedicular, costotransversectomy, lateral extracavitary), as have thoracoscopic and miniopen approaches, in response to the perceived morbidity associated with thoracotomy,[3-7] transthoracic approaches remain a safe and effective option in treating anterior pathology in the thoracic spine.[8-10]

Anatomic Considerations

SUPERFICIAL (EXTRAPLEURAL)

The anterolateral transthoracic approach begins superficially with an incision oriented along the rib, which is covered superficially by loose connective tissue and periosteum. Posteriorly, the fibers of the latissimus dorsi muscle cross the ribs nearly perpendicularly. Deep to the latissimus, the erector spinae muscle group—the iliocostalis, longissimus, and spinalis, from lateral to medial—run vertically on either side of the spinous processes. The scapula limits the posterior extent of the exposure, because it overlies the posterior aspect of the second through seventh ribs. Following the rib posteriorly will lead first to the tip of the transverse process, which covers the angle of the rib, and subsequently to the rib head, articulating with paired demifacets over the intervertebral disk.

Because the ribs angle caudally on leaving the spine, careful attention to selection of level is crucial; the rib to be exposed and resected will often originate one or two levels cranial to the spinal pathology to be addressed. The inferior edge of each rib has a costal groove that contains the intercostal artery, nerve, and vein. After rib resection, the rib bed is encountered, consisting of the deep periosteum and adherent parietal pleura, along with the remaining intercostal vessels and nerve. Incision of the rib bed will allow entry into the pleural potential space.

DEEP (INTRAPLEURAL)

Incision of the rib bed opens the pleural space, created by a continuous layer of connective tissue covering the inner surface of the thoracic wall (parietal pleura) and the outer surface of the lungs (visceral pleura). In the normal anatomic state, the pleural space is a potential space; the visceral and parietal pleura held in close approximation by negative hydrostatic pressure allows for thoracic wall excursion to expand the lung during respiration. Incision of the parietal pleura, however, temporarily disrupts this negative pressure and allows the lung to collapse.

Once the pleural space is entered, several important structures are encountered. The arch of the aorta is normally at the T4 vertebral level, and it becomes the descending aorta, traveling inferiorly along the left side of the vertebral bodies from T5–T12 before passing through the diaphragm and becoming the abdominal aorta. The thoracic duct is the main avenue for lymphatic drainage for three quarters of the body. It ascends on the anterior aspect of the vertebral bodies, crossing from right to left of midline between T4 and T6. The duct is dull white in color and sometimes appears beaded because of multiple valves. The duct is thin-walled and fragile, and if the anterior aspect of the spine is exposed, care should be taken to identify and protect it, because treatment of a persistent chyle leak can be problematic. The thoracic sympathetic trunk and its associated ganglia lie along the rib heads and are generally safe in the upper thoracic spine. In the lower thoracic spine, however, these structures become more anterior and may lie along the sides of the vertebral bodies.

The thoracic spine itself lies posterior to the posterior mediastinum and is covered in parietal pleura. Segmental vessels from the aorta and vena cava run from anterior to posterior at the midportion of the each vertebral body. The intervertebral disk is generally identified by its shiny white annulus fibrosis and by the fact that it is generally more prominent than the midvertebral body (i.e., a "hill" rather than a "valley").

Indications

- Treatment of anterior compressive lesions
  - Tumor
  - Thoracic disk herniations
  - Bony fragments resulting from trauma
- Treatment of spinal instability resulting from infection (vertebral osteomyelitis/diskitis), tumor, or trauma
- Mobilization of the thoracic spine for deformity correction

Contraindications

- Significant preexisting pulmonary compromise
- Posterior compressive lesions (may require a combined approach if compression is circumferential)

Operative Technique

1. The patient is positioned on a radiolucent operating room (OR) table in the straight lateral decubitus position on a vacuum beanbag; all bony prominences must be well padded. A dual-lumen endotracheal tube is used to allow for selective deflation of one lung. The entire hemithorax, from the midline of the sternum to the spinous processes, is draped into the surgical field. If the approach is to be proximal (T4 or above), the arm may need to be draped into the field to allow for manipulation of the scapula. Regarding the side of approach, if the pathology is clearly one-sided, that side should be chosen. If not, we generally prefer to approach the low thoracic spine (T10 and below) from the left side, because the liver and elevated hemidiaphragm make the right-sided approach more difficult this low. Above T10, the right-sided approach is preferred, because the heart and descending aorta can make the left-side approach more difficult.
2. Care in selection of the level is especially crucial in the thoracic spine, because counting of levels can be difficult using intraoperative fluoroscopy. Ribs are most reliably counted from caudal to cranial, because the first rib can be medial to the second rib and may be difficult to palpate. If any doubt exists as to the correct level, intraoperative fluoroscopy should be compared with preoperative imaging, which may include either sagittal magnetic resonance imaging (MRI) showing both the sacrum and the herniation on a single cut or a computed tomography (CT) scan with coronal reconstruction to demonstrate the ribs at each level; this allows a precise count of thoracic and lumbar vertebrae. The interventional radiologist can place a marker on the spine at the level of pathology before the CT that can act as an intraoperative guide for identification using fluoroscopy. For lesions of the vertebral body, we typically resect two ribs higher (e.g., we resect the sixth rib for a T8 lesion). For disk herniations, if rib head resection is required for adequate exposure, the rib head over the affected disk space is resected (the ninth rib head is resected for a T8–T9 disk herniation).
3. Once the appropriate level is selected, the skin is incised from the lateral border of the paraspinal musculature to the costochondral junction in line with the selected rib. Less skin can be taken if less exposure is needed. Using a slightly more transverse incision tangential to the rib allows for skin mobilization in the event that the next cranial or caudal rib must be resected for greater exposure (Fig. 28-1).
4. Using electrocautery and maintaining meticulous hemostasis, the chest wall musculature is divided to expose the superficial surface of the rib. For proximal exposures with planned resection of the third or fourth rib, the retraction of the scapula cranially and medially may be required to adequately expose the rib (Fig. 28-2).
5. Once the periosteum covering the superficial surface of the rib is exposed, and the appropriate level has been confirmed, the periosteum is incised sharply, and curved-tip elevators are used to strip the periosteum

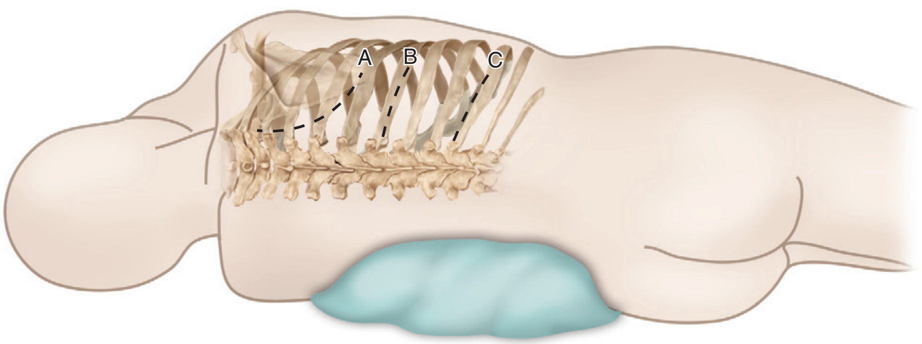

Figure 28-1 Patients are positioned in the lateral decubitus position. Skin incisions are made longitudinally along the planned rib resection (*dashed lines B or C*), unless the planned exposure is proximal such that the scapula overlies the targeted rib. In this case, the skin incision follows the medial border of the scapula (*dashed line A*).

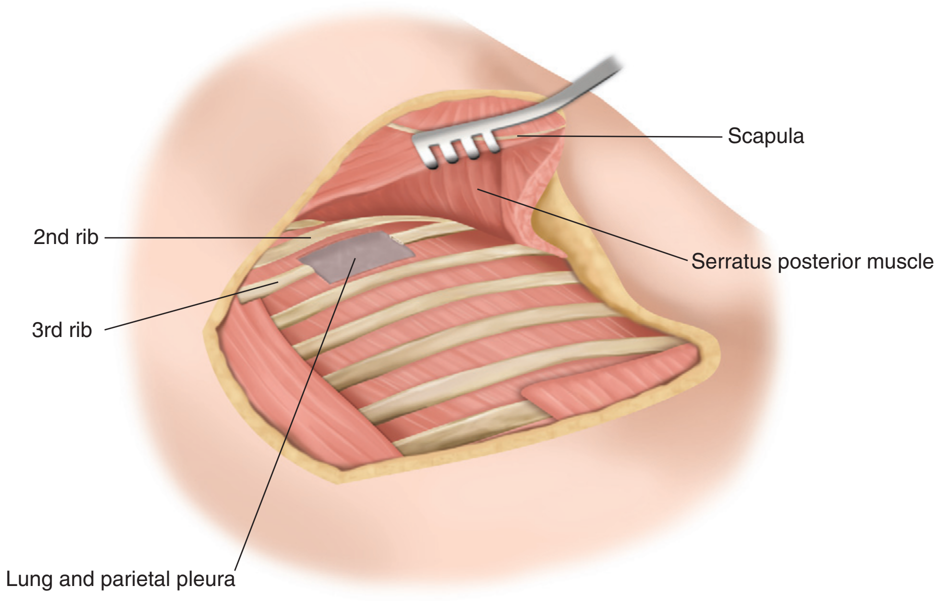

Figure 28-2 Exposures proximal to T6 may require mobilization of the scapula. Mobilization proceeds in a cranial and medial direction.

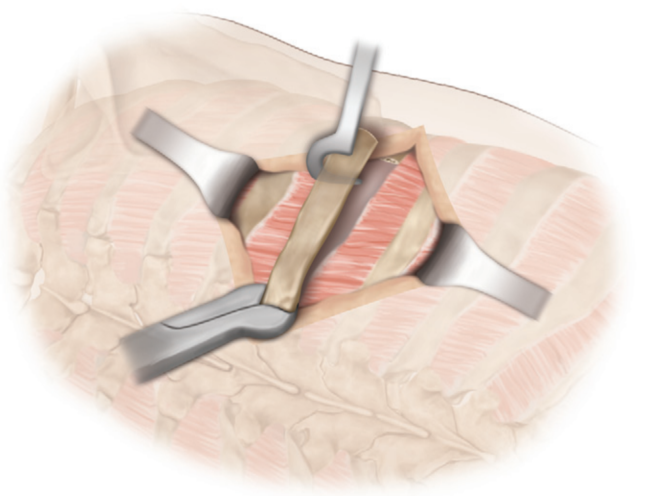

Figure 28-3 After circumferential elevation of the periosteum, rib cutters are used to resect a section of the intended rib to allow access to the parietal pleura.

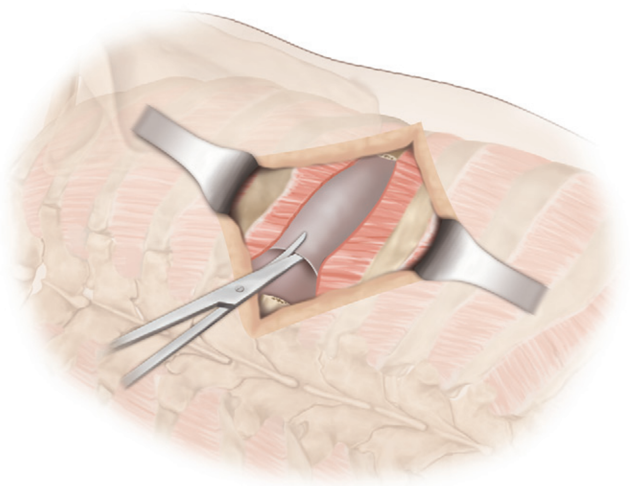

Figure 28-4 Incision of the rib bed and parietal pleura allows entry into the thoracic cavity.

circumferentially as far posteriorly as possible. To avoid injury to the intercostal vessels, caution should be exercised during this step, particularly when dissecting under the caudal surface of the rib. In cases of a thoracic disk herniation, when the approach is to be limited to a single disk space, rib resection may not be necessary. In this case, the dissection can be limited to the superior aspect of the rib, and the spine can be exposed through the intercostal space without resection of the rib.

6. The rib cutter is then used to resect the exposed portion of rib (Fig. 28-3). This resection should be performed anteriorly at the costochondral junction and as far posteriorly as possible. If a need for autogenous bone graft is anticipated, the resected portion is saved, and bone wax is applied to the remaining cut ends of the rib.
7. Once the resected portion of rib is removed, the rib bed, consisting of the periosteum off the deep surface of the rib and the contiguous underlying parietal pleura, is exposed. The caudal portion of the rib bed contains the intercostal vessels and nerve, and the thorax should be entered cranially to these structures.
8. The rib bed is incised sharply, taking care not to plunge and risk injury to the underlying lung. Once a small opening is made, a blunt dissector or finger is swept under the parietal pleura to ensure that no lung or visceral pleura is adherent to the undersurface of the parietal pleura. Extension of the thoracotomy is then performed with Metzenbaum scissors (Fig. 28-4).
9. After an adequate thoracotomy has been performed, the lung is deflated and retracted with a fan retractor. Ventilation continues through the dual-lumen

endotracheal tube to the contralateral lung, while the anesthesiologist occludes the ipsilateral portion of the dual-lumen tube. This allows access to the anterolateral aspect of the thoracic spine.

10. Because the segmental arteries arising from the aorta cross the spine around the midpoint of the vertebral body, the safest place to begin exposure of the spine is generally at the disk space. The disk itself is more prominent, whiter in color, and softer than the adjacent vertebral body, making identification relatively easy in the absence of severely distorted anatomy. Once the disk is identified, the parietal pleura overlying the spine is incised longitudinally over the disk space and is extended cranially or caudally as needed (Fig. 28-5). As the midpoint of the vertebral body is reached, the segmental vessels will be encountered. These vessels are isolated with a right-angle clamp and are ligated with braided suture (Fig. 28-6). Caution must be exercised not to ligate the vessels too closely to their origin from the aorta, because leaving a short proximal stump may result in extensive bleeding that is difficult to control if the tie is lost.
11. The parietal plural incision can now be extended cranially or caudally as necessary to expose the lesion, taking care to identify and ligate the segmental vessels at each level. In rare cases that require exposure of a large segment of the spine, resection of a second or even third rib may be necessary.
12. When decompression and stabilization are complete, closure of the parietal pleura over the lateral spine may prevent pleural adhesions, and it provides a means of containing any graft material that has been placed. The lung is reinflated, and a chest tube is placed. The rib bed, subcutaneous tissue, and skin are closed in layers.

Disk Lesions

Thoracotomy is an ideal approach for decompression of a centrally located disk herniation causing myelopathy, which can be difficult to completely decompress from a posterolateral approach. If a single thoracic disk is to be addressed, the cranial and caudal extent of the pleural incision may be such that ligation of the segmental vessels may be unnecessary. Although decompression of a thoracic disk herniation can generally be accomplished through a smaller approach and may not require rib resection, some bony work is generally necessary, because these disks are commonly calcified. A high-speed burr can be used to remove the end plates above and below the disk, creating a space into which the herniation can be pushed using down-turned curettes. Strict attention must be paid to avoid pressure on the ventral thecal sac during this maneuver. Following thorough decompression, stabilization can be performed anterolaterally through the thoracotomy or posteriorly through a separate incision.

Foraminal Decompression

After elevation of the parietal pleura off of the lateral aspect of the vertebral body, the dissection is carried posteriorly until the pedicle is identified. Once the ventral and cranial borders of the foramen are identified, decompression can be performed using Kerrison rongeurs, taking care to avoid injury to the nerve root located just inferior to the pedicle (Fig. 28-7).

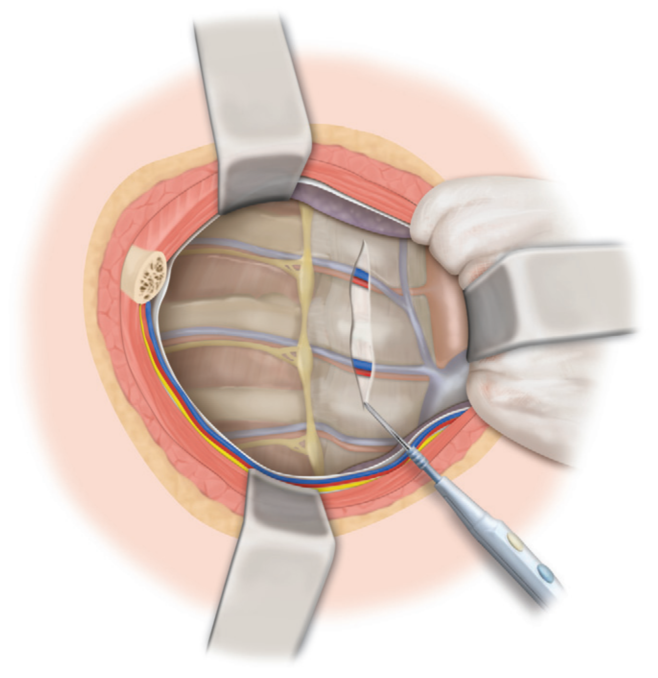

Figure 28-5 Incision of the parietal pleura over the lateral vertebral body. Note that the segmental vessels cross at the midbody of each vertebra. Beginning this incision over the disk space allows for isolation of the segmental vessels as they are encountered cranially and caudally.

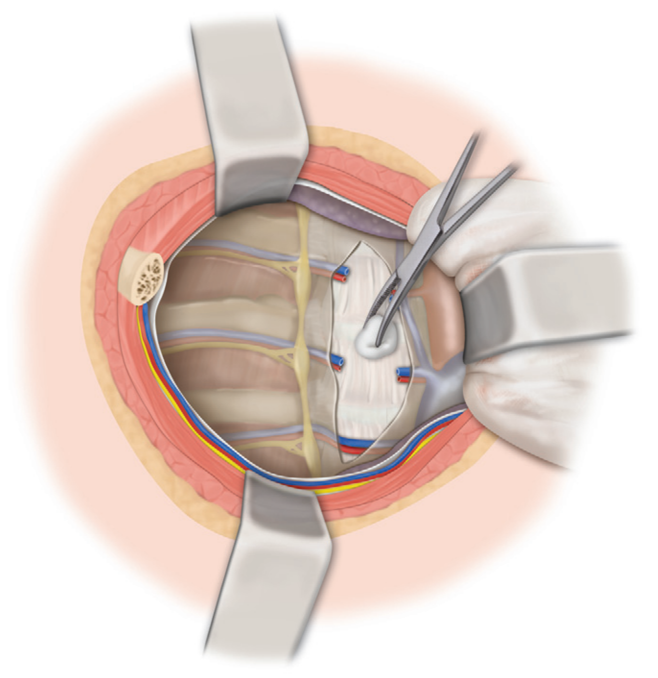

Figure 28-6 After division of the segmental vessels, the lateral aspect of the spine is exposed by blunt dissection, elevating the pleura off of the vertebral bodies.

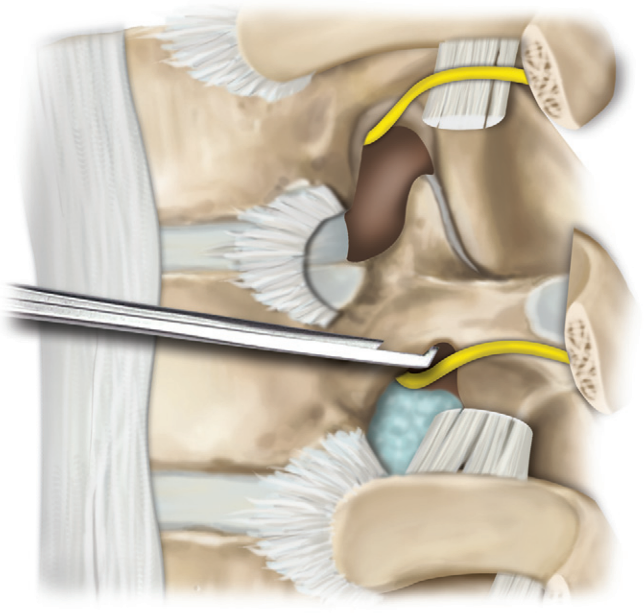

Figure 28-7 Foraminal decompression is accomplished by proceeding posteriorly along the pedicle of the vertebral body, until the ventral border of the foramen is encountered. The foramen can now be enlarged with Kerrison punches.

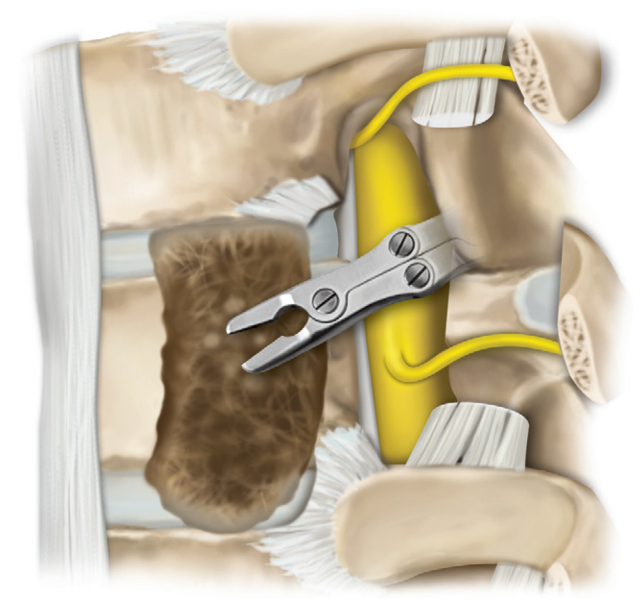

Figure 28-8 Thoracic corpectomy is accomplished by first removing the majority of the vertebral body with rongeurs.

Corpectomy

Removal of one or more vertebral bodies may be necessary in the case of infections, fractures, or tumors of the thoracic spine. Abscesses or tumors may make identification of the segmental vessels challenging, and exposure of the spine should again start at the intervertebral disk, which is less vascular. Corpectomy can then be performed beginning at the lateral vertebral body with a combination of high-speed burr and rongeurs, leaving a thin shell of bone to be removed with curettes (Figs. 28-8 and 28-9). Care must be taken to protect the anterior and anterolateral structures—the aorta, vena cava, and thoracic duct—during the corpectomy to prevent inadvertent injury.

Postoperative Care

The chest tube is maintained until no leak is identified on cough, and drainage has dropped below 150 mL per 24 hours. It is pulled while holding petroleum jelly gauze over the wound to prevent leak. Aggressive pulmonary toilet is encouraged, because thoracotomy has been shown to lead to a short-term decrease in pulmonary function.[11,12] Mobilization of the patient is dependent on the degree of reconstruction performed and the surgeon's assessment of postoperative spinal stability.

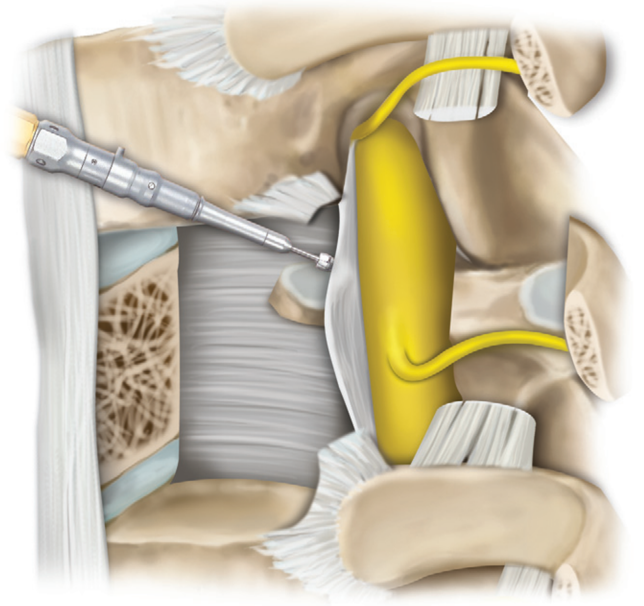

Figure 28-9 A high-speed burr is used to thin the remaining bone to a thin cortical shell, taking care to avoid burring through the contralateral cortex and endangering the great vessels.

Considerations Specific to the Proximal Thoracic Spine Approach

When the thoracotomy is to be performed proximal to T5 or T6, the scapula will need to be mobilized in a cranial and medial direction (see Fig. 28-8). To accomplish this, a curvilinear incision around the medial and inferior border of the scapula may be used (Fig. 28-10). Once the skin and subcutaneous tissue have been incised, division of the serratus anterior and trapezius muscles at the inferior border of the scapula will generally be necessary to allow full mobilization of the scapula (Fig. 28-11). By draping the ipsilateral upper extremity into the surgical field, the upper arm can be used to help manipulate the scapula and assist in retraction. Once the scapula has been mobilized and the

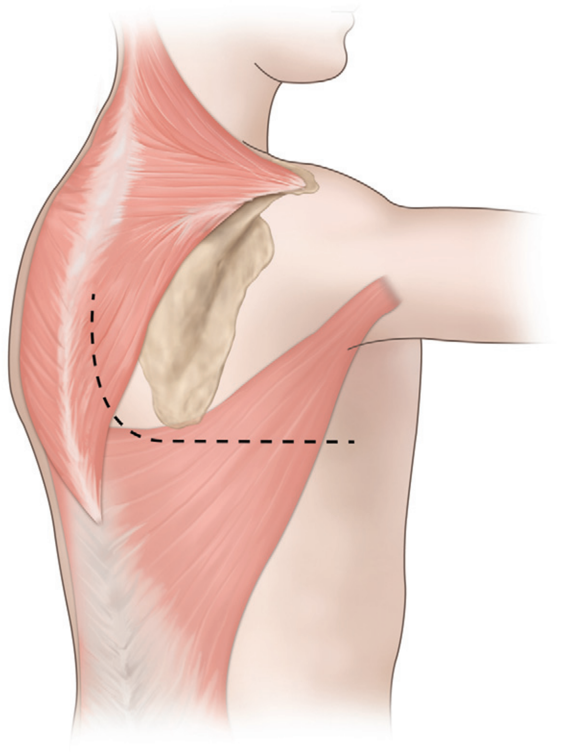

Figure 28-10 Curvilinear incision for proximal exposures requiring scapular mobilization.

appropriate rib is identified, exposure can proceed using the steps previously discussed.

Considerations Specific to the Thoracolumbar Junction Approach

In cases requiring exposure of the thoracolumbar junction (T10–L2), extension of the exposure caudally necessitates a takedown of a portion of the diaphragm. This approach is performed from the left side, because the liver causes the right hemidiaphragm to ride higher, and a right-sided approach requires more extensive mobilization to reach the spine.

Complications

DECREASED PULMONARY FUNCTION

Less a complication than an expected consequence of thoracotomy, moderate decreases in pulmonary function tests and exercise capacity have been demonstrated[11,12] and are likely related in large part to postoperative pain. Aggressive pulmonary toilet should be encouraged to avoid postoperative atelectasis and pneumonia, which may occur in up to 10% of cases.[13] Milder decreases have also been shown at longer follow-up, but these were small and likely not clinically relevant in an otherwise normal patient. However, this may be relevant in deciding whether

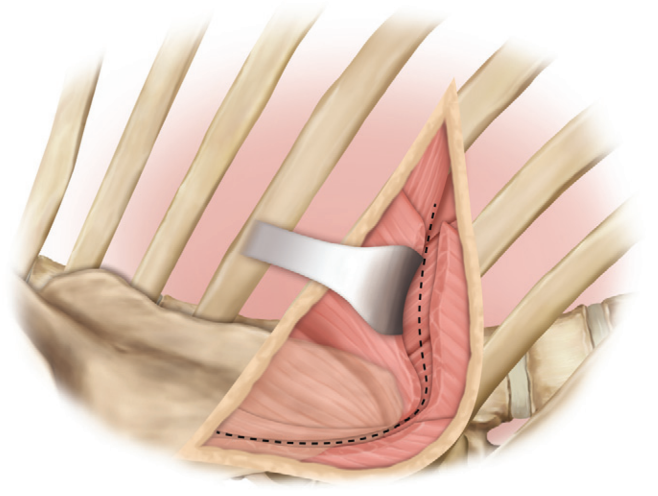

Figure 28-11 Division of the serratus anterior and trapezius at the inferior border of the scapula may be required for adequate scapular retraction.

thoracotomy is appropriate in a patient with preexisting pulmonary dysfunction.

INFECTION

We are not aware of any published infection rates for thoracotomy specifically performed for treatment of spinal lesions. The thoracic surgery literature, however, reports rates of superficial infection of 3% and rates of empyema of 2% in patients undergoing thoracotomy for pulmonary wedge resection.[13] These rates may be higher in the setting of diskitis or vertebral osteomyelitis. As always, a high index of suspicion must be maintained, and suspected infections must be treated aggressively with intravenous antibiotics and surgical débridement if necessary. In cases of complicated infection with severe pleural extension or mediastinal involvement, the assistance of a thoracic surgeon may be required.

CHYLE LEAK

Persistent leak of lymph into the thorax is a rare but potentially devastating consequence of thoracic duct injury, with reported mortality rates as high as 50%.[14] Persistent chyle leak can cause significant nutritional and immunologic consequences that result from loss of serum albumin and peripheral lymphoctyes. Because of the difficulty and morbidity associated with reoperation, the best treatment is avoidance and careful protection of the thoracic duct during surgery. Should an injury occur, prompt diagnosis is critical. If not noted at the time of surgery, diagnosis can be made with thoracentesis. Early consultation of thoracic surgeons should be considered in the event reoperation is necessary. Initial conservative management includes keeping the patient status as NPO and using total parenteral nutrition. In the event of a high-output leak or a leak that fails to respond to conservative management, reoperation may be necessary and typically involves ligation or embolization of the thoracic duct.

DURAL TEAR/CEREBROSPINAL FLUID LEAK

As in other areas of the spine, recognized durotomies are generally treated uneventfully with acute repair and, in some cases, with placement of a lumbar drain. Fibrin glue or a hemostatic agent can be helpful in augmenting the repair and sealing the dura. Persistent large leaks can lead to accumulation of CSF within the pleural space, leading to respiratory embarrassment that requires emergent revision surgery.

Conclusion

The anterolateral transthoracic approach to the thoracic spine is an important technique in the armamentarium of the spine surgeon. It is used in a wide variety of pathologies, including deformity, disk herniation, trauma, infection, and tumor. It can be safely performed in most cases with little long-term morbidity. The technique has been reviewed in detail.

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29 Anterior and Posterior Cervicothoracic Junction Stabilization Techniques

NOOJAN KAZEMI and TRENT L. TREDWAY

Overview

The cervicothoracic junction (CTJ) represents a unique feature of the spinal column with significant biomechanical, anatomic, and functional aspects because of the transition between the cervical and thoracic spine. Most consider the CTJ to involve C7 to T3; therefore stabilization of the CTJ commonly involves instrumentation of these vertebrae.

The CTJ represents a transitional region from the mobile cervical spine to the rigid thoracic spine, which is splinted by rib attachments that greatly limit its mobility. The CTJ is also unique in that it represents a change from the lordotic cervical spine to the kyphotic thoracic spine. As a result of this curvature shift, a significant stress riser can develop during instances of instability.

The CTJ is often a difficult region to image adequately, because the shoulders obscure the lateral radiographs acquired with the C-arm fluoroscope. Careful study of the preoperative imaging, in particular, the computed tomography (CT) scan, is of utmost importance in planning accessibility and surgical approach, and it also serves as a guide to placement of instrumentation.

The major reasons for stabilization at the CTJ include structural instability and lesions that result in spinal canal compromise. Structural deformities include those arising from trauma and potential deformities at the CTJ, whereas causes of spinal compromise include tumors, infections, and disk herniations at these levels.

Stabilization of the CTJ may be performed from either an anterior or a posterior approach. Each approach has its own unique indications, operative considerations, and pitfalls.

Operative Anatomy

Some key anatomic considerations apply to the stabilization of the CTJ:

- The C7 vertebra is a transitional vertebra, and it is different from the rest of the subaxial spine in that it has small, thin lateral masses compared with the rest of the subaxial cervical spine. Lateral mass thicknesses decrease from 11 mm at C5 to 8.7 mm at C7 on average; therefore often bone is lacking for screw placement.[1]
- Although lateral mass decreases in size, pedicle size increases gradually in width from 5.2 mm at C5 to 6.5 mm at C7. However, the height of the C7 pedicle still averages 6.9 mm.[1]
- C7 is better placed to take a pedicle screw for insertion, rather than a lateral mass screw, and numerous studies have been done to confirm the safety and adequacy of such a screw.[2]
- In the remaining subaxial cervical spine (C3–C6), the placement of pedicle screws is demanding and poses particular hazards. As a result, lateral mass screws are often more appropriate at these levels.
- Translaminar screws are another option for fixation, particularly at C2 and C7. They are not considered as safe for the remaining subaxial spine, because the laminar thickness of these segments is usually less than 3.0 mm; thus it is usually unrewarding to place a 3.5-mm or bigger diameter screw.[3]
- The C3–C5 pedicles are often too small and narrow to allow good screw placement. The angle of the pedicles also decreases from around 50 degrees medially at C5 to approximately 11 degrees medially at T5.
- Biomechanically, posterior fixation at the CTJ has been shown to be superior to stand-alone anterior stabilization unless accompanied by posterior fixation as well.

Surgical Approaches

Selection of the surgical approach is dependent on the goals of the surgery. Stabilization may be achieved with a posterior, anterior, or combined approach. Current implant technology provides excellent reconstruction and stabilization options for many pathologic conditions. The surgeon must be able to tailor the stabilization to the specific case and thus must be familiar with all the devices currently available in the spine surgeon's armamentarium.

ANTERIOR SURGICAL APPROACHES TO THE CERVICOTHORACIC JUNCTION

Exposure of the lower CTJ is often limited by important anatomic structures in the region; namely, the great vessels, clavicle, sternum, rib cage, thoracic duct, laryngeal nerves and sympathetic chain, and esophagus and trachea.

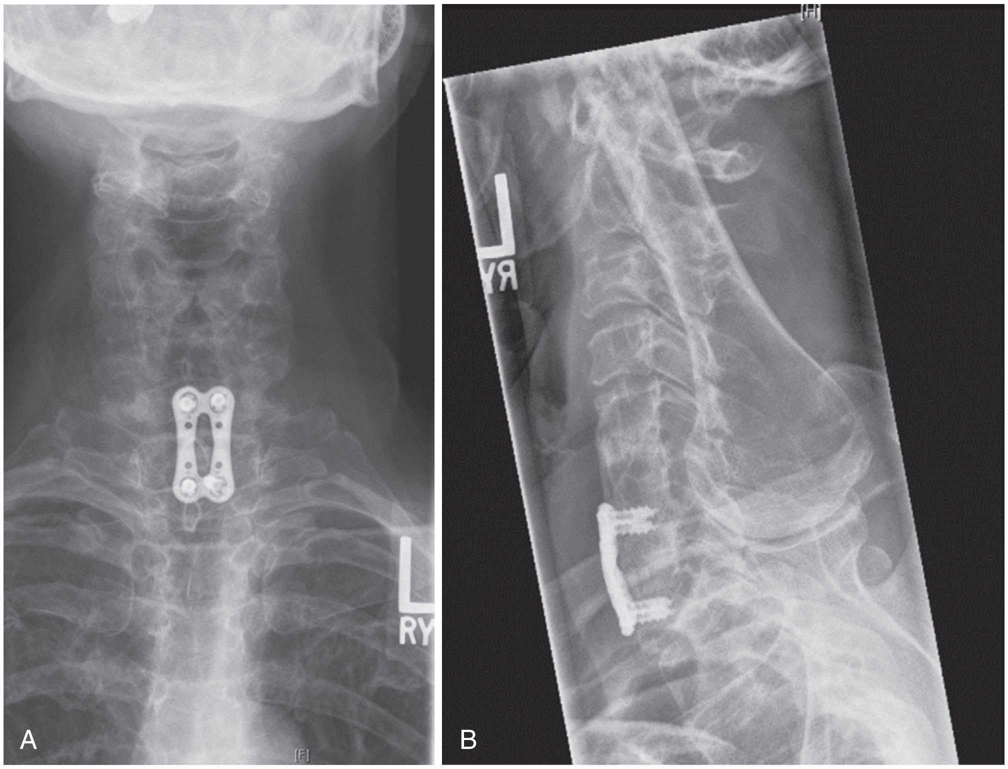


Figure 29-1 Postoperative radiographs of C7–T1 anterior cervical diskectomy and fusion in a 43-year-old woman with C7–T1 disk herniation resulting in myelopathy. **A,** Plain anteroposterior view. **B,** Lateral view.

Fortunately, most stabilization procedures can be performed from the posterior or posterolateral approaches. However, two specific indications have been established for ventral stabilization of the CTJ:

1. *Resection of structural lesions of the body of C7 to T3–T4.* Structural lesions can include intervertebral disk herniation at these levels as well as infections and tumors.
2. *Kyphotic deformity of the CTJ.* Such deformities may need to be corrected through both an anterior and posterior stabilization.

At the CTJ, the indication for anterior-only fixation is limited. Although uncommon for disk pathology, single-level anterior diskectomy and fusion at the C7–T1 level have been used (Fig. 29-1). Because of the biomechanical forces mentioned earlier, anterior plating is recommended at this level. Likewise, single-level corpectomies, either at C7 or T1, are successfully managed with anterior plate stabilization and strut graft or cage, providing no posterior pathology or instability is present. When two or more levels of corpectomy are done at the cervical–thoracic level, supplemental posterior fixation is also recommended (Fig. 29-2).

Positioning

Patients are positioned supine on the operating table. The arms are tucked on the sides, and the neck is placed on a gel donut in a slightly extended position.

Technique

LOW CERVICAL APPROACH

This is an extension of the cervical approach to the anterior C- spine.

- A longitudinal incision is made just medial to the sternocleidomastoid (SCM), and dissection is carried down to the vertebrae; the carotid sheath is kept lateral, and the esophagus and trachea are kept medial. We usually use a left-sided approach to minimize injury to the recurrent laryngeal nerve, which has a more constant course on the left side. Note the thoracic duct is at greater risk on the left and can be found as high as C7.
- Radiolucent retractor systems are placed to allow maximal visualization and to retract viscera away (Fig. 29-3, *A*). Care is taken to ensure no undue excessive pressure is put on viscera, such as the esophagus and carotid sheath. Intermittent deflation of the endotracheal tube cuff may also be helpful to reduce pressure on the recurrent laryngeal nerve.
- We use a translatable plate and allograft (see Fig. 29-3, *B*) for our anterior approaches, but we typically use a titanium cage in patients with tumor.
- Using the low-cervical approach, the T1–T2 level can be approached in most cases. A transsternal or transmanubrial approach is usually needed for access to the T3–T4 level. This can be combined with a low-cervical incision for access to the lower cervical spine.

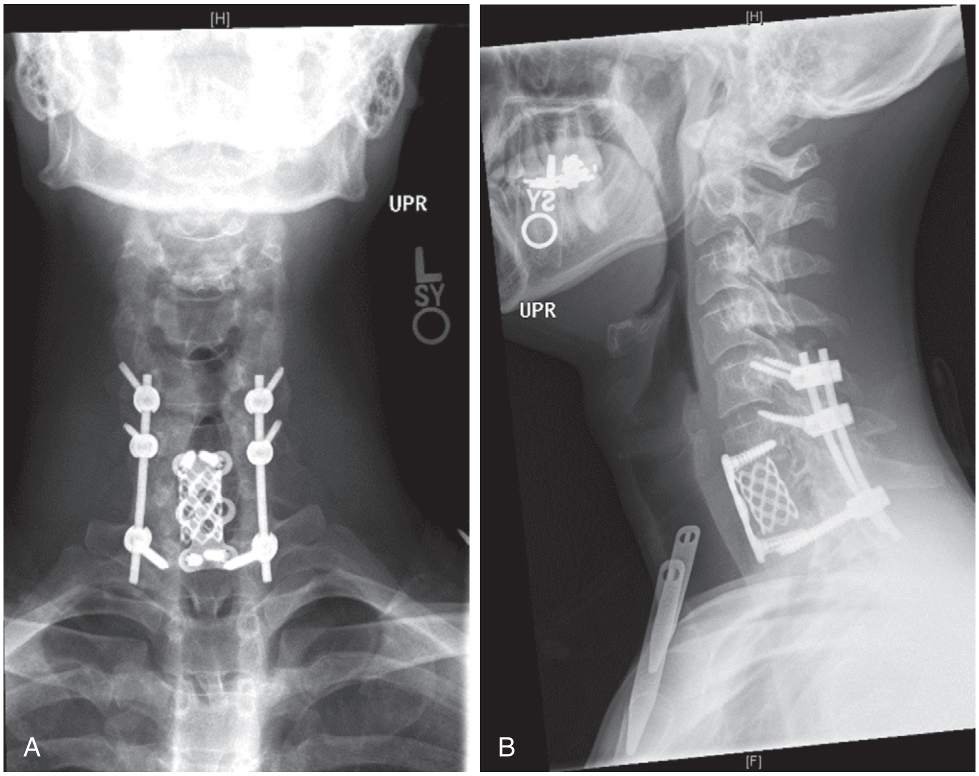


Figure 29-2 Plain radiographs of a C7 corpectomy with C6–T1 anterior cervical diskectomy and fusion and posterior C5–T1 stabilization in a 50-year-old man with C7 metastatic involvement. **A,** Plain anteroposterior view. **B,** Lateral view.

TRANSSTERNAL-TRANSMANUBRIAL APPROACH

- The original technique has been modified to involve a manubriectomy with osteotomies of the clavicle and resection of part of the SCM.
- A more modern approach has involved either a unilateral manubriectomy or a median manubriectomy, in which the sternoclavicular joints are left intact. In this technique, exposure down to T5 has been attained.[4]
- Once exposure is achieved and the esophagus has been satisfactorily retracted, care must be taken with regard to the great vessels, because great anatomic variation is possible with respect to position. Typically, the superior portions of the great vessels overlie T3–T4; however, in the kyphotic patient, this can extend as high as T2.
- A corpectomy can be performed after removing the disk at the superior and inferior margin of the planned resection area. The intervertebral bone is then removed with the aid of a high-speed burr.
- Once the pathology at the CTJ has been rongeured or drilled away, an appropriately sized and shaped interbody graft is placed. We use allograft for degenerative conditions and titanium mesh cage for tumor. For tumor or infection, these cages are typically packed with allograft bone before being tamped into place.
- An anterior cervical plate is positioned over the inferior and superior vertebral body end plates, and we use the shortest adequate plate to stay away from adjacent disk spaces. The plate is fixed with appropriately sized screws based on lateral fluoroscopy.
- If the manubrium has been split, it is reapproximated with miniplates or with sternal wires. If the clavicle or clavicular head has been removed, this is also reapproximated with miniplates.
- Potential complications include injury to the recurrent laryngeal nerve, thoracic duct, esophagus, carotid sheath—which includes the carotid, internal jugular vein, and vagus nerve—and the great vessels, including the innominate, brachiocephalic, and aortic arteries.
- Great attention must be paid to preoperative imaging to identify the position of the vessels as well as to obtain as much information about the angle of the approach to avoid instrumentation malpositioning.

THORACOTOMY

- When access below T4 is required, a thoracotomy may be necessary. Unfortunately, a thoracotomy cannot be used to access the lower cervical spine, unless a "carotid" incision is extended to the sternum and swung around horizontally at the fourth intercostal space to the midaxillary line. In this way, a sternotomy can be followed by a thoracotomy to achieve access from C3 potentially down to T4–T5.

POSTERIOR APPROACH

- Many situations at the cervical–thoracic junction will need only secure posterior stabilization. In this situation, no fixed deformity should be present, and the cervical lordosis can be restored during extension.

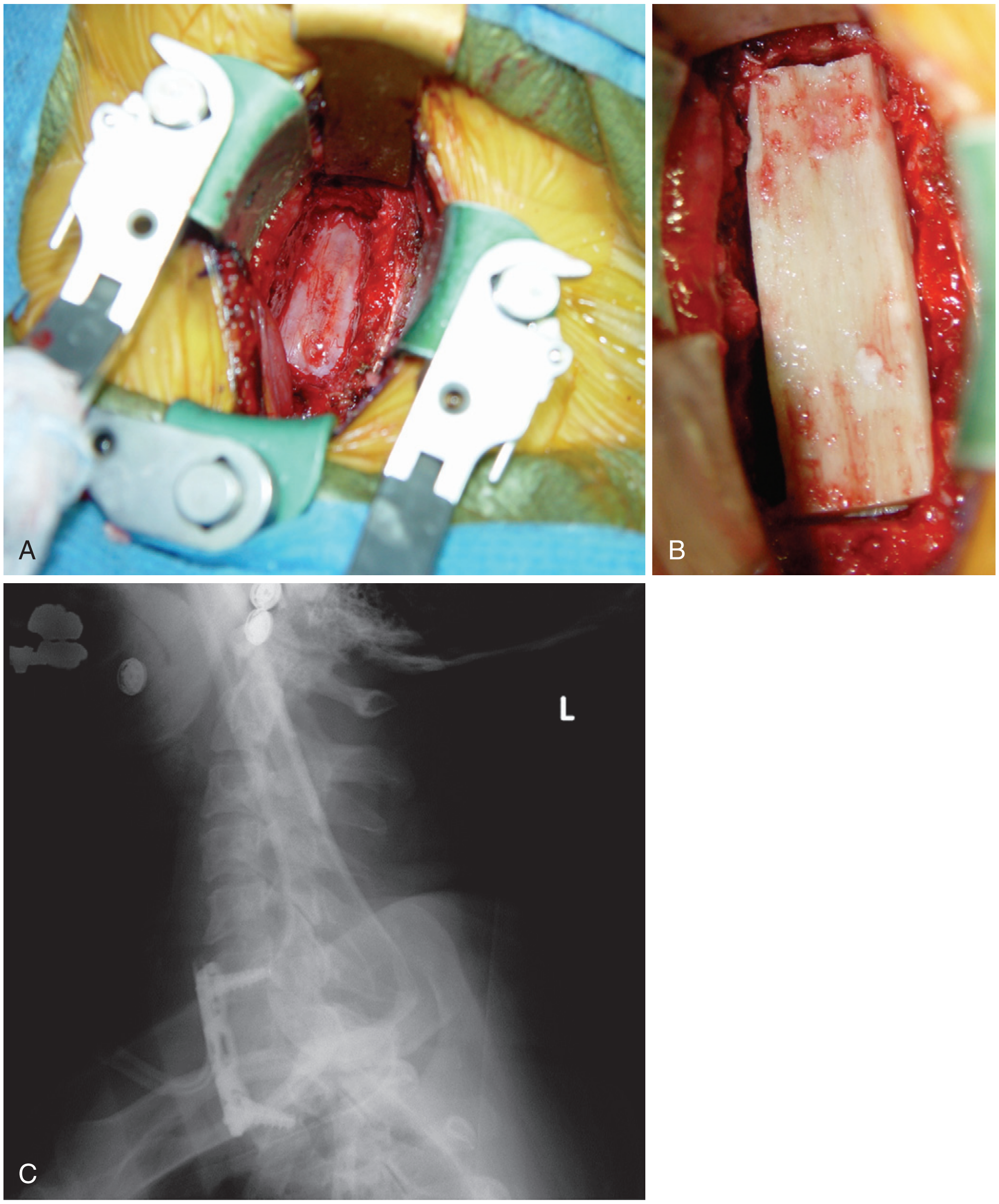


Figure 29-3 Use of (**A**) translucent retractors to achieve access for a C7 corpectomy and (**B**) allograft insertion for subsequent fusion (**C**). Postoperative plain radiograph shows the construct with a translatable plate placed between C6–T1.

- Posterior-only fixation can provide restoration of the tension band or prevent progressive deformity in cases of multilevel decompression for spondylotic myelopathy.
- Interspinous wiring and hook constructs have been successfully used when posterior elements are sufficient.
- Hook-and-wire constructs may need to include nondecompressed motion segments into the fusion construct to ensure stability. The strongest posterior construct that maintains motion in the nondecompressed segments is the lateral mass subaxially from C3–C6 and the pedicle screw system at C7.[2]
- Excellent results have been reported with first-generation systems (plate and screw), but long constructs that cross the cervicothoracic junction are more challenging. Second-generation polyaxial screw-and-rod systems are constrained and lock the screw onto the rod. Because the screw is placed independently of the rod, there is more freedom of screw placement into lateral masses or pedicles.
- Polyaxial screw-rod systems are much less challenging in the longer constructs, because variations in the lateral position of the screws are managed by the mobile polyaxial screw head and offset connectors.
- Several rod-to-rod connecting devices, both side-to-side and end-to-end, are now available to connect thin-rod cervical constructs into the cervical and thoracic regions with wider rods (Fig. 29-4).

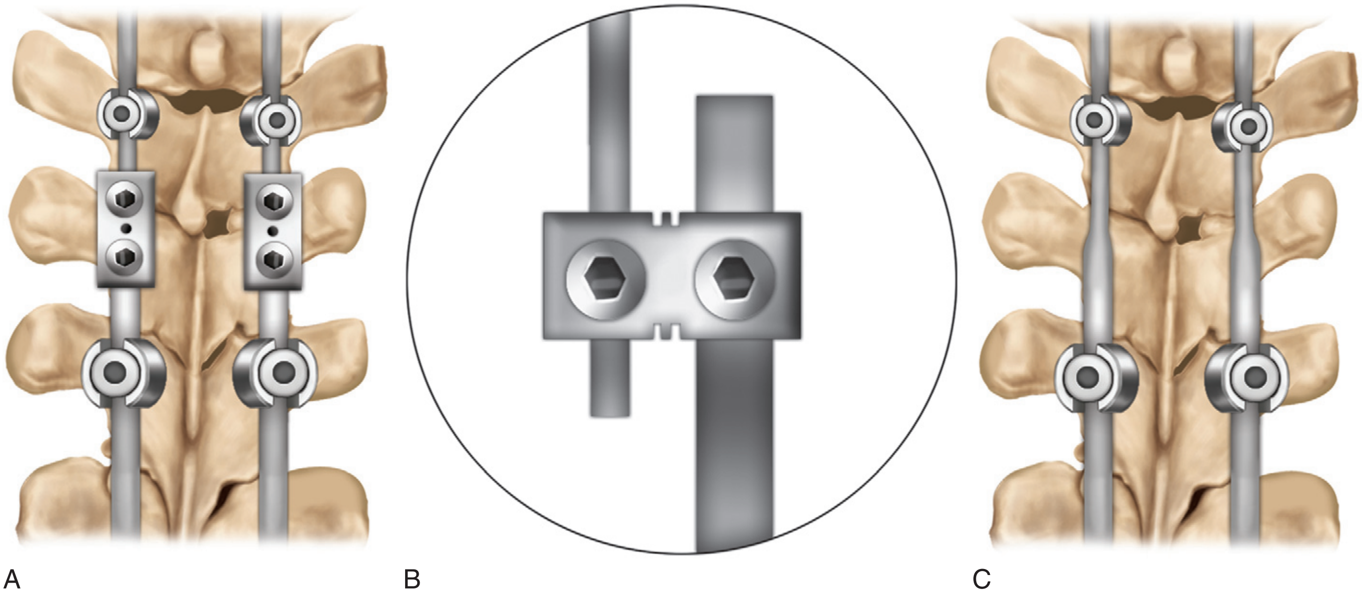


Figure 29-4 Different connectors link the instrumentation in the cervical to the thoracic spine. **A,** End-to-end connectors. **B,** Side-to-side "domino" connectors. **C,** Tapered rods have been developed to avoid the use of connectors.

Posterior Surgical Approaches to the Cervicothoracic Junction

LATERAL MASS SCREWS

Indications for lateral mass screws include fixation for instability resulting from degenerative posterior spinal conditions, trauma, and tumor, and the need for additional posterior fixation following anterior procedures such as anterior cervical diskectomy and fusion (ACDF) or corpectomy. Great attention must be paid to preoperative imaging, such as CT scans, to exclude conditions that may render placement of these screws ineffective, such as erosive arthropathy, tumor, or infection.

Positioning

Mayfield tongs are typically used to rigidly fix the skull and stabilize the neck in the prone position. The neck is positioned in a neutral or slightly lordotic position, but its position can be altered after decompression is performed in order to treat kyphotic deformities. To minimize motion and increase cervical spine stability, the additional use of rotating tables or immobilizing collars may be made once pins have been placed. Care must be taken to fix the patient in an anatomic and neutral position to attain the best possible functionally normal position postoperatively. Fluoroscopy should be used to visualize cervical alignment before the surgery and during placement of instrumentation.

Technique

To avoid a breakout of the screw, we place the lateral mass insertion point 2 mm medial and inferior to the midpoint of the lateral mass (Fig. 29-5). Our direction of screw placement is 30 degrees cephalad and 30 degrees lateral for C3 to C6. If the screw is inserted too inferiorly, it may violate the facet joint; if placed too medially, it may injure the vertebral artery. Bicortical placement of the screw in the lateral mass can be used to ensure maximal screw purchase.

Preparation of the insertion site involves clear exposure of the boundaries of the lateral mass, which can be difficult in a highly degenerative spine. A useful guide to correct screw placement is to use a dissector that can be placed in the facet joint space to keep the drill aligned in the sagittal plane parallel to the joint.

Typically we use 3.5-mm screws with polyaxial heads and a matching 4.0-mm rod. This can be connected to thoracic pedicle screws with a domino connection (side-to-side connector) or a tapered rod (see Fig. 29-4).

PEDICLE SCREWS

We routinely use pedicle screws at the C7 level and in the upper thoracic region (T1–T3) for the CTJ.

Technique

Wide exposure of the laminae and lateral mass (C7) and transverse processes (T1–T3) are required. This includes removal of the widened medial aspect of the transverse process of T1–T3 to allow the head of the pedicle screw to be seated. The starting point of the T1 to T2 pedicles is slightly more lateral and inferior than for the lower thoracic spine (Fig. 29-6). Once a posterior cortical breach is made, for example with a Midas burr, a pedicle finder is placed into the base of the pedicle, and imaging is obtained to document a correct trajectory. The pedicle finder is advanced through the pedicle approximately 25 to 30 mm. A medial-to-lateral angle of approximately 30 to 35 degrees is usually appropriate for screw insertion at C7, and 15 degrees is usually best for the upper thoracic spine (Fig. 29-7).

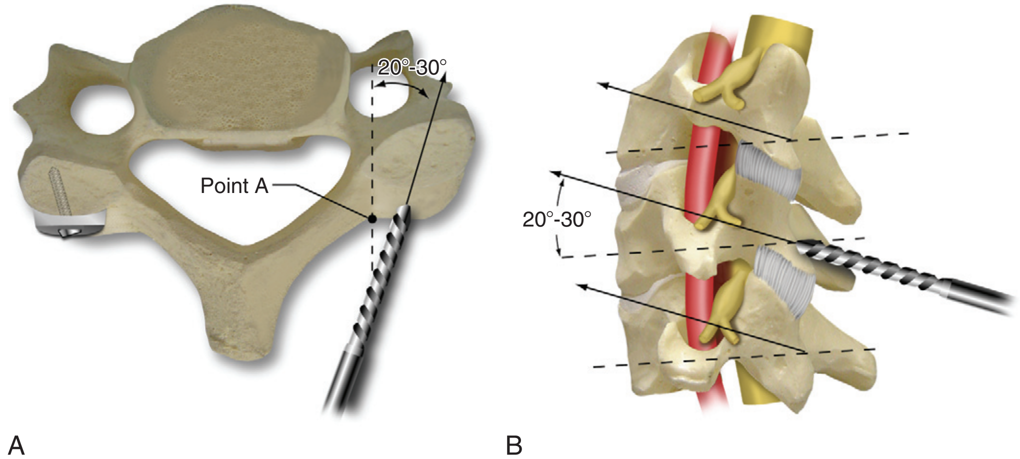
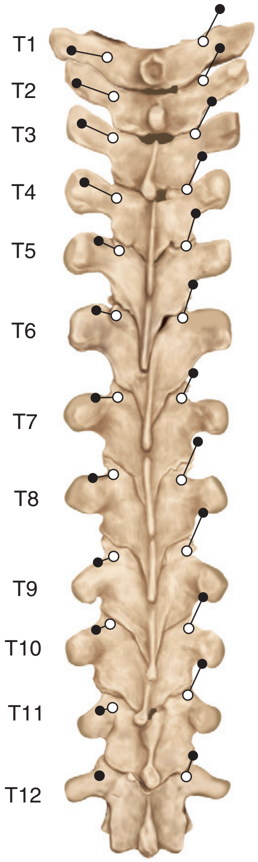


Figure 29-5 Entry point and trajectory of cervical lateral mass screws. The lateral mass screw is placed approximately 30 degrees lateral to the horizontal plane (**A**) and 30 degrees cephalad to the midsagittal plane (**B**).



Level	Cephalad-caudad starting point	Medial-lateral starting point
T1	Midpoint TP	Junction: TP lamina
T2	Midpoint TP	Junction: TP lamina
T3	Midpoint TP	Junction: TP lamina
T4	Junction: proximal third-midpoint TP	Junction: TP lamina
T5	Proximal third TP	Junction: TP lamina
T6	Junction: proximal edge–proximal third TP	Junction: TP lamina facet
T7	Proximal TP	Midpoint facet
T8	Proximal TP	Midpoint facet
T9	Proximal TP	Midpoint facet
T10	Junction: proximal edge–proximal third TP	Junction: TP lamina facet
T11	Proximal third TP	Just medial to lateral parts
T12	Midpoint TP	At the level of lateral parts

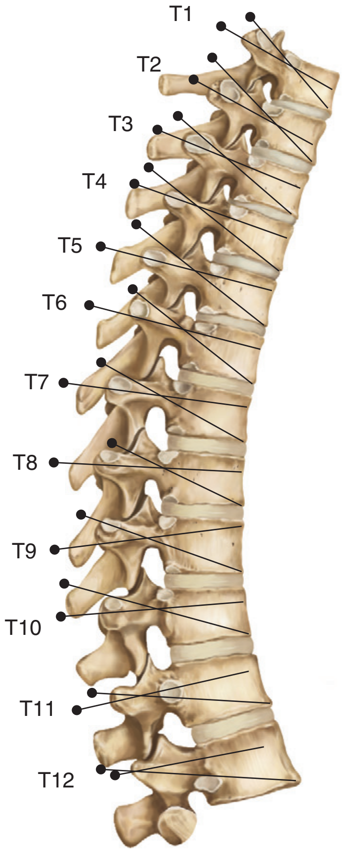


Figure 29-6 Cephalad-caudal and medial-lateral pedicle screw insertion starting points for each of the thoracic vertebrae. *TP,* transverse process.

The pedicle finder is removed, and the tract is visualized to see that no cerebrospinal fluid is present. A pedicle sounding probe is typically used to palpate five distinct bony borders, including a floor and four walls to ensure no bony breach. The appropriate length of the pedicle screw is determined by measuring the length of this probe using a hemostatic clamp. We undertap the tract by 1 cm less than the diameter of the intended screw, which is inserted into the pedicle and body in the same alignment as that of the sounding probe removed just before screw placement. Proper final placement is confirmed with fluoroscopy.

TRANSLAMINAR SCREW

Often the T1–T3 pedicles are difficult to cannulate and place pedicle screws in because of either a paucity of adequate pedicle or the risk of breach and neural injury from an excessively medially angled screw. As a result, just as a

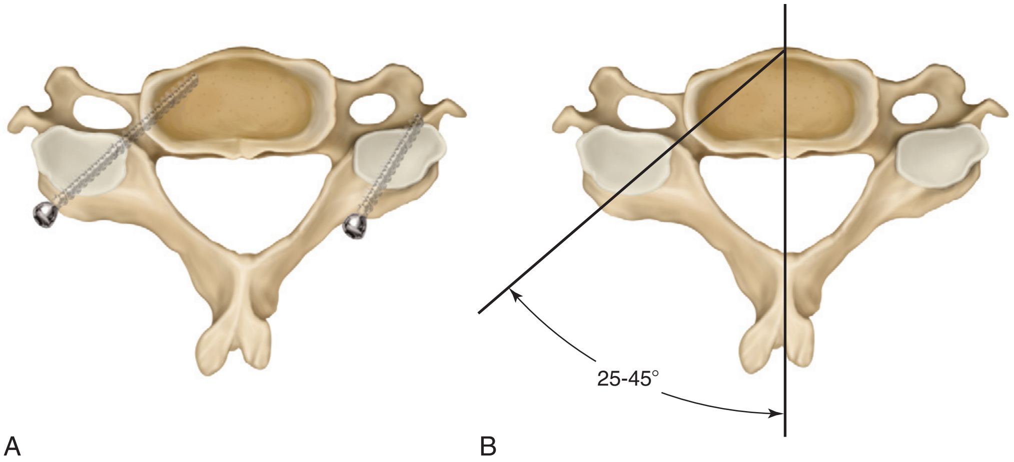


Figure 29-7 **A,** C7 pedicle screw (*left*) and lateral mass screw (*right*). **B,** The medial to lateral C7 trajectory angle is approximately 30 to 35 degrees.

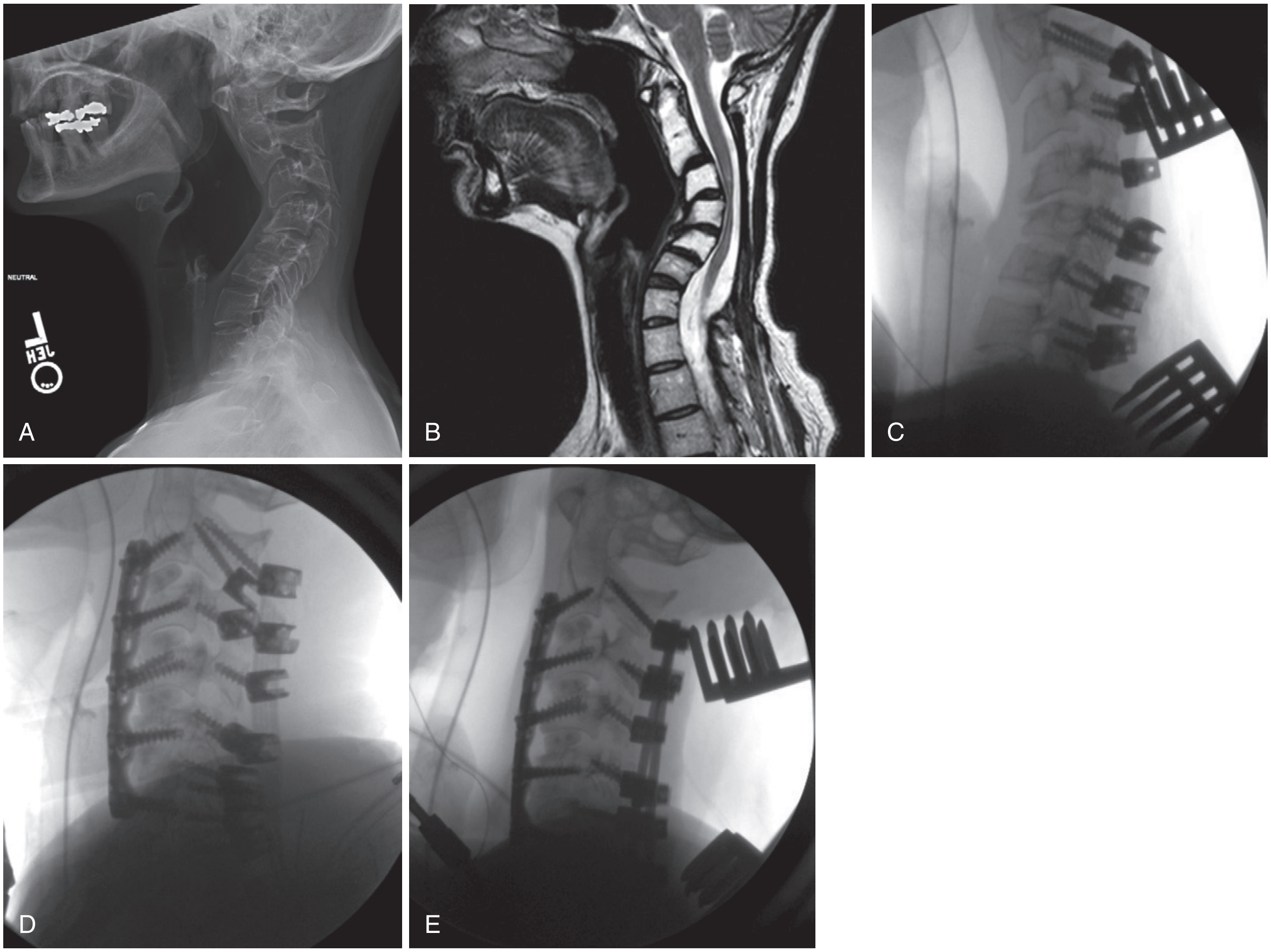


Figure 29-8 Radiographic images of a 51-year-old woman who came to medical attention with neck pain and bilateral upper limb paresthesia following previous decompressive laminectomy for resection of extrinsic cord lymphoma. The patient had received subsequent chemotherapy and radiotherapy following the first procedure. **A,** Plain lateral radiograph demonstrates the presence of severe kyphotic swan-neck deformity. **B,** Cervical cord myelomalacia on magnetic resonance imaging. **C,** The patient underwent a posterior-anterior-posterior deformity correction after placement of posterior C2–T2 instrumentation; this was followed by a C2–C6 anterior cervical diskectomy and insertion of translatable plate. **D,** With the patient returned to the prone position, the instrumentation is connected and locked to bilateral rods.

translaminar screw has been described for C2,[5] for similar indicated reasons, Kretzer and colleagues[6] reported the first use of translaminar screws in the upper thoracic spine. Biomechanical studies[7] have demonstrated equal efficacy between translaminar and upper thoracic pedicle screws.

The translaminar screw insertion point is at the junction of the contralateral spinous process and lamina. The trajectory is approximately along the angle of the ipsilateral lamina with the target being the intersection of the ipsilateral transverse process and superior facet. Note that if bilateral translaminar screws are to be placed, the starting points have to be slightly different cephalad-caudal, and the lateral trajectories must be slightly divergent, to avoid collision of the screws.

Anterior-Posterior Approach

The anterior-posterior approach is used when pathology is present in both the front and back or when a corpectomy is required. The first part of the approach is usually anterior decompression or release followed by the posterior stabilization.

Anterior reconstruction can be done with allograft, a titanium mesh cage, or an expandable cage in addition to a locking plate. Deformity correction, including corpectomy, must be done in the first stage, because the posterior implants and cervical spine may not be able to resist stress loads associated with deformity correction through a posterior approach only. A change in the head position is a useful way to restore lordosis after performing diskectomies or corpectomy. The second stage, either during the same operation or surgery at a later stage, involves the addition of the posterior stabilization.

Posterior-Anterior-Posterior Approach

This method is used in patients with a fixed deformity of both the anterior and posterior CTJ. These deformities are often longstanding, either congenital or degenerative, such as chin-on-chest deformity or even following kyphotic cervical collapse from a previous dorsal decompression (Fig. 29-8). Both an anterior and a posterior release are needed to achieve a successful correction.

The initial stage is a posterior release with combined multiple facetectomy and laminectomy. One option is to insert the posterior instrumentation at this stage to prevent the risk of dislodging anterior grafts or cages. The second stage involves multiple anterior diskectomy, osteotomy, or corpectomy as needed. Anterior reconstruction is performed with multiple autografts, often either from iliac crest or fibula, and titanium mesh or expandable cages packed with bone graft. An anterior locking plate can help stabilize the construct. In the third stage, the patient is again turned prone, and the posterior instrumentation is fixed to the rod. Adjustments can be made with compression, distraction, and bending of the rods as needed.

Conclusion

The CTJ represents a unique region because of its anatomic and biomechanical properties, and it is prone to traumatic injuries, tumor, and iatrogenic instability. Access to the anterior CTJ is certainly limited by visceral and bony considerations of the thoracic cage. As a consequence, most surgeons attempt to approach the CTJ from a dorsal perspective. However, surgeons should familiarize themselves with the ventral approach and its modifications and not hesitate to use these when indicated.

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30 Thoracic Microdiskectomy: Lateral and Posterolateral Approaches

HANI R. MALONE and ALFRED T. OGDEN

Overview

Thoracic disk herniations are heterogeneous with respect to presenting symptoms, anatomic relationship to the spinal cord, and intrinsic tissue characteristics. Accordingly, thoracic diskectomy exists along a continuum of surgical complexity that has mandated the development of a wide array of surgical techniques to treat this pathology. Ultimately, the choice of surgical approach depends heavily on the individual characteristics of each disk herniation and the expertise of the surgeon.

Early experience with surgical outcomes reflected the limitations of the treatment of thoracic disk herniations with dorsal laminectomy and diskectomy. This approach led to unacceptably high rates of neurologic injury.[1-4] Poor outcomes were largely attributed to spinal cord retraction, particularly in cases where the disk herniation was calcified and centrally located.[1] Accordingly, the evolution of thoracic disk surgery has been driven by an emphasis on adequate surgical exposure with minimal spinal cord manipulation. This has led to the development of posterolateral, lateral, and anterolateral approaches that have mitigated the neurologic morbidity seen with laminectomy[1] but often at the expense of approach-related morbidity. As imaging technology has become more refined and less invasive techniques and equipment have become available, it has become apparent that many thoracic disk herniations do not require large, open exposures for safe removal.[5-11]

The most important guiding principle in thoracic disk surgery is that no single, optimal approach for every thoracic disk herniation exists. It is of paramount importance that each thoracic disk herniation be evaluated individually to assess its internal consistency and relative position to neural elements. Ultimately the choice of approach is dependent not only on these factors but also on individual preferences and the expertise of the operating surgeon. In this chapter, we will review the advantages and disadvantages of the principal approaches to thoracic disk herniations, and we will describe the fundamental surgical techniques used.

Prevelance and Presentation

Prompt diagnosis of a thoracic disk herniation can be challenging given the heterogeneity of presenting signs and symptoms, potential similarities to lumbar disk herniation presentations, and an often insidious early course.[12-14] Fortunately, advances in imaging quality and availability have expedited the diagnostic process. Manifestations include pain that may be localized, axial, or radicular; sensory loss or paresthesias; hyperreflexia and spasticity; bowel, bladder, or sexual dysfunction; and lower extremity weakness that can lead to paraplegia.[10,15,16] Patients usually come to medical attention with a combination of these symptoms.

Thoracic disk herniations are rare and account for only 0.25% to 0.75% of all disk herniations.[3,16,17] This is likely due to the stabilizing effect of the rib cage and the resultant limited mobility of the thoracic spine.[14] A history of trauma is reported in 22% to 50% of symptomatic patients,[15] most of whom are between the fourth and sixth decades of life, with a nearly even sex distribution.[16,17] Thoracic diskectomy accounts for less than 4% of all spinal diskectomy procedures.[10,18]

Anatomic Considerations

Thoracic intervertebral disks are less prone to degradation, compared with cervical and lumbar regions, because of the relative lack of motion that results from the stabilizing effect of the rib cage. In contrast, the blood supply to the thoracic spinal cord renders it relatively vulnerable; this is due to a watershed zone at the upper thoracic levels, which is fed by small radicular arteries, and the dominance of the artery of Adamkiewicz, a large radicular artery that supplies the ventral cord from the lower thoracic levels down to the conus. Although highly variable, this artery usually enters the spinal canal at T8–L2 on the left side.[1] This variability has led some to advocate spinal angiograms before thoracic diskectomy to delineate major feeders; however, this is not common practice.[19]

Approximately 90% to 94% of symptomatic thoracic disk herniations are located either centrally or paracentrally.[10,15,20] Intradural extension of herniated thoracic disks is not uncommon and occurs in 7% to 12% of cases.[10,20] Thoracic diskectomy is further complicated by the consistency of thoracic disks, the majority of which contain a calcified component.[5] Even in the absence of intradural extension, the incidence of dural adhesion is much greater with calcified disks, further arguing the importance of a surgical approach that adequately exposes the ventral spinal canal.[10]

Imaging

The widespread use of magnetic resonance imaging (MRI) has had a profound impact on the accurate and timely diagnosis of thoracic diskectomy; it has led to earlier treatment and has likely resulted in improved prognosis.[17,21,22] MRI facilitates precise localization of the offending pathology, provides an excellent depiction of the relationship of the disk herniation to the neural elements, and gives information as to the consistency or "softness" of the herniated disk material (Fig. 30-1). Contrast may be useful to distinguish such lesions from a spinal tumor. Abnormal signal within the cord—hyperintensity on T2-weighted images and, more specifically, hypointensity on T1-weighted sequences—suggest parenchymal injury or gliosis. Although MRI is very sensitive for discerning thoracic disk herniations, it is important to keep in mind that the false-positive rate is estimated to be as high as 14.5%; this makes appropriate clinical correlation paramount to treatment decisions.[23]

As an adjunct to MRI, computed tomography (CT) is particularly useful in the evaluation of calcification of disk material. This cannot be reliably ascertained with MRI. Although rarely used, CT myelogram can be more sensitive at ruling out intradural extension (Fig. 30-2).[20,24]

Surgical Indications

Radiographic studies suggest that the prevalence of thoracic disk herniation may be as high as 20%,[12,25] yet the vast majority of these lesions are asymptomatic and require no surgical intervention. Like comparable lesions in the cervical and lumbar spine, herniated thoracic disks should be treated conservatively in the absence of myelopathy or

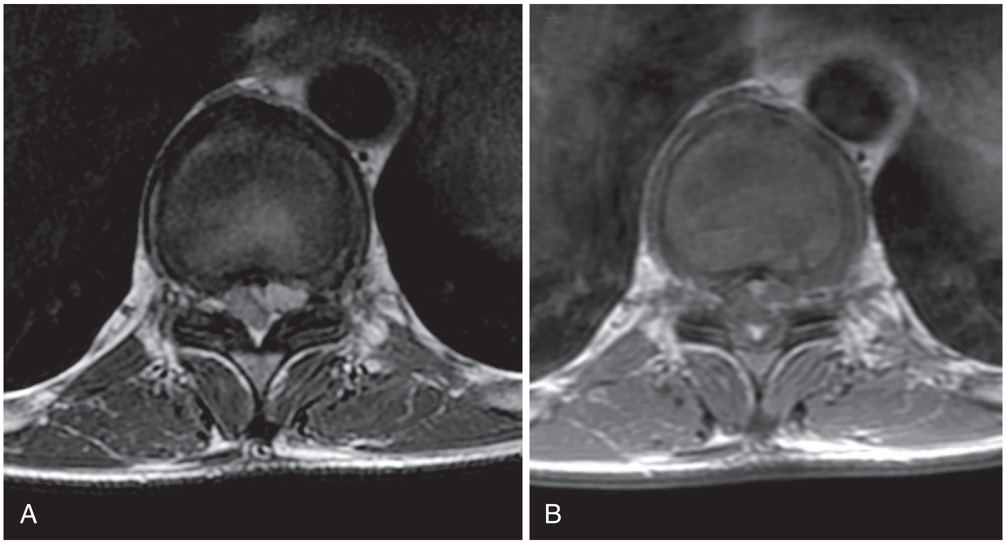

Figure 30-1 Soft thoracic disk herniation. Axial T2 (**A**) and T1 with contrast (**B**) show a lateral T2 hyperintense and T1 isointense lesion with peripheral enhancement consistent with a soft-disk herniation. This herniation was removed using a transpedicular approach.

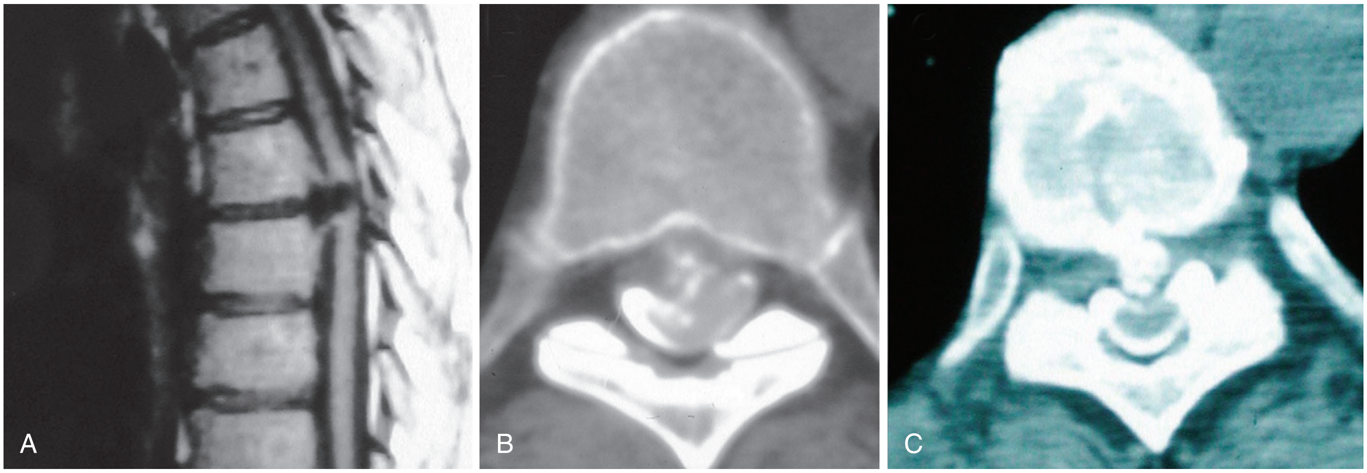

Figure 30-2 Calcified thoracic disk herniation. Sagittal T1 (**A**) and axial computed tomography (CT) (**B**) demonstrate a central calcified disk herniation. CT myelogram (**C**) confirms that the lesion is entirely extradural. This herniation was removed using a retropleural approach.

intractable pain. Conservative therapy may include nonsteroidal antiinflammatory medications, analgesics, and epidural steroid injections in cases of thoracic radiculopathy.[15] Patients with radiographic evidence of nerve compression who do not improve following 4 to 6 weeks of conservative treatment are candidates for surgical intervention.[20,26] However, patients with radiographic evidence of spinal cord compression and signs or symptoms of myelopathy usually require surgery.[27,28]

Once the decision has been made to proceed with surgery, the optimal approach to the thoracic spine must be selected based on the characteristics of the individual disk herniation and the comfort level and expertise of the operating surgeon. Effective surgical management is contingent on an understanding of the various approaches to the thoracic spine and the advantages and disadvantages associated with each. Primary considerations related to approach include adequate exposure of the herniated disk, limited manipulation of the dura, potential iatrogenic instability from surgical exposure, preservation or sacrifice of the intercostal neurovascular bundle, postoperative pain, approach-related morbidity, and patient health and age.[1,15,17,18]

Although no precise algorithm exists for selecting which surgical approach is optimal for each patient, useful guidelines based on large clinical series highlight the efficacy of anterior, lateral, and posterolateral approaches in different clinical scenarios (Table 30-1).[10,18,29,30] Posterior thoracic laminectomy for diskectomy has been associated with unacceptably high rates of neurologic deterioration[3,15,31] and is contraindicated.[15,32] Midline and calcified disk herniations are relative indications for lateral or anterolateral approaches, given the degree of ventral exposure needed for safe decompression. Soft and lateral disks are potentially amenable to less invasive posterolateral approaches. The extent of bone removal and approximate operative angles for each approach are illustrated in Figure 30-3.

To date, objective comparisons of different approaches are limited by the low incidence of symptomatic thoracic disk herniation, the varying appropriateness of certain approaches given disk location and consistency, and a paucity of standardized outcome measures. For this reason, surgeon familiarity is an important factor in decision making, because often more than one alternative can effectively address the pathologic disk.

Table 30-1 Surgical Approaches for Thoracic Diskectomy

Approach	Indications (+) and Contraindications (–)	Advantages	Disadvantages
ANTERIOR			
Transthoracic	(+) Central and paracentral disks (+) Calcified disks (+) Can facilitate anterior fusion (–) Medically ill patients	Best visualization/exposure of large or calcified ventral midline disks Access to multiple levels	Postoperative pain Morbidity risk Chest tube required
Thoracoscopic	(+) Central and paracentral disks (+) Calcified disks (+) Can facilitate anterior fusion	Good visualization of large or calcified ventral midline disks Access to multiple levels Amenable to MIS	Chest tube required Technically challenging Limited exposure of multilevel OPLL
ANTEROLATERAL			
Retropleural	(+) Central and paracentral disks (+) Calcified disks (–) Medically ill patients	Less medical risk than transthoracic approach, yet still provides good exposure of ventrolateral disk space	Pleural violation and chest tube possible
POSTEROLATERAL			
Lateral extracavitary	(+) Lateral disks (+) Paracentral disks (+) Calcified disks (+) Can facilitate anterior fusion (–) Medically ill patients	Best exposure of ventral midline structures among posterior and posterolateral approaches Extrapleural Can access multiple levels from single approach	Limited visualization of ventral dural sac Considerable postoperative pain Greater risk of radicular artery injury
Costotransversectomy	(+) Lateral disks (±) Paracentral disks (+) Calcified disks	Extrapleural	Difficult to visualize ventral dural sac Difficult to resect midline calcified disks
POSTERIOR			
Transpedicular	(+) All soft herniated disks (+) Lateral calcified disks (–) Central calcified disks	Less invasive than anterior and lateral approaches to thoracic diskectomy Amenable to MIS	No visualization of ventral dural sac Limited exposure of OPLL Reports of postoperative localized back pain
Transfacet	(+) All soft herniated disks (+) Lateral calcified disks (–) Central calcified disks	Less invasive than anterior and lateral approaches to thoracic diskectomy Amenable to MIS Preservation of the ipsilateral pedicle	Primarily limited to soft lateral disk herniations
Dorsal laminectomy	(–) Central and paracentral disks	Common, technically straightforward procedure	Limited exposure of midline structures Dural retraction High incidence of neurologic morbidity

±, Although not contraindicated, this approach is not preferred for the specified pathology.
MIS, minimally invasive surgery; OPLL, ossified posterior longitudinal ligament

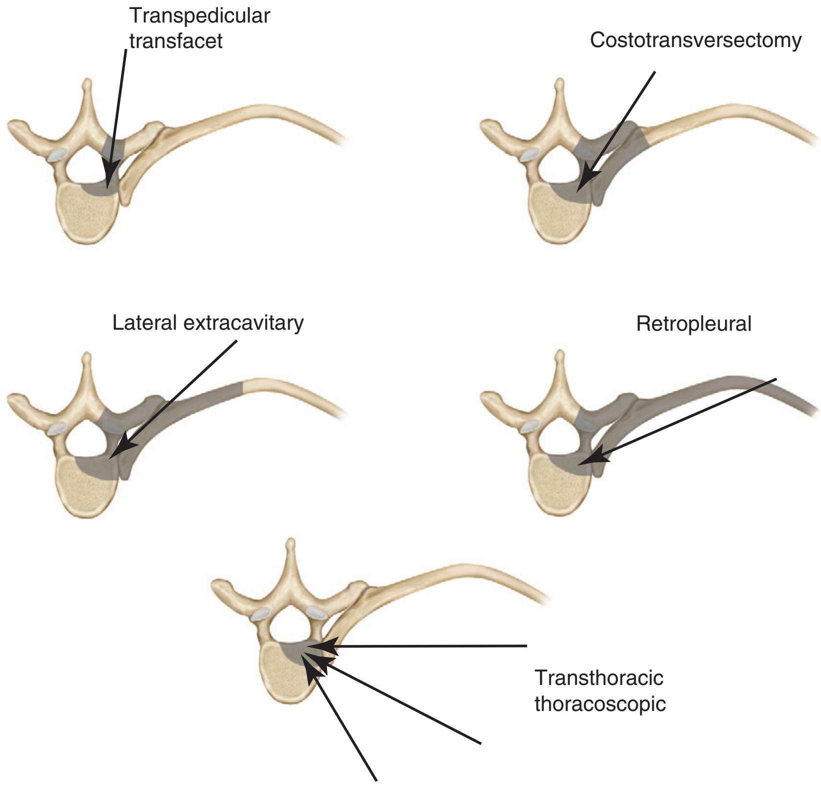

Figure 30-3 Osseous exposures and angles of approach for thoracic diskectomy. Drawings depict the anticipated bone removal and/or angle afforded by the various approaches.

Anterolateral Approaches

TRANSTHORACIC APPROACH

The transthoracic approach allows for midline exposure of the ventral cord without dural retraction, making it particularly advantageous in the treatment of densely calcified centrally herniated disks.[1,2] Of note, reoperation following thoracic diskectomy is most often attributed to incomplete diskectomy as a result of inadequate visualization of calcified midline disks.[1,15,33] When feasible, an anterior exposure should be used in the context of calcified midline disks, particularly if the spinal cord is draped over the disk herniation.[34] However, it is important to note that the standard transthoracic approach is an extensive undertaking associated with potential morbidity; this may make it unsuitable for medically ill patients with poor cardiac or pulmonary function.[1,35]

With this is mind, less invasive thoracoscopic diskectomy techniques have evolved rapidly in recent years.[5] Proponents of the thoracoscopic approach argue that excellent endoscopic visualization and reductions in morbidity make this the ideal approach for central disk herniations. Small clinical series that have compared thoracoscopic and "open" transthoracic approaches have reported equivalent operative time, reduced postoperative pain, and comparable clinical results.[36] However, it should be noted that thoracoscopic disk surgery is associated with a steep learning curve and requires specialized equipment and training.

Anterior approaches to the thoracic spine, including transthoracic and thoracoscopic techniques, are discussed in detail in Chapter 28.

Lateral Approaches

RETROPLEURAL APPROACH

Indications and History

The modern retropleural approach, as described by McCormick,[13,35] provides the shortest direct route to the thoracic spine and leaves the pleura intact. In doing so, the retropleural approach avoids some of the shortcomings of the transthoracic approach—including direct retraction of the lung, creation of a deep surgical field, and postoperative closed-chest drainage—while achieving comparable ventral access to the thoracic spine.[35]

Positioning

The patient is positioned in the lateral position and supported by a beanbag. A soft roll is placed in the inferior axilla, and the lower leg is flexed at the knee and hip. When possible, thoracolumbar lesions should be centered over the break in the table to help maximize exposure of the lesion. For laterally herniated disks, ipsilateral exposure provides the most direct surgical route. In cases of central or paracentral herniations, the side of approach is often dependent on the vertebral level. Rostral thoracic lesions are best approached from the right, limiting exposure to cardiovascular structures. Conversely, for more caudal thoracic lesions, a left-sided approach allows the surgeon to avoid the inferior vena cava and liver.[10,35] When exposing the caudal thoracic spine from the left, the artery of Adamkiewicz is an important consideration. When approaching the upper thoracic spine, rostral to T6, a double-lumen endotracheal tube should be used to allow for ipsilateral lung deflation.

Incision, Dissection, and Diskectomy

Intraoperative fluoroscopy should be used to confirm the level of pathology and proper positioning before marking the course of the incision. In the rostral thoracic spine (T3–T4), a paramedian "hockey stick" incision is made, curving lateral in parallel with the medial and caudal border of the scapula. This incision can be carried through the trapezius and rhomboid muscles, allowing for superior rotation of the scapula and exposure of the underlying rib. For lesions between T5 and T10, a curvilinear incision is made that extends from the posterior axillary line to a point approximately 4 cm lateral the dorsal midline along the caudal rib of the involved segment. When approaching the thoracolumbar junction, the incision is usually made two levels rostral to the surgical target (Fig. 30-4, *A*).[13,35]

A subperiosteal dissection of the intercostal musculature is then carried out to expose 8 to 10 cm of the rib. This exposed

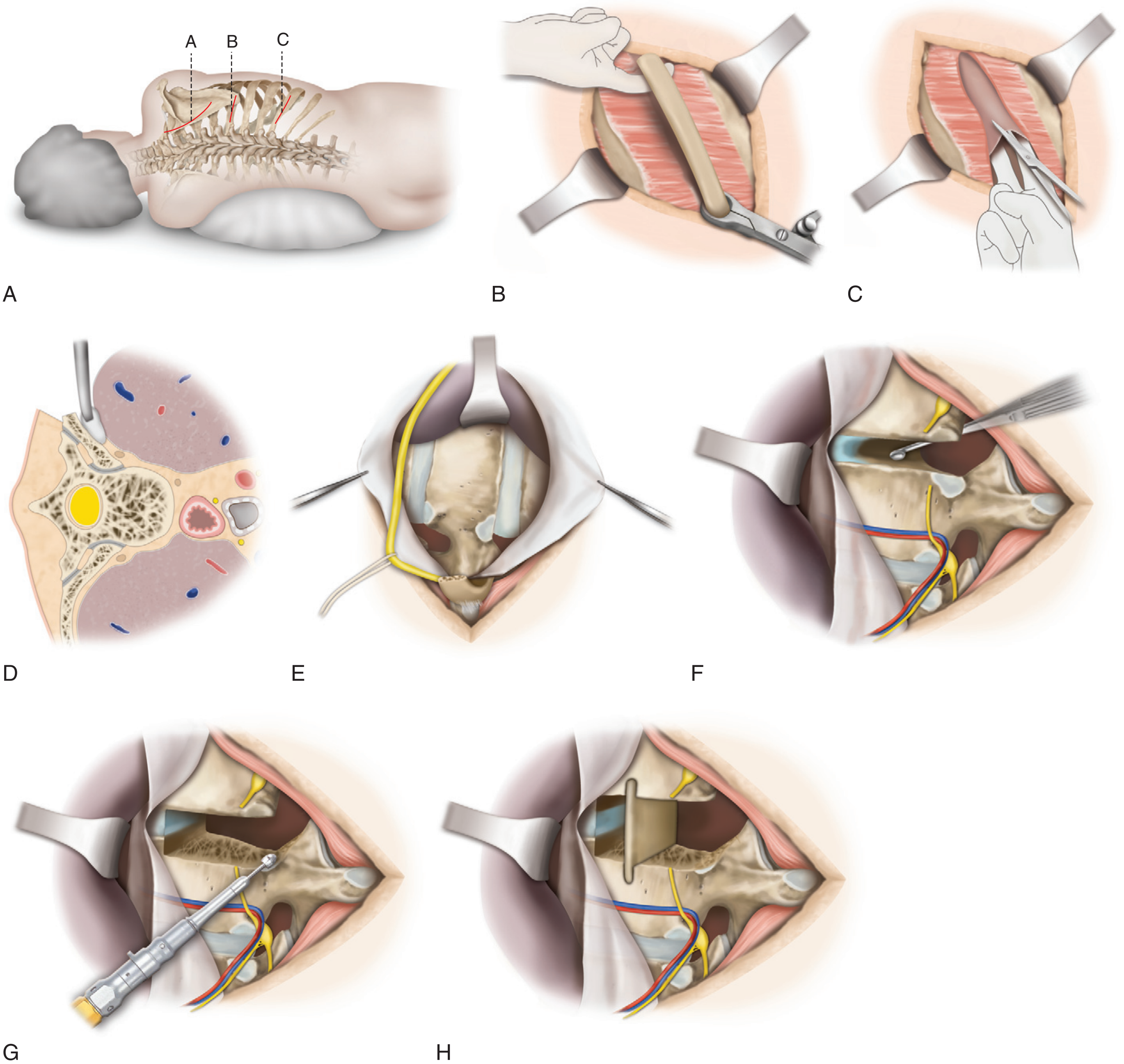

Figure 30-4 Patient position for retropleural thoracotomy. **A,** Incision A is used for upper thoracic lesions, and incisions B and C are used for midthoracic and thoracolumbar lesions, respectively. The exposed portion of the rib is resected. **B,** The endothoracic fascia in the resected rib bed is incised. **C,** Blunt dissection of the pleura is extended to the vertebral body (**D**). Dissecting the pleura rostral and caudal to the involved segment helps to prevent tears. With a retractor on the lung (**E**), the neurovascular bundle is freed and partially mobilized from the underlying fascia. The fascia is incised and elevated from the vertebrae in the subperiosteal plane. The dissection is carried out over the rib head, disk space, and vertebral bodies; the rib head is removed to expose the pedicle and disk space. **F,** The sympathetic chain is divided, and the disk is removed. **G,** The end plates are drilled, and the pedicle is removed. **H,** Grafting with structural rib allograft is performed. The construct can be augmented with vertebral body screws if desired.

portion of the rib is resected and saved for later autograft, if needed, leaving the proximal rib attached to the vertebral body and transverse process. Cut rib edges are waxed to prevent lung injury.[18,35] Removed rib exposes the underlying endothoracic fascia, which lines the thoracic cavity and lies flush to the ventral border of the vertebral body (see Fig. 30-4, *B*). The intercostal neurovascular bundle, azygous vein, thoracic duct, and sympathetic chain all lie within this important layer of fascia.[10,13] With this in mind, the fascia is incised in line with the imprint of the resected rib and is then carefully separated from the underlying parietal pleura via blunt dissection to create a potential space between the layers (see Fig. 30-4, *C*).[35] A retractor distracts adjacent ribs. For lesions rostral to T6, the ipsilateral lung should be deflated. For more caudal lesions, a table-mounted malleable retractor can be used to protect the lung and clear it from the operative field, avoiding the need for deflation.

The endothoracic fascia opening can then be followed posteriorly to the proximal rib head and anterior vertebral column (see Fig. 30-4, *D*).[18] When incising fascia over the involved disk space, the sympathetic chain will be divided. This rarely has clinically significant repercussions in the thoracic spine.[35] The fascia and vertebral periosteum are subsequently dissected free from the ventral spine and proximal rib and are reflected rostrally and caudally, away from the disk space (Fig. 30-4, *E*). The intercostal vascular pedicle runs in the fascia layer at the level of the midvertebral body. It is possible to preserve this structure in single-level diskectomies.

Costotransverse ligaments are divided to free the rib head and proximal rib, which are removed. The underlying neural foramina and pedicle are then visualized. Removal of the transverse process further exposes the neural foramen and lateral dura. The rostral portion of the pedicle directly caudal to the disk space can also be drilled down to improve exposure of the disk space.

The pathologic disk can now be incised and removed with rongeurs and curettes (see Fig. 30-4, *F*). A high-speed drill is used to extend the dissection into the adjacent vertebral bodies (see Fig. 30-4, *G*). Next, the caudal pedicle is removed with Kerrison rongeurs, further exposing the lateral spinal canal and dura. Drilling of the posterior vertebral bodies is extended to create a cavity that lies roughly 1.5 cm rostrally and caudally from the disk space and 3 cm medially.[35] Drilling is carried out until only a thin shell of bone remains on the posterior border of the vertebral body, along with the posterior longitudinal ligament (PLL).

The PLL is then divided with a reverse-angled curette, with all applied force directed away from the spinal cord into the vertebral body trough. Remaining bone and ligament can then be evacuated through this cavity, and a nerve hook is used to survey the thecal sac for residual disk fragments. Final decompression should be performed in a timely fashion to limit the effects of epidural bleeding, which can be addressed with electrocautery. Resected rib can be placed in the vacated disk space in the form of a strut autograft, and additional vertebral body drilling may be needed to establish proper disk height and to allow the graft to sit flush (see Fig. 30-4, *H*).[13,35] The fusion can be augmented with vertebral body screws.

The endothoracic fascia is released back over the ventral vertebral body, and the pleura is inspected for injury. If no appreciable injury is present, chest tube drainage is unnecessary. Chest tubes should be placed in the case of significant intrathoracic air or persistent pleural leakage, which can be better assessed during positive-pressure ventilation. Chest wall deformity is reduced by approximating ribs adjacent to the resection site with suture, taking special care not to injure underlying intercostal nerves, which might cause intercostal neuralgia.

Minimally Invasive Considerations

Tubular retractors have made possible a less invasive retropleural approach. The surgery is performed essentially as described but requires a smaller incision (3 to 4 cm) placed over rib that lies directly over the posterior aspect of the disk space and ventral canal.[37] Depending on the level of the disk herniation and the patient's individual anatomy, the initial thoracotomy in a minimally invasive retropleural approach may be at the level of the disk space of interest or one to two levels above. The more caudal the segment, the more angulated the rib and the more likely the initial thoracotomy will need to be performed at the level above. In contrast to the open retropleural approach, a smaller window of rib is resected in the initial thoracotomy, which mitigates potential postoperative morbidity from pain or a chest wall deformity. If greater exposure is needed, this approach is easily converted to an open retropleural thoracotomy.

Advantages

- Achieves access to the ventral spinal canal comparable to that achieved with transthoracic approaches
- Does not penetrate the pleura, avoiding the need for routine chest tube drainage
- Provides the shortest direct route to the ventral thoracic spine, facilitating smaller incisions and less invasive soft-tissue dissection compared with other anterolateral and lateral approaches[18]
- Preserves the intercostal neurovascular bundle and minimizes the risk of postoperative neuralgia and radicular artery injury[13,35]

Disadvantages

- This approach requires more bone resection and soft-tissue manipulation than a posterolateral transpedicular-transfacet approach.
- The sympathetic chain is divided, which may result in a Horner syndrome in the rostral thoracic spine. This approach should not be used above the T3 level.

COSTOTRANSVERSECTOMY

Indications and History

Original descriptions of costotransversectomy for Pott disease were later adopted and refined by Hulme[4] for the treatment of thoracic disk herniation. Resection of the rib head and transverse process provides more exposure to the ventral thecal sac for the removal of paracentrally herniated disks. Achieving good clinical results, costotransversectomy became the first safe alternative to laminectomy for thoracic diskectomy.[4] With time, the technique described by Hulme would be expanded on to provide surgeons with more options to individualize treatment.

Positioning

Positioning for costotransversectomy varies. The procedure can be performed in the prone, semiprone, and modified lateral decubitus positions.[18,38,39] If the disk is laterally herniated, an ipsilateral approach is generally taken. When laterality is clinically arbitrary some advocate a right-sided approach to minimize risk of injury to the artery of Adamkiewicz, which usually originates from the lower left intercostal arteries.[39,40]

Incision, Dissection, and Diskectomy

Similar to positioning, skin incisions for costotransversectomy vary.[18] Most surgeons prefer a midline incision, with or without a hockey stick extension, although semilunar and paramedian incisions are also described.[18] Following a midline incision, a traditional midline subperiosteal dissection of the paraspinal muscles is performed, extending the dissection laterally to expose the transverse processes, facets, and rib heads. The rib head below the level of the disk herniation sees the most lateral exposure. Alternatively, a paramedian incision can be made; the lateral border of the erector spinae muscle is identified, and the fascial plane is followed to the costovertebral junction. The muscle belly is then mobilized laterally, exposing the transverse process and facet.

Before initiating bone work, intraoperative fluoroscopy should be compared with preoperative imaging to confirm the level of pathology. An initial laminectomy or laminotomy is performed to effect dorsal spinal cord decompression. Next, the transverse process is removed to expose the rib head of the segment below the disk herniation. The proximal rib is carefully dissected out from the parietal pleura, taking care to preserve the neurovascular bundle that lies along the caudal ventral margin. The lateral aspect of the rib is cut using a drill or narrow Leksell rongeur. The rib head is disarticulated from the spine using curettes and Kerrison rongeurs to expose the lateral cortex of the pedicle, and the proximal rib is removed and saved if arthrodesis is to be performed. If not readily apparent, the neural foramina can be localized by tracing the intercostal nerve medially under the rib bed.[17] The pleura is then dissected subperiosteally along the lateral aspect of the disk space and end plates of the adjacent vertebral body and is retracted with a malleable retractor. The pedicle and facet can then be removed with a drill and rongeurs to afford a complete dorsal and lateral skeletonization of the spinal canal. The neurovascular bundle can be sacrificed to provide more exposure.

Before decompression, a space is made ventral to the spinal canal, into which the compressive disk material can be delivered. This requires at least a partial diskectomy and often necessitates extension into the adjacent vertebral bodies. The thecal sac is then carefully defined in relationship to the disk herniation, and disk material is delivered into the ventral space with minimal manipulation of the dura. One technique uses a down-angled curette and gentle and judicious use of a mallet. Resection of the PLL is preferable, when technically feasible, because it allows for confirmation of complete disk resection and adequate decompression. The ventral dural surface should then be inspected for any residual disk fragments or osteophytes. This may be accomplished with endoscopic assistance or with the use of angled mirrors. Stabilization and fusion can then be performed as indicated; this is required for lower thoracic exposures.

Advantages

- Better exposure of the ventrolateral spinal cord than can be achieved via the transpedicular-transfacet approach
- Less soft-tissue and muscle manipulation and rib resection compared with the lateral extracavitary approach (LECA), resulting in less postoperative pain[18]

Disadvantages

- Limited visualization of the ventral spinal canal compared with LECA; not advised for calcified centrally herniated disks, particularly those with intradural extension
- Significant postoperative pain, although less painful than transthoracic approaches and LECA

LATERAL EXTRACAVITARY APPROACH

Indication and History

The lateral extracavitary approach was originally developed by Capener[41] for the treatment of tuberculous spondylitis and was later applied to thoracolumbar fractures.[18] Its safety and efficacy for thoracic diskectomy has since been consistently proven in clinical series.[6,12,19,30] Although it shares many similarities to costotransversectomy, the LECA provides better exposure of the ventral spine while maintaining an extrapleural trajectory. The exposure provided by the LECA is particularly useful when corpectomy is indicated for the treatment of infectious, neoplastic, or traumatic disease.[15]

Positioning

Patients are traditionally placed in a prone position with arms taped to the sides. However, a "three-quarter" prone position with slight lateral rotation away from the surgeon may improve operative line of sight.[12]

Incision, Dissection, and Diskectomy

A "hockey stick" incision is made with the vertical segment centered at the level of the herniated disk. Caudally, the incision curves laterally 8 to 12 cm toward the side of the herniated disk to facilitate soft-tissue reflection and increase the amount of rib that may be exposed and removed.[18,42,43] Paramedian lunar-shaped incisions may also be used.[18] A flap consisting of skin, subcutaneous tissue, and superficial fat is reflected and rotated laterally to expose the ipsilateral erector spinae muscles. The erector spinae are isolated circumferentially, joining a typical subperiosteal dissection medially and ventrally along the spinous processes, laminae, transverse processes, and ribs with a blunt dissection along the lateral fascial border of the muscle. Once mobilized, the muscle belly is translocated medially, providing a continuous exposure of the posterior elements and rib heads up to several centimeters lateral to the tip the transverse process.

Once the muscle mobilization has been performed, the surgical approach mimics costotransversectomy. The key difference is that mobilization of the erector spinae permits more rib to be resected, enabling more pleural retraction and a more lateral view of the canal and disk space. Accordingly, greater rib resection facilitates greater exposure of the ventral spinal cord.

Advantages

- Extrapleural exposure of anterior spinal elements is allowed without pleural violation.
- The dura may be directly visualized during decompression of the disk space and PLL, enhancing the safety and efficacy of decompression.
- Ventral spinal canal exposure can be augmented by extending rib resection.
- LECA exposure may provide the requisite ventral exposure for midline calcified disks.

Disadvantages

- Risk of postoperative neuralgia and radicular artery injury
- Relatively high rate of exposure-related postoperative morbidity
- Suboptimal for medically ill patients who may respond poorly to prolonged anesthesia or prone positioning

Minimally Invasive Considerations

Minimally invasive variations of costotransversectomy and the lateral extracavitary approach have been reported with encouraging results (Fig. 30-5).[7,15,44] Here the angle of approach is selected according to the patient's pathology, the paraspinal musculature is dilated instead of mobilized, and the surgery is performed essentially as described in the text. This is a technically demanding procedure that requires specialized equipment and extensive experience with minimally invasive techniques.

Posterolateral Approaches

A primary advantage of posterolateral approaches to the thoracic spine is the limited soft-tissue dissection and bone resection required to access the thoracic disk space. More lateral approaches, such as costotransversectomy and the LECA, offer good exposure of the ventral dura but do not spare the ipsilateral facet joint and are considerably more invasive, potentially causing segmental instability at lower thoracic levels. Transpedicular and transfacet approaches are not appropriate for central and calcified herniated disks. However, these posterolateral approaches do provide adequate access to soft paracentral and lateral disks with minimal dural retraction. They reduce disruption of the bony and ligamentous anatomy and lessen postoperative pain.[45]

TRANSPEDICULAR APPROACH

Indication

Motivated by the high morbidity associated with posterior laminectomy for thoracic diskectomy and the pulmonary risks inherent with transthoracic approaches, Patterson and Arbit[42,45] developed the transpedicular approach in 1978. By removing the entire pedicle and facet, the transpedicular approach provides a more direct line of exposure to the disk space. It is important to note that despite its improved ventral exposure over laminectomy, the transpedicular approach does not achieve adequate ventral exposure for the removal of calcified, centrally herniated disks.[45] The transpedicular approach does allow for resection of lateral and soft paracentral herniated disks with limited bone resection and soft-tissue manipulation.[45]

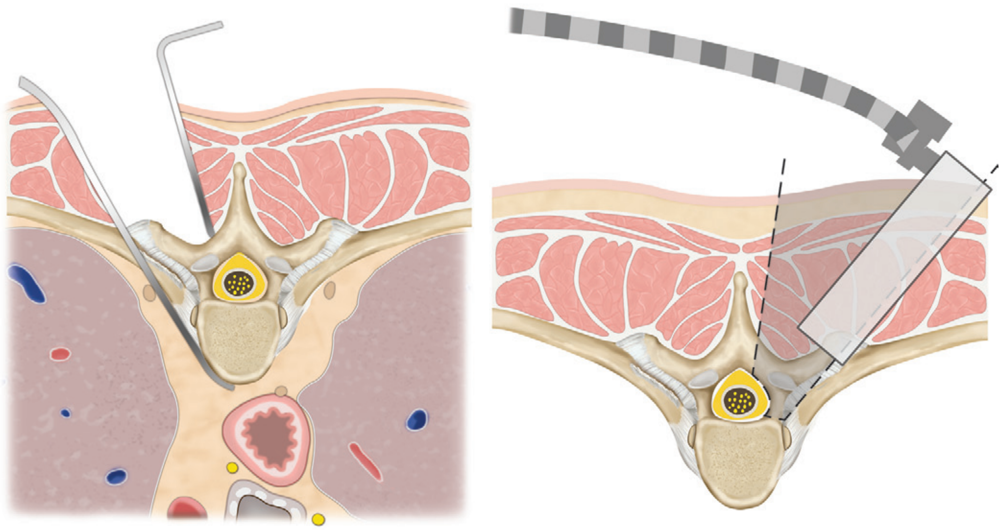

Figure 30-5 Comparison of exposures for open versus minimally invasive costotransversectomy/lateral extracavitary approach. In the open approach, lateral exposure is generated through mobilization of the erector spinae muscles, using fascial planes (*left*). In the minimally invasive approach, the laterality of retractor placement is according to surgeon preference, because the muscle is dilated, not mobilized (*right*).

Positioning

Patients are placed in the prone position, secured to the table such that they can be rotated during surgery to maximize the surgeon's line of sight. A radiolucent table should be used to facilitate intraoperative fluoroscopic confirmation of the appropriate pathologic level. This should be done in both anteroposterior (AP) and lateral views, using radiopaque marker placed on the transverse process overlying the appropriate pedicle. The thoracic level can be carefully estimated by counting up from the twelfth rib.[45]

Incision, Dissection, and Diskectomy

A standard midline linear incision is made over the levels of interest. Midline soft-tissue dissection is then carried out, exposing the spinous process, lamina, and facet joints.[18,45] The paraspinous muscles are further dissected free and are then reflected laterally to expose the medial transverse process and the facet joint. The caudal pedicle adjacent to the disk space is then located; at thoracic levels it lies beneath the intersection of the pars interarticularis, transverse process, and lamina.[45] A high-speed drill is used to achieve partial superior and inferior medial facetectomies, facilitating the drilling of the pedicle. The cancellous bone of the pedicle is drilled down to a depth at which drill resistance suggests the cortical bone of the vertebral body has been reached.[18,45]

A small cavity is drilled out to a depth of approximately 1.5 to 2 cm[15,18] in the vertebral bodies rostral and caudal to the disk space to facilitate careful decompression of the herniated disk away from the dura. The lateral disk space is incised, and the cavity is extended into the intervening disk space, using curettes and pituitary rongeurs to remove disk tissue. Residual fragments can be removed with down-angled curettes in a trajectory away from the exposed cord. Following decompression, right-angle probes and angled mirrors can be used to confirm the removal of pathologic disk fragments.[42,45]

Minimally Invasive Considerations

Minimally invasive variations of the transpedicular approach have been performed with or without the aid of an endoscope[46] with promising clinical results.[5,8,9] Minimally invasive endoscopic posterior approaches to the thoracic spine are discussed in greater detail in Chapter 31.

Advantages

- This approach is less invasive than anterior and lateral approaches to the thoracic spine.[18]
- Accordingly, relatively less blood loss occurs, operative time is shortened, postoperative pain is reduced, and hospital stays are shortened.[10,18,42]
- Fusion can often be avoided at the mid and upper thoracic levels because of the stabilizing effects of their articulations with the rib cage.[15]
- Risk of damage to radicular vessels is reduced.[45]

Disadvantages

- Visualization and access to central and contralateral portions of ventral dura are limited.[18]
- This approach is contraindicated for calcified paracentral or central disks.
- Postoperative localized back pain is common.[10,18,42,45]

TRANSFACET APPROACH

Indication and History

A modified version of the transpedicular approach, the transfacet approach, was developed in part because of concerns that pedicle resection performed without stabilization in the transpedicular approach could explain chronic postoperative back pain seen in some patients.[10,18,42,45] The transfacet approach was designed to spare the ipsilateral pedicle.[10,29] Cadaveric studies carried out by Stillerman and colleagues[29] determined that thoracic spine exposure comparable to that achieved with the transpedicular approach could be accomplished via a transfacet bone window, leaving the lamina and pedicle intact.[10,29] The transfacet pedicle-sparing approach is an excellent posterior approach most suitable for lateral and preferably soft-disk herniations that can be removed with minimal manipulation of the thecal sac.

Positioning

The patient is positioned prone with arms out to the sides, similar to the transpedicular approach. A radiolucent spinal table must be used to facilitate pathologic-level localization via AP and lateral fluoroscopic imaging.

Incision, Dissection, and Diskectomy

A linear midline incision is centered over the disk space.[10,18,29] Soft-tissue dissection is then carried out in a subperiosteal plane, preserving midline dorsal ligaments and reflecting paraspinal musculature laterally. The ipsilateral lamina, facets, and transverse processes above and below the herniated disk are exposed. With this exposure achieved, fluoroscopy should again be used to verify the correct disk space and, if disk material has calcified, the location of the disk. A high-speed drill can then be used to perform a medial facetectomy, taking care to preserve the lateral margins and caudal pedicle. Once the bone facet window has been made, electrocautery can be used to remove underlying adipose tissue to expose the annulus of the ipsilateral herniated disk.[10,18,29] Vertebral end plate osteophytes that obscure the disk can be removed with a narrow-bladed osteotome.[47] The superior edge of the pedicle can be drilled away to create additional exposure, in the same fashion as is often performed during a posterior cervical microdiskectomy. Alternatively, instead of a facet "window," exposure can be obtained through a lateral, partial facetectomy.

The offending disk can then be removed with standardized microdiskectomy techniques, working in a lateral-to-medial direction with down-angled curettes and pituitary rongeurs to create a central cavity. Residual herniated disk fragments can be decompressed with down-angled curettes into the empty cavity. Care must be taken to avoid the exiting nerve root as it courses under the rostral pedicle. Right-angle probes can then be used to confirm decompression and removal of all pathologic disk fragments.[47] As with the transpedicular approach, endoscopy may be used to improve visualization of the central and contralateral ventral dural surface.

Minimally Invasive Considerations

Minimally invasive variations of the transfacet approach have been described. These vary in terms of muscle dissection, retractor type (self-retaining or tubular), method of operative visualization (microscope vs. endoscope), and extent of facet resection (lateral, partial, or "window"). Advantages include direct exposure over the lateral disk with minimal approach-related morbidity, sparing of the caudal pedicle, and disk removal without risk of entering the thoracic cavity.[29,46,48,49] In small clinical series of soft thoracic disk herniations, the transfacet approach accomplished with muscle-splitting tubular retractors and endoscopic visualization achieved excellent outcomes.[48]

Advantages

- Considerably less invasive than anterior and lateral approaches to the spine, leading to reduced blood loss, reduced operative time, and a shorter hospital stay.
- Sparing of the pedicle and partial facet reduces postoperative pain, expedites return to normal activity, and provides local stability.[10,18,29]
- This approach is amenable to minimally invasive surgical techniques.

Disadvantages

- Dorsal surgical trajectory makes this approach inappropriate for calcified paracentral or central herniated disks.
- Like the transpedicular technique, the transfacet approach provides limited visualization of the ventral dural surface. This may be augmented by the use of an endoscope (see Chapter 31).

Postoperative Course

Recovery from thoracic diskectomy varies greatly according to surgical approach. This spectrum is best conceptualized by reviewing the range of exposures discussed in this chapter. The recovery from an open transthoracic resection of a centrally herniated calcified disk with chest tube placement can entail an extensive surgery-related recovery, whereas the recovery from a minimally invasive transfacet resection of a soft and laterally herniated disk can be quick. In patients with myelopathy on presentation, recovery is highly dependent on the patient's preoperative neurologic condition and individual response to surgery, which can be highly variable.[15] As with cervical myelopathy, the hallmark of a successful surgery is halting of the progression of neurologic deterioration. Improvement in symptoms is frequently seen but should not be an expected outcome, and complete recovery, especially in cases of chronic or subacute myelopathy, is unlikely. Patients should have their expectations appropriately guided regardless of the surgical approach used.

Complications

A review of reported complication rates for thoracic diskectomy led McCormick and colleagues[1] to conclude that, excluding laminectomy, the overall rates of morbidity and mortality are similar among thoracic approaches. More specifically, no significant difference was found in the incidence of cerebrospinal fluid (CSF) leak, infection, pulmonary embolism, or postoperative neuralgia.[1] In an earlier review, Fessler and Sturgill[50] arrived at similar conclusions, finding no significant difference in approach-related rates of morbidity (excluding laminectomy) in all clinical series reported before 1993. Devastating complications, such as paralysis and mortality, have become very rare since laminectomy was abandoned.[1,50]

In a large, modern series of 82 patients with symptomatic herniated thoracic disks who were treated using a variety of approaches, Stillerman and colleagues[10] reported a complication rate of 14.6% (12/82). Three of these complications were considered major and included a cardiopulmonary event in a medically ill patient that led to death, spinal instability that required reoperation, and increased postoperative paraparesis. The remaining minor complications were transient in nature and resolved without additional surgery.[10]

Some authors advocate the use of preoperative angiography to localize the artery of Adamkiewicz and other major medullary feeders. If a significant vessel is identified at the level of the disk herniation,[17,19,51] a contralateral approach can sometimes be attempted. In all cases, special care must be taken when performing dissection within the neural foramina, where radicular arteries are most vulnerable to injury.

CSF leaks are of particular concern following thoracic procedures that violate the pleura. Dura–pleura fistulas can result from CSF leaks in this situation and are often very difficult to resolve. If the dura is violated—either iatrogenically or volitionally, to remove an intradural herniated disk—a watertight seal must be pursued via a dural graft and other dural closure aids. If a watertight seal cannot be achieved, placement of a chest tube to low wall suction and/or a lumbar drain may help facilitate resolution of a potential dura-pleura fistula.[1]

One of the most common complications identified by McCormick and is operation at the wrong thoracic level.[1,33] Special care must be taken to identify and confirm the appropriate level when performing thoracic diskectomy. The reference points used in cervical and lumbar surgery are not readily available in thoracic surgery. Instead, the level of the disk herniation must be determined by correctly by counting the number of ribs on preoperative imaging, and the method of counting used must be the same method used in the operating room.

Generally speaking, caudal thoracic levels are localized using intraoperative anteroposterior fluoroscopy to identify the most caudal rib and count upward. Rostral thoracic levels can be correctly localized on AP fluoroscopy by identification of the first thoracic vertebra, which has a characteristic appearance, and counting down to the level of pathology. This process, however, is contingent on the identification of any anatomic variants, such as cervical ribs that lie rostrally and transitional or rudimentary ribs or large transverse processes caudally. These features may be poorly visualized or simply not within the imaging field of a standard thoracic MRI. Thus a good preoperative chest x-ray or a CT scan that includes either the lumbar or cervical segments and extends into the thoracic spine and through the level of the pathology can be extremely helpful. Equally important is the quality of intraoperative fluoroscopy,[15] although in some cases, uncontrollable factors, such as body habitus or osteoporosis, can make it extremely difficult to produce quality x-rays.

Localization for thoracic disk herniation can be very challenging and is never a routine matter. Some have explored the use of intraoperative stereotactic image guidance, with[52] or without[53] preoperative percutaneous fiducial pin placement.

Conclusion

Thoracic disk herniations are heterogeneous with respect to presenting symptoms, intrinsic physical properties, and anatomic relationship to the spinal cord. This explains why an array of approaches has been developed for this relatively rare surgical condition. The history of surgery for thoracic disk herniations reflects disaffection with neurologic outcomes from a purely dorsal approach (i.e., laminectomy) and the subsequent adoption of anterolateral, lateral, and posterolateral approaches—transthoracic, retropleural, lateral extracavitary, and transpedicular-facet—that were more invasive but have resulted in excellent neurologic outcomes.[12,13,42,51]

The more recent development of minimally invasive approaches has been driven by a desire to mitigate postoperative pain and recovery time while maintaining excellent outcomes. Minimally invasive thoracic diskectomy is likely to become more prevalent as technology and techniques evolve and more surgeons become comfortable with these methods. However, minimally invasive approaches are not ideal for all disk herniations; therefore open approaches will remain a mainstay in the treatment of thoracic disk herniation for the foreseeable future.

The evidence cannot clearly elucidate the superiority of one approach over another for all thoracic disk herniations. Indeed, given the relative rarity of this pathology and the case-to-case heterogeneity, such comparisons are difficult and likely inappropriate. The decision whether to employ a less invasive approach over a more invasive one, and which approach to select, is likely to remain primarily influenced by the constraints of the pathology and the training and expertise of the individual surgeon. Thoracic pathology thus challenges the practicing clinician to maintain competency in multiple approaches.

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31 Thoracoscopic and Posterior Endoscopic Approaches to the Thoracic Spine

ILSUP KIM and DANIEL H. KIM

Thoracoscopic Approach

OVERVIEW

For the surgery of thoracic spinal tumors, open thoracotomy is usually used. However, morbidity associated with conventional open thoracotomy often limits the application of anterior approaches to the thoracic spine. Most of the vertebral body tumors of the thoracic spine involve the anterior column; these tumors require rib removal and parietal pleura opening, which can cause complications, such as postthoracotomy syndromes and intercostal neuralgia.[1] Open thoracotomy also requires extensive exposures, and incisions measure up to 20 cm. In recent years, minimally invasive open microscopic approaches using special retractors have been developed that can minimize the size of the operative access to 6 to 10 cm. These "mini approaches" are quite feasible in surgery on the upper and midthoracic spine. The limited working space available through small incisions may block the microscopic view and result in difficult manipulation of instruments. However, video-assisted thoracic surgery (VATS) using four portals in the chest wall permits surgery that is as effective as the open approaches, and it provides a better view than the microscopic one. Unlike the open approaches, the surgeon's operative view is not obscured by hands or operative instruments, and the high morbidity associated with open procedures can be avoided. Biomechanically, as with any other anterior approach to the spine for reconstruction, the VATS approach significantly increases the axial load-bearing capabilities of the spine.[2]

The goals of thoracoscopic surgery include neural decompression, restoration of normal curvature, and stability of any affected motion segments. This is usually achieved in a two-step procedure that includes posterior reduction and stabilization with a pedicle screw system if necessary in patients with significant deformity or three-column involvement. Anterior decompression of the spinal canal, reconstruction of the vertebra, and interbody fusion with autogenous bone graft (or bone-impacted cage) and screw-plate fixation are performed through a thoracoscopic anterior approach; this can be extended into the retroperitoneal space down to L3 with thoracoscopic diaphragm detachments, if necessary.

INDICATIONS

- Fractures of the thoracic spine located at the thoracolumbar junction from T4 to L3
- Fractures classified as A 1.2, 1.3, 2, and 3; B; and C according to the Association of Osteosynthesis (AO) classification, with significant curvature disturbance of 20 degrees or more in the sagittal or frontal plane[1]
- Fractures of type B and C
- Posttraumatic, degenerative, or tumorous narrowing of the spinal canal
- Diskoligamentous segmental instability
- Posttraumatic deformities
- Vertebral body tumor, primary or metastatic, that affects only the anterior column
- Neurogenic tumors in the thoracic spine (schwannoma, neurofibroma)
- Dumbbell tumor with large intrathoracic component
- Tumors of nerve origin that arise from segmental intercostal nerve

CONTRAINDICATIONS

- Significant previous cardiopulmonary disease with restricted cardiopulmonary function
- Acute posttraumatic lung failure
- Significant disturbances of hemostasis

SURGICAL TECHNIQUE

Instruments

The following instruments are necessary to perform endoscopic-assisted anterior approaches to the thoracic spine:

- Routine surgical set for skin incision and preparation of the intercostal space
- Instruments for removal of bone graft from the iliac crest
- Video-endoscopy tower and endoscopes
- Instruments for thoracoscopic dissection of the prevertebral anatomic structures and resection of bone and ligaments; osteotomes; hooks for dissection and hook probes;

sharp, blunt, and Kerrison rongeurs; curettes; a graft holder; reamers; and monopolar and bipolar probes. All thoracoscopic instruments are of suitable length and have large handles, making it possible to guide the instruments with both hands and to work safely and securely with them.

- Instruments for implant placements (modular anterior construct system for thoracolumbar spine [MACS-TL]; B. Braun Melsungen AG, Tuttlingen, Germany): Most currently available spinal implants for anterior thoracic instrumentation are developed for open surgery and thus have to be modified to make them compatible for endoscopic use, whereas the MACS-TL system is designed for thoracoscopic use and thus greatly simplifies the instrumentation technique. Emphasis was placed on endoscopic insertion and intracorporeal assembly of the implants and free placement of screws and angular stability by using polyaxial screws. Targeting and centering sleeves guide self-centering of the assembly instruments.
- Instrument preparation set: K-wires, cannulated punch/cortical drill for decortication
- Instrument insertion set: centralizer attachment, screw insertion assembly instrument, distraction ratchet, cannulated nut driver
- Implant set twin screw (MACS-TL)
- Disposable instruments, lung retractor, clip applicator

Anesthesia

The procedure is performed with the patient under general anesthesia. Selected intubation with one-lung ventilation facilitates intrathoracic preparation. The positioning of the double-lumen tube is controlled by a bronchoscopic technique. A Foley catheter is placed along with central venous lines and an arterial line for continuous blood pressure monitoring.

Positioning

The patient is placed in a stable lateral position on the right side and is fixed with a four-point support at the symphysis, sacrum, and scapula; arm rests are also provided (Fig. 31-1). A left-sided position is preferred for the treatment of fractures from T4 to T8, whereas a right-sided position is preferred for the approach to the thoracolumbar junction (T9–L3). Care must be taken to abduct and elevate the upper arm so as not to disturb the placement and manipulation of the endoscope. Before the operation starts, the position and free tilt of the C-arm must be checked. Sterile draping extends from the middle of the sternum anterior to the spinous processes posteriorly and from the axilla down to about 8 cm caudal to the iliac crest. Both monitors should be placed at the lower end of the operating table on opposite sides to enable free vision for the surgeon and the assistant. The surgeon and cameraman stand behind the patient, the C-arm approach is between the surgeon and the cameraman, and the assistant and the C-arm monitor are placed on the opposite side.

The surgical technique of thoracoscopic spine surgery has been described in detail by various authors. Early in our experiences, we often reserved the thoracoscopic approach for thoracic fractures involving the T4 to T10 vertebrae. With increasing experience, we extended the indications to pathologies that involve the thoracolumbar junction.

Localization

The target area is projected onto the skin level under fluoroscopic control. The borders of the lesion vertebra are marked on the skin to indicate the line of the anterior and posterior edges and the end plates of the affected segments (Fig. 31-2). The working channel is centered over the target vertebra (12.5 mm).

The optical channel (10 mm) is placed two or three intercostal spaces cranial to the target vertebra in the spinal axis (Fig. 31-3). For fractures of the middle and upper thoracic spine, the optical channel is placed caudal to the target vertebra. The approach for the suction/irrigation (5 mm) and retractor (10 mm) is about 5 to 10 cm anterior to the working and optical channels.

Placement of Portals

Through a 1.5-cm skin incision above the intercostal space, small Langenbeck hooks are inserted. Muscles of the

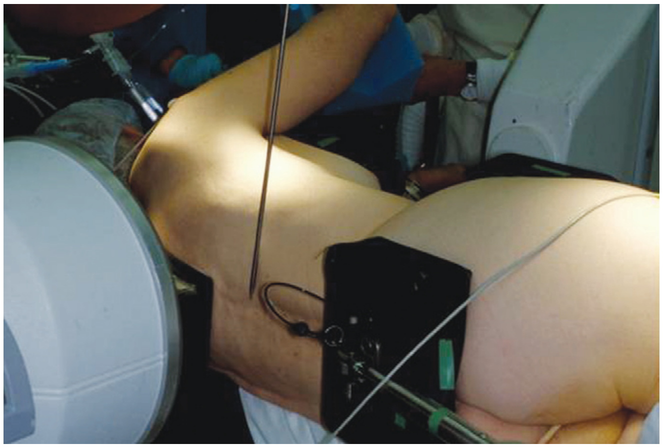

Figure 31-1 Position and level confirmation. The patient is placed in a stable lateral decubitus position and is fixed with a four-point support.

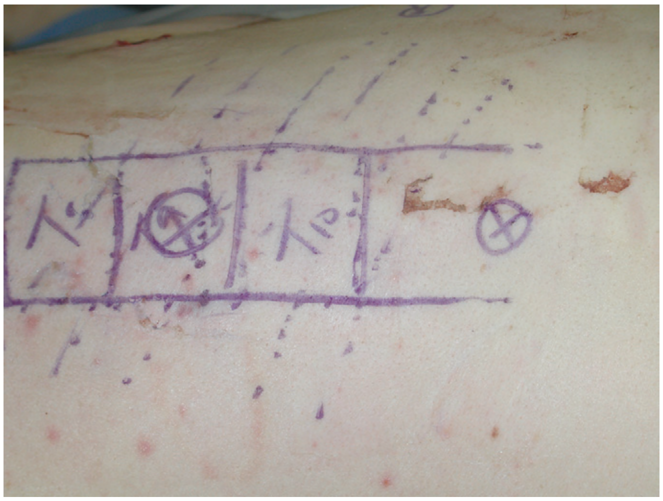

Figure 31-2 Localization for the lesion. The target area is projected onto the skin under fluoroscopic control. The borders of the lesion vertebra are marked on the skin.

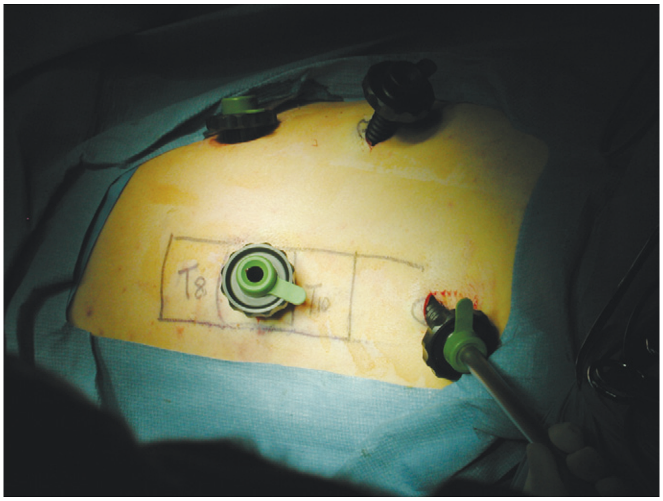

Figure 31-3 Locations of the portals for T9 lesion. The optic channel is located on the caudal side. The retractor and suction instrument are located on the ventral side.

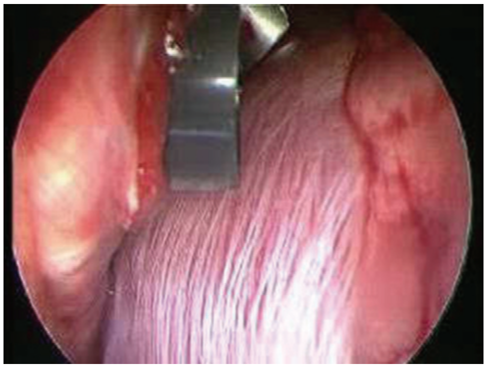

Figure 31-4 The portal is seen from the endoscopic channel. Perforation of the thoracic wall with the third trocar is performed under visual control through the scope.

thoracic wall are crossed in a blunt, muscle-splitting technique; the intercostal space is opened by blunt dissection, thus exposing the pleura and creating an opening to enter the thoracic cavity. The 10-mm trocar is inserted, and one-lung ventilation is started. The 30-degree scope is inserted at a flat angle in the direction of the second trocar. Perforation of the thoracic wall to insert the second, third, and fourth trocar is performed under visual control through the scope, and the other trocars are inserted as shown (Figs. 31-3 and 31-4).

Prevertebral Dissection and Diaphragm Detachment

The target area can now be exposed with the help of a fan retractor inserted through the anterior port. The retractor sweeps away lung tissue and holds down the insertion of the diaphragm on the spine. The anterior border of the vertebral body and disk, as well as the course of the aorta, is palpated with a blunt probe (Fig. 31-5).

Parietal pleura is widely incised with a hook diathermy electrode (Fig. 31-6). The incision starts from the anterior border of the vertebral body and continues to the rib head and to the proximal rib segment. The incision line should

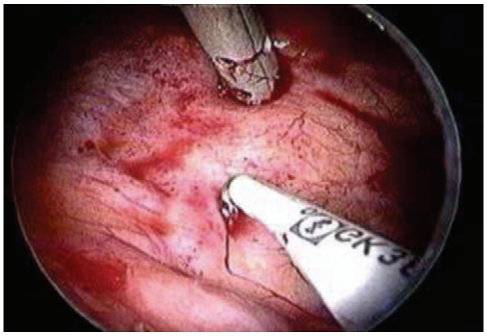

Figure 31-5 The greater vessels are palpated with a blunt probe.

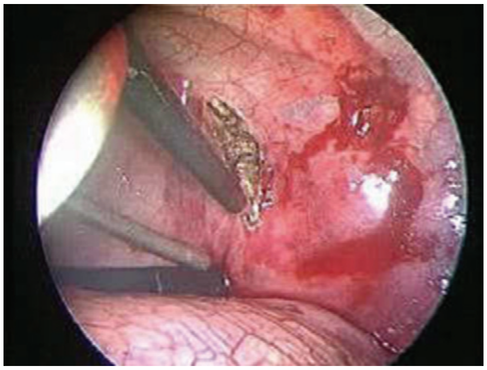

Figure 31-6 Prevertebral dissection of the T10 vertebral body.

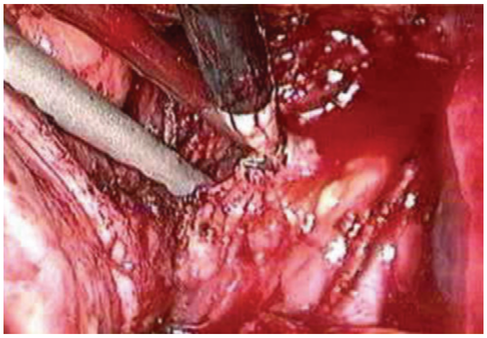

Figure 31-7 Extension of the parietal pleura dissection.

be at the disk level, and care should be taken not to injure the segmental vessels located in the midportion of the vertebral body. The parietal pleura over the vertebral body caudal side to the lesion is stripped off first, and sometimes the pleural membrane is so thick that grasping is needed for the dissection.

After the linear dissection of the pleura is done, the enlargement of the dissection continues from disk level to the adjacent vertebral bodies (Fig. 31-7). The segmental vessels can be coagulated and divided with clips or cautery.

Screw Insertion

Before the cannulated screw is inserted into the adjacent vertebral body, the K-wire is impacted (Figs. 31-8 and 31-9). The insertion point is 1.5 cm from the posterior border of the vertebral body and 10 mm away from the end plate, and the insertion depth is about 20 mm. The correct point should be confirmed with fluoroscopic guidance; it is also

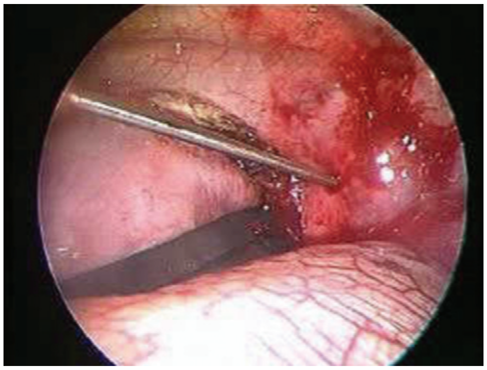

Figure 31-8 K-wire insertion.

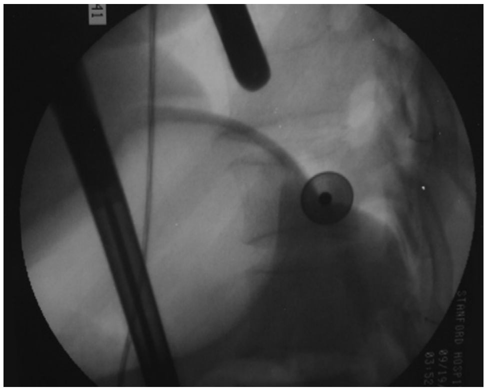

Figure 31-9 Intraoperative radiograph shows the correct location of the K-wire.

Figure 31-10 A polyaxial posterior screw is inserted.

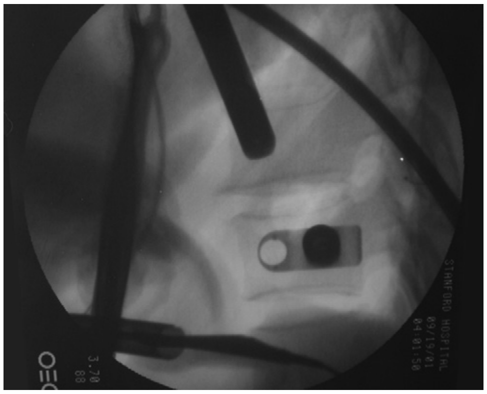

Figure 31-11 After the screw is inserted, the plate is shown.

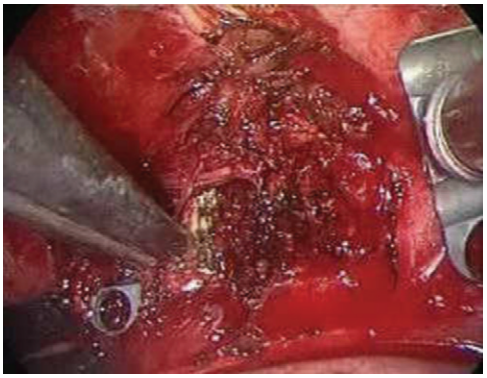

Figure 31-12 Coagulation of caudal-side disk before diskectomy.

Figure 31-13 Margin demarcation of the tumor mass (T9).

important to confirm the perpendicular position of the patient to the beam. The polyaxial posterior screw is placed over the K-wire (Figs. 31-10 and 31-11). The direction of the polyaxial clamp can be controlled by the handle. The clamp must be oriented such that the hole for the anterior stabilization screw comes to lie anteriorly. After the first turns of the screw into the vertebral body, the K-wire must be removed to avoid the risk of tissue perforation by pushing the K-wire forward during screw insertion. After partial insertion of the polyaxial screws, the K-wire must be removed.

Diskectomy

After the screw is inserted into the adjacent vertebral body, the disks are removed. The disk is shrunken with a monopolar coagulator and removed with a curette (Fig. 31-12). For the effective removal of the disk, the rib head should be drilled away. The proximal 2 cm of the rib is removed using a high-speed drill to expose the lateral surface of the pedicle and neural foramen.

Corpectomy

After the disk is removed, the corpectomy margin is prepared with a monopolar coagulator (Fig. 31-13). When the anterior margin is coagulated, the coagulation point should be 10 mm away from the great vessels (Fig. 31-14). After the parietal pleura is coagulated, the extent of the planned vertebrectomy is defined with an osteotome. The tumor mass is removed piece by piece with a curette and pituitary forceps (Fig. 31-15). For the complete decompression of the

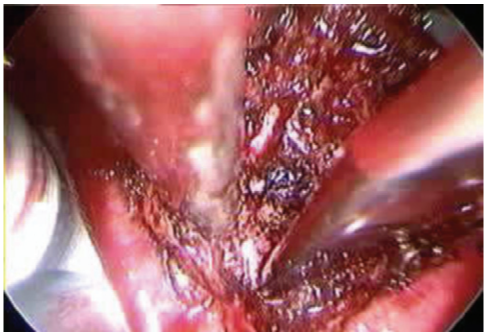

Figure 31-14 Anterior margin of the corpectomy is cut with an osteotome.

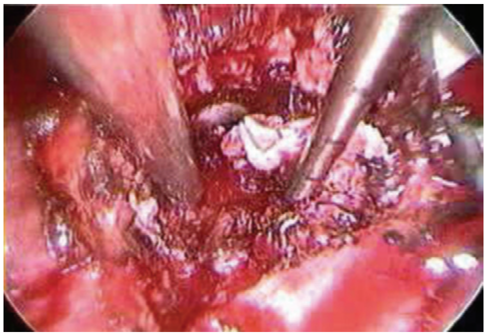

Figure 31-15 Tumor removal with curette.

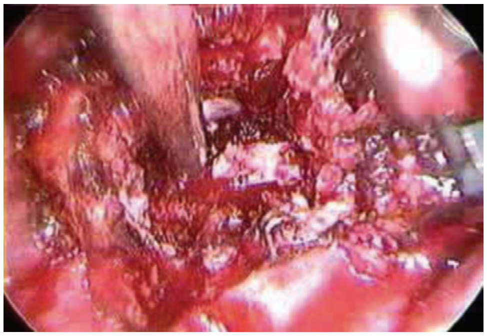

Figure 31-16 After tumor removal, the ventral surface of the spinal cord is seen.

spinal cord, the pedicle should be removed. The lower border of the pedicle should first be identified with a blunt hook. The base of the pedicle is then resected in a cranial direction with a Kerrison rongeur, and the thecal sac can be identified from the lateral direction. The decompression is continued until the ventral surface of the dura is visualized (Fig. 31-16). The posterior longitudinal ligament can be removed with the Kerrison rongeur to expose the dura. Bone bleeding is controlled with bone wax, and epidural hemostasis is achieved with Gelfoam and bipolar cautery.[3,4]

Reconstruction of the corpectomy site can be done with either a bone graft or titanium mesh cage, depending on the pathology (Fig. 31-17). An autograft, allograft, and bone cement–filled titanium mesh are used. In cases of metastatic tumor, bone cement graft is favored. Preparation of the graft bed is then completed, the length and the depth of

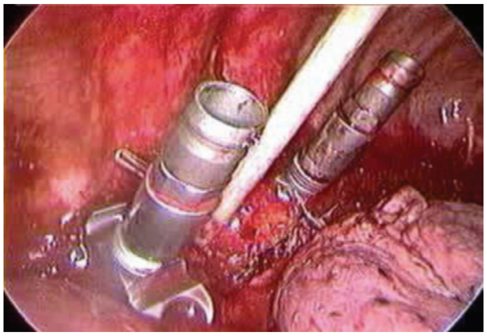

Figure 31-17 The allograft bone is inserted into the corpectomy site.

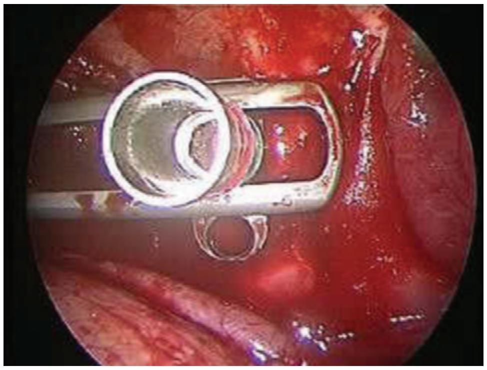

Figure 31-18 The plate is inserted over the screw head.

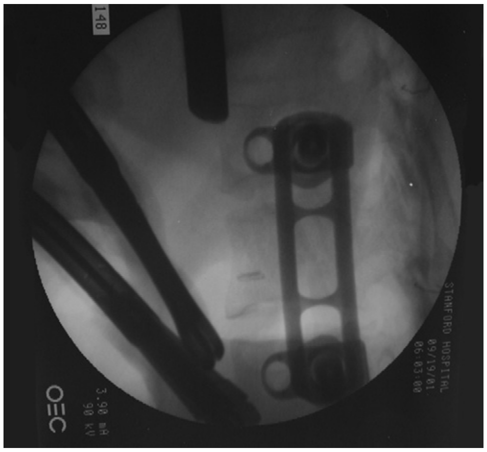

Figure 31-19 The plate is applied into the screw (radiographic confirmation).

the bone graft are measured with a caliper, and the bone graft is prepared for insertion and mounted on a graft holder. The cortical bone is perforated with several burr holes to facilitate vascular ingrowth and new bone formation. The working portal is removed, and a speculum is inserted. This allows the insertion of a bone graft up to 1.5 cm in length into the thoracic cavity.

Plate or Rod Placement

Using the measurement device, the distance between the polyaxial heads must be measured. If the plates are used, 30 mm must be added to select the proper plate length (Figs. 31-18 and 31-19). The stabilization plate is then placed onto the polyaxial heads; the rounded side with the markings is the upper side of the plate. In cases of multisegment assemblies, rod connection must be chosen.

Final Fixation

After the plate or rod is placed and the polyaxial plate is well aligned, the assembly can be closed by using a fixation nut (Fig. 31-20). The nut should be placed with the smooth part against the stabilization plate. Using the cannulated nut driver, the nut can be placed and tightened onto the screw. An anterior screw is added with the aid of the guiding instrument.

Closure

The retractor should be rearranged, and the gap in the diaphragm is closed with staples or adaptive sutures using the endoscopic technique. The thoracic cavity is irrigated to remove any blood clots, and a chest tube is inserted with the end placed in the costodiaphragmatic recess. The portals can be closed with sutures after removal of the trocars.

POSTOPERATIVE CARE

The patient is extubated immediately after the operation. Anteroposterior (AP) and lateral radiographs of the target area are taken postoperatively. In patients with chronic obstructive pulmonary disease (COPD), elderly patients, and patients with cardiovascular disease, artificial ventilation may be necessary for the first 24 hours after the operation. Low-dose, low-molecular-weight heparin is given for thromboembolic prophylaxis, and the patient stays in the intensive care unit for 24 hours. Chest tubes can usually be removed on the first postoperative day. Mobilization and ventilation training start on the first postoperative day, and physiotherapy is started (1 hour/day) on the second postoperative day. From the third postoperative week, physiotherapy is intensified to 2 to 3 hours daily. A plain radiograph is obtained on the second postoperative day, after 9 weeks, and after 6 and 12 months. The patient is allowed to return to work after 12 to 16 weeks.

COMPLICATIONS

The thoracoscopic procedure for corpectomy and instrumentation is relatively new, but the spectrum of complications is similar to that of open thoracotomy or thoracoabdominal approaches. The overall complication rate of the thoracoscopic technique is similar to or even less than the rate associated with postoperative functional recovery.

Injuries to major organs (lung or heart), the aorta, and vena cava are the most hazardous intraoperative complications. Distorted spine anatomy and insufficient preparation of the segmental vessels can result in accidental injury, bleeding, and loss of visual control. Other complications can occur and include dural tear, peritoneum opening, lung injury, and nerve injury by uncontrolled monopolar coagulation. Possible intraoperative complications are hemothorax, recurrent pleural effusion, intrathoracic adhesion, deep wound infection, and implant failure. Most of these complications occurred early in the series as a result of technical difficulties, and some required thoracotomy or open revision, which abolished all the advantages of a minimally invasive procedure.

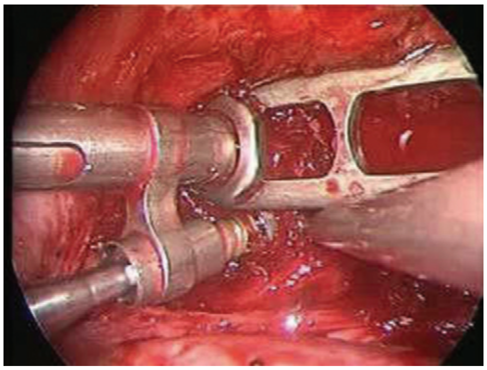

Figure 31-20 The anterior screw is inserted with the help of the guiding instrument.

CASE ILLUSTRATION

A 19-year-old man was asymptomatic except for chronic coughing. He was diagnosed with pneumonia. Although the sputum examination for bacteria and tuberculosis all turned out to be negative, chest radiograph showed questionable paraspinal thickening. Physical examination turned up no skin lesions, palpable masses, or deformities, and no neurologic abnormality was found. Computed tomography (CT) and magnetic resonance imaging (MRI) scans were taken. MRI showed a long, slender paraspinal mass along the right side of the thoracic spine from T10 to T12 (Fig. 31-21). The mass was adhered to the vertebral bodies on right side and was attached to the dome of the diaphragm (Fig. 31-22). The aorta was about 3 or 4 mm

Figure 31-21 Sagittal magnetic resonance image shows the low-signal mass ventral to the vertebral body from T10 to T12.

away from the mass, and no connection of the mass to the spinal cord was found (Fig. 31-23). The possibility of a schwannoma was low.

Operation was done thoracoscopically from the right side. When the lower thoracic cavity is entered, the pulmonary ligament is seen. The pulmonary ligament represents the transition between the parietal and visceral pleural surfaces adjacent to the diaphragm posteroinferiorly. The lower thoracic spine is exposed after the pulmonary ligament is cut (Figs. 31-24 and 31-25). The diaphragm is carefully retracted caudally with an endoscopic fan retractor to expose the costodiaphragmatic recess. Within the thoracic cavity, the thoracolumbar junction can be visualized endoscopically as low as the T12–L1 disk space and L1 vertebral body.

If the right lung collapses, the lower border corresponds to the T10–T11 disk space. It does not prohibit access to the surgical field. After lung collapse, the pericardial surface is seen.

The exposed lower thoracic vertebral bodies show the elevated appearance. After parietal pleura is incised enough to expose the whole length of the mass, marginal dissection is started (Fig. 31-26). The superficial vessels on the tumor are sealed with bipolar cauterization, and the tumor mass is incised and divided into small sections with a scapel.

A large piece of tumor is grasped with a disk rongeur and removed through the endoscopic portal. The intercostal nerve from which the tumor originated is identified and sectioned distal to the tumor to mobilize the tumor mass

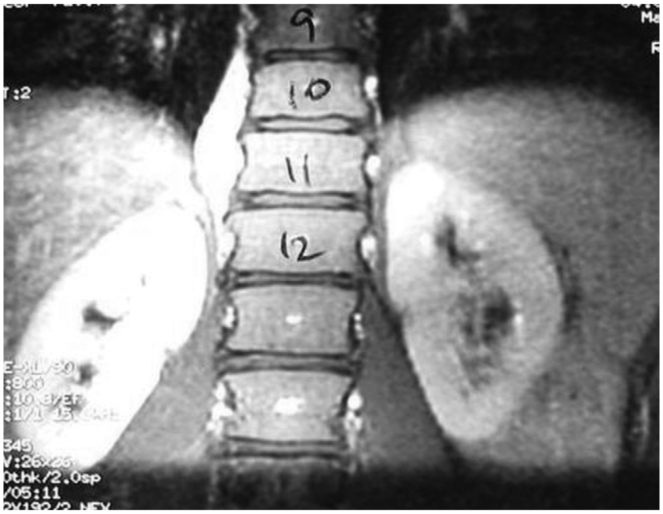

Figure 31-22 Coronal magnetic resonance image shows the mass located between the diaphragm and the lower thoracic spine.

Figure 31-23 Axial magnetic resonance image shows the mass is paraspinal but has no connection to the spinal cord.

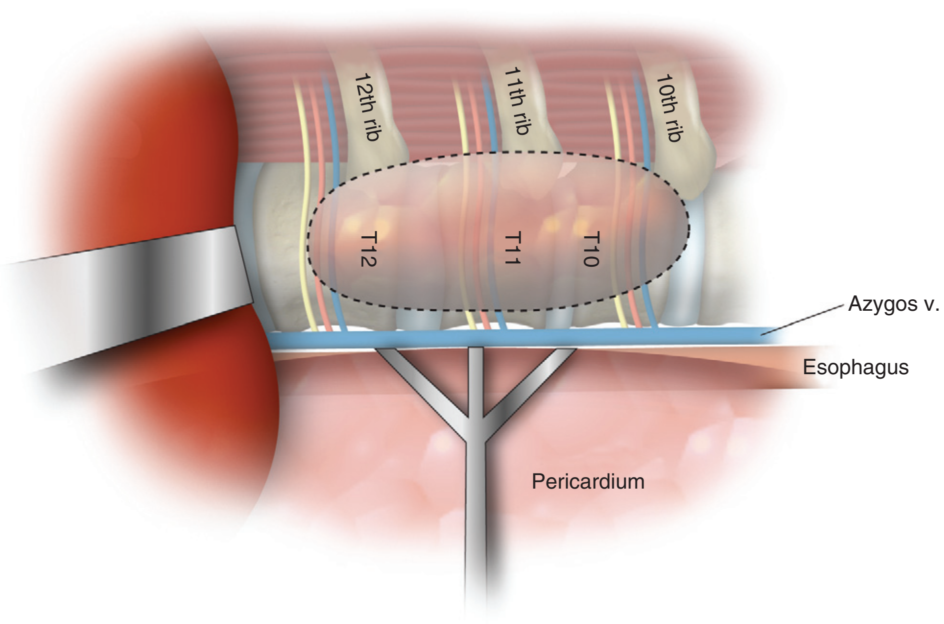

Figure 31-24 Thoracoscopic view of the paraspainal mass at the level of the lower thoracic spine.

(Fig. 31-27). The residual portion located near the neural foramen is removed using microdissection tools and a disk rongeur; the segmental vessels lie beneath the mass. With careful dissection, the lower surface of the mass is easily dissected from the vertebral body (Fig. 31-28). If the underlying segmental vessels are injured, the use of bipolar coagulation or hemoclip application can control the bleeding. The pathology was ganglioneuroma.

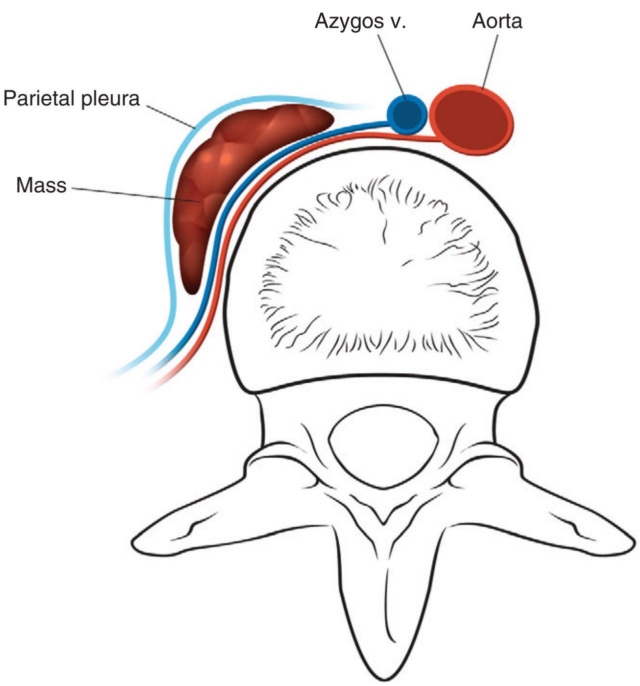

Figure 31-25 Axial view of the mass located between the diaphragm and segmental vessels.

Posterior Endoscopic Approach

INTRODUCTION

Posterolateral endoscopic thoracic diskectomy (PLETD) developed from percutaneous endoscopic lumbar diskectomy.[5-13] However, this procedure is technically demanding, because the thoracic disks are difficult to approach surgically, even for the experienced surgeon.[12-16] Two kinds of percutaneous PLETDs are common. The first is *C-arm–guided percutaneous endoscopic thoracic diskectomy* (PETD) using a rigid working-channel scope.[12] The working channel allows passage of a side-firing holmium yttrium-aluminum-garnet (Ho:YAG) laser and microforceps, and excellent visualization via the endoscope permits the surgeon to selectively remove a portion of the herniated disk; after the annular anchorage is loosened by the side-firing laser, the herniated fragment can be easily removed by the microforceps. The second procedure is real-time CT-guided percutaneous endoscopic thoracic annuloplasty (PETA) using laser-assisted spinal endoscopy (LASE; Clarus Medical, Minneapolis, MN). CT fluoroscopy, which is one of the most recent advances in interventional radiology, provides accurate spatial and real-time information. LASE integrates a Ho:YAG laser, endoscopy, illumination, and irrigation, and it allows vaporization and shrinkage of disk tissue through a small cannula. LASE is especially developed for targeted posterior decompression and posterior annuloplasty. The major advantages of these minimally invasive thoracic diskectomies include 1) minimized muscular and bony damage, 2) no dural sac and root manipulation, 3) less risk

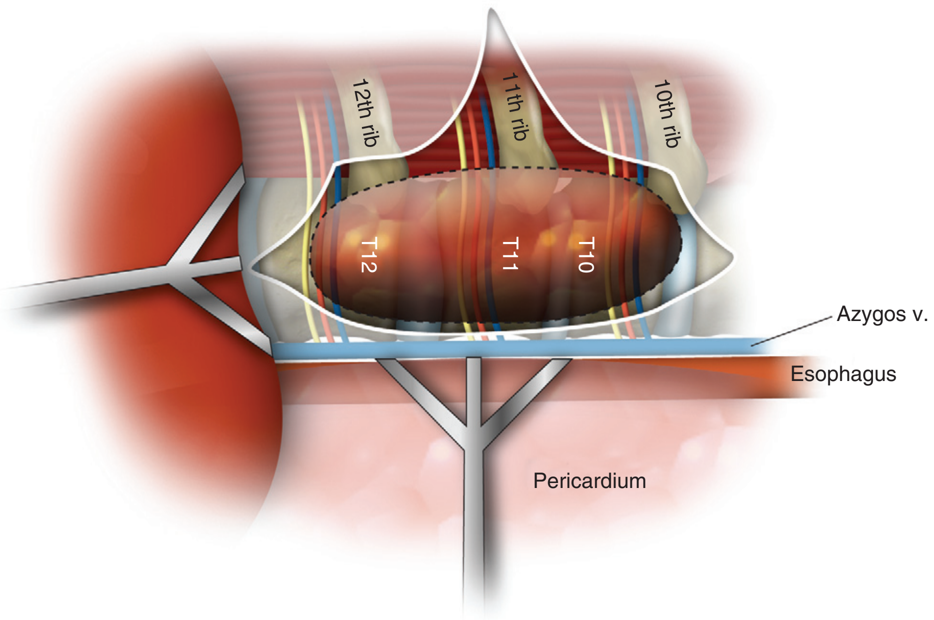

Figure 31-26 Wide pleural opening for tumor removal.

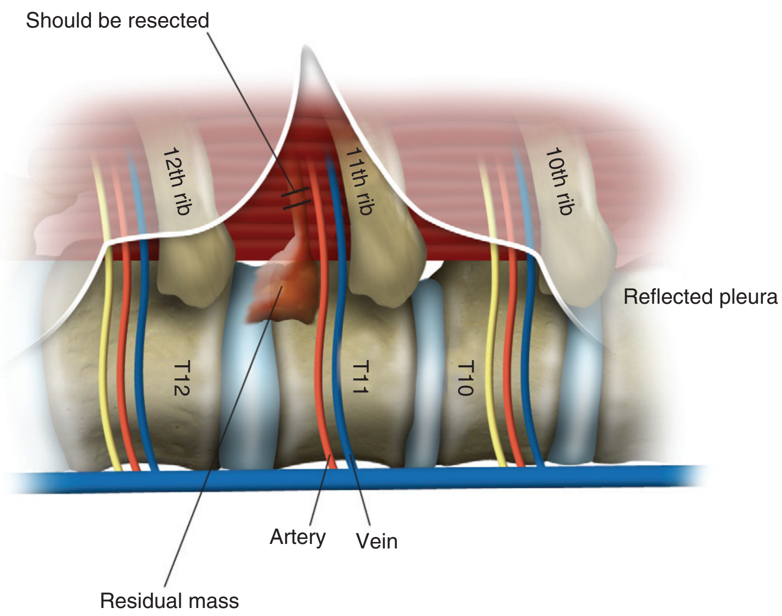

Figure 31-27 After large pieces are removed, the remnant mass is seen at the origin site of the intercostal nerve. The distal portion should be resected.

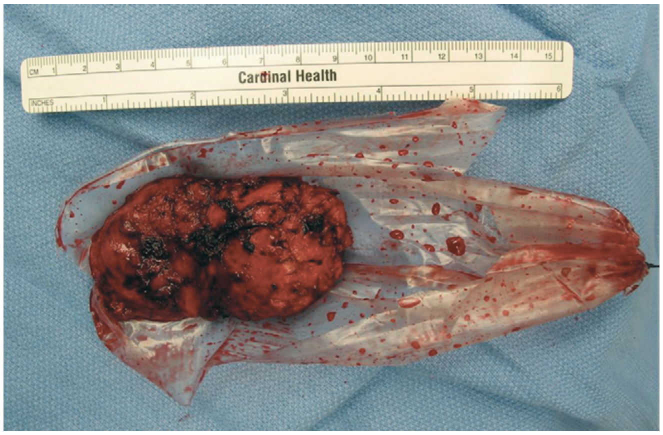

Figure 31-28 En bloc removed mass is seen. It is characterized by a firm round or oval and well-encapsulated mass.

of neurologic compromise and infection, 4) little bleeding, 5) an excellent cosmetic effect, 6) reduced operation time, and 7) reduced hospital stay. All of these allow the patient to recover to normal daily activity more rapidly.

INDICATIONS

- Soft thoracic disk herniations
- Pain refractory to conservative therapy

CONTRAINDICATIONS

- Calcified disk
- Ossification of the posterior longitudinal ligament
- Central disk herniation
- Progressive textual myelopathy
- Severe spinal cord compression
- Vascular pathologies

SURGICAL TECHNIQUE

Preoperative Preparation

Imaging diagnosis:

- MRI must correspond with the findings on examination.
- CT must depict a soft-disk herniation.
- Plain films are used for intervertebral space measurement preoperatively.

Medications:

- Major analgesia: weak opioids, such as codeine, along with nonsteroidal antiinflammatory drugs and/or acetaminophen
- Adjuvant analgesia: gabapentin for neuropathic pain

Anesthetics/other medications:

- Preoperative antibiotics (i.e., usually cefazolin 1.0 g) should be given to decrease the risk of infection.
- Preoperative sedatives are recommended. The procedure is performed via a posterolateral approach.

Instruments

- CT (Fig. 31-29)
- 18-gauge spinal needle
- Dilating obturators and working cannulas (Fig. 31-30)
- Microforceps (Fig. 31-31)
- Oblique sleeves
- Rigid working-channel scope (Fig. 31-32) or Knight Endoscopic Spine System (ESS) scope (Richard Wolf Medical, Vernon Hills, IL) (Fig. 31-33)
- Nucleotome probe set or LASE set (Fig. 31-34)
- Bipolar flexible radiofrequency probe (Ellman Trigger-Flex Bipolar System; Ellman Innovations, Hewlett, New York; Fig. 31-35) or side-firing Ho:YAG laser (VeraPulse PowerSuite; Dreieich, Germany; Fig. 31-36)

Figure 31-29 Computed tomographic fluoroscopy (Somatom Sensation 4; Siemens, Erlangen, Germany).

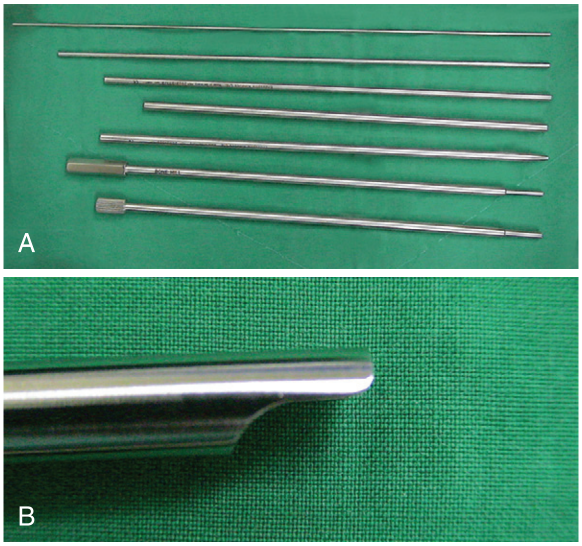

Figure 31-30 **A,** Serial dilators. **B,** Tip of dilating obturator. **C,** Working cannula.

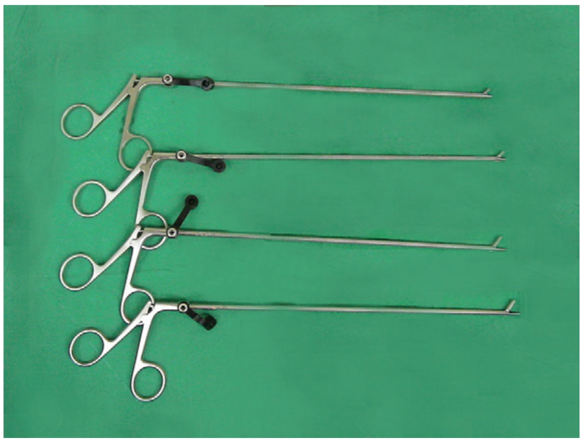

Figure 31-31 Microforceps.

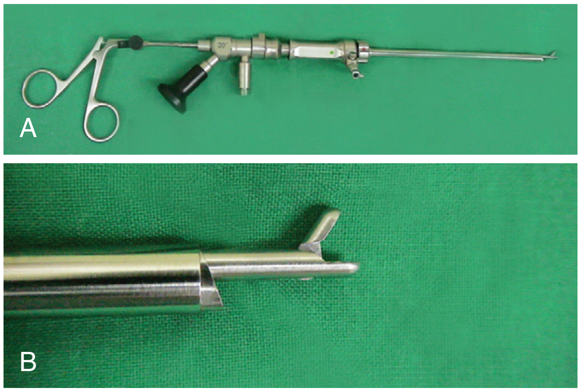

Figure 31-32 Rigid working-channel scope (KISS, Arthro Kinetics, Krems an der Donau, Austria).

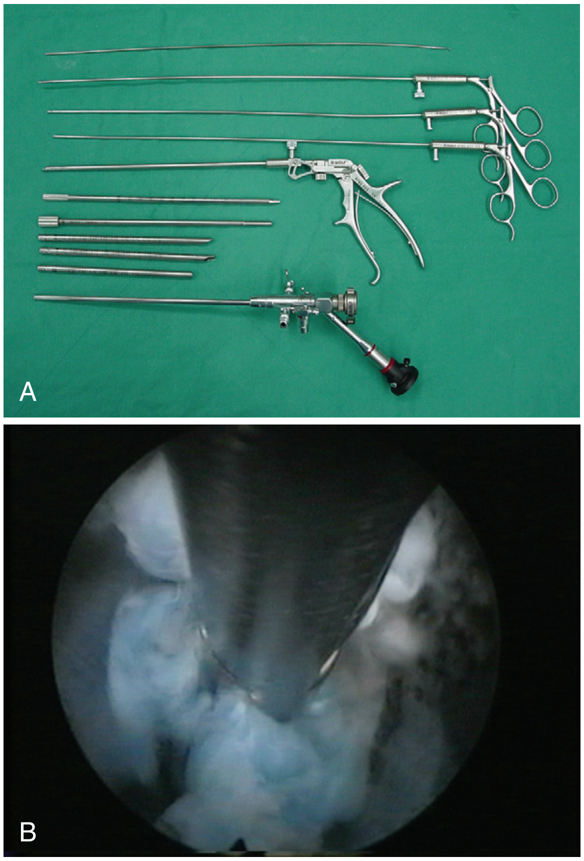

Figure 31-33 **A,** Rigid working-channel scope (YESS; Karl Storz, Germany). **B,** Endoscopic view while removing disk material.

Procedures of C-Arm–Guided PETD using Rigid Working-Channel Scope

1. The patient should be placed prone on a radiolucent operating table with conscious sedation. A patient who has a disk herniation at the upper thoracic level is placed in a lateral swimmer's position on a flat table with a chest pad. The others are positioned in the knee-flexion and hands-up posture, the same as a routine PELD position.
2. Under fluoroscopic guidance, the affected disk level and pedicles are marked on the skin. The lateral coordinates

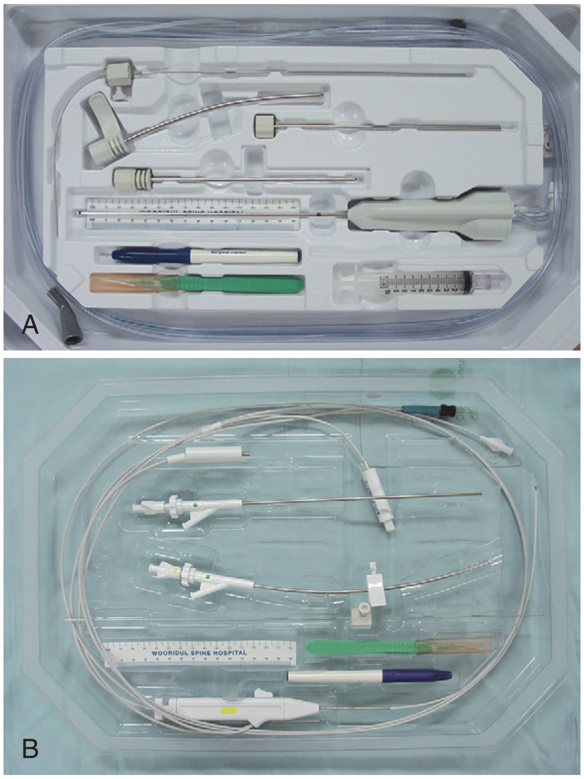

Figure 31-34 **A,** Nucleotome probe set (Clarus Medical, Minneapolis, MN). **B,** Laser-assisted spinal endoscopy set (Clarus).

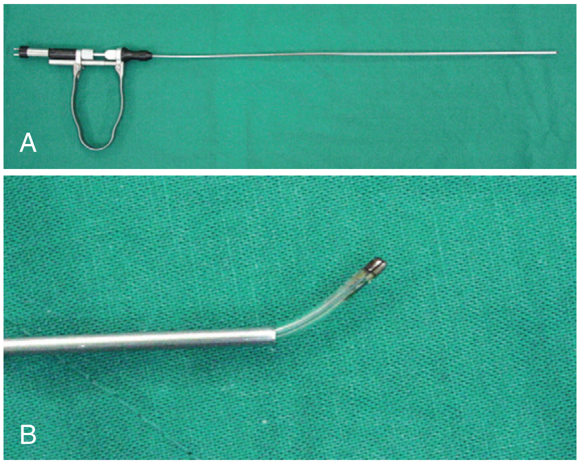

Figure 31-35 **A,** Bipolar flexible radiofrequency probe (Ellman Trigger-Flex Bipolar System; Ellman Innovations, Hewlett, NY). **B,** The probe's tip.

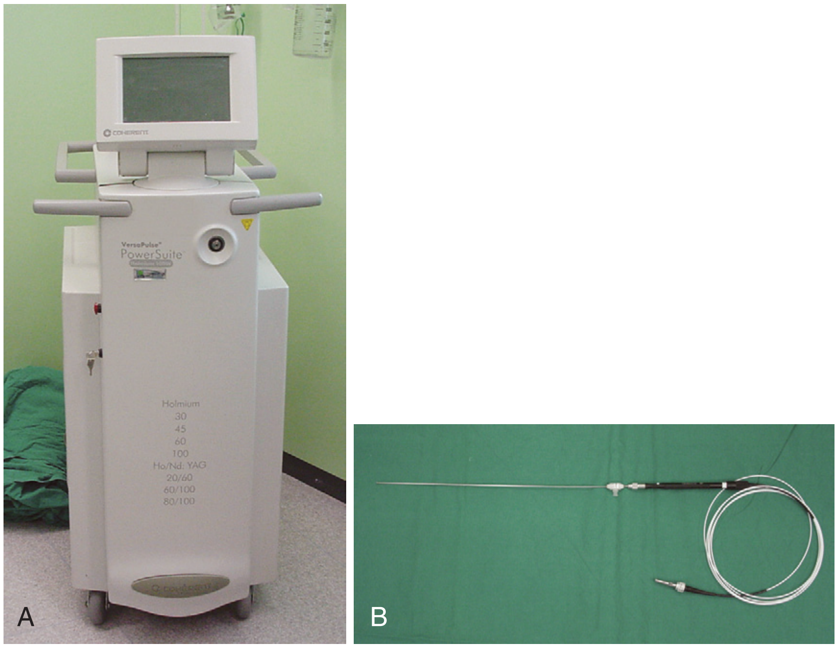

Figure 31-36 **A,** Side-firing holmium yttrium-aluminum-garnet (Ho:YAG) laser (Trimedyne, Irvine, CA). **B,** Side-firing delivery device.

of the skin entry point are determined from preoperative CT or MRI scan by extrapolating a line from the midpedicular annulus to the lateral margin of the facet and extending it up to the skin surface. The skin entry point is approximately 5 cm from the midline (Fig. 31-37). The latitude of the skin entry point is selected on the lateral view of the fluoroscope at the operating table, just parallel to the upper end plate (Fig. 31-38).

3. The pathway from the skin to the facet is infiltrated with 1% lidocaine, and an 18-gauge spinal needle is inserted into the foramen, touching the outer surface of the annulus. 1 to 1.5 mL (<2 mL) of 1% lidocaine is injected,

and a guidewire is inserted into the epidural space through the needle.

4. After removal of the needle, a cannulated obturator is passed over the guidewire to the posterolateral margin of the facet. A beveled cannula is passed over along the obturator, until the beveled opening is facing medially and inferiorly, and the tip of the cannula is compressed against the annulus just lateral to the midpedicular line on a fluoroscopic AP view, just like grasping the superior facet with a beveled opening. The lateral aspect of the superior facet is cut to enlarge the foramen with a round cutter, as in lumbar endoscopic foraminotomy, and the foraminal annulus is also cut simultaneously. Next, an obturator is introduced into the disk, and the cannula is tapped again to obtain the intradiskal position. At the thoracic spine, the posterior vertebral body line on the C-arm lateral view does not represent the true anterior margin of the thecal sac because of the pear-shaped body of the thoracic vertebra, thus every step of decompression is done under direct endoscopic view. The posterior portion of the bulging annulus is removed first to avoid blurring of vision from epidural bleeding and excessive epidural irrigation, which is the cause of severe headache during the procedure. Therefore a side-firing Ho:YAG laser is very useful to constrict the superior and inferior slope of the herniation to lessen the height of the dome of the herniation.
5. After initial decompression, the cannula is drawn back slightly or tilted posteriorly to expose the foraminal epidural space, then the remaining extruded portion of thoracic disk herniation is pulled down into the disk space and removed by laser ablation or endoscopic forceps (Fig. 31-39). At the end of the decompression, the free movement of the thecal sac is checked by changing the irrigation pressure, which is accomplished by alternately blocking and releasing the irrigation flow into the working-channel endoscope (Fig. 31-40). A subcuticular suture is placed, and a sterile strip is used.

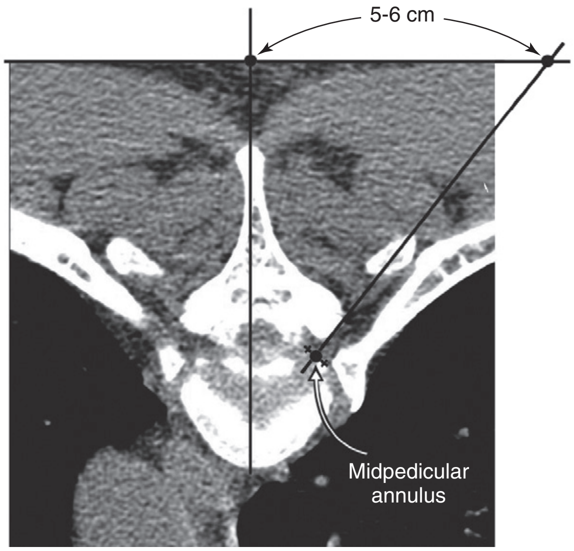

Figure 31-37 Preoperative computed tomography for determining the entry point. The skin entry point is approximately 5 to 6 cm from the midline.

Procedures of Real-Time CT-Guided PETA Using LASE

1. The procedure is performed via a posterolateral approach with the patient placed prone on the sliding CT table (Somatom Sensation 4; Siemens, Erlangen, Germany). The back is prepared and draped in the usual sterile fashion.
2. Under CT guidance, a spinal needle is used to identify the affected disk level. An imaginary line is drawn on the CT image to delineate the proper operating trajectory, and the skin is marked accordingly. The skin entry point is approximately 3 to 6 cm off the midline (Fig. 31-41). Under local anesthesia and CT fluoroscopy guidance, a 20-gauge spinal needle is incrementally introduced from the previously marked entry point along the imaginary line, aiming toward the center of the disk along the costovertebral groove.

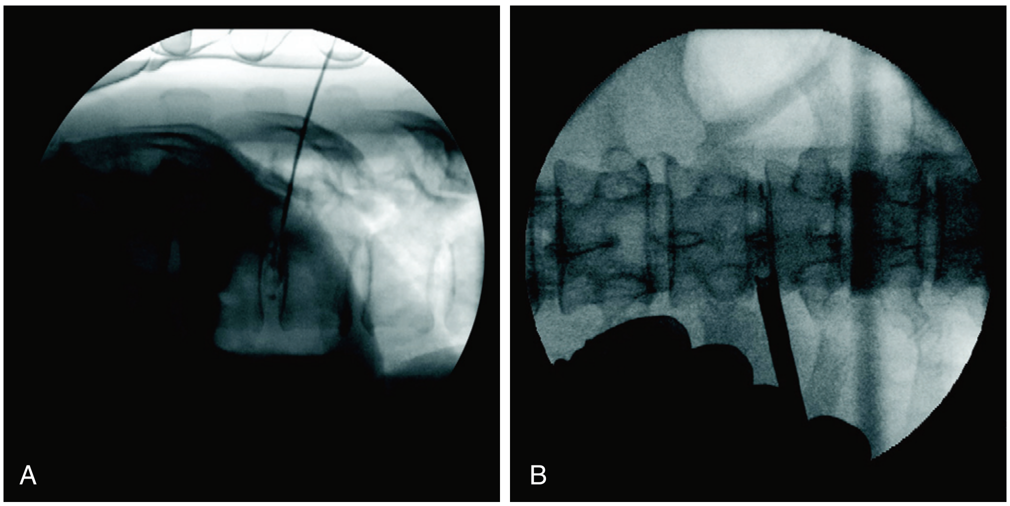

Figure 31-38 **A,** Intraoperative fluoroscopic lateral view demonstrates the entry point, which is parallel to the upper end plate. **B,** Fluoroscopic anteroposterior view demonstrates a beveled cannula facing medioinferiorly; the tip of the cannula compresses the annulus just lateral to the midpedicular line.

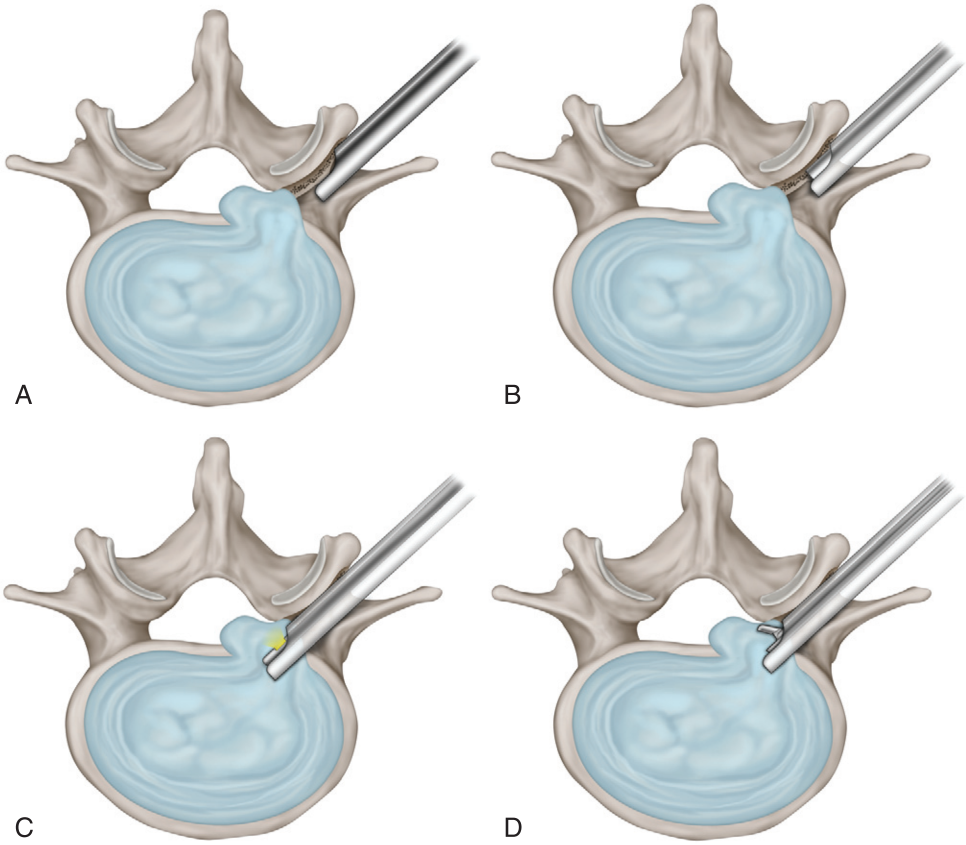

Figure 31-39 Schematic drawings of the procedure. **A,** The beveled cannula faces the superior facet before cutting. **B,** The lateral aspect of superior facet and foraminal annulus are cut using a round cutter. **C,** After initial decompression, the cannula is drawn back slightly or is tilted posteriorly to expose the foraminal epidural space. The herniated disk is ablated by a side-firing laser. **D,** The remaining extruded portion of the disk herniation is pulled down into the disk space and removed by laser ablation or endoscopic forceps.

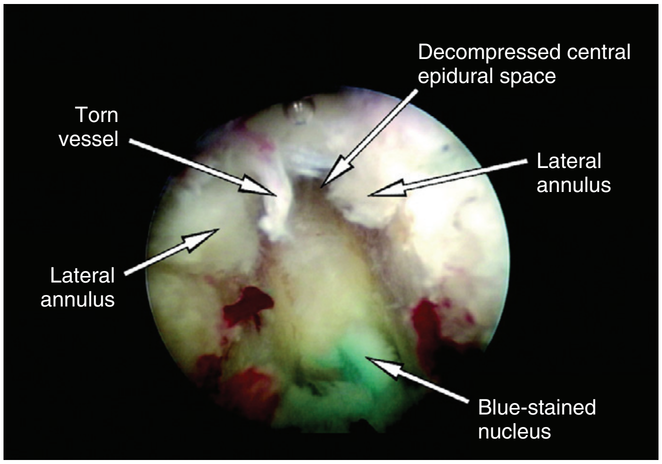

Figure 31-40 Intraoperative endoscopic view demonstrates a decompressed central portion of the thoracic disk herniation.

3. After the annulus is punctured, the needle point is advanced to the posterior one third of the disk. Diskography is performed with contrast media, including Indigo Carmine, to identify the pathologic lesion (Fig. 31-42). A thin guidewire is inserted through the needle channel into the center of the disk. The needle is then removed, and a small skin incision is made at the entry site of the needle. The first dilating cannula is passed over the guidewire, the guidewire is exchanged with a thin cannula for rigid guidance, and then a serial dilating cannula is inserted. A 3-mm final working sheath is positioned within the posterior one third of the disk space under CT guidance. Using the real-time cross-section images, the ipsilateral or central portion of the protruded disk is decompressed with an automated nucleotome and microforceps (Fig. 31-43).
4. During the procedure, the patient is asked whether the pain has disappeared, and if not, what it feels like.
5. The procedure is finished after checking the patient's symptom relief. Finally, the disk tissue is potentially more shrunken, and annuloplasty is performed using the Ho:YAG laser under endoscopic view. The working sheath is removed after checking the bleeding point with endoscopy.

CASE ILLUSTRATION

A 73-year-old man had midspine and low-back pain. Preoperative CT and MRI showed thoracic soft-disk herniation (Fig. 31-44, *A* and *B*). The patient underwent PETA with the LASE system, and postoperative MRI confirmed a well-decompressed spinal cord (Fig. 31-44, *C*).

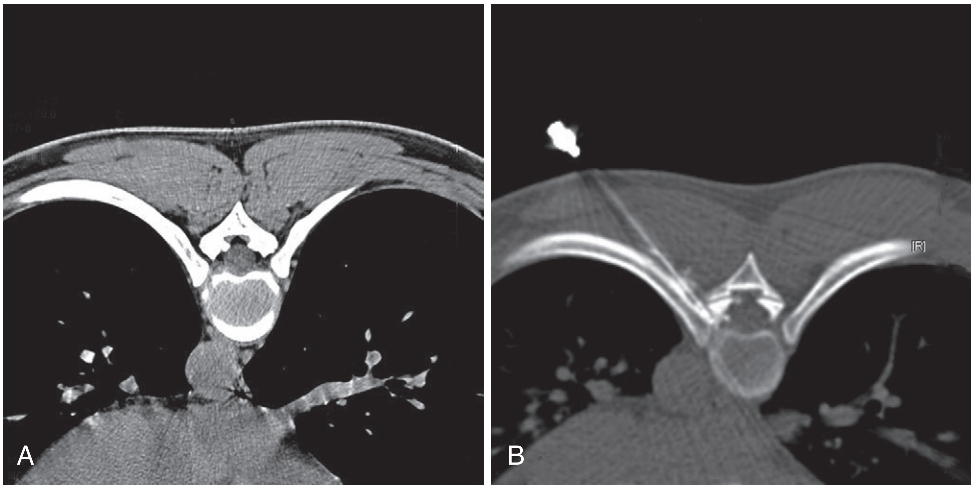

Figure 31-41 Determination of the approach route with interventional computed tomography (CT). **A,** An imaginary trajectory line is drawn to determine the entry point. **B,** Insertion of the spinal needle into the disk space along the imaginary line under CT guidance.

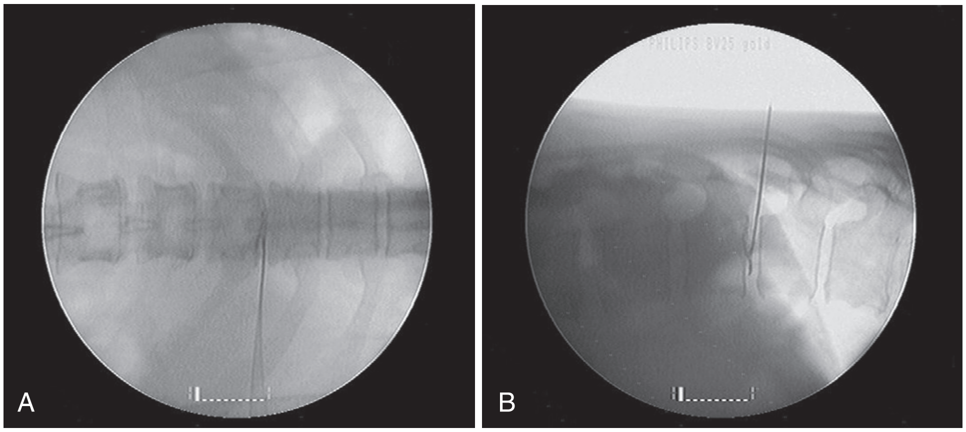

Figure 31-42 Diskography for provocative test.

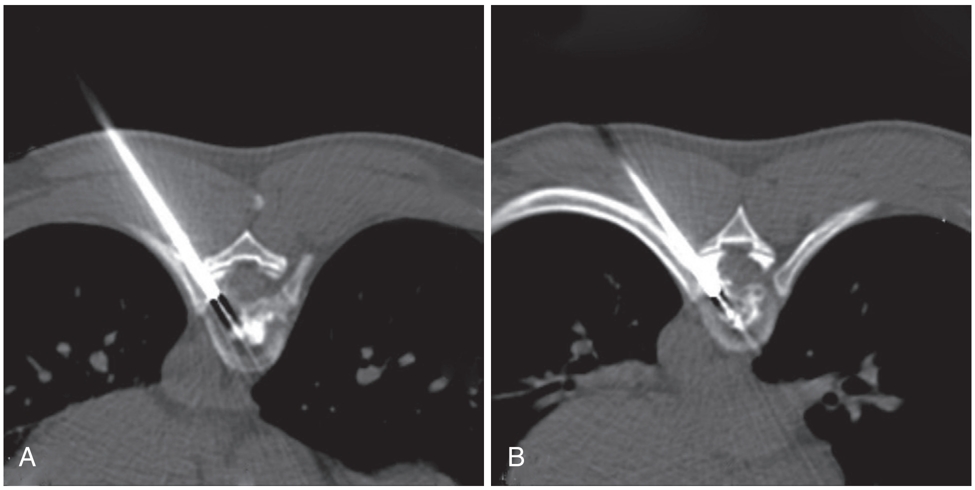

Figure 31-43 The anatomic space for insertion of the 3-mm final working sheath into the disk space. **A,** The safe route for the needle into the thoracic disk passes between the rib head and thoracic facet. **B,** The trajectory is determined with a preoperative axial computed tomographic scan, based on an imaginary line projected toward the skin from the target area (between the rib and facet).

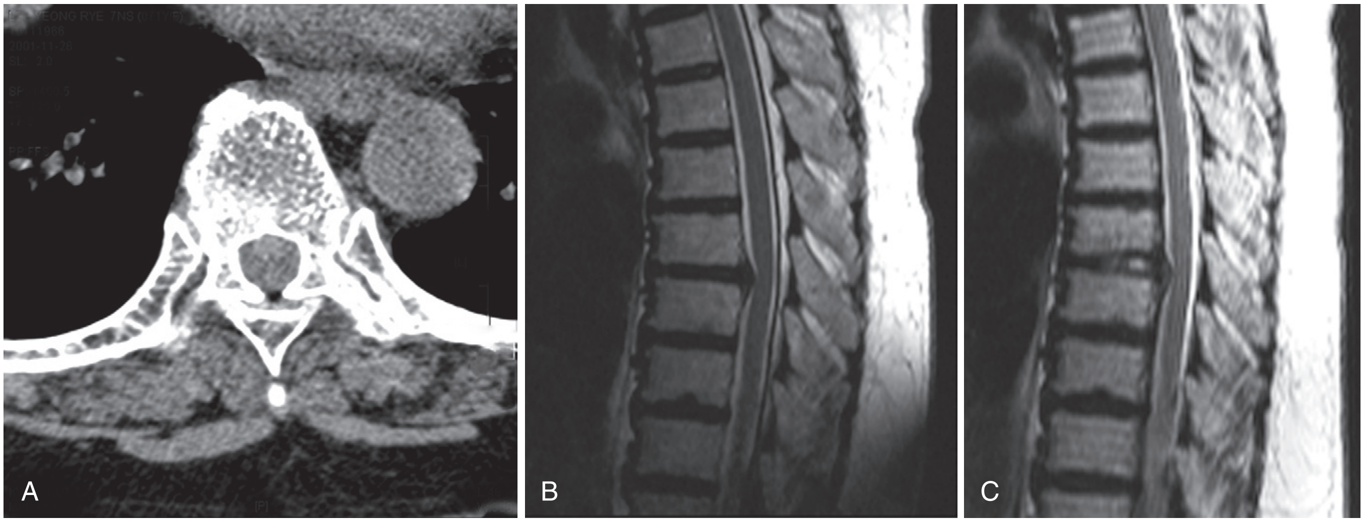

Figure 31-44 Case illustration. **A,** Preoperative axial computed tomography scan shows soft-disk herniation. **B,** Preoperative sagittal magnetic resonance (MR) image demonstrates thoracic disk herniation. **C,** Postoperative sagittal MR image shows well-decompressed spinal cord.

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32 Surgical Decompression and Stabilization Techniques in Thoracic Trauma

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Overview

More than 1 million acute spinal injuries occur in the United States every year, of which approximately 50,000 result in vertebral fractures, and less than 10,000 result in spinal cord injury.[1] Trauma involving the thoracic spine can be quite morbid, given that this segment of the spine has the narrowest canal-to-cord ratio and has the poorest prognosis for neurologic recovery compared with other spinal segments.[2] However, thoracic fractures are less common than fractures of the cervical and lumbar spine, and one study shows that only 16% of spine fractures occur between T1 and T10.[3]

Numerous classification systems have been and continue to be developed. For the purposes of this chapter, understanding the different types of thoracic spine fractures requires understanding the Denis three-column classification system.[4] According to this system, the spine has three columns: anterior, middle, and posterior. The *anterior column* consists of the anterior half of the disk space and vertebral body, including the anterior longitudinal ligament. The *middle column* consists of the posterior half of the disk space and vertebral body, including the posterior longitudinal ligament. The *posterior column* consists of the dorsal bony structures, including the pedicles, facets, pars interarticularis, laminae, and spinous processes. The ligaments that make up the posterior column include the supraspinous and interspinous ligaments and the ligamenta flava. Spinal instability occurs when two of the columns are violated.

In general, five types of fractures can affect the thoracic vertebrae: burst fractures, fracture-dislocation, flexion-distraction, Chance fractures, and compression fractures. *Burst fractures* are defined as a three-column axial compression injury, and they generally follow the 50 : 20 : 50 rule: greater than 50% loss of vertebral body height and/or greater than 20 degrees of segmental kyphosis and/or less than 50% retained anteroposterior spinal canal diameter as a result of retropulsion of bone. *Fracture-dislocation* involves all three columns with translation and/or rotation of the spine, a classic example of a shear-type injury. *Flexion-distraction* fractures occur when the anterior and middle columns are compressed and the posterior column is distracted. *Chance fractures,* also known as *seatbelt fractures,* are a flexion-distraction injury in which a transverse fracture extends from the anterior column through the posterior column. *Compression fractures,* the most common fractures of the thoracic spine, are isolated fractures of the anterior column. With compression fractures, there is no loss of posterior vertebral body height, nor is there evidence of subluxation; these are generally caused by axial loading. All of these fractures require surgical stabilization except for compression fractures, which are generally managed conservatively via orthosis.

In this chapter, we review the pertinent anatomy of the thoracic spine, list the indications and contraindications for surgery, describe techniques to decompress and stabilize the thoracic spine from both posterior and anterolateral approaches, and discuss potential complications for the more common surgical techniques.

Anatomy Review

The thoracic spine is a unique structure that consists of 12 vertebrae, compared with 7 in the cervical and 5 in the lumbar spine. Its alignment is kyphotic, as opposed to the lordotic alignment of cervical and lumbar spines; this is secondary to the anterior portion of the vertebral bodies being 2 to 3 mm shorter than the posterior portion.[5]

As opposed to the consistent orientation of the cervical and lumbar facets, the orientation of the thoracic facets changes from rostral to caudal. In the upper levels of the thoracic spine, the facets are coronally oriented; this changes to a sagittal orientation in the lower levels. As a result, facets of the upper thoracic levels have little resistance to rotational forces but do resist anterior translational forces. The converse is true in the lower thoracic spine, where resistance to rotational forces is greater than to translational ones. These factors are important in terms of mechanism of injury.

Motion in the thoracic spine is further restricted by its articulations with the rib cage. The stability provided by the rib cage requires greater forces to injure the thoracic spine compared with the other segments.[6] In fact, an intact rib cage increases the force needed to compress the spinal column by four times.[2] Adjacency of the rostral and caudal thoracic spine to the flexible cervicothoracic and thoracolumbar junctions lends them protection from injury, whereas the rigidity of the midthoracic spine increases its predilection for fracture. Aside from T12, the most commonly fractured thoracic vertebral bodies are T6–T8.[7]

Familiarity with the anatomy of the thoracic pedicle is essential for proper placement of instrumentation. The thoracic pedicle is oriented in a posterolateral to anteromedial direction by approximately 10 degrees along most of the thoracic spine, although at T12 a slight anterior and lateral angulation of the pedicle is apparent.[8] Techniques for pedicle screw entry will be discussed elsewhere.

Indications and Contraindications

INDICATIONS

- Spinal biomechanical instability
- Neurologic dysfunction from spinal cord and/or nerve compression
- Progressive deformity

CONTRAINDICATIONS

- Poor pulmonary function or other medical illnesses that would preclude surgery
- Limited life expectancy

Operative Technique

POSTERIOR

In cases of predominantly dorsal compression, or when ventral compression is minimal, decompression of the thoracic spinal cord can be adequately accomplished via *thoracic laminectomy.* For this procedure, the patient is positioned prone with the arms supported upright on rests. Diligent care must be taken for proper positioning and padding of the upper extremities to avoid positional nerve palsies. Fluoroscopy is used to localize the correct spinal level. Correct localization is imperative, because there may be an anomalous number of thoracic vertebrae, ribs, and so on. A midline incision is planned, and a subperiosteal dissection is performed to expose the lamina. To perform the laminectomy, some surgeons prefer to create troughs in the lateral laminae with rongeurs or a high-speed air drill. The lamina is then removed en bloc. Another technique is to use the drill to remove bone down to the level of the ligamentum flavum, first centrally and then out laterally. Local bone can be saved for autologous grafting if fusion is planned. The ligamentum flavum is then resected to expose the dural sac, completing the laminectomy (Fig. 32-1).

When the amount of ventral compression on the spinal cord is significant, and simple laminectomy for decompression is inadequate, the surgeon can accomplish further decompression via *transpedicular decompression*. This procedure was first described in 1978, and it has been used for excision of herniated thoracic disks.[9] By removing the pedicle, the surgeon gains access to the anterolateral portion of the thecal sac and, hence, the dorsal aspect of the vertebral body. The positioning and localization for this procedure are the same as described above for the thoracic laminectomy. Subperiosteal dissection is also the same, with the exception that the exposure must be out lateral to the transverse process to adequately visualize the facet and pedicle. Pediculectomy can be performed with a high-speed drill by starting centrally and "hollowing out" the pedicle so that the "eggshell" outer cortex remains. This cortex can

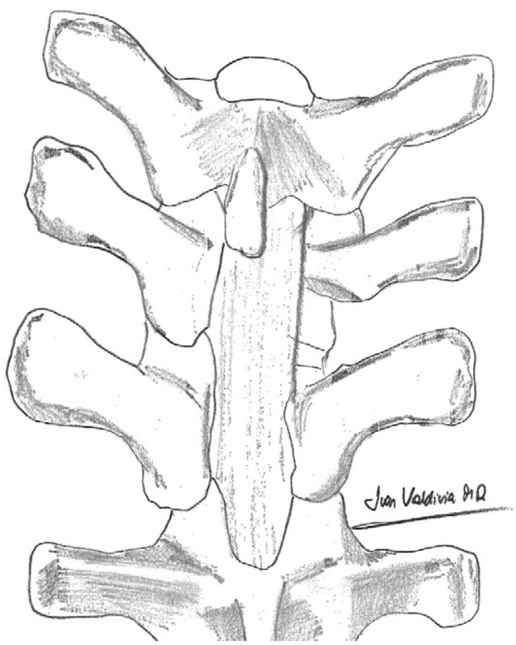

Figure 32-1 A completed thoracic laminectomy.

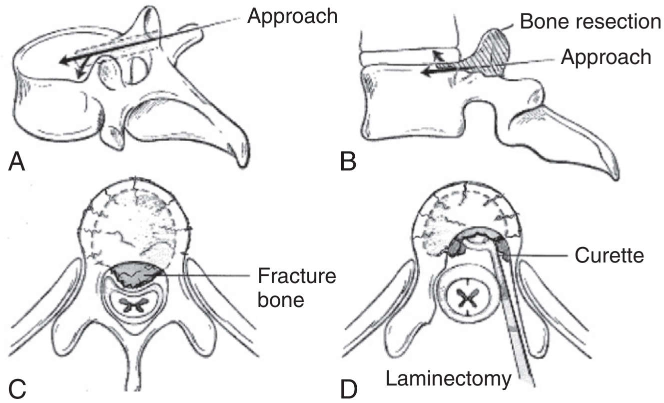

Figure 32-2 **A,** The transpedicular approach to the vertebral body. **B,** Removal of the superior articular facet facilitates exposure to the thoracic pedicle. **C,** Axial view of fragmented bone causing ventral compression on the thecal sac. **D,** An instrument can be used to decompress the bone from the thecal sac.

then be resected with rongeurs (Fig. 32-2, *A* and *B*). With the lateral aspect of the spinal canal now exposed, an angled instrument—such as a 45- to 90-degree downbiting curette, Woodson dental instrument, or the like—can be used to tamp down any bony elements that impinge on the spinal cord ventrally (see Fig. 32-2, *C*) and to remove disk and/or fractured bone fragments away from the thecal sac (see Fig. 32-2, *D*). This procedure can be performed after adequate decompressive laminectomy of that spinal level to further decompress the spinal canal.

Another posterolateral approach to the ventral spine can be accomplished via *costotransversectomy* (Fig. 32-3, *A*), first described in 1894 to treat a patient with Pott disease and epidural abscesses.[10] The advantages of this approach are avoidance of the morbidity associated with ventral approaches (discussed below) and the ability to decompress

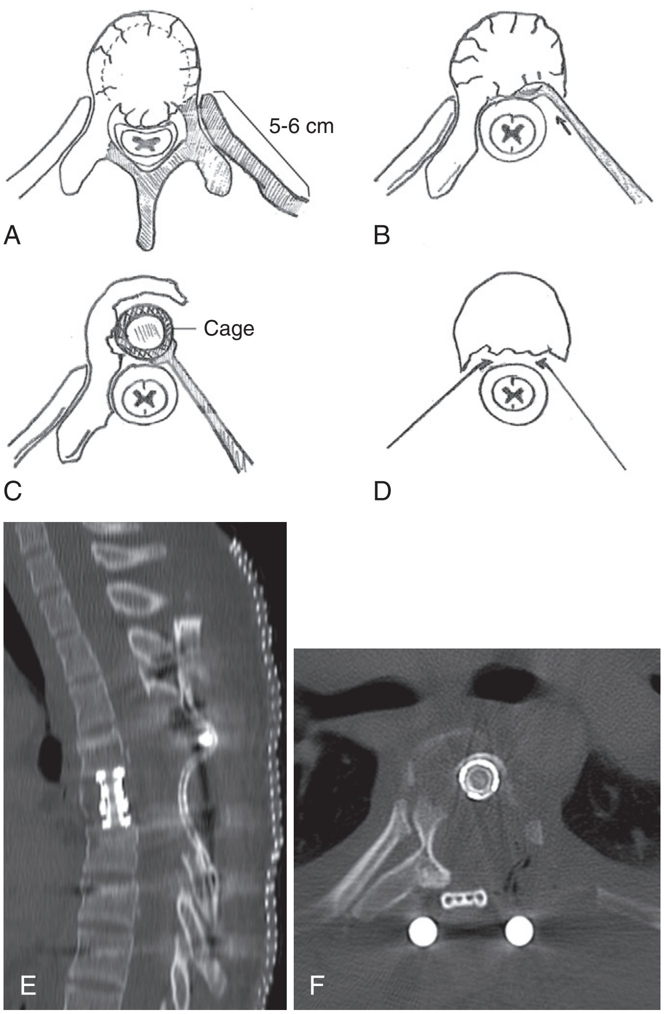

Figure 32-3 **A,** Axial view of the bony resection undertaken with the costotransversectomy (*shaded*). **B,** The bony resection allows for decompression of the fragmented vertebral body from the thecal sac. **C,** If corpectomy is performed, this approach allows for facile placement of an interbody cage. **D,** A bilateral costotransversectomy allows for bilateral decompression. **E,** Sagittal reformatted computed tomograph (CT) scan shows placement of expandable interbody cage after traumatic T5 vertebral fracture with retropulsed bone. **F,** Axial CT scan shows bony removal for the extended costotransversectomy approach used for decompression, partial corpectomy, and expandable interbody cage placement.

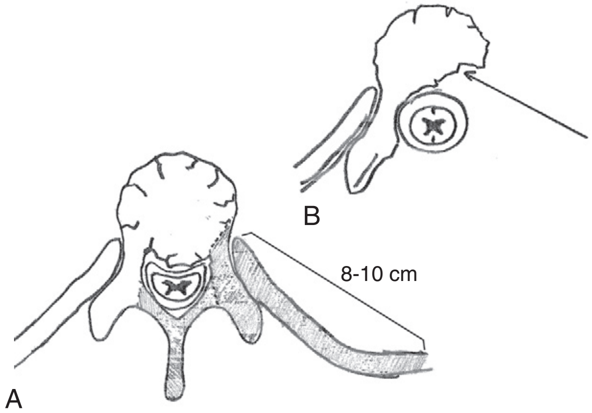

Figure 32-4 **A,** Axial view of the bony resection undertaken with the lateral extracavitary approach (*shaded*). **B,** Bony resection allows for decompression of the fragmented vertebral body from the thecal sac.

the spinal canal and implant instrumentation through the same exposure. The disadvantage of this approach is that, although it provides better visualization of the anterior canal than a transpedicular decompression, it is more limited than a lateral extracavitary approach (described below).

To perform a costotransversectomy, the patient is positioned prone. The type of incision can vary from midline to paramedian, with or without a "T" or "hockey stick" extension. Reflection of the muscles of the back will occur laterally when the incision is midline, as opposed to medially with a paramedian incision. A subperiosteal dissection is performed as described above, with skeletonization of the rib(s) to be disarticulated. During this process it is essential to identify, mobilize, and protect the pleura to prevent pneumothorax. It is also important to remember that the neurovascular bundle runs beneath each rib. With the bony anatomy fully exposed, removal of the transverse process and dissection of the costovertebral ligaments allows for rib disarticulation. Typically, the rib is transected approximately 5 to 6 cm from its head (see Fig. 32-3, *A*). The pedicle is identified and drilled away to better visualize the lateral aspect of the thecal sac.

At this point, clear visualization of the pathologic vertebral body is attained, and the appropriate decompressive procedure can be performed (see Fig. 32-3, *B*). In the extended approach, corpectomy can also be performed (see Fig. 32-3, *C* through *F*). The costotransversectomy can be performed bilaterally (see Fig. 32-3, *D*) to accomplish a circumferential decompression; however, with this approach it is essential to place temporary rods to prevent the vertebral column from collapsing on itself when the facets of both sides are removed.

The *lateral extracavitary approach* was first described in 1976.[11] It is quite similar to the costotransversectomy but, as can be inferred from its name, it simply provides more lateral exposure to the spinal canal and vertebral body (Fig. 32-4, *A*). The positioning, incision, and midline exposure for this approach are the same as for costotransversectomy. Laterally, the thoracolumbar fascia is incised and elevated from the underlying erector spinae muscles, and it is retracted laterally with the skin and subcutaneous tissue. This extrafascial incision allows for 8 to 10 cm of rib exposure (see Fig. 32-4, *A*), compared with just 5 to 6 cm with the costotransversectomy. Using blunt dissection, a plane is developed beneath the erector spinae muscles along the ribs of interest, until this plane is continuous with the subperiosteal dissection of the midline bony structures. The rib(s) can then be transected and disarticulated. As with the costotransversectomy, the neurovascular bundle can now be followed medially to the neural foramen, a pediculectomy can be performed, and visualization of the thecal sac and vertebral body is clear (see Fig. 32-4, *B*).

With decompression of neural structures accomplished via laminectomy, transpedicular decompression, costotransversectomy, and/or the lateral extracavitary approach, the next step in spinal trauma surgery is stabilization. Although historically this was accomplished via in situ fusion, with advancing technology, this is now essentially universally accomplished via *pedicle screw instrumentation*. By using pedicle screws, all three columns of the spine are traversed, which provides improved fixation and higher rates of arthrodesis. Positioning and exposure for such a procedure are identical to that of transpedicular decompression, in that exposure must be lateral to the transverse processes. Length and diameter of screws for the intended fusion levels is generally planned preoperatively via computed tomography (CT). Although the number of levels to be fused depends on the clinical situation and varies from surgeon to surgeon, at our institution it is commonplace to instrument two levels above and two levels below the level of pathology, taking into consideration proximity to a junctional segment and to the apex of a curve. The entry site for the thoracic pedicle screw can be grossly identified by the intersection of a horizontal line connecting the transverse processes with a vertical line connecting the middle of the facet joints.[8] The angle between the facet complex and the transverse process is a common entry point. Specific starting points vary by level, however, and are summarized in Table 32-1.

Once the screws are placed, they are connected by longitudinal rods. A drill is used to decorticate the facets and transverse processes, and autologous and/or allograft bone is placed along decorticated bone before closure.

ANTEROLATERAL

Anterolateral approaches to the traumatized spine are now infrequent, given that a circumferential decompression and arthrodesis can generally be accomplished via the posterior approaches described above. Nonetheless, familiarity with the following anterolateral approaches is important for a spine surgeon's armamentarium.

Lateral transthoracic thoracotomy was first described in 1956 as a treatment for Pott disease.[12] This approach provides the most direct exposure for vertebrectomy and reconstruction of the anterior and middle columns[13,14]; however, when the posterior elements need to be fused, it does necessitate two separate exposures. For this procedure, the patient is intubated with a double-lumen endotracheal tube, which allows deflation of the ipsilateral lung and concurrent ventilation in the contralateral lung. The patient is positioned in the lateral decubitus position, with care taken to appropriately pad all pressure points. The approach is generally from the left, especially for the lower thoracic spine (T5–T12) to avoid the liver and inferior vena cava; although if the pathology is at T3 or T4, a right-sided approach will avoid visual obscuration by the aortic arch. Upper thoracic lesions (T1–T4) may also be addressed with scapular mobilization.[15] The surgeon should also consider the course of the thoracic duct, which usually originates at L2 on the right and crosses over to the left at T5, as well as the artery of Adamkiewicz, which is generally on the left between T9 and L2.

The incision is generally two ribs above the pathologic level, because the ribs turn rostrally as they approach the spine. The incision is curvilinear along the rib itself, from the anterior border of the latissimus dorsi posteriorly to the costochondral junction anteriorly. The latissimus dorsi and serratus anterior muscles are retracted, and the periosteum and intercostal musculature are stripped from the rib. The rib is resected from the costochondral junction out to the posterior bend of each rib.[15] This can be repeated with additional ribs if more exposure is needed, and ribs should be saved for autograft. Care should be taken to preserve the neurovascular bundle beneath each rib.

The thoracic cavity is now exposed, and the pleura is opened. The lung is deflated and gently retracted, and the thoracic spine should be readily visible. Segmental arteries can be sacrificed if necessary. The parietal pleura on the vertebral column itself is incised along the lateral aspect of the anterior longitudinal ligament, exposing the vertebral bodies and disk spaces, with care not to dissect the pleura too far laterally to avoid damage to the sympathetic trunk. More access can be obtained by resecting the rib head, which is accomplished by incising the costovertebral and costotransverse ligaments, followed by transection of the rib approximately 2 cm distal to the rib head. The appropriate bony work can now be performed. At least one thoracostomy tube is placed. Closure of the wound involves closure of the parietal pleura, pleura, muscle, subcutaneous tissue, and skin.

It is important to note that the lateral transthoracic thoracotomy can be extrapleural (retropleural). This is performed by bluntly dissecting the parietal pleura from the chest wall. Although this provides less exposure than the method described above, it does avoid the need to place a thoracostomy tube postoperatively.

The *thoracoabdominal approach* provides visualization of the ventral spine from T10 to L2 and avoids manipulation of intraperitoneal structures. Thus it may be particularly useful in patients with prior abdominal surgery. Just as with the transthoracic approach, patients are generally placed in the right lateral decubitus position to avoid the inferior vena cava and liver on the right. The skin incision is made over the tenth or eleventh rib, from the posterior axillary line to the lateral margin of the rectus sheath. The selected rib is exposed and harvested as much as possible to gain access to the thoracic cavity. After rib removal, the costal cartilage is incised, and the retroperitoneal space is entered. The diaphragm is incised approximately 2 cm from its attachment to the rib cage, with special care to tag the free edges of this

Table 32-1 Starting Points for Thoracic Pedicle (TP) Screws

Cephalad-Caudad Starting Points	Level	Medial-Lateral Starting Points
Cephalad one third of TP	T1	TP-lamina junction
	T2	
	T3	Lateral to midpoint of superior articular facet
	T4	
	T5	
	T6	
On downward slope of TP-facet junction	T7	
	T8	
	T9	
Superior ridge of TP	T10	
Cephalad one third of TP	T11	Slightly medial to lateral edge of pars interarticularis
	T12	

structure with sutures so that it can be reapproximated at the end of the procedure. Subsequently, the pleura is identified, incised, and elevated from the spine along with the diaphragm. At this point, after retraction and lung deflation, T10–L2 should be readily visible, and the appropriate disk and bony work can be completed. Mobilization of the aorta can be accomplished by sacrificing segmental vessels if necessary. If this is performed, it must be done at least 1 cm from the neural foramen so as not to injure the anastomotic blood supply to the spinal cord. Mobilization of the psoas muscle should also be performed carefully to avoid injury to the genitofemoral nerve. Obviously, at completion of the procedure, the diaphragm and pleura are reapproximated, and at least one thoracostomy tube must be placed.

RECONSTRUCTION

When a vertebrectomy is performed using any of the above approaches, specific techniques exist for reconstruction of the vertebral column. The first important concept is preparing the end plates; by removing the disks and cartilaginous end plates, bone is exposed to facilitate fusion. The second step is to choose the appropriate graft material. Options include autologous sources—rib, iliac crest, femoral ring, tibia, or fibula—allograft, or manufactured cages made from titanium or carbon fiber. These are sometimes used in combination with biologics such as bone morphogenetic protein. The graft should be fitted and placed with adjacent levels under distraction. After adequate positioning, distraction is relaxed to allow appropriate compression of the interbody graft. Currently, the use of expandable cages allows adequate positioning and seating of the cage without prior distraction across the corpectomy site, and it can potentially correct a deformity by distraction. These expandable cages can be used via either the posterolateral or anterolateral approach. When the approach is anterolateral, the construct can be further supplemented with plating or rod-screw fixation.

Complications

As with any spinal procedure, thoracic decompression and stabilization procedures for trauma can have their share of complications. To minimize further neurologic injury, intraoperative neurologic monitoring is recommended in the setting of incomplete neurologic injury. The presence of "watershed" zones in the thoracic spinal cord can also predispose patients to neurologic deficit, if normotension to hypertension is not maintained, or if segmental arteries are sacrificed too close to neural structures, as described above. Adequate mean arterial pressures should be maintained for at least a few days following operative stabilization.

Cerebrospinal fluid leaks can be encountered in the operating room if a thoracic fracture has penetrated the thecal sac, or leaks may be iatrogenic. When possible, such leaks should be repaired using any combination of suture, muscle or synthetic grafts, blood patch, and/or fibrin glue. When this is insufficient, a trial of lumbar drainage may be of benefit. Alternatively, or in cases refractory to lumbar drainage, reexploration for repair of the durotomy is indicated.

Complications can also be unique to specific approaches. In a comprehensive review, Lubelski and colleagues[10] found that the mean complication rate for the lateral extracavitary approach was 17% in 157 patients. The reoperation rate was 1.3%, and the mortality rate was 0.6%. The most common complications were the need for a thoracostomy tube in 10% of patients and postoperative wound infection in 6% of patients. In the largest of the included studies, Resnick and Benzel[16] also reported hemothorax, pleural effusion, pneumonia, and incisional hernias. In comparison to costotransversectomy and transthoracic thoracotomy, the authors found that the lateral extracavitary approach required more operative time and also resulted in greater blood loss.

For costotransversectomy, the mean complication rate in 164 patients was 15%.[10] The most common complications were wound infection and deep venous thrombosis or pulmonary embolism; both occurred in 4% of patients. Reoperation and mortality rates were both 1.2%.

With transthoracic thoracotomy, Lubelski and colleagues[10] found a mean complication rate of 39%, a reoperation rate of 3.5%, and a mortality rate of 1.5% in 453 patients. The most common complications were intercostal neuralgia in 5.1% and pneumonia in 4.2% of patients. In a larger review that included 707 thoracic procedures, Faciszewski and colleagues[17] found a complication rate of 29% and a mortality rate of 0.33%. Complications included wound infection, aortic laceration, Horner syndrome, pleural effusion, pneumothorax, pseudarthrosis, durotomy, radiculopathy, and paraplegia. Other possible pulmonary complications include lung contusions, empyema, hemothorax, chylothorax, lung herniation, pulmonary emboli, and respiratory failure.[18,19] Mobilization of the scapula can cause shoulder atrophy and morbidity.

Lastly, the thoracoabdominal approach can be fraught with complications. These include injury to abdominal organs and ileus, iatrogenic sympathectomy, hernia, and the aforementioned pulmonary complications. For transthoracic and thoracoabdominal approaches, consideration should be given to enlisting the assistance of a surgeon more familiar with thoracic anatomy than the typical spine surgeon.

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33 Surgical Approaches to Thoracic Primary and Secondary Tumors

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Overview

The past four decades have witnessed major advances in spine surgery, and these pioneering developments have dramatically influenced the culture and attitudes surrounding surgical management of spine tumors. At one point considered controversial, surgical intervention for spine tumors is now considered the primary management modality for many tumors, and such intervention has significant advantages over medical management. The safety and efficacy of such advancements has recently been underscored in several key publications with respect to three major outcomes: 1) spinal cord compression, 2) pain relief, and 3) improvement in quality of life.[1-3] In most cases, the goals of surgery are to offer decompression and stabilization and, as a consequence, to provide tremendous palliative support to the patient. In fact, in more unique circumstances, such as that of rare primary tumors of the spine or solitary metastases, surgery may actually be curative. There is no doubt these breakthroughs have created an exciting landscape in spine surgery, and particularly in the thoracic spine, more so than any other area of the spine, these advances have converged to make the complex management of tumors truly a multidisciplinary enterprise.

Incidence of Primary and Secondary Tumors of the Thoracic Spine

Current studies estimate that about 50% to 70% of all cancer patients have metastases at the time of their death. Osseous lesions represent a significant disease burden in this population, and the axial spine has the highest predilection to such lesions. The primary site of malignancy for the majority of these spine lesions most often includes the prostate, breast, skin, and lung. Remarkably, the aggressive biology of these neoplastic lesions leads to pathologic fractures that often result in epidural spinal cord compression; the majority of these events arise from direct metastases from breast (22%), lung (15%), and prostate (10%) cancers. Of all the patients who develop metastatic spinal disease, approximately 20% will develop pathologic fractures that cause thecal sac compression, which accounts for the symptomatic presentation of nearly 20,000 to 30,000 patients annually for such cases. The majority of secondary tumors of the spine will often present in the thoracic spine, (70%) with the remainder presenting in either the lumbar (20%) or cervical spine (10%). A recent study has delineated the precise involvement of the vertebral elements and surmises that the majority of these lesions often present with involvement initially of the posterior half of the vertebral body, but with time, the lesion invades into the anterior body, lamina, and pedicles.

Primary tumors of the vertebral column are rare neoplastic lesions, but they account for approximately 10% of all primary osseous tumors, which culminate in 7500 new spinal column tumor diagnoses each year. This number is dwarfed by the nearly 90,000 new cases of metastatic axial spine tumors diagnosed annually, and it quickly puts into perspective the incidence of primary versus secondary tumors of the spine. Despite this, primary tumors of the axial spine should be strongly considered in the differential diagnosis of spinal lesions, because major advances in the excision of these tumors may undoubtedly influence the prognosis and surgical approach.

The majority of primary tumors of the spine can be classified as either benign or malignant. *Benign primary spinal tumors* include aneurysmal bone cysts, hemangiomas, osteoid osteomas, osteoblastomas, osteochondromas, enchochondromas, chondroblastomas, and giant cell tumors. *Malignant spinal tumors* include chordomas, chondrosarcomas, Ewing sarcomas, osteosarcomas, plasmacytomas, and multiple myelomas. In contrast to the management of secondary tumors of the spine, the major goal of surgical intervention for primary tumors is to achieve local tumor control to influence survival and possibly relieve the patient of the total tumor burden. Currently the most accepted and advanced surgical intervention for these tumors includes en bloc resection with wide excision margins for invasive, benign primary spinal tumors and nearly all malignant primary spinal tumors not responsive to chemotherapy or radiation.

Clinical Presentation and Evaluation

Despite the broad spectrum of pathology that can exist among various primary and secondary tumors of the spine, a single unifying feature between them is that pain is central to their initial presentation. Back pain is often exhibited by patients well before neurologic deficits manifest. This pain is often characterized as either mechanical or biologic (tumor related). *Biologic pain* is associated with advanced tumor burden and is often insidious and dull in character, persistent in nature, and most often reported to be worse at night (nocturnal pain) or early in the morning. For clinicians, this pain can be distinguished from muscular or inflammatory pain because this pain is often described as unremitting, exacerbated in the supine position, and often less relieved by positional changes; it is most notably not responsive to analgesics. The pathophysiology of biologic pain is most often mechanistically associated with invasive margins destroying one or more of the facet joints. Several other mechanisms have been proposed that include local release of cytokines, periosteal irritation, and stimulation of intraosseous nerves. Others postulate that this pain is often secondary to venous engorgement of the tumor, causing increasing mass effect on pain-sensitive nerve roots, dura, and periosteum. Unlike mechanical back pain, biologic back pain is responsive to low-dose steroids. Patients with mechanical pain describe pain exacerbated with movement that is often dependent on the level of spinal involvement. Of particular note, patients with thoracic or thoracolumbar compression fractures will complain of tremendous pain when lying flat, in part because of the extension forces that exacerbate an already unstable kyphosis. Medically, this mechanical pain responds well to narcotics and orthosis therapy and is often exacerbated by activity, standing, and coughing, very similar to the pain experienced in traumatic instability. These hallmarks classically distinguish mechanical pain from biologic pain, which is important for the practicing clinician, because mechanical back pain appears to be more amenable to relief via surgical intervention.

Radiculopathy and myelopathy are late-stage signs and symptoms of the sequelae of neoplastic processes of the spine and most often are secondary to compression from a directly enlarging neoplastic mass, pressure caused by retropulsion of bony fragments, and/or severe kyphosis form vertebral collapse. Thoracic radiculopathies occur in band-like segmental levels, unlike lumbar, sacral, and cervical involvement, in which pain or weakness usually involves distinct dermatomal distributions. Myelopathy often initially manifests as hyperreflexia, an upward-going plantar reflex and clonus that will often transition to weakness and loss of proprioception, as corticospinal and dorsal column tracts are damaged secondary to compression. Autonomic dysfunction secondary to spinal cord compression or cauda equina compression marks a distinguishing and ominous symptom of advanced cancer disease of the spine, and patients at this stage often come to medical attention with bowel and bladder dysfunction characterized by painless urinary retention or overflow incontinence.

Radiographic Studies and Preoperative Diagnosis

The initial study of choice often selected to evaluate axial spine tumors is plain radiography, which often can localize lesions and is diagnostic in particular cases; however, often this requires a 30% to 60% loss of mineralization before osteolytic lesions can be detectable, making radiography a poor screening test for neoplastic lesions. Remarkably, plain film radiographs can identify kyphosis and scoliosis deformities in weight-bearing patients, unlike magnetic resonance imaging (MRI) and computed tomography (CT) scans, which are done in the supine position; lesions that result in only minimal vertebral collapse may go undetected using MR and CT imaging.

Advances in imaging have dramatically improved the sensitivity for detecting primary and secondary tumors of the spine, and the repertoire of imaging modalities at the disposal of the practicing clinician are constantly undergoing development to help improve diagnosis and resolve tumor burden from surrounding tissue. The most heavily used imaging techniques include MRI, CT, myelogram, positron emission tomography (PET), bone scans, and angiography.

CT and MRI scans have become the standard imaging modalities used to determine the location and extent of tumor burden. MRI provides powerful tissue resolution, and with the use of gadolinium, it can discriminate tumor from surrounding soft tissue. CT scans are often used in conjunction with MRI and are often used to assess the extent of bony destruction and the quality of the surrounding bony architecture. When used in conjunction, CT and MRI can provide enough imaging characteristics that a diagnosis may be made predominantly from these features without further interrogation of the lesion.

Before MRI became widely available, CT myelography was the test of choice for assessing cord compression. This imaging modality, which uses the injection of contrast into the cerebrospinal fluid space, is now often used when patients cannot get an MRI, either because of metallic foreign objects or implanted medical devices. Bone scans, PET imaging, and angiography can collectively provide insightful information to supplement MRI and CT data. Bone scans that rely on a nuclear tracer, such as technetium-99m-methylenediphosphonate, allow for the identification of areas of bone growth or bone breakdown, thus making them highly sensitive, but poorly specific, for identifying neoplastic processes. PET imaging exploits cancer metabolism and the differential uptake of a glucose-labeled radiotracer by cancer cells. The technique has become popular because it allows for whole-body surveillance in a single study, with reasonably accurate anatomic and functional information regarding tumors. Angiography may often be used dually for diagnostic purposes and therapeutic intervention, and it can aid in the diagnosis of primary vascular lesions, such as aneurysmal bone cysts or hemangioma. Alternatively, it may be used to embolize highly vascular pathologies in the spine, such as renal cell carcinoma or melanoma, while at the same time identifying primary segmental feeders to the tumor.

Ultimately, before any surgical intervention and in the absence of a leading diagnosis of the lesion of interest, an accurate biopsy is essential to surgical planning and decision making regarding management. Histopathologic examination is most commonly achieved via CT-guided biopsy. This procedure has become safe, economical, and reasonably reliable; percutaneous CT-guided biopsy of spinal lesions is diagnostically accurate 93% of the time, with higher rates of success associated with high-grade versus low-grade lesions.

Once all the data have been acquired, the decision to manage and treat these patients is complex and relies on a multidisciplinary team that includes spine surgeons, oncologists, and radiation oncologists as well as the patient and family. Compelling arguments for surgery include palliation, decompression, and/or cure with some rare primary lesions; however, all of this is factored in with the context of the patient's overall survival, prognosis, and extent of disease burden, making the decision to operate a very difficult one given all these variables.

Surgical Decision Making and Patient Expectations

PATIENTS WITH PRIMARY OSSEOUS LESIONS

After a tissue diagnosis is obtained, the decision to operate depends on several factors that include tissue histology and grade, surgical accessibility, patient symptoms, and premorbid conditions. Each case must be evaluated on an individual basis. The histology of some tumors may predict a primarily nonoperative intervention, such as chemotherapy and/or radiation therapy, but patient symptoms or radiographic evidence of instability may dictate a need for operative intervention. For example, patients with multiple myeloma or plasmacytoma may benefit from surgical decompression and stabilization in the setting of acute vertebral collapse with neurologic sequelae.[4,5]

Primary malignant tumors of the thoracic spine present a very difficult problem for patients and surgeons. En bloc removal of the tumor with wide excisional margins is required for long-term cure in many cases, such as with chordoma or chondrosarcoma histology. The spinal cord, surrounding axial skeletal support, and structures of the mediastinum often make an en bloc resection a formidable task. Although neurologic preservation surgeries have been described,[6,7] aggressive tumor debulking with focused proton-beam radiation has demonstrated good overall and progression-free survival at 3 years and may be the best option in some situations.[8] In these cases, residual tumor greater than 30 mL, identified on postoperative imaging, had a negative effect on these outcomes.[8]

A thorough discussion regarding the techniques of en bloc resections of primary thoracic spine lesions is beyond the scope of this chapter; however, it should be mentioned that the typical preoperative evaluation will generally not suffice. Preoperative evaluation with the oncology team, a mental health professional, and a physical medicine and rehabilitation specialist will help educate the patient and anticipate postoperative needs. A meticulous operative plan that involves anesthesia and the cardiothoracic, vascular, plastic, and neurologic surgery teams is necessary. In addition, a preoperative consult with the critical care team will help anticipate immediate postoperative needs. Needless to say, before performing an en bloc resection, every detail of the patient's treatment course should be outlined, with any potential complication anticipated.

PATIENTS WITH METASTATIC DISEASE

When considering surgery for a patient with metastatic cancer to the spine, a realistic discussion regarding the goals of surgery, an anticipated extended postsurgical course, including rehabilitation, and overall prognosis is paramount. The patient and his or her family must understand that surgery will only be palliative. Reduction in mechanical back pain, preservation or restoration of spinal stability, and neurologic protection are the primary aims of an intervention. The risks of significant operative blood loss and routine spine surgical morbidity, extended recovery, and failure to improve neurologic status must be emphasized with patients and their families. In one retrospective study, 63% of patients recovered or improved their neurologic function at 3-month follow-up. However, it cannot be overstated that a large percentage of neurologically impaired patients may not functionally improve.[9]

Although a recent population-based analysis showed an approximate increase in survival of 50% in patients with breast cancer metastasis to the spine treated with spinal fusion over the past decade,[10] no prospective randomized trial has shown an increased survival rate among surgically treated patients. As with all patients with a terminal illness, the primary goal is to improve quality of life. In a 2005 landmark paper by Patchell and colleagues,[11] patients with metastatic disease and epidural extension with displacement of the spinal cord confirmed radiographically were randomized to surgery with adjuvant radiation or radiation alone. The surgical techniques were not standardized, but statistically significant benefits were found in patients' retention or recovery of ambulation in the surgery-with-radiation group. Similarly, a recent multicenter observation study demonstrated significantly improved quality of life in those patients who underwent surgical decompression for osseous metastatic disease.[3] This benefit should be stressed, especially in patients who suffer from diseases with relatively long survival times, such as patients with breast, prostate, or renal carcinomas.

In our institution, patients who are medically able to tolerate surgery and have an expected survival of at least 6 months are evaluated for surgery. However, in the setting of an acute neurologic decline, most patients are considered for an intervention regardless of prognosis. Although Patchell and colleagues[11] found that 62% of nonambulatory patients recovered their ability to walk, preoperative status often predicts postoperative status, and this should be considered before surgery. Patients who have complete loss of motor and sensory function before surgery and those who have American Spinal Injury Association (ASIA) class A deficits are rarely considered for surgery.

Preoperative Embolization

Regardless of the surgical approach, thoracic spine tumors have the added morbidity of increased blood loss. The literature is much more robust with retrospective data on benefits in metastatic cases compared with the current practice for primary spinal lesions. Although efficacy has not been established, several authors advocate for preoperative embolization of primary osseous tumors as well. These tumors include chondrosarcoma, chordoma, and osteosarcoma among others.[12,13] Yang and associates[14] described the benefit derived from preoperative embolization of both primary and metastatic disease to the sacrum in their series of patients.

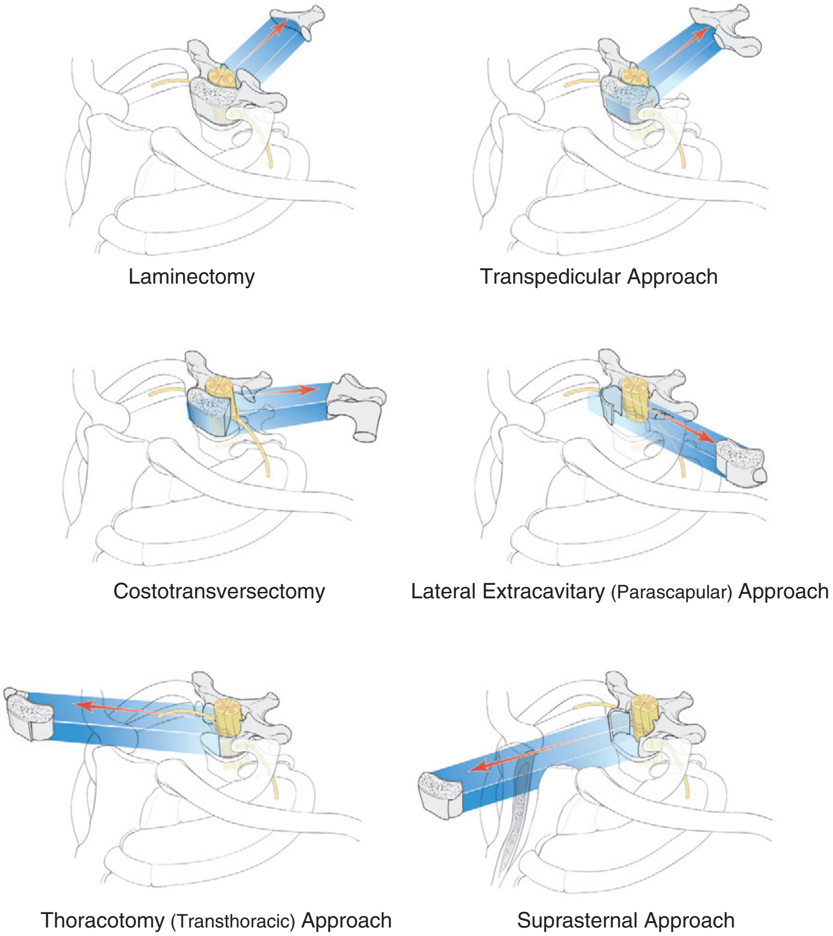

Figure 33-1 Approaches to the thoracic spine. Thoracic laminectomy, transpedicular approach and costotransversectomy, lateral extracavitary (parascapular) approach**,** thoracotomy (transthoracic approach), and suprasternal approach.

To date, no prospective randomized trial has been performed to clearly delineate the possible benefits of preoperative embolization for metastatic disease. However, this practice has evolved a large number of single-institution experiences that show benefit. Gellad and colleagues[15] found that preoperative embolization reduced intraoperative blood loss by nearly 50%. Renal cell carcinoma is often hypervascular and is traditionally regarded as the most common metastatic histology with risk of increased intraoperative hemorrhage. Therefore several authors advocate for preoperative embolization of all suspected renal cell carcinoma metastases and have shown a benefit in reduction of blood loss.[16,17] Schirmer and colleagues[18] found less than anticipated blood loss in patients with renal cell carcinoma metastasis when patients were preoperatively embolized percutaneously with n-butyl cyanoacrylate embol.

Although many surgeons find preoperative embolization to be a useful adjunct for renal cell metastasis, it is not the most useful predictor of blood loss. Rehak and colleagues[19] found an average blood loss of 4750 mL in their embolized group and an average blood loss of 1786 mL in their nonembolized group, a difference they explained largely by the complexity of the surgery. Tumor histology may also play a major role in the benefits of embolization; Robial and associates[20] found a significant decrease in blood loss with renal cell carcinoma but found no benefit in patients with primary breast and lung carcinoma. Although preoperative embolization may not predict intraoperative blood loss, embolization should be considered in any lesion suspected to be hypervascular.

Approaches to the Thoracic Spine (Fig. 33-1)

THORACIC LAMINECTOMY

Since its description in the early nineteenth century, laminectomy has become one of the most common neurosurgical procedures performed. Unfortunately, its use in isolation is seldom appropriate for thoracic tumors; rather, it is indicated for use in patients with bony neoplasms that involve the posterior elements of the spine and for tumors with dorsal epidural extension and significant mass effect. As stated, few patients will benefit from laminectomy alone. Before recent advancements in spine surgery, its use was associated with poor outcomes.[21]

Advantages

- Can be done at any level of the thoracic spine
- No need for an "approach" surgeon
- Less morbidity than with a thoracotomy
- Lower risk of postoperative instability, if anterior and middle columns are intact

Disadvantages

- Not appropriate for ventral pathology
- Limited visibility of pathology without disruption of the facets
- Can be difficult to localize levels

As with a typical thoracic laminectomy, the patient is positioned prone on chest rolls with the arms supported on either side. Before incision, correct localization is critical. External landmarks—such as the spinous process of C7, the superior scapular angle (T3), and the inferior scapular tip (T7)—are beneficial, but we always use intraoperative radiography or fluoroscopy for localization. Preoperative radiographs and a full-spine CT scan or MRI are helpful for delineating sacralized vertebrae and rudimentary or accessory ribs.

A midline incision is planned and marked approximately one level above and below the level of interest. Local anesthetics are often not used; however, dermal epinephrine may be of benefit with subcutaneous blood loss. The skin and subcutaneous tissues are incised down to the deep fascia. After the fascia is divided over the spinous processes, the paraspinal muscles are dissected from the spinous process and lamina subperiosteally. The muscles that have attachments to the upper thoracic spine are the trapezius and rhomboids, whereas the lower thoracic spine has attachments to the latissimus dorsi. The deeper layer of muscles—the erector spinae, spinalis thoracis, iliocostalis, and transversospinal group—are subsequently divided off the lamina. If lateral exposure is required, care must be taken not to injure tissues deep to the ribs and lateral to the pars interarticularis; otherwise, you may encounter a pleural injury with a consequent pneumothorax.

Especially in tumor surgery, exposure lateral to the facet joint is necessary. If a fusion is not planned, care must be taken to avoid injury to the facet capsule. Similarly, the neurovascular bundle runs in the isthmus between the zygapophyseal articulation and the base of the transverse process. Injury to this can result in significant postoperative pain.

Once adequate exposure and hemostasis are obtained, removal of the spinous processes and laminae may be performed in the typical fashion. The spinous processes are usually removed with Leksell rongeurs, and the laminectomy may be performed with a rongeur, high-speed burr, or a combination of both. The bony work of this intervention must proceed with caution, because bone infiltrated with tumor has a tendency to hemorrhage more than anticipated. Agents such as bone wax, Gelfoam with Thrombin, and Floseal may assist with hemostasis.

For tumor within the canal, satisfactory debulking can often be obtained with bipolar cautery and aspiration alone. In cases where tumor has infiltrated lateral to the spinal cord, a unilateral facetectomy and pediculectomy can be performed in patients with intact anterior and middle columns. If instability is a concern, this procedure should be supplemented with a posterior fixation.

It is imperative that adequate hemostasis be obtained before closure. Any bony bleeding or residual tumor increases the risk of a symptomatic hematoma. We typically use at least two drains, one in an epidural location, unless the dura has been violated. The fascia, subcutaneous tissue, and skin are closed sequentially to obliterate any potential dead space.

TRANSPEDICULAR APPROACH AND COSTOTRANSVERSECTOMY

The transpedicular approach and costotransversectomy provide a more ventrolateral exposure. The obvious benefit is that these procedures can be performed without having to work with one lung collapsed, unlike the usual transthoracic approach. Some patients may not have the pulmonary reserve to tolerate surgery on one-lung ventilation. This is encountered more frequently in patients with cancer, such as after pneumonectomy, with pulmonary metastases, or in the presence of preexisting chronic obstructive pulmonary disease (COPD). Also, in lesions of the upper thoracic spine, it does not require the surgeon to work around the great vessels, as might be done in a ventral approach. Thus, for planned anterior and posterior fusions, a bilateral transpedicular approach with vertebrectomy is often ideal for vertebral body lesions with ventral compression from T2 to T6.

A transpedicular approach may be beneficial for performing an open biopsy, for tumor that has infiltrated discretely into the ventrolateral portion of the spinal canal, or for extensive debulking ventrally, when a bilateral approach is performed or combined with a contralateral costotransversectomy. The unilateral transpedicular approach will not afford an adequate exposure for decompression of the medial aspects of the vertebral body. The costotransversectomy gives the added exposure to more medially located lesions of the vertebral body by removal of the rib head and transverse process. This approach is also often used when the tumor has extended laterally from the vertebral body into the adjacent soft tissue or has infiltrated the rib and costotransverse articulation.

Advantages

- Best option for patients who cannot tolerate one-lung ventilation, in which access to the anterior vertebral column is necessary
- Can access high thoracic lesions anteriorly without dissection around the great vessels or organs of the mediastinum
- Provides greater lateral access to the spinal cord than laminectomy alone
- Allows biopsies of the vertebral body and pedicle to be performed posteriorly (transpedicular)
- Allows instrumentation with anterior cage placement after decompression (bilateral transpedicular approach or costotransversectomies)
- Able to fixate anteriorly and posteriorly with one surgery

Disadvantages

- The medial vertebral body is difficult to visualize without a bilateral approach.
- Placement of the anterior construct is more cumbersome than with an anterior approach.
- Violation of the pleura is common.
- Ventral bleeding can be difficult to control.
- Bilateral approaches require posterior fixation and a longer construct than would normally be needed for a unilateral approach or lateral extracavitary approach.

Transpedicular Approach

Pedicle anatomy varies greatly from the upper thoracic spine to the lower thoracic spine, and preoperative MRI or CT should be reviewed extensively before surgery to evaluate such variations. The patient is made to lie prone on two rolls that support the chest. The arms are tucked, and the head is placed in a Mayfield head holder if posterior fusion across the cervicothoracic junction (CTJ) is anticipated. For both the transpedicular approach and costotransversectomy, a dual-lumen endotracheal tube should be used in case a pleural injury occurs.

If a unilateral decompression is desired, a midline incision with dissection of the ipsilateral muscles is all that is necessary. Even if preservation of the costotransverse articulation is the goal, the bony window should include at least a hemilaminotomy and the medial aspect of the transverse process, if tumor debulking is anticipated; blood loss will be difficult to control without removing these structures. Also, removal of the lateral pedicle wall will allow for decompression of more ventromedial structures. Fluoroscopy is beneficial to see the depth of the working area, because it is not ideal to breach the anterior fifth of the vertebral body, if anterior instrumentation is not planned.

Patients with tumors of the spine often require extensive decompression. We often use a "radical" transpedicular approach, which requires medial removal of the transverse process and bilateral pediculectomies. This allows for a posterior vertebrectomy without having to dissect out the rib or remove the costotransverse articulation, which saves time and decreases the risk of a pleural injury. Once these bony structures have been removed and the dura is visualized circumferentially, the vertebral body can be removed with a high-speed burr. If an anterior construct is required, ligation and division of the exiting nerve root will allow for easier placement of the cage.

Utilizing this approach and the costotransversectomy, the spinal cord is directly in front of the surgeon; thus injury to the spinal cord will usually not occur with exposure, but when a deformity is corrected, such as when significant kyphosis is evident from vertebral body collapse. For this reason, monitoring with somatosensory-evoked potentials (SSEPs) and motor-evoked potentials (MEPs) may be beneficial.

Costotransversectomy

The costotransversectomy has many variations; however, we will describe only those most commonly used at our institution for the purposes of oncologic processes. Although some surgeons have used the lateral decubitus position for this approach, we usually position the patient prone on a radiolucent table with the chest supported by gel rolls and the arms tucked in. Again, if instrumentation is to cross the CTJ, the head is pinned with a Mayfield head holder.

Some surgeons use a paramedian incision or midline incision with a tee over the rib to be resected. Because a large ventral decompression is often required, we tend to use a large midline incision without a tee, because we frequently need to perform bilateral exposure of the vertebral body. When a unilateral decompression is anticipated, a supplemental incision is appropriate. We make an extra incision approximately 70 degrees off midline in a tee over the rib and have found this allows for less soft-tissue breakdown at the junction of the skin edges.

Once adequate exposure has been obtained, the ribs to be removed are skeletonized with a subperiosteal dissection. This part of the surgery requires absolute correlation with preoperative radiographs and intraoperative imaging to identify the correct target level. The surgeon may then proceed to gently dissect the pleura from the inner surface of the rib. The rib should be cut at least 2 cm from the costotransverse articulation. For a single-level vertebrectomy, removal of one to two ribs is appropriate. If an en bloc resection is required, removal of three to four ribs may be required. The neurovascular bundle on the inferior aspect of the rib should either be retracted caudally or divided before rib removal. In oncology cases, it is often necessary to instrument anteriorly, and sacrifice of the nerve root facilitates a larger window to the anterior spine and decreases postoperative intercostal neuralgia. The rib articulates with the superior aspect of the vertebral body, thus removal of the T7 rib will give exposure to most of the T7 vertebral body, the T6–T7 disk, and the inferior aspect of T6.

Difficulty may be encountered when the pleura is dissected from the inner surface of the rib, and pleural injury is not uncommon. If it occurs, a chest tube must be placed at the end of the case. The most significant bleeding will occur with decompression of the vertebral body, especially if it is infiltrated with tumor, therefore hemostatic agents must be available before an anterior decompression. Finally, this approach is often limited in the upper four thoracic vertebrae by the scapula, such that the scapula must be retracted laterally, with the rhomboid and trapezius muscles dissected medially.

LATERAL EXTRACAVITARY (PARASCAPULAR) APPROACH

Transthoracic approaches can provide limited working space to the upper thoracic vertebrae, because the thoracic cage narrows significantly toward the thoracic inlet. In addition, some patients with pulmonary disease are not candidates for a transthoracic approach. The lateral parascapular approach is a lateral extracavitary approach performed in the upper thoracic area, and it provides excellent access to the upper thoracic vertebrae; it is ideal for patients with upper thoracic tumors that not only involve the vertebral bodies but also extend to the posterior elements and paraspinal musculature.

Advantages

- Can address ventral pathology without entering the pleural cavity
- Allows access to perform circumferential decompression and simultaneous placement of both anterior and posterior instrumentation

Disadvantages

- Extensive paraspinal muscle mobilization is required for adequate exposure.
- Blood loss is siginificant.
- The potential for pneumothorax is created.
- Ventral durotomies are hard to repair primarily.

The patient is positioned prone with arms tucked in at the sides. A hockey stick incision is made that extends from three levels above to three levels below the level of interest. Subperiosteal dissection of the muscles from the spinous process releases the scapula muscle attachments, which allows the scapula to rotate anteriorly and laterally and out of the field, along with its neurovascular supply. The subperiosteal dissection is taken over the tip of the transverse processes to expose the costotransverse joint and the ribs. The lateral dissection should be taken 6 to 8 cm lateral to the junction of the rib with the transverse process to obtain access to the ventral portion of the spine. A costotransversectomy is then performed, and the parietal pleura and underlying lung are mobilized. The posterior and ventrolateral portions of the body should be readily identified now, and levels should be confirmed radiographically. Following the intercostal neurovascular bundle allows identification of the neural foramen and the pedicle, which is thinned with a high-speed drill to expose the lateral dura.

Next, ventral decompression is performed, and a down-angled curette is used to push the remaining bone away from the thecal sac and into the cavity created, well across the midline. Rotating the bed away from the surgeon improves visualization of the ventral aspect of the canal, and a dental mirror or ultrasound can be used to document the extent of the decompression. Epidural bleeding can be tedious, and ventral dural tears may be extremely difficult to repair during this approach. Anterior column reconstruction and posterior instrumentation proceeds using standard techniques. Finally, the muscle layer and skin are closed in layers.

THORACOTOMY (TRANSTHORACIC APPROACH)

The transthoracic approach provides excellent access to the lateral and ventral aspect of the thoracic spine. Any level of the thoracic spine can be accessed by this approach; however, exposure of the most rostral levels (T1–T3) can be very challenging. It requires mobilization of the scapula, and the thoracic inlet can be narrow, which limits the working space at the upper levels. With this is mind, this approach is better suited for ventral thoracic tumors that span T4 to T12 when anterior reconstruction alone is required.

The decision to perform a right-sided or left-sided approach should be guided by the side with greater tumor involvement. If neither side is predominantly involved by tumor, the spine is generally approached from the right side, at or above T5, to avoid the aortic arch; but, ultimately, the side of the approach will depend on the location of the tumor. The surgeon should bear in mind that the aorta is easier to mobilize and repair than the vena cava, so a left-sided approach might be preferred.

Advantages

- Access to anterior column allows for decompression of the ventral spinal cord under direct visualization.
- Anterior column reconstruction and stabilization can proceed without disruption of the posterior column.

Disadvantages

- An access surgeon is needed.
- Some patients with a previous pneumonectomy or COPD will not tolerate single-lung ventilation.
- Approach morbidity includes great vessel injury, the need for a chest tube, and intercostal neuralgia.

The operation is performed on a radiolucent table with the patient in a lateral decubitus position supported by a beanbag; baseline SSEPs and MEPs are obtained before and immediately after positioning. The beanbag should be no higher than the midline for unobstructed fluoroscopy, an axillary roll should be placed to protect the brachial plexus, and all bony prominences should be well padded. The desired level can be placed in proximity to the break in the table to assist in exposure by opening the disk spaces, which can help with the anterior column reconstruction. The patient is secured to the table, and the level is marked on the skin using fluoroscopy. This is particularly important in cases with severe cord compression or spinal instability, where even subtle changes in position can result in a neurologic deficit. Neurologic function is monitored throughout the procedure with SSEPs and MEPs.

Usually, the skin incision will be over the rib one or two levels above the pathology; it begins at the midaxillary line and extends over the rib posteriorly to the edge of the paraspinal muscles. Dissection is carried down through the subcutaneous tissues and muscle layers, until the rib is identified. In younger patients, entry into the thoracic cavity can be performed through the costal interspace, because the ribs are sufficiently mobile, but in adults the exposed rib is resected instead. The periosteum, neurovascular bundle, and parietal pleura are carefully separated from the undersurface of the rib before its resection. Once the rib is resected, the parietal pleural is sharply incised, and the lung is carefully retracted to expose the spine, which remains covered with parietal pleura. A retropleural approach can be performed instead of opening the pleura by carefully dissecting the parietal pleura with "sponge dissectors" alongside the residual rib. This path is followed downward, until the head of the rib and spine are reached. This retropleural technique is more challenging: the parietal pleura is thin and frail, and it can very easily be opened while being elevated from the ribs. If the surgeon is successful in staying behind the pleura, a chest tube is not needed postoperatively.

The spine is easily identified upon entry into the thoracic cavity, and the appropriate level is identified radiographically. The surgeon should proceed with caution if the tumor has a significant paravertebral component, because it can obscure the anatomy in the area. This is critical when trying to stay outside the tumor capsule during an en bloc resection. If the anatomy is not altered by tumor, the concave portions over the spine represent the vertebral bodies, and the disks appear as prominent, elevated portions or "hills" on the spine. The segmental vessels course over the midvertebral bodies, and they should be coagulated and divided at this point. Most surgeons agree that up to three contiguous segmental vessels can be ligated with minimal risk of neurologic deficit.

Next, the head of the rib is identified and resected to expose the underlying pedicle, the key landmark point to the location of the spinal canal. A small, blunt dissector can be used to palpate the neural foramen and the ventral aspect of the spinal canal. The disk spaces and end plates of the levels above and below should be identified to delineate the corpectomy site. Resection of the vertebral body can now begin with removal of large segments with osteotomes initially; a high-speed burr will be required to remove the posterior cortex of the vertebral body. Once the vertebral body is paper thin, a small curette can be used to "crack" these away from the canal and spinal cord.

Some tumors can be very vascular and will bleed profusely until completely resected. During an intralesional resection, the decompression should encompass the interpedicular area to ensure complete decompression of the cord. The end plates above and below can then be freed of disk material and prepared for anterior column reconstruction. For patients with a short life expectancy, anterior column reconstruction with polymethylmethacrylate (PMMA) is acceptable. Otherwise, expandable cages can be used to provide both anterior column support and arthrodesis. For single-level corpectomies, anterior segmental instrumentation can be placed using a lateral plate or a dual-rod construct to obviate the need for posterior instrumentation.

A chest tube is placed before closure of the chest cavity. If an unintended durotomy occurred during the procedure, the chest tube should not be placed to suction; a lumbar drain may be required in this case, if primary closure of the durotomy is not possible. The lung is then reexpanded, and the muscle and skin are closed in layers.

SUPRASTERNAL APPROACH

The suprasternal approach is very useful to the surgeon, because it offers the benefit of accessing the lower cervical and upper thoracic bodies without much muscular dissection in an avascular plane. Also, it allows a direct view of the vertebral body for decompression, deformity correction, and fixation. For tumor cases that involve the thoracic spine, this approach is often limited to the first vertebral body. If the patient is barrel chested or has a manubrium that does not allow for adequate access to the top of T2, the surgeon will be limited in regard to instrumentation. Preoperative radiographs or a CT scan that includes the manubrium will allow the surgeon to decide whether this approach is feasible or if a transmanubrial or transsternal approach would be best.

For oncologic purposes, this approach is optimal for lesions restricted to the first thoracic vertebral body with some level of kyphotic deformity. If the tumor is contained within the body, without invasion of the pedicles or posterior elements, this approach can achieve all surgical goals. Similarly, the surgeon can supplement a posterior decompression with this anterior approach when significant invasion of the pedicles or posterior elements is present. The surgeon must be mindful of invasion of tumor into superior mediastinal vessels and of previous radiation to this area; both can make dissection more challenging.

Advantages

- Allows for simultaneous decompression and tumor debulking, graft placement, and instrumentation
- Direct view of great vessels anterior to vertebra
- May easily correct deformity
- May supplement posterior decompression and instrumentation

Disadvantages

- The view of vertebrae below the first thoracic level is limited.
- Tumor extending into the spinal canal can distort planes and may make a single-level anterior approach more difficult.
- Tumor extending to posterior elements will often require a posterior approach.

For a supraclavicular approach to T1, general anesthesia is induced, and the patient is placed supine with the head slightly extended and turned away from the lateralized incision. We typically use a left-sided approach, because the anatomy of the recurrent laryngeal nerve is more predictable. We also tape the shoulders down to assist with localization of the correct level with radiography or fluoroscopy.

We usually make a transverse incision approximately 2 cm above the left clavicle from the medial border of the sternocleidomastoid (SCM) to 1 to 2 cm across midline. The platysma will be the first muscle encountered, and it is invested in superficial fascia; the fascia is typically separated from underlying structures with Metzenbaum scissors and is then divided and undermined. Sometimes the external jugular vein will lie directly underneath, and it must be ligated and divided.

The SCM is encountered deep and in the lateral extent of the incision. Blunt dissection is used to isolate this muscle, and its sternal and clavicular attachments are dissected away in a periosteal fashion superiorly. Some surgeons advocate for disarticulation of the clavicle from the manubrium at this point, but we can typically obtain adequate exposure without this. The omohyoid, sternohyoid, and anterior scalene muscles are then divided and reflected medially to give the surgeon adequate visualization of the trachea and esophagus medially and the carotid sheath laterally.

Critical structures that are vulnerable to injury include the subclavian veins, internal jugular vein, and thoracic duct laterally and the phrenic and recurrent laryngeal nerves medially. At this point, the trachea and esophagus are retracted medially, and the carotid sheath is retracted anteriorly and laterally after division of the inferior thyroid artery.

Next, the prevertebral fascia and longus colli are identified. The longus muscles are undermined and freed from the lateral vertebral bodies on both sides, and the prevertebral fascia is incised in the midline for at least one vertebra above and below the affected level. Forming a muscular cuff of longus colli for retraction is essential for protection of the carotid artery, esophagus, and sympathetic chain. The correct level is identified with a bent spinal needle in the disk space by radiography or fluoroscopy. Once the correct level has been identified, the periosteum is stripped from C7, T1, and T2. At this point, diskectomies above and below T1 are performed, and the vertebral body can be removed with a high-speed burr.

If tumor has infiltrated into the spinal canal, the posterior longitudinal ligament will likely be involved, and planes will be distorted. In these cases, we perform a staged procedure with a posterior decompression, and we place a silastic sheath between the dura and the vertebral body. At the conclusion of the case, we typically place at least one drain on top of the construct and reattach the strap muscles and SCM, after which the plastysma is closed with a running suture, and the skin is reapproximated and closed in two layers.

Conclusion

Primary and metastatic lesions to the thoracic spine represent a common pathology that has received tremendous attention over the years. New imaging technologies and novel surgical approaches combined with involvement of a multidisciplinary team have made the decision to operate on these patients a very complex one. All of the technical variables are ultimately factored in: the context of the patient's overall survival, prognosis, and extent of disease burden make the decision to operate a challenging but often rewarding one.

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SECTION D

Thoracolumbar and Lumbar Spines

34 Surgical Anatomy and Posterior Approach to the Thoracic and Thoracolumbar Spine

JAI-JOON SHIM and DANIEL H. KIM

Overview

Several surgical approaches have been developed to remove thoracic vertebral lesions in an anterior to posterolateral direction. The choice of surgical approach is decided depending on the disease entity, level of the lesion, laterality, multiplicity, presence of instability, and the necessity of reconstruction. The posterior approach provides a less extensive exposure of the vertebral body than the anterior approach, but the involved anatomy is familiar to spine surgeons, and it can be applied to patients with anesthetic risk.[1]

Advantages of the posterior approach over the anterior approach are numerous[2,3]:

- The spinal cord is identified earlier.
- Disease in the posterior elements can be treated.
- The spinal column can be simultaneously stabilized with posterior instrumentation devices.
- Imbalances in the sagittal plane (listhesis), coronal plane (scoliosis), and axial plane (rotation) can be more easily corrected with a posterior approach.
- Thoracotomy is avoided.

With increasing bone removal, from the transpedicular approach to the costotransversectomy and finally to the lateral extracavitary/lateral parascapular approach, the operative trajectory becomes more lateral to visualize the affected vertebrae better.[4] In this chapter, an overall review of the posterior or posterolateral approach to the thoracic spine will be presented with the pertinent anatomic assessment.

Muscular Anatomy

The most superficial muscle of the dorsal spine is the trapezius muscle (Fig. 34-1), which originates along the external occipital protuberance and each spinous process from C1 to T12. The insertion of the trapezius is the lateral third of the clavicle, the acromion, and the scapular spine. This muscle provides the stabilization and abduction of the shoulder. Immediately deep to the trapezius muscle on the upper thoracic level lie the rhomboid major, rhomboid minor, and levator scapulae muscles (see Fig. 34-1). The rhomboid muscles originate from the spinous processes of the cervical and thoracic spine and insert at the ventral edge of the scapula.[5] The levator scapulae muscles connect the scapula to the upper cervical vertebrae.

The serratus posterior superior muscle is another muscle that fixes the cervicothoracic junction area spinous processes to the lateral part of the rib cage (Fig. 34-2). In the exposure of the cervicothoracic junction, the spinous process insertions of these muscles are taken down as a single group for lateral retraction.[6] As these muscles are taken down, the scapula is released from its attachments to the spinous processes and rotates anterolaterally out of the operation field.

On the lower portion of the back, the latissimus dorsi muscle spans over the body. It originates from the spinous processes of the six lower thoracic vertebrae, lumbar and sacral vertebrae and ilium, inserting onto the humerus (see Fig. 34-1).

In the deeper part of the back are two large groups of muscles: the erector spinae (sacrospinalis) and transversospinalis muscles. The erector spinae consists of three separate groups of muscles that run from the sacrum and iliac crest to the ribs or transverse process of the vertebrae: the iliocostalis (lateral), longissimus (middle), and spinalis (medial; see Fig. 34-2). The *iliocostalis muscle* inserts into the angles of the ribs and into the cervical transverse processes from C4 through C6. The *longissimus thoracis muscles* insert into the thoracic transverse processes and nearby parts of the ribs between T2 and T12. The *spinalis muscle* is largely aponeurotic and extends from the upper lumbar to the lower cervical spinous processes.

The transversospinalis muscle group passes obliquely cephalad from the transverse processes to the spinous processes immediately deep to the erector spinae muscle. These muscles fall into three layers. The most superficial layer, the *semispinalis* muscle, arises from the tips of the transverse process and inserts into the tips of the spinous processes. The *semispinalis capitis* passes from the upper six thoracic transverse processes and lower four cervical articular processes to the occipital bone between the superior and inferior nuchal lines. The *semispinalis cervicis* muscle starts from the upper thoracic and lower cervical transverse process and attaches to the spinous processes of C2 through C5.

The *semispinalis thoracis* muscle runs from the transverse processes of the lower six thoracic vertebrae onto the spinous processes of the upper thoracic and the last two cervical vertebrae. The intermediate layer, the *multifidus,* arises from the sacrum, posterior sacroiliac ligament, accessory processes of the lumbar spine, and articular processes of the thoracic spine and inserts to the spinous processes of the vertebrae up to C2. The deepest muscles of this group, the *rotators,* are small muscles that bridge from the

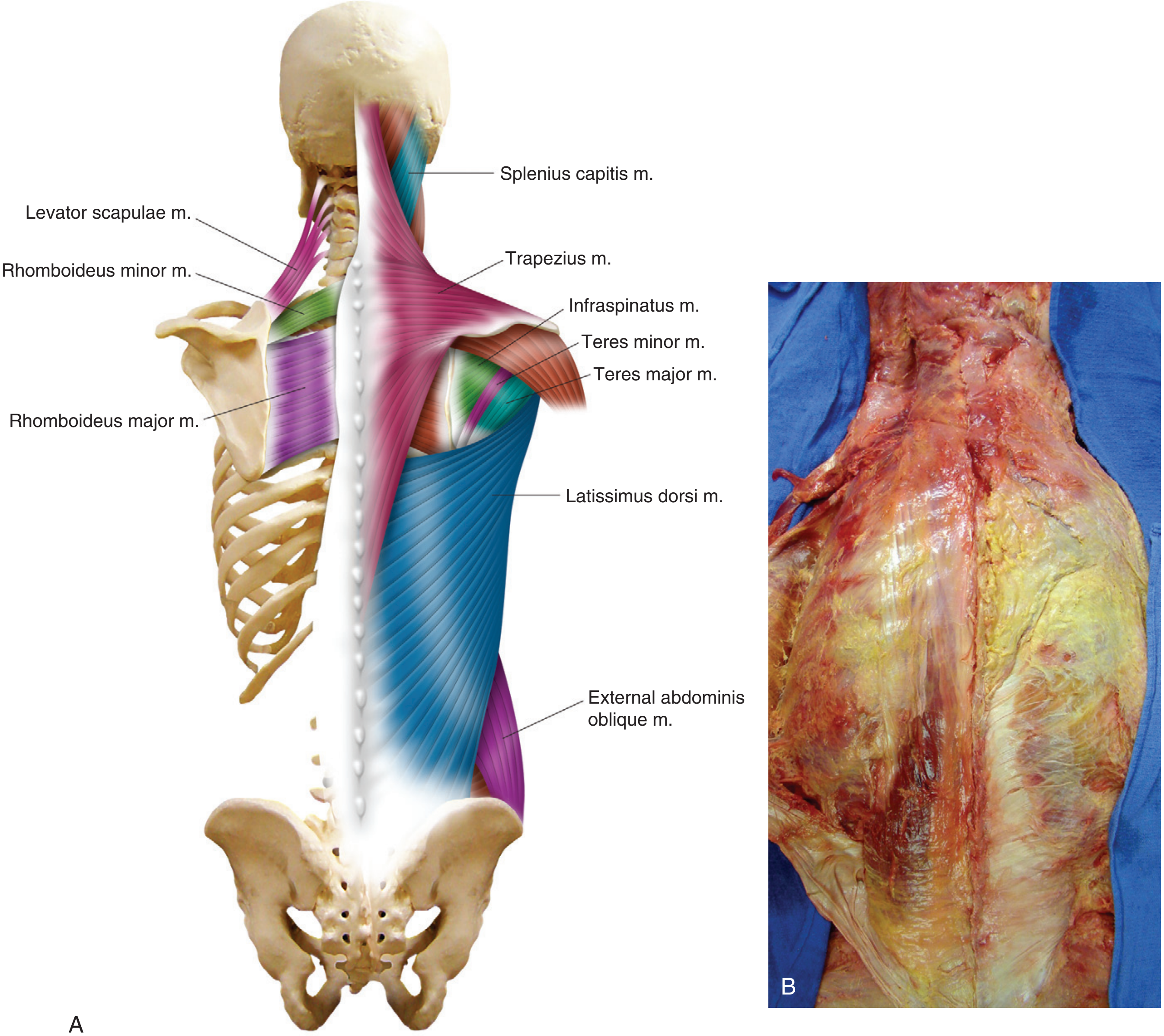

Figure 34-1 Superficial layer muscles: trapezius, rhomboids, levator scapulae, and latissimus dorsi muscles.

transverse processes to the lamina of the vertebra directly above.

Posterior Thoracic Cage

The head of a rib articulates with the adjacent parts of its own vertebral body, the vertebra above, and the intervertebral disk between them (Fig. 34-3). The exceptions to this general rule are the first, eleventh, and twelfth ribs, which articulate only with their own vertebral body. On the vertebral body from the second to the tenth level, each rib head has two synovial joints with a vertebral body and intervening radiate ligament enforcing the joint. These are two independent joint surfaces, separated by the posterolateral position of the intervertebral disk. The inferior articular surface is numbered the same way as the rib and has a height slightly greater than the pedicle, and its posterior limit corresponds to the point of insertion of the pedicle. Its height represents about one third of the height of the body. In contrast, the superior facet represents only half the height of the inferior facet.

The third synovial joint is the costotransverse joint, which is strengthened by superior and lateral costotransverse ligaments (Fig. 34-4). The superior costotransverse ligament joins the neck of the rib to the transverse process immediately above. The ribs are also attached to one another through the intercostal musculature, which originates medially on each superior rib and inserts laterally on its immediately inferior rib. This strip of muscles contains the intercostal nerve, artery, and vein. Most frequently, the intercostal vein is most cephalad, with the intercostal artery close to it but caudad (Fig. 34-5). The intercostal nerve is frequently found separate from these structures and is

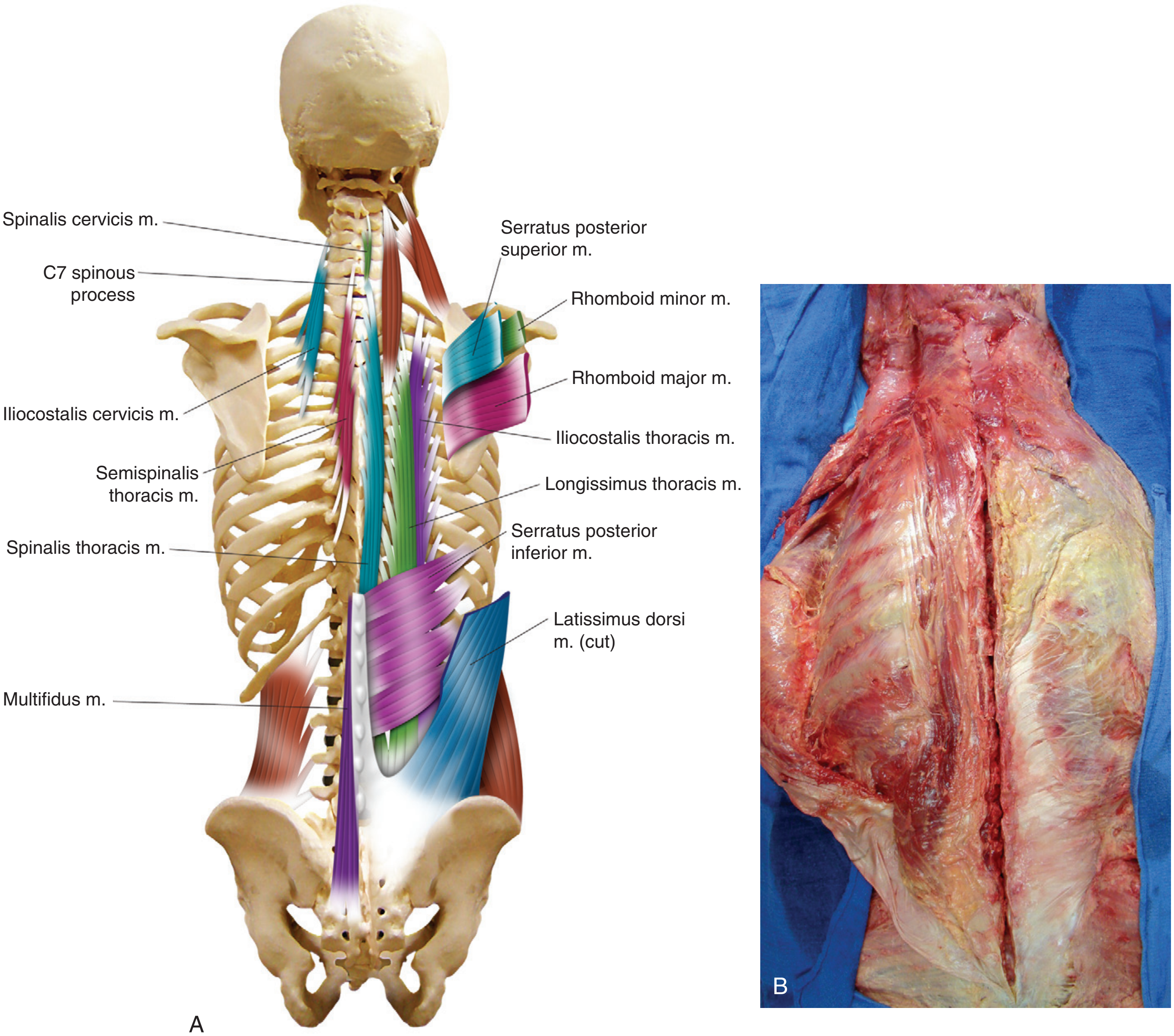

Figure 34-2 Deep-layer muscles. Erector spinae and transversospinalis muscles.

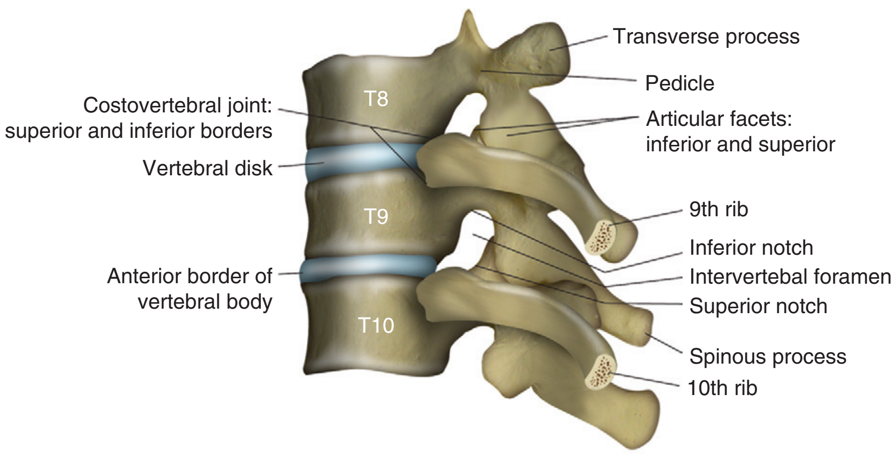

Figure 34-3 Thoracic bony structures from the inside of the thoracic cavity. Rib head contacts intervertebral disk on the superior portion of the pedicle. At lower thoracic levels, rib head contacts on the midportion of the pedicle.

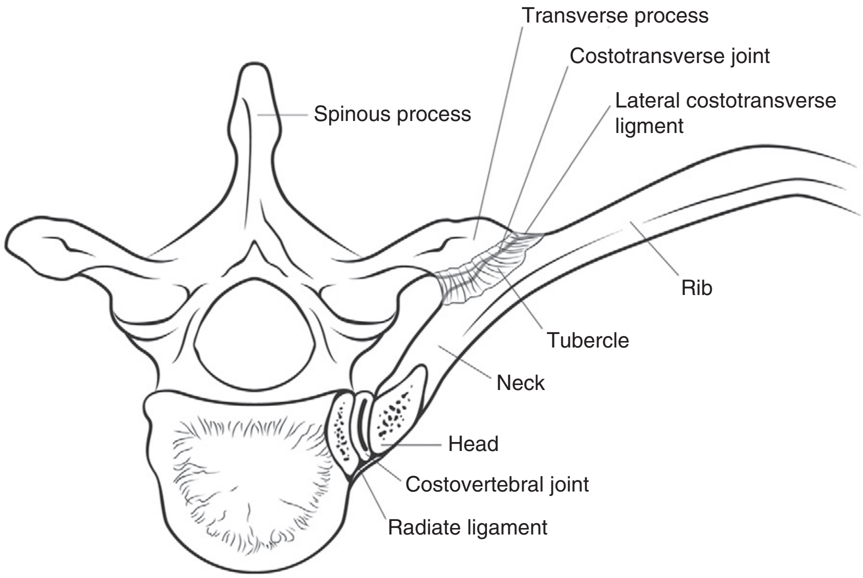

Figure 34-4 Rib head contact with vertebral body via two joints, the costotransverse and costovertebral joints. The costotransverse joint is wrapped with the lateral costotransverse ligament; the costovertebral joint is surrounded by the radiate ligament.

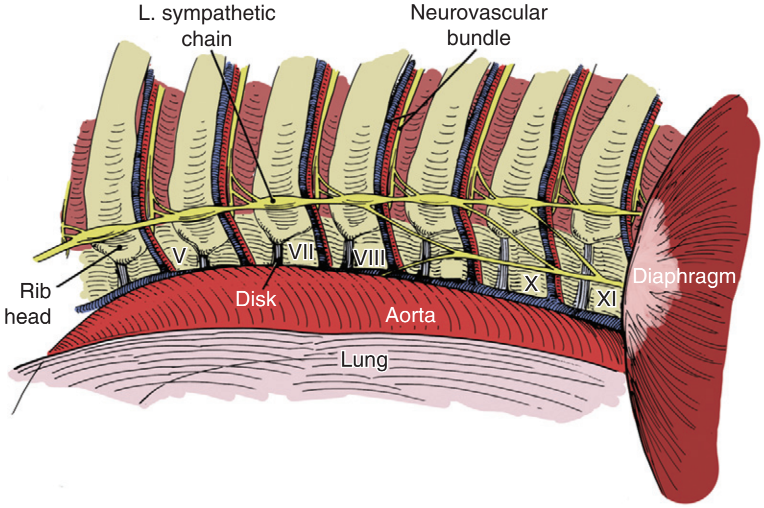

Figure 34-5 Retromediastinal structures in left thoracic cavity. The aorta is seen to run along the anterolateral surface of the thoracic vertebral body, and the sympathetic chain is laid over the rib heads.

located most caudad of the three. Immediately ventral to the intercostal bundle and intercostal muscles lies the pleura.

Posterior Mediastinal Space and Neurovascular Structure

Some neurovascular structures are related to the spine in the posterior mediastinal space. Between T4 and T7, the aorta has a close relationship with the left lateral surface of the vertebral bodies. It then moves medially to occupy a more anterior position, and at the level of the diaphragm, it is strictly prevertebral. The segmental arteries arise from the posterior surface of the thoracic aorta and run horizontally, following the concavity of the vertebral body. At the level of the foramen, they bifurcate into a radiculomedullary and intercostal branch. The principal medullary artery, the artery of Adamkiewicz, is located on the left side in about 60% of patients and originates mostly between T9 and T11.

In the upper thoracic region, the first two intercostal spaces are supplied by branches of the costocervical trunk through the highest intercostal artery. Because the aorta is displaced downward and to the left, the upper four intercostal arteries ascend to reach intercostal spaces three through six. They stretch obliquely across each vertebral body from caudad to cephalad in direct apposition to the periosteum of the vertebral body and are located deep to the azygos and hemiazygos vein, the thoracic duct, and the sympathetic trunk. On the left side, the superior hemiazygos vein occupies a position lateral to the aorta and receives collateral branches down to the sixth or seventh interspace.

The azygos vein is lateral to the esophagus on the right side and runs inferiorly to join the superior vein cava at the fourth interspace. At the point where it turns medially, it may receive some branches, which may be divided if necessary (Fig. 34-6).

The sympathetic chain runs vertically and lies atop the heads of the ribs at the anterior edge of the foramina. From the intercostal nerves the chain receives the rami communicantes. A section of a few of these will be of no functional

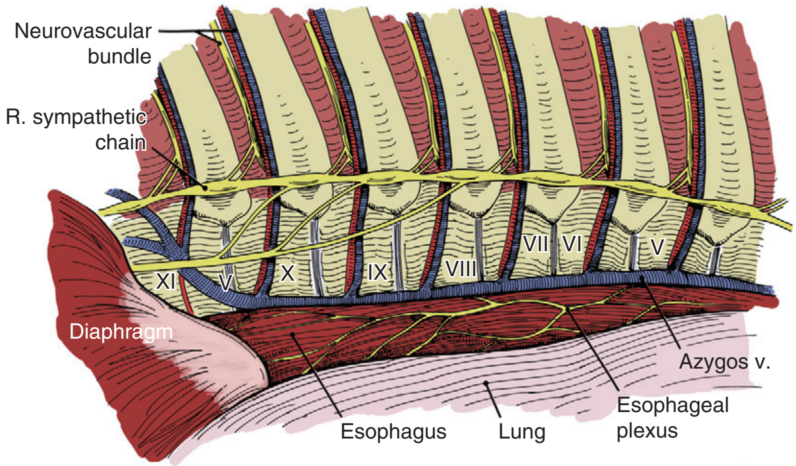

Figure 34-6 Retromediastinal structures in right thoracic cavity. The azygos vein runs cephalocaudal to the right sympathetic chain and contributes to the formation of the greater splanchnic nerve.

consequence as long as the major chain is preserved. From the inferior thoracic ganglia are derived larger trunks that constitute the splanchnic nerves, and these should be spared.

Lateral Extracavitary Approach

The lateral extracavitary approach (LECA) is an extension of the costotransversectomy. The more extensive rib resection provides a more ventral and wider operative view across the midline.[7] LECA is indicated for the removal of extradural mass lesions anterior and lateral to the spinal cord or cauda equina, followed by anterior vertebral fusion. It can be applied for the management of thoracic disk herniation, upper lumbar disk herniation, trauma, tumors, and inflammatory diseases that involve up to three and sometimes four vertebral levels.[1,8] LECA may not be applicable above the T4 level because of the scapula and below the L4 level because of the iliac crest.

POSITIONING AND INCISION

A midline vertical incision (three levels above and three levels below) is made with a gently curved lateral portion (12 to 14 cm). This incision offers access to both the posterior midline and anterior vertebral body through the lateral approach (Fig. 34-7).[9]

MUSCLE DISSECTION

Skin and subcutaneous tissue are incised and reflected to the extended incision side. The thoracodorsal fascia is then dissected from the midline and is incised along the horizontal skin incision line. The thoracolumbar fascia appears silver to white. When it is dissected and retracted, the lateral branch of the dorsal ramus of the spinal nerve is seen to run over the surface of the muscle layer (Fig. 34-8).[10]

Trapezius or latissimus dorsi muscle is divided with the attached fascia, depending on the level of the lesion. The entire skin, subcutaneous tissue, muscle, and fascia flap are then elevated and retracted laterally. A plane is defined at the lateral aspect of the erector spinae group, and these

Figure 34-7 L-shaped skin incision on the thoracic and lumbar spine.

Figure 34-8 Exposure of thoracolumbar fascia and erector spinae muscles. The lateral branch of the dorsal ramus of the spinal nerve is tied with string.

muscles are elevated as a layer off the ribs and are retracted medially (Fig. 34-9).

RIB RESECTION

All muscles and attached ligaments are cleaned from the ribs, and the rib is transected 7 to 10 cm lateral to the costovertebral junction. The endothoracic fascia and pleura are separated using blunt dissection. On identification of the neurovascular bundle, the intercostal nerve is separated from the vessels. The transverse processes and associated intertransversarii muscles are removed.

The superior costotransverse ligaments and radiate ligament, post costotransverse ligament, are incised with a scalpel. After the costovertebral joint is opened, the rib head is elevated out of the field. It is important to remove the rib and transverse process at the articulation to ensure full exposure (Fig. 34-10).

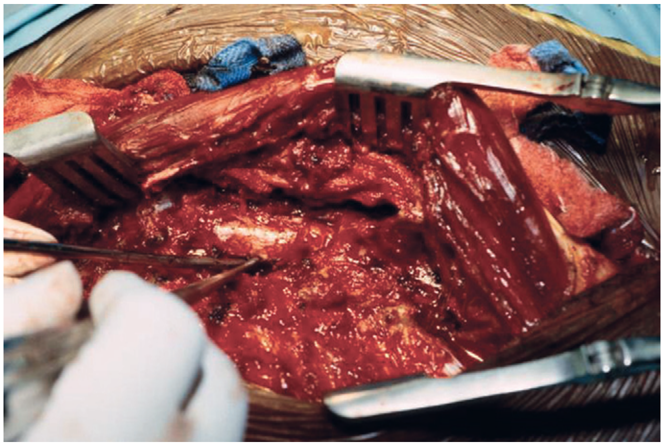

Figure 34-9 The erector spinae muscle group is elevated and retracted medially to expose the posterolateral surface of the spinal canal.

Figure 34-10 The intercostal bundle—vein, artery, and nerve—under the lower margin of the rib (*inside view*).

IDENTIFICATION OF THE NEURAL FORAMEN

Each intercostal nerve is then traced into its respective foramen (Fig. 34-11). A ligature is placed around the nerve, which is cut 3.0 cm distal to the dorsal root ganglia, and the nerve is retracted to the dorsal side. The retracted nerve roots cause the spinal cord retraction, which enables the surgeon to view the vertebral body across the midline.

The parietal pleura is dissected off the vertebral bodies using a Cobb elevator. If the rami communicantes that connect the nerve root and sympathetic ganglion are divided, the vertebral body can be exposed easily to the ventral tip. The sympathetic chain is contained within a fascial compartment formed by fusion of the mediastinal and prevertebral fascia over the costovertebral articulation. Displacing the sympathetic chain anterolaterally via subperiosteal dissection reveals the anterolateral surface of the vertebral body, pedicle, and foramen. The segmental arteries are dissected off the vertebral bodies and are divided between clips. The foraminal margins above and below the lesion are defined with a blunt nerve hook. Care is taken not to dissect into the spinal canal. After identification of the foramen, the pedicle is removed using a combination of rongeurs and thin foot-plated punches. The table is then rotated 15 to 20 degrees away from the surgeon to maximize visualization of the spinal canal.

Removal of the pedicle provides the lateral view of spinal cord. To facilitate exposure of the dorsal cord, the ipsilateral facet complex and lamina can be removed. When the epidural space is opened, epidural venous plexus bleeding is severe.

CORPECTOMY OR DISKETOMY

The annuli adjacent to the vertebral bodies to be removed are incised with a No. 15 blade, and a punch is used to create a seat for a drill bit (Figs. 34-12 and 34-13). With use of a brace and bit, the disk material and end plates are drilled out about three fourths of the way across the vertebral body, thus ensuring that the surgeon is across the spinal canal. The posterior intervertebral disk space, about 1 cm ventral to the canal, is the portion to be drilled out. The intervening vertebral bone is removed using a rongeur or a high-speed drill to go deep through the vertebra. At this

Figure 34-11 The exposure of the neural foramen following the intercostal nerve. The trace of the nerve can identify the neural foramen and epidural fat.

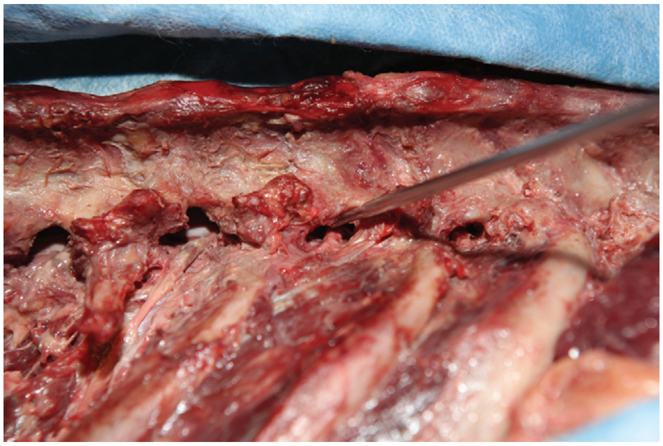

Figure 34-12 Diskectomy is performed during the retraction of the dorsal rami of the spinal nerve. The string is tied on the spinal nerve to be retracted.

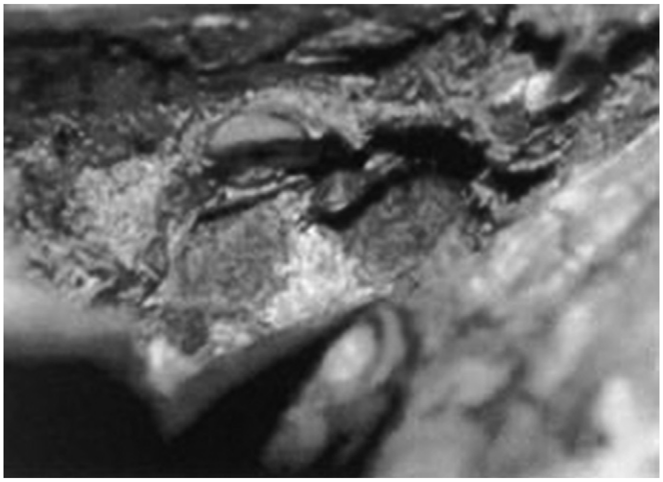

Figure 34-13 After partial removal of the disk, the intervening vertebral body is resected. The distal end of the dorsal root ganglion is cut.

point, there should be at least 1 to 2 cm of bone left anteriorly and dorsal shelf posteriorly. Careful dissection of the dura–bone interface can be helpful to break up adhesions and to define spicules, which may be stuck to the sac. The backward-angled curette is used to remove the posterior cortex from the ventral dura. The posterior cortex can be removed in a single piece by working primarily at the junctions of the intervertebral disks, and the posterior cortex removal can be extended across the spinal canal (Fig. 34-14).

VERTEBRAL BODY RECONSTRUCTION

Following decompression, troughs are cut into the intact bone adjacent to the corpectomy site to seat the interbody strut graft. If posterior instrumentation is needed, this is done before the impaction of the interbody graft. When posterior instrumentation is performed, realignment of even severe deformities can be tried without risk of cord injury.

The bone graft is prepared 10% to 15% longer than the defect to be spanned. The ends are trimmed to 45-degree angles with the shorter length the leading edge. The graft should be positioned at least 1 cm away from the dural sac to prevent cord compression if cull correction is not maintained.

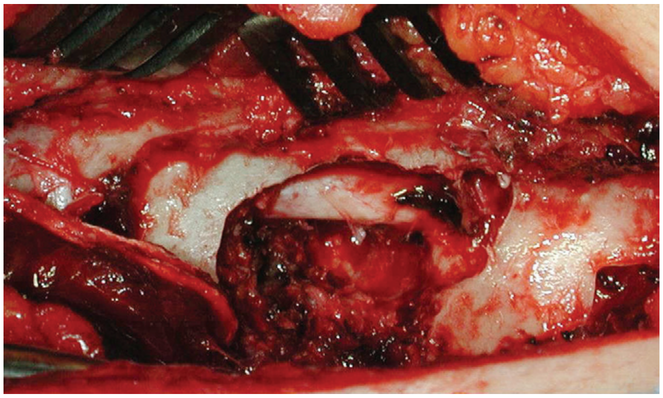

Figure 34-14 After the vertebral body is removed, the ventral dura is decompressed.

WOUND CLOSURE

The paravertebral muscle layer and the thoracodorsal fascia are tightly closed, and the midline muscles are reapproximated using nonabsorbable sutures. If the pleurae have been entered inadvertently, an attempt to primarily close the defect should be made. If primary closure is impossible, a #32 chest tube should be placed in the pleural cavity.

Transcostovertebral Approach

Posterior surgical approaches to the thoracic spine include the transpedicular, transfacetal, costotransversectomy, and lateral extracavitary approaches. Transpedicular and transfacetal approaches are included in the transcostovertebral approach.[11]

Midline incision and usual posterior exposure are done. The transverse process of the involved level is resected en bloc to uncover the costotransverse junction and to provide access to the costovertebral joint (Fig. 34-15).[4]

The lateral portion of the facet joint and the superior half of the pedicle are removed with a drill. The thoracic pedicle can be identified by following the superior facet. The pedicle is the landmark for the inferior margin of the disk. After removing the facet and pedicle, the surgeon can reach the costovertebral joint (Fig. 34-16), which consists of the lateral end of the disk, rib head, and lateral aspects of the pedicle. From the center of the joint, the drilling is continued outward circumferentially to include immediately adjacent structures, such as the posterior cortex of the rib head and lateral end plates above and below the annulus (Fig. 34-17). This maneuver exposes the lateral and anterior aspects of the spinal cord.

Costotransversectomy

The costotransversectomy was first used for the drainage of tuberculous paraspinal abscesses in Pott disease.[4,12] This

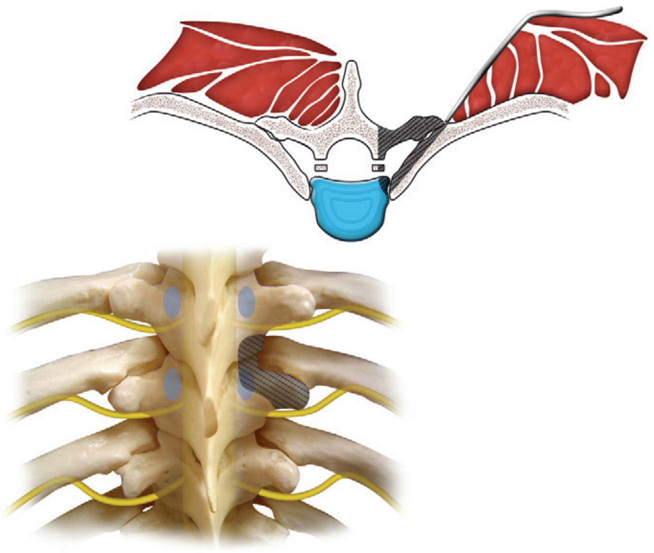

Figure 34-15 Transverse process resection with pedicle. The facet joint is drilled away with the superior portion of the pedicle and the entire transverse process. The underlying rib head is cut away partially.

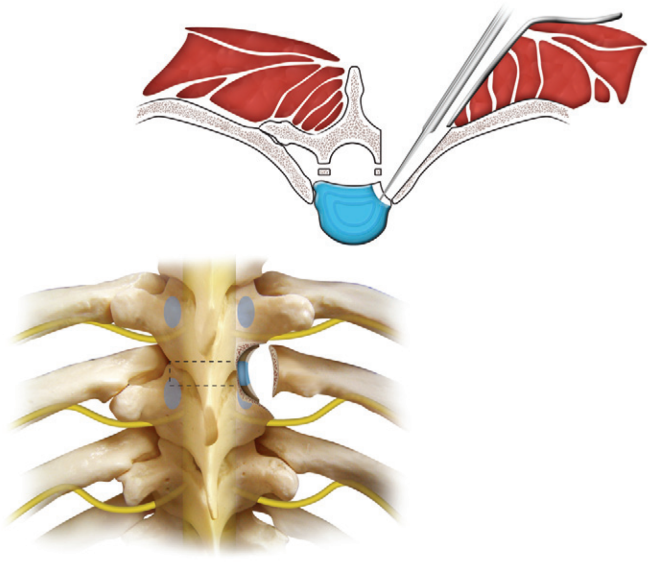

Figure 34-17 The lateral disk, rib head, and pedicles are removed. This procedure can reveal the lateral surface of the spinal cord.

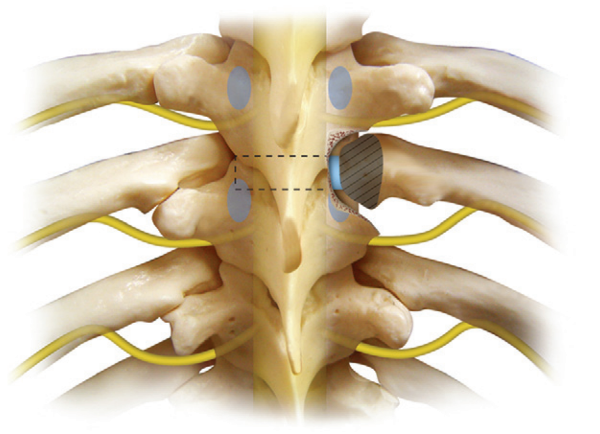

Figure 34-16 After the facet and pedicle are removed, the costovertebral joint is visible. *Dotted lines* show the disk space.

approach provides access to the posterior and lateral aspects of the vertebrae. It extends the exposure provided by the pediculectomy by resecting the transverse process, medial portion of the rib and rib head, and costovertebral ligaments (Fig. 34-18).[12]

POSITIONING AND INCISION

The operation may be performed with the patient in the prone or lateral decubitus position. For the upper thoracic region, the arm on the affected side is maximally elevated to move the scapula as far away from the midline as possible.

Three types of skin incision can be used depending on the lesion to be dealt with: paramedian, oblique, or T-shaped. A straight paramedian incision can be made approximately three fingerbreadths beside the spinous process. An oblique incision following the rib to be resected and extending across the midline is preferred for relatively localized lesions, such as herniated disks or neurofibroma. In more extensive lesions, and particularly in cases where a fusion procedure with instrumentation is needed, a T-shaped incision is better (Fig. 34-19), because it will allow the surgeon to resect several ribs and expose the spinal column at multiple levels. The transverse limb is at the level of the vertebra to be exposed.

MUSCLE DISSECTION

After the skin incision, the trapezius or latissimus dorsi muscle is divided along the skin incision line to expose the underlying rib. The intrinsic muscles of the back, in accordance with the skin incision, are now first separated from the spinous processes close to the bone. The intrinsic muscles of the back are dissected with a rasp from the vertebral arches and transverse processes above and below the transverse incision. After this, the longissimus muscle is transversely dissected and retracted superiorly and inferiorly (Fig. 34-20). The ribs, laminae, facet joints, and transverse processes are visualized at this point. The proximal 5 to 6 cm of the selected rib is resected, as well as any other soft tissues, after stripping of the periosteal covering.

RIB RESECTION

The periosteum over this rib is split with the electrocautery knife and is cautiously retracted with an elevator. To begin with, the lower border of the rib is dissected subperiosteally from lateral to medial. The upper border of the rib is dissected subperiosteally, from medial to lateral, until the entire circumference of the rib is exposed. Medially the subperiosteal exposure is continued as far as the costotransverse articulation. The rib is initially divided laterally with rib cutters; the costotransverse joint is then opened with a knife, and the transverse process is exposed subperiosteally as far as the lamina. The transverse process may

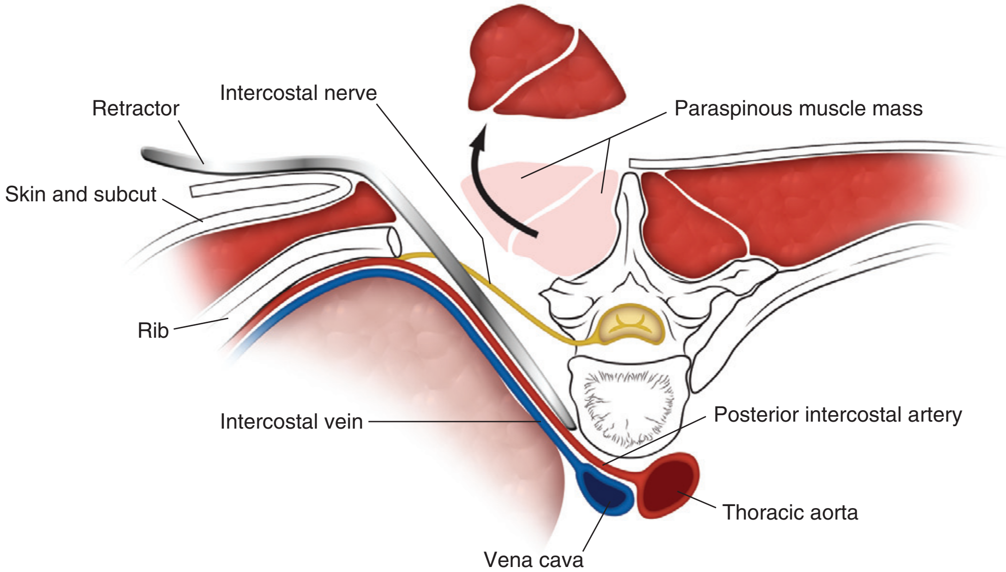

Figure 34-18 Costotransversectomy for ventral lesion removal. The transverse process, the medial portion of the rib, rib head, and costovertebral ligament are removed.

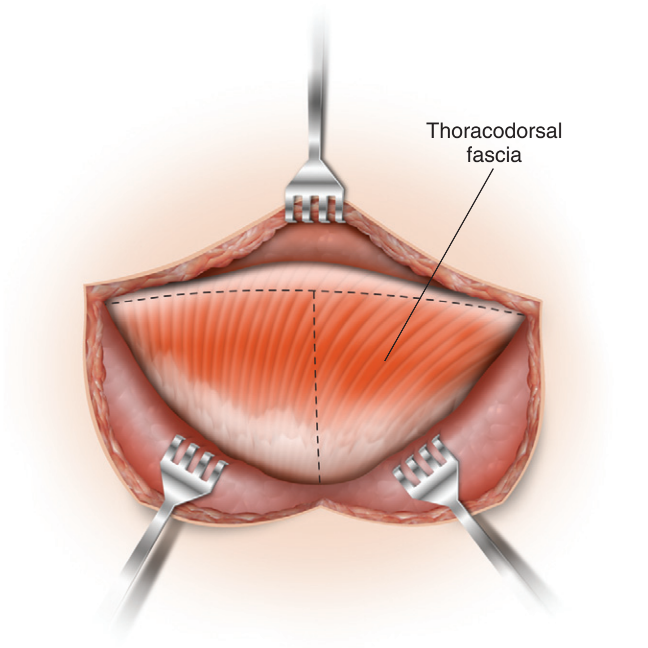

Figure 34-19 T-shaped skin and muscle incision. The initial incision is made vertically along the spinous process, and the additional incision is made as a perpendicular line to extend the surgical field.

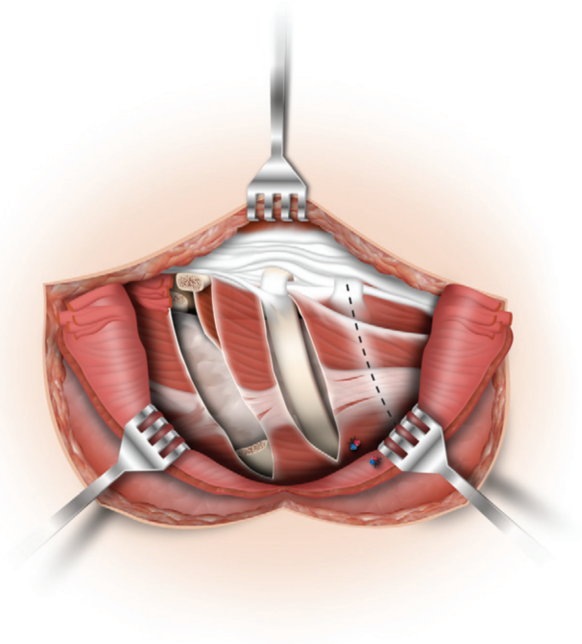

Figure 34-20 Muscle division and rib resection. The longissimus muscle is incised and retracted superiorly and inferiorly. The proximal 5 to 6 cm of the selected rib is resected after stripping of the periosteal covering with other soft tissue.

subsequently be separated at its base with a narrow chisel and removed with a Luer bone rongeur. The laterally separated rib is lifted from the wound bed, and the periosteum below the rib is now cautiously stripped with an elevator as far as the costovertebral articulation, sparing the neurovascular bundle lying caudal to the rib. Removal of the rib is accomplished with rotatory movements on the rib and simultaneous retraction of the costovertebral joint capsule (see Fig. 34-20).

EXPOSURE OF VERTEBRAL BODIES AND SPINAL CORD

With a peanut sponge stick, the endothoracic fascia beneath the rib periosteum, as well as the parietal pleura, is cautiously retracted from the anterior side of the vertebrae and the intervertebral disks, sparing the neurovascular bundles.

For easy dissection, the sympathetic chain is identified and released with disconnection of the rami communicantes. The remnants of the intercostal muscles lying between the resected ribs are dissected off the segmental vessels (Fig. 34-21). If necessary, the intercostal vessels may be ligated and transected anterior to the vertebral body, but the segmental nerves should be preserved. Following retraction of the parietal pleura from the anterior side of the vertebrae, flexible spatulas may be inserted such that two to three vertebrae may be laterally visualized from behind (Fig. 34-22).

The spinal canal is exposed by removing the ipsilateral laminae, facet joint, and pedicle. The lateral aspect of the dural sac and spinal cord is seen at this point, and the disk space can be seen and palpated.

WOUND CLOSURE

Before wound closure, positive-pressure breathing should be used to make certain that the parietal pleura has not been injured, because pleural injury would require insertion of a chest tube. Wound closure is achieved by reapproximating the divided musculature in layers.

Total En Bloc Spondylectomy: Thoracic Spine

INDICATIONS

En bloc spondylectomy is the treatment of choice for solitary and oligometastatic spinal metastases with biologically favorable histologic findings.[13] In appropriately selected patients, neurologic outcome, pain control, and oncologic control are significantly better after en bloc spondylectomy compared with radiation therapy. Oncologic outcomes also exceed those of intralesional techniques. Total end bloc spondylectomy (TES) decreases the rate of local recurrence and can provide long-term survival in selected patients with spinal metastasis.[14]

SURGICAL TECHNIQUE

Total spondylectomy is performed through the posterior procedure alone or the anteroposterior combined procedure. The TES technique consists of two steps, including en bloc resection of the posterior element and en bloc resection of the anterior column.[13,15]

Step 1. En Bloc Resection of the Posterior Element of the Vertebra by Posterior Approach

Exposure. The patient is placed in a prone position over a four-poster frame to avoid compression of the vena cava. A straight vertical midline incision is made over the spinous processes and is extended three vertebrae above and below the involved segments. The paraspinal muscles are dissected from the spinous processes and the laminae and are then retracted laterally over the facet joint. After careful dissection, a large retractor is applied. The surgical field must be wide enough on both sides to allow dissection under the surface of the transverse processes. In the thoracic spine, the ribs on the affected level are transected 3 to 4 cm lateral to the costotransverse joint, and the pleura is separated bluntly from the vertebra. To expose the superior articular process of the uppermost vertebra, the spinous and inferior articular processes of the neighboring vertebra are osteotomized and removed with dissection of the attached soft tissues, including the ligamentum flavum (Fig. 34-23). After the spinous process, the lower part of the lamina and inferior facet are removed, and the dorsal dura is exposed.[15,16]

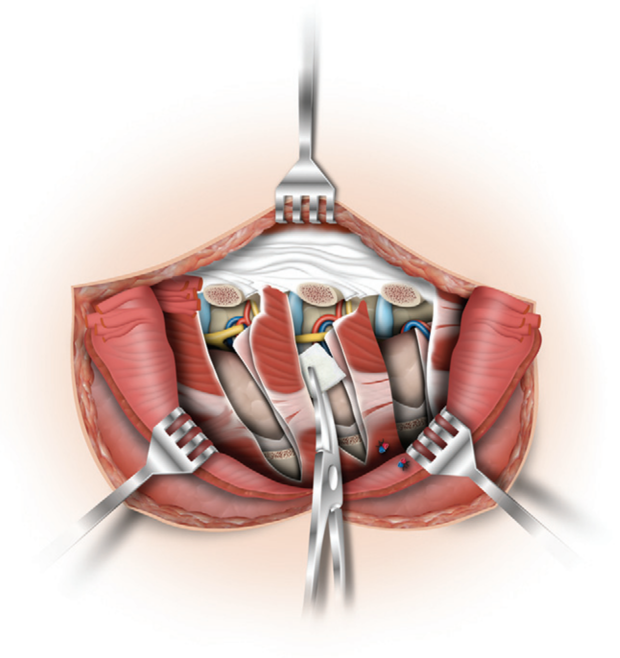

Figure 34-21 Exposure of vertebral body. Intercostal vessels are ligated and transected anterior to the vertebral body. The sympathetic chain is released with disconnection of the rami communicantes.

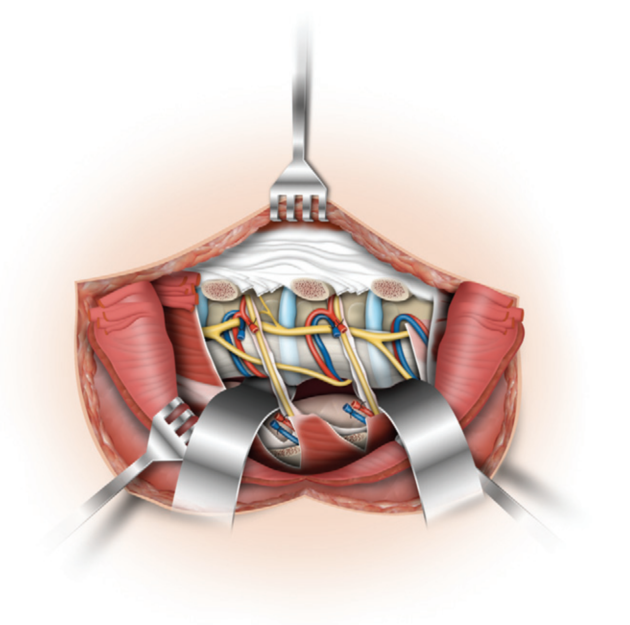

Figure 34-22 Exposure of the ventral surface of the vertebral body. The intercostal nerve should be preserved. If it is damaged, the patient may suffer from severe intercostal neuralgia.

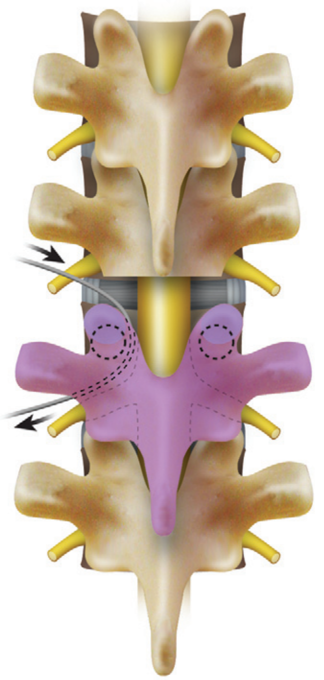

Figure 34-23 The saw is inserted from the superior side of the spinal canal to the intervertebral foramen. For easier insertion, the facet joint is resected. (Modified from Abe E, Kobayashi T, Murai H, et al: Total spondylectomy for primary malignant, aggressive benign, and solitary metastatic bone tumors of the thoracolumbar spine. *J Spinal Disord* 2001;14(3):237–246.)

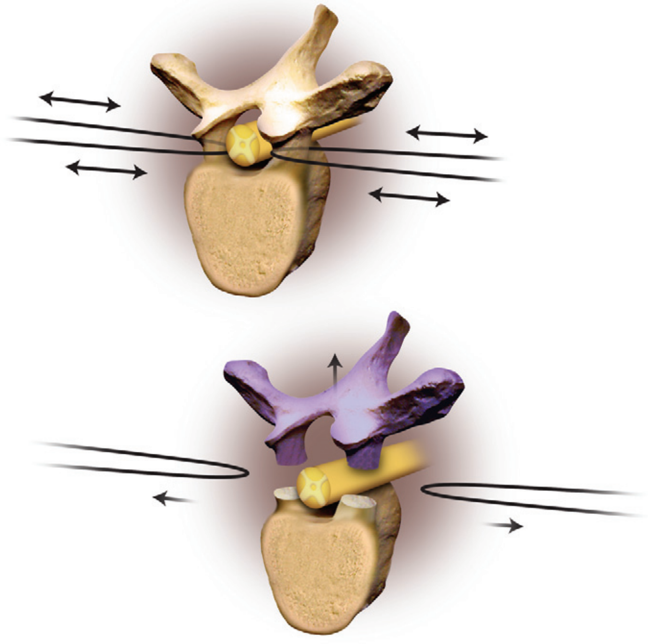

Figure 34-24 Pediculotomy with saw. Sawing proceeds from the medial side of the pedicle to the lateral side. (Modified from Abe E, Kobayashi T, Murai H, et al: Total spondylectomy for primary malignant, aggressive benign, and solitary metastatic bone tumors of the thoracolumbar spine. *J Spinal Disord* 2001;14(3):237–246.)

Introduction of the T-Saw Guide. With blunt-tipped dissectors, the soft tissue attached to the inferior aspect of the pars interarticularis is dissected and removed so as not to damage the corresponding nerve root. A C-curved, malleable, T-saw guide is then introduced through the intervertebral foramen in a cephalocaudal direction.[15] In this procedure, the tip of the T-saw guide should be introduced along the medial cortex of the lamina and the pedicle, so that the spinal cord and the nerve root are not injured. After the T-saw guide is passed, its tip at the exit of the nerve root canal can be found beneath the inferior border of the pars interarticularis. In the next step, a flexible threadwire saw (0.54 mm in diameter) is passed through the hole in the T-saw guide and is clamped at each end. The T-saw guide is removed, and tension on the threadwire saw is maintained. This procedure is also applied to the contralateral side.

Cutting the Pedicles and Resection of the Posterior Element. While tension is maintained, the threadwire saw is placed beneath the superior articular and transverse processes. With this procedure, the saw placed around the lamina is moved to around the pedicle. With a reciprocating motion of the saw, the pedicles are cut, and then the whole posterior element of the spine—spinous process, superior and inferior articular processes, transverse process, and pedicle—is removed in one piece (Fig. 34-24). The cut surface of the pedicle is sealed with bone wax to reduce bleeding and to minimize contamination by tumor cells.

If the unilateral pedicle is affected by the tumor, osteotomy is performed through a healthy lamina, and the cut surface is blocked with bone wax immediately after osteotomy. The threadwire saw is passed under the lamina in a sublaminar fashion after carefully dissecting a passageway for it in the epidural space. If the tumor invades the bilateral pedicles and the pedicle and lamina, an electric cautery knife is inserted into the affected pedicle to coagulate tumor tissue inside the pedicle before pediculotomy to prevent tumor cell contamination. In these cases, the nerve root involved sometimes must be ligated and included in the tumor mass. If the affected pedicle or vertebral body markedly compresses the nerve root, the more severely affected side is sacrificed. In the thoracic regions, the nerve root can be sacrificed without any functional deficit, except for the T1 nerve root.[17] After the posterior bony column is removed, the epidural and foraminal vessels are meticulously coagulated using the bipolar coagulator. Before the anterior column is resected, a posterior instrumentation should be performed (Fig. 34-25).

Step 2. En Bloc Corpectomy by Posterior Approach

Posterior Ligamentous Release of the Vertebral Body. At the beginning of the second step, the segmental arteries must be identified bilaterally. The spinal branch of the segmental artery, which runs along the nerve root, is ligated and divided. This procedure exposes the segmental artery, which appears just lateral to the cut edge of the pedicle. In the thoracic spine, the nerve root is cut on the side from which the affected vertebra is removed. The blunt dissection is done anteriorly on both sides through the plane between the pleura (or the iliopsoas muscle in the lumbar spine) and the vertebral body. Usually, the lateral aspect of the body is dissected easily with a curved vertebral spatula, then the segmental artery should be dissected from the vertebral body. To aid with retraction of paraspinal

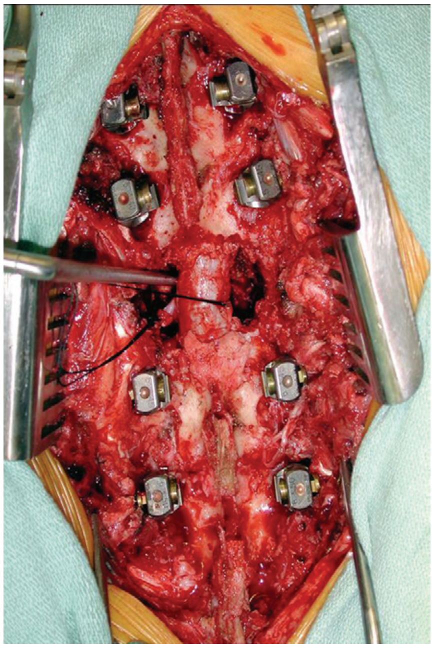

Figure 34-25 With posterior element removed, bilateral thoracic nerve roots are cut. The posterior elements are totally removed at the pedicle level.

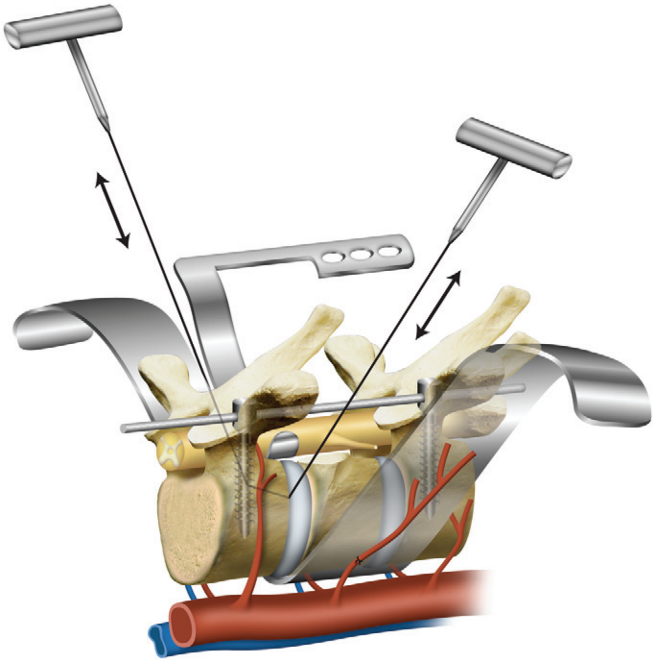

Figure 34-27 The adjacent disk is cut with a threadwire saw with the spatula applied between the spinal cord and vertebral body. (Modified from Tomita K, Kawahara N, Baba H, et al: Total en bloc spondylectomy. A new surgical technique for primary malignant vertebral tumors. *Spine* 1997;22(3):324–333.)

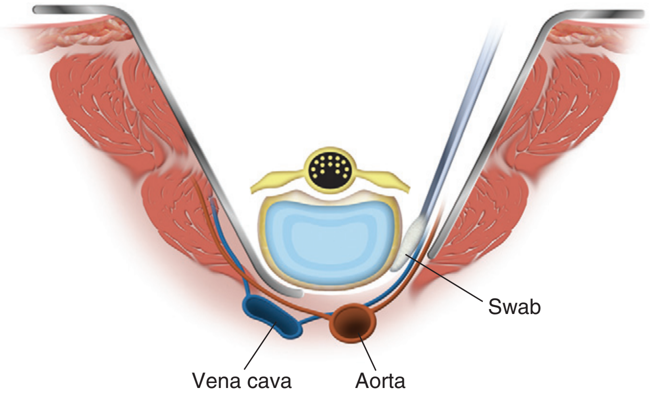

Figure 34-26 Disk sawing from the posterior side. Great care should be taken when performing dissection of the vessels from the vertebral body. (Modified from Abe E, Kobayashi T, Murai H, et al: Total spondylectomy for primary malignant, aggressive benign, and solitary metastatic bone tumors of the thoracolumbar spine. *J Spinal Disord* 2001;14(3):237–246.)

structures, cottonoids or rolled gauze pads can be inserted between the vertebra and laterally dissected tissue. By continuing dissection of both lateral sides of the vertebral body anteriorly, the aorta is carefully dissected posteriorly from the anterior aspect of the vertebral body with a spatula and the surgeon's fingers.

After dissection of the lateral surface, the dural sac is freed from the posterior longitudinal ligament (PLL), and the medial portion of the annulus fibrosus is sharply divided with a knife under direct visualization (Fig. 34-26). For the anterior release of great vessels from the anterior longitudinal ligament, blunt finger dissection is applied. After the potential space is provided with finger dissection, a series of spatulas, starting from the smallest size, is inserted sequentially to extend the dissection. A pair of the largest spatulas is kept between the anterior surface of the vertebral body and great vessels to maintain the dissected space and to make the surgical field wide enough for manipulating the anterior column. Threadwire saws are inserted at the proximal and distal intervertebral disks, where grooves are made along the desired cutting line.

Dissection of the Spinal Cord and Removal of the Vertebra. With a cord spatula, the spinal cord is mobilized from the surrounding venous plexus and the ligamentous tissue. The cord protector, which has teeth on both edges to prevent the threadwire saw from slipping, is then applied. The anterior and PLLs are cut by the threadwire saw. After cutting the anterior column, the mobility of the vertebra is checked again to ensure a complete corpectomy. The freed anterior column is rotated around the spinal cord and removed carefully. With this procedure, a complete anterior and posterior decompression of the spinal cord (circumferential decompression) and total en bloc resection of the vertebral tumor are achieved (Fig. 34-27).

CORPECTOMY WITH ANTERIOR APPROACH

Anterior column removal can be done with a separate incision after position change. If the posterior ligamentous release procedure is complete, the anterior procedure is easy. The lateral approach is favored. The ipsilateral segmental vessels are identified and dissected off from the vertebral body. The elevation of the segmental vessels makes it easy to dissect the great vessels from the anterior longitudinal ligament, and after the great vessels are away, contralateral segmental vessels are seen; they can be dissected away from the vertebral body surface. All the vascular structures are kept off of the vertebral body, which means the vertebral body is freed from the surrounding structures. Proximal and distal disks are removed with mess or a threadwire saw (Fig. 34-28).

ANTERIOR RECONSTRUCTION AND POSTERIOR INSTRUMENTATION

Bleeding occurs mainly from the venous plexus within the spinal canal and should be controlled completely. An anchor hole on the cut end of the remaining vertebra is made on each side to seat the graft. A vertebral spacer—such as autograft, fresh and/or frozen allograft, vertebral body replacement cage, ceramic prosthesis, or titanium mesh cylinder—is inserted properly to the anchor holes within the remaining healthy vertebrae. After checking the appropriate position of the vertebral spacer radiographically, the posterior instrumentation is adjusted to slightly compress the inserted vertebral spacer.

POSTOPERATIVE MANAGEMENT

Draining by suction is the preferred treatment for patients 2 to 3 days after surgery, and the patient is allowed to begin walking 1 week after surgery. The patient wears a thoracolumbosacral orthosis for 2 to 3 months, until the bony union or incorporation of the artificial vertebral prosthesis is attained.

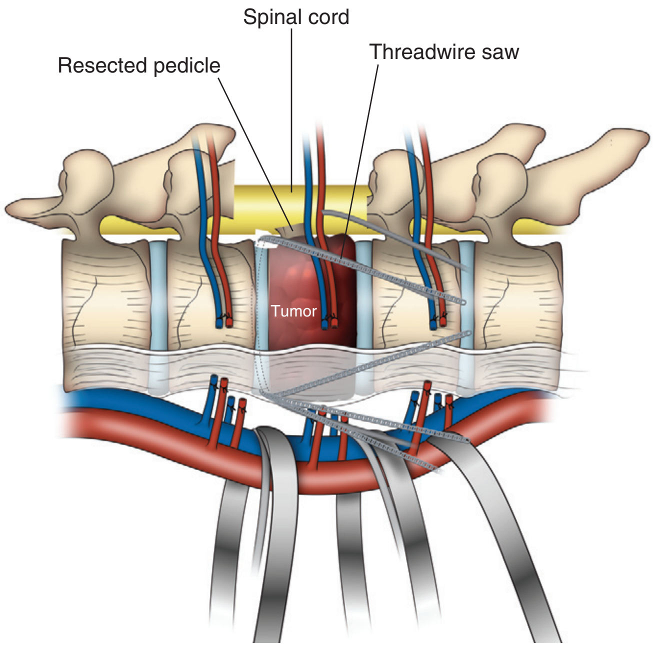

Figure 34-28 Vertebral body removal with staged anterior approach. The ipsilateral segmental vessels are dissected and cut. The great vessels are dissected away from the vertebral body, and contralateral segmental vessels are cut. The vertebral body is freed from the surrounding vessels.

Staged Operation of Thoracic Spine Tumors with Involvement of the Ribs

INDICATIONS

This approach is indicated in cases of thoracic spine tumors with the rib involvement.[18,19] The rib involvement of thoracic tumor can originate from several causes (Fig. 34-29). First, malignant vertebral body tumor, primary or secondary, develops from the bone marrow of the vertebral body and invades the pedicle, breaking the cortical margin. The adjacent rib head is involved. As a result, tumor spread to the rib bone can form a paraspinal mass.

Second, the paraspinal structures, such as sympathetic ganglia, can be the source of the tumor (paraganglioma). Third, hematogenous malignancy, such as lymphoma, can be the diagnosis of the paraspinal mass. In this case, the tumors invade the spinal canal without pedicular destruction (Fig. 34-30). These tumors can be attacked posteriorly only, or they can be targeted from both directions.

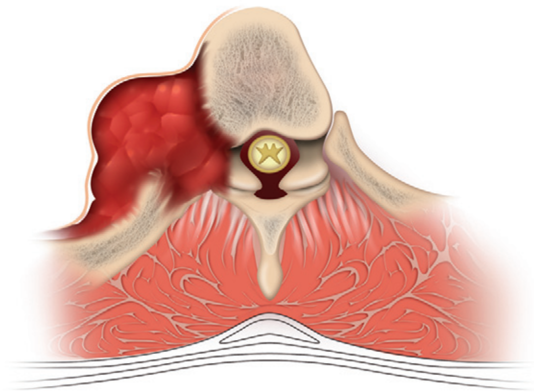

Figure 34-29 Paraspinal mass with rib involvement. Rib-involving tumors can develop as local invasion of a malignant vertebral body tumor, primary tumor occurrence from paraspinal structures, or hematogenous malignancy.

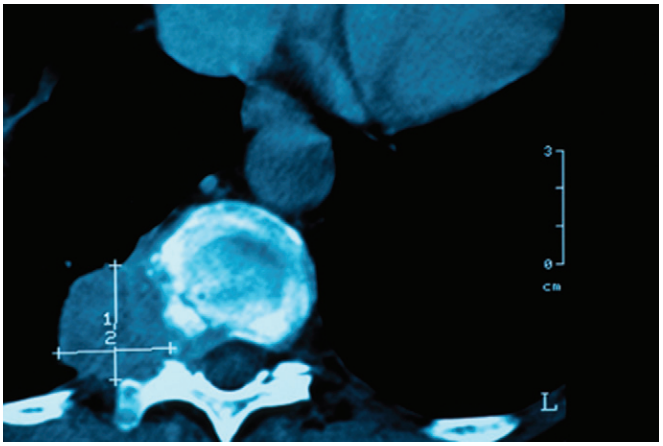

Figure 34-30 On magnetic resonance imaging, the tumor (lymphoma) shows foraminal invasion and periosteal invasion of vertebral body.

INCISION AND POSITIONING

The resection plan for the tumor mass is set from both sides. Anteriorly the vertebral body and proximal rib are included. Posteriorly the partial body resection is performed just lateral to the spinal cord (Fig. 34-31).

The patient is positioned in left lateral decubitus position with right arm elevated.[20] If the lesion is located on the T6 and T7 body, a straight incision is made along the fourth rib from just lateral to the paraspinal muscles, and the fourth rib is removed (Fig. 34-32).

The posterior end of the incision is then extended cranially and caudally in a Y-shaped fashion for the posterior approach.[20] Posterior spinal elements are exposed subperiosteally from T5 to T8. A laminectomy is performed from T5 to T8, revealing the thecal sac. The T6, T7, and T8 nerve roots are coagulated and severed (Figs. 34-33 and 34-34).

After the roots are retracted, the vertebral body is penetrated from the posterior cortex to the anterior cortex (Fig. 34-35). The medial aspects of the T6 and T7 pedicles are secured, and the vertebral osteotomy is completed by penetrating posteroanteriorly, while still protecting the spinal cord and the major vessels (see Fig. 34-33).

With the anterolateral skin incision, the anterolateral surface of the vertebral body is exposed. Segmental vessels are ligated and severed (Fig. 34-36). The sixth, seventh, and eighth ribs and the intercostal muscles around the tumor

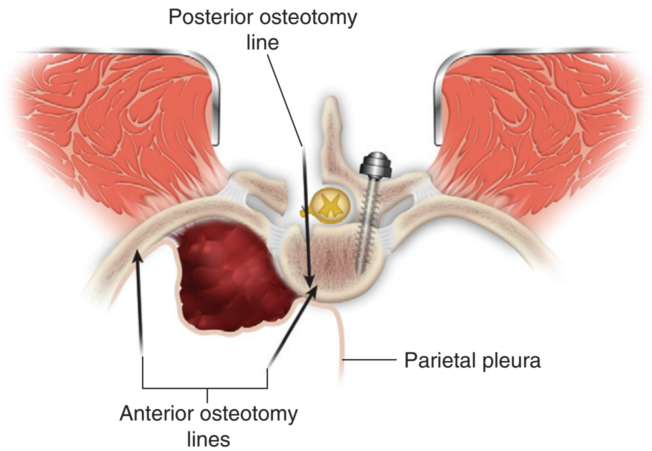

Figure 34-31 Resection plan from anterior and posterior side. Anteriorly, the vertebral body and proximal rib are included. Posteriorly, partial body resection is planned just lateral to the spinal cord.

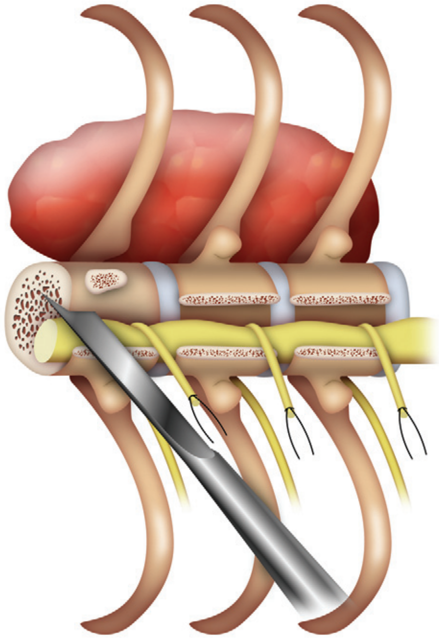

Figure 34-33 Laminectomy and root resection. When the tumor is located at T7–T9, total laminectomy is performed at these levels. Right T6–T8 nerve roots are transected and retracted to the left side. The vertebral osteotomy is performed just medial to the pedicle.

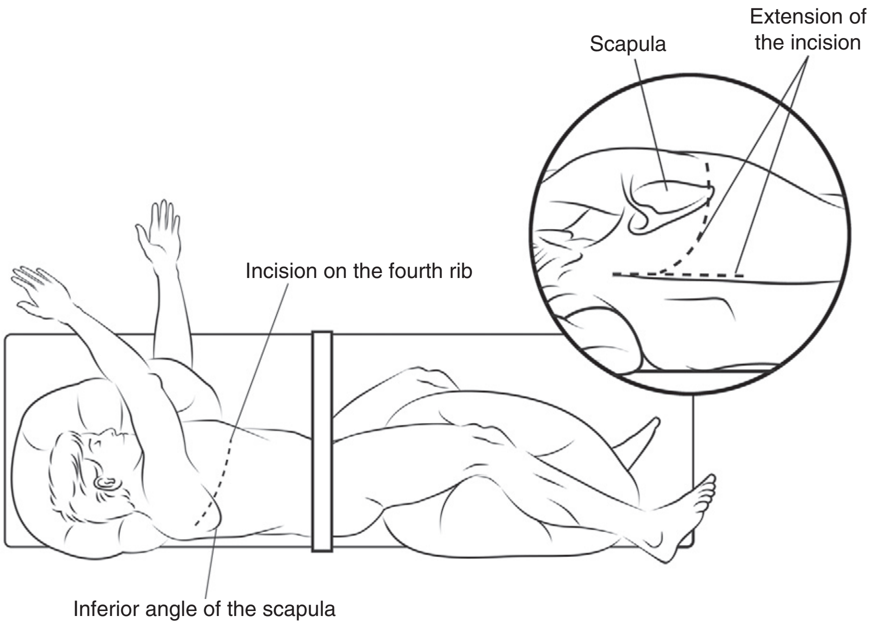

Figure 34-32 Position and skin incision. When the tumor is located at the T6–T7 levels, a straight incision is made along the fourth rib from just lateral to the paraspinal muscles.

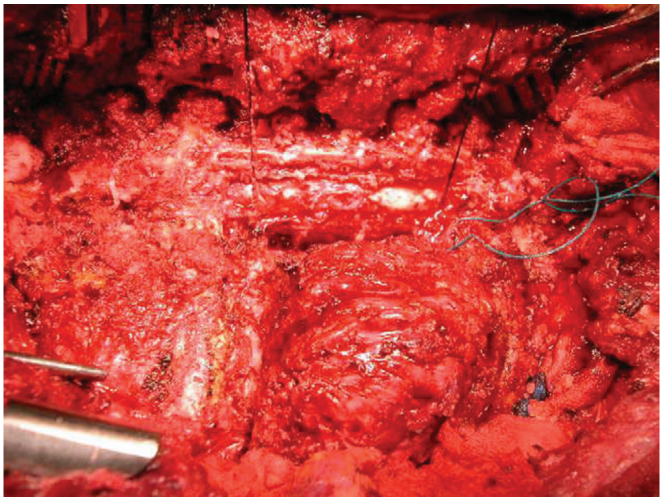

Figure 34-34 Operative view of thoracic laminectomy and vertebral body resection from the posterior approach. The thoracic roots were transected, ligated with black silk, and retracted. Rib mass is removed.

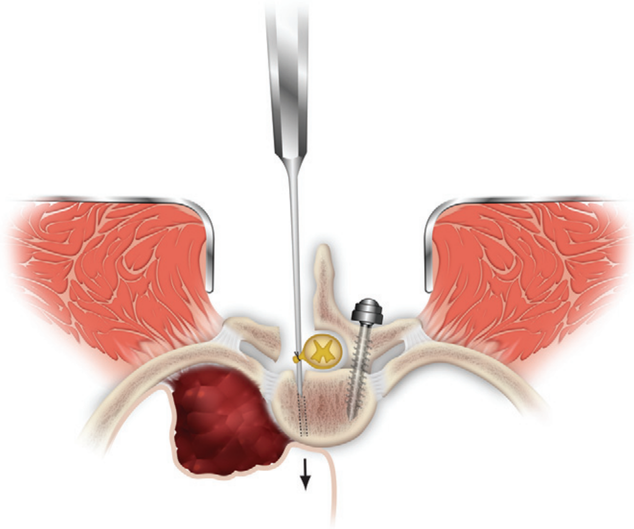

Figure 34-35 Vertebral body resection posteroanteriorly. Vertebral osteotomy is completed by penetrating posteroanteriorly.

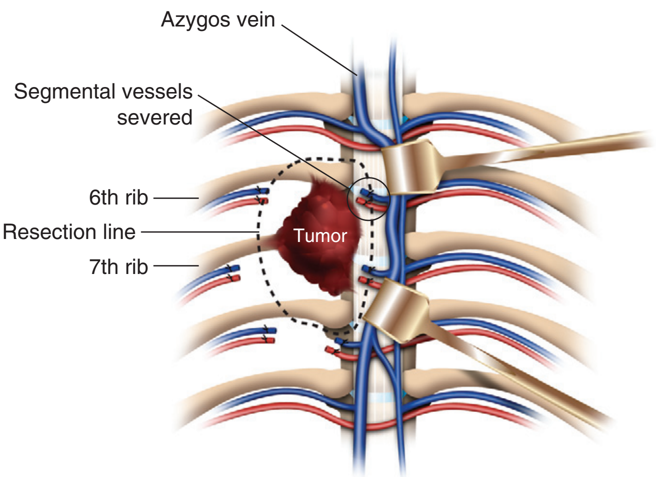

Figure 34-36 The pleural dissection and segmental vessel ligation are done. Anterior osteotomy and rib resection is made with at least a 1-cm margin to the tumor.

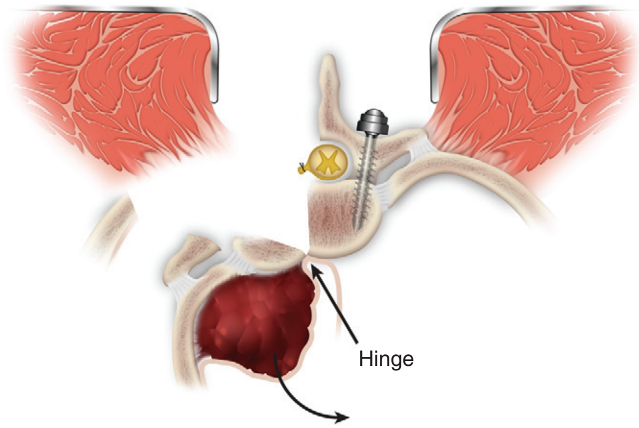

Figure 34-37 The tumor resection is completed. Parts of the vertebral body, pedicle, transverse process, and rib are removed en bloc with tumor mass.

covered by the parietal pleura as a barrier are severed with at least a 1-cm margin to the tumor. An anterior osteotomy of T6 and T7 is done using a chisel with more than 1-cm margin to the tumor.

The tumor mass—including parts of the vertebrae, pedicles, transverse processes, and ribs—is removed en bloc by turning it anteriorly, using the anterior margin of the vertebra as a hinge and avoiding injury to the spinal cord (Fig. 34-37).

Illustrative Case

A 48-year-old man complained of thoracic back pain with intercostal pain around the right nipple area. The workup showed a right paraspinal mass that originated from the right fourth rib and invaded the adjacent pedicle and lamina (Fig. 34-38). The nature of the mass seemed to be bony. Computed tomography scan showed the hyperdense lesion; however, the mass did not invade the thoracic cavity. The patient was operated on in the prone position (Fig. 34-39). A T-shaped incision was made. After the muscle incision, the erector spinae muscles were retracted to the medial side (Fig. 34-40). Laminectomy was done, and the roots were cut and tied (Fig. 34-41). The roots were retracted to the midline, and facet was removed with partial corpectomy. The rib mass was dissected from surrounding muscles (see Fig. 34-40), and the vertebral body was removed with facet and adjacent ribs. After the rib and facet were removed along with the parietal pleura, the lung tissue was exposed (see Fig. 34-41). The mass was removed en bloc (Fig. 34-42), and the pathology was osteochondroma.

Single-Stage Posterolateral Transpedicular Approach for Spondylectomy and Epidural Decompression[21]

Patients are positioned prone on lateral chest supports. A midline incision is made at least two segments above and

Figure 34-38 Right rib mass invades spinal canal. High-density mass lesion is seen on computed tomography scan.

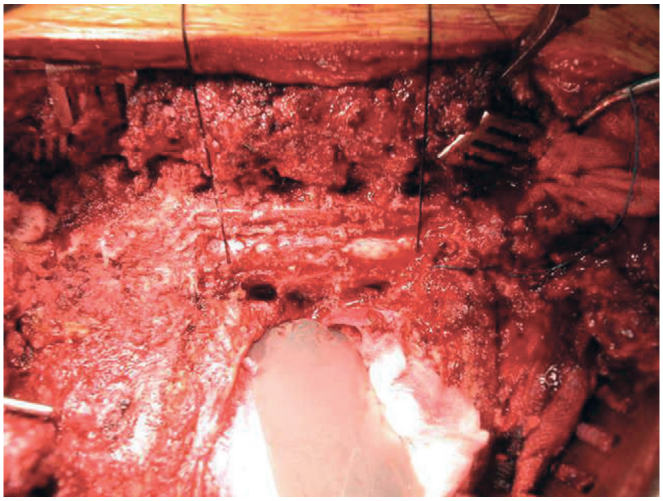

Figure 34-41 The mass is resected en bloc with parietal pleura. After the mass is removed, lung tissue is seen.

Figure 34-39 Position and skin incision. The patient was operated on in the prone position. A T-shaped incision was made.

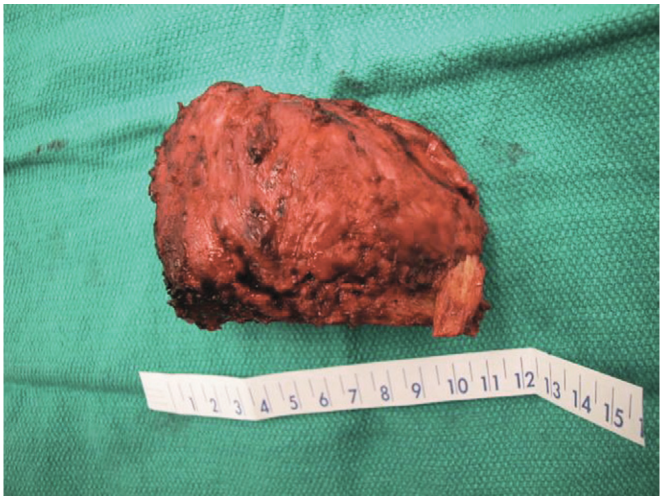

Figure 34-42 En bloc removed mass. The pathology was osteochondroma.

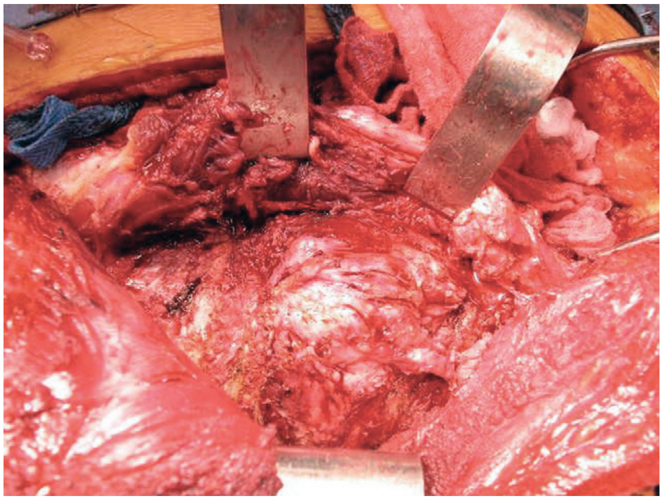

Figure 34-40 Bony mass exposure. After muscle incision, the erector spinae muscles were retracted to the medial side. The hard mass was seen to involve the rib and transverse process.

below the level to be fused. Paraspinal muscles are dissected off the posterior bony element. If the posterior elements are involved with the tumor, care must be taken to dissect the muscles off of the tumor without transmitting pressure to the spinal cord. Posterior element and adjacent soft-tissue tumor is then resected piecemeal to the level of the lamina.

The posterior bone work is initiated by removing the spinous processes with a rongeur, then a drill or Kerrison rongeur is used. The presence of an anterior mass compressing the spinal cord prohibits the use of large Kerrison rongeurs in the spinal canal. The laminectomy includes the bone overlying the disk spaces adjacent to the involved vertebral body segment and a normal dural plane adjacent to the epidural tumor (Fig. 34-43). Bilateral facetectomies and complete pedicle resection to the base of the vertebral body are accomplished with the drill and curettes (Figs. 34-44 and 34-45). In the lumbar spine, a unilateral facetectomy is often sufficient to gain exposure to the vertebral body tumor.

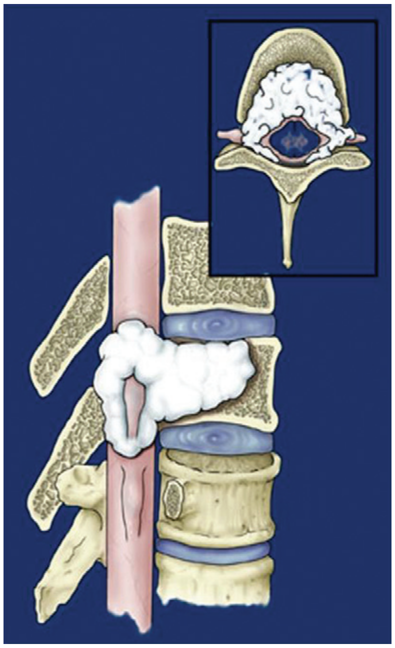

Figure 34-43 Typical tumor pattern with vertebral body disease extending into the epidural space. The vertebral body mass invades the spinal canal with a bilobed appearance, because the posterior longitudinal ligament is thickest at the midline. As a result, cord compression develops from the anterolateral direction.

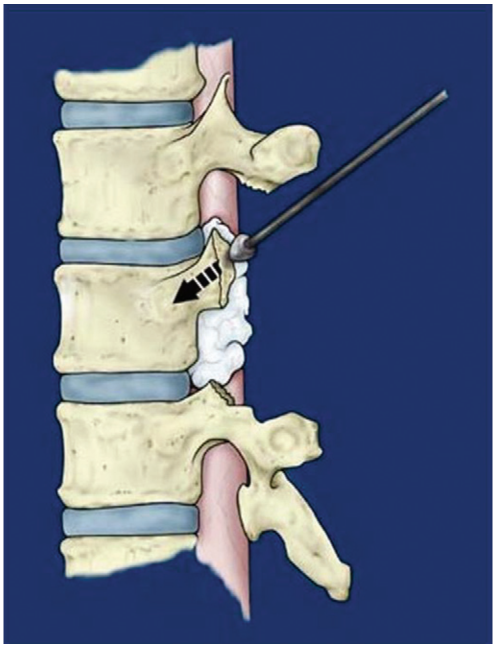

Figure 34-45 Pedicle resection and facetectomy for entrance to the vertebral body. Bilateral facetectomies and complete pedicle resection to the base of the vertebral body are accomplished with the drill and curettes.

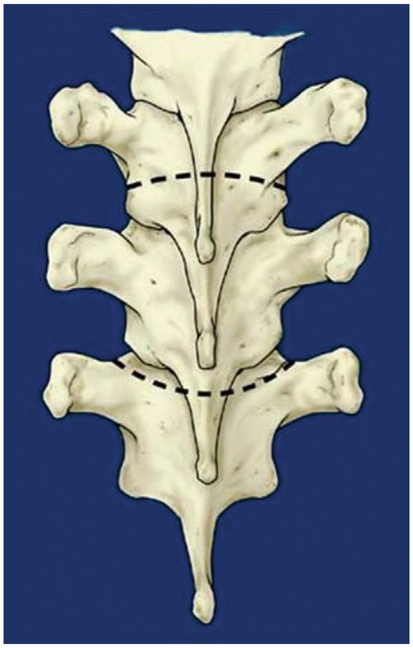

Figure 34-44 Dotted lines indicate laminectomy extending to the levels of the adjacent disk spaces to the vertebral body.

After bone removal, the ligamentum flavum and epidural tumor are resected using tenotomy scissors, starting at the interface between the tumor and dura. Bipolar cautery used on a low setting at this interface may help define the proper plane for dissection. To maximize the epidural tumor resection, nerve roots are ligated only if they are enveloped by the tumor. The nerve roots are dissected free of tumor before ligation with vascular clips or suture ligatures. Nerve roots are not ligated in the lumbar spine or when a major radicular feeding artery to the spine has been identified on preoperative angiogram.

Having dissected the epidural tumor from the posterior and lateral dura, the disk spaces adjacent to the diseased vertebral body are exenterated to expose normal end plates. In the thoracic spine, it may be necessary to resect a portion of the pedicle caudal to the involved vertebral body to provide exposure of the caudal disk space. A cavity is created in the vertebral body by piecemeal resection of tumor using curettes and pituitary rongeurs.

It is rare for a tumor to insinuate between the PLL and the dura. In these cases, the anterior compressive tumor appears bilobed with a hypointense line on magnetic resonance imaging, representing the PLL, between the vertebral body tumor and the spinal dura. Resection of the intact PLL helps provide a gross resection of tumor at the anterior dura. In the thoracic spine, the plane between the dura and PLL may be difficult to identify, but it can be sharply dissected with tenotomy scissors (Fig. 34-46). Curettage or blunt dissection of the ligament may put excessive traction on the spinal dura and should be avoided. Once the anterolateral plane between the dura and PLL has been identified, the PLL often can be dissected along the anterior dura. No significant epidural bleeding has been encountered using this maneuver. Piecemeal resection of the vertebral body then is completed. The drill may be used to create a larger cavity or to resect infiltrated bone.

Spinal reconstruction is initiated anteriorly. Right-angle clamps are used to create starting holes in the vertebral body at the proper depth for placement of the Steinmann pins. The pin generally is bent at a 20-degree angle and is driven into cranial vertebral body using a needle driver with a gentle rotational movement. The pin is then driven

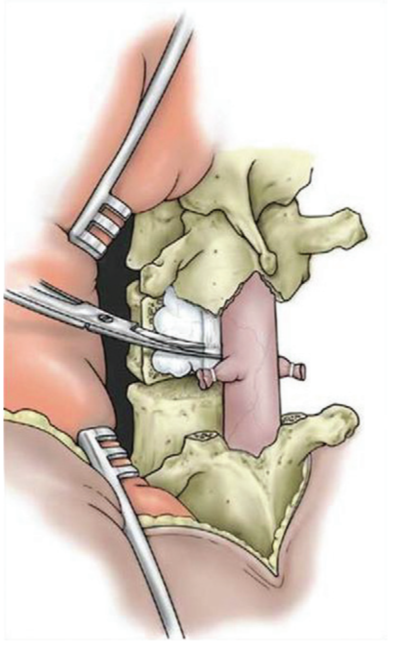

Figure 34-46 After rhizotomy, the posterior longitudinal ligament is dissected along the anterior dura and is cut with tenotomy scissors.

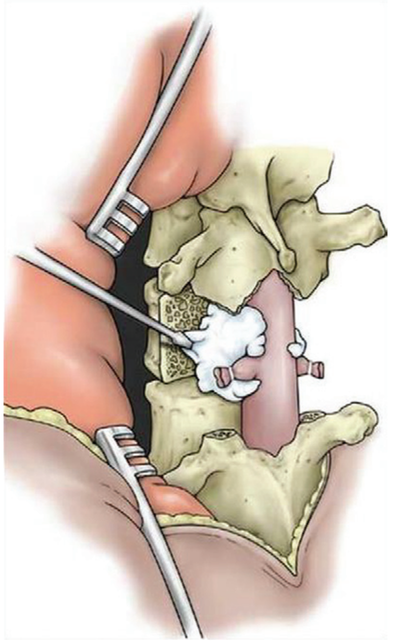

Figure 34-47 Polymethylmethacrylate and pins are placed in the vertebral body defect. The pin is bent at a 20-degree angle and is driven into the cranial vertebral body using a needle driver with gentle rotation. The pin is then driven back into the caudal vertebral body.

back into the caudal vertebral body, and another pin is placed on the contralateral side. Once radiographic confirmation shows good pin placement, polymethylmethacrylate (PMMA) mixed with tobramycin is placed into the defect covering the Steinmann pins (Fig. 34-47). The PMMA conforms well to the defect and end plates if allowed to harden slightly before administration, and if the area of blood is dried. The PMMA expands slightly just before it hardens, so it should not directly abut the anterior dura.

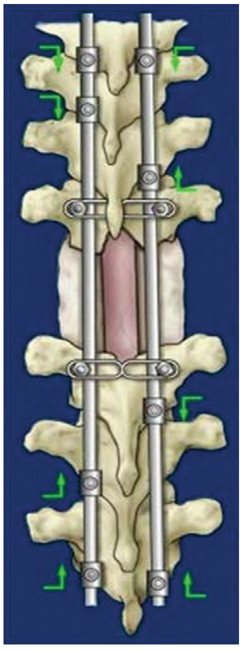

Figure 34-48 Segmental fixation is applied to the posterior spine. A claw construct is applied to the right side of the spine, and a compression construct is applied to the left side.

The PMMA should be compressed against the vertebral end plates with a Penfield #3 dissector to prevent gaps from forming at the bone–cement interface. Segmental fixation is then applied to the posterior spine.

In the thoracic spine, a claw construct is applied to one side of the spine, and a compression construct is applied on the contralateral side (Fig. 34-48). Pedicle screw fixation is used most often in the lumbar spine and for selected thoracic fixation. When correction of kyphosis is attempted, a single rod is placed before administration of the PMMA. Kyphosis correction may be achieved by underbending the rod and translating the spine into alignment. Crosslinks are applied unless they are too prominent. The wound is pulse-irrigated with bacitracin irrigant. Posterolateral bone graft then may be applied to decorticated bone for patients with an expected survival time of at least 1 year.

Illustrative Case

A patient showed a tumor mass that involved the posterior element (lamina and facet) and right-side proximal rib (Figs. 34-49 and 34-50). For the wide resection margin, the tumor mass was removed with the posterior element of one level above and below. The tumor mass originated from T7 lamina and spinous process. Posterior decompression was done at T6, T7, and T8. At T7, the pedicle was resected, and T6–T7 and T7–T8 bilateral facets were removed. The right-side T7 pedicle-rib complex was drilled out, and adjacent parietal pleura was excised (Fig. 34-51). The T7 nerve root was resected bilaterally; nerve root resection requires wide margin resection, and for this, the posterior dura should be resected. If radiation or other adjuvant therapy is planned, the dural resection should not be performed.

Figure 34-49 Tumor involving the posterior element of the midthoracic spine compresses the spinal cord (T7 vertebral body level).

Figure 34-50 Axial magnetic resonance image shows that the posterior element mass compresses the spinal cord.

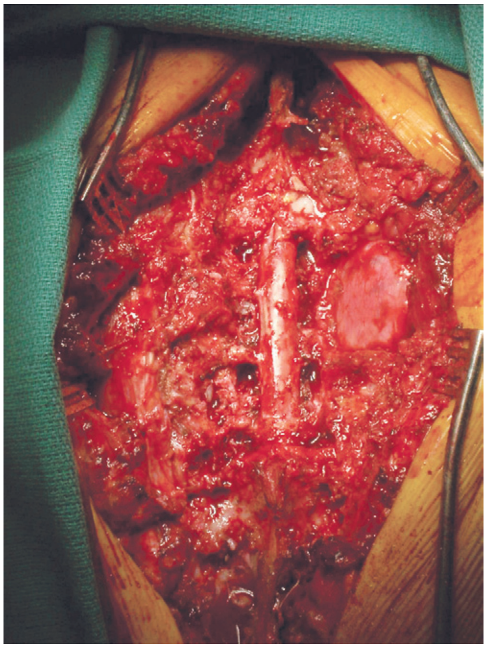

Figure 34-51 Operative view after mass removal. For the wide margin resection, the posterior mass was resected with parietal pleura.

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35 Thoracoabdominal Approach to the Thoracolumbar Junction

JAI-JOON SHIM and DANIEL H. KIM

Overview

The transthoracic approach to the midthoracic level is indicated when the anterior column is involved with tumor mass. This approach enables surgeons to accomplish complete ventral decompression of the spinal cord with simultaneous anterior reconstruction.[1] Depending on the intactness of the pleura, two kinds of approaches might be taken: *transpleural* or *extrapleural.* Patients should possess competent lung function to perform one-lung ventilation. If preoperative evaluation shows a partial pressure of oxygen (PO_2) of less than 60, partial pressure of carbon dioxide (PCO_2) of more than 45, oxygen (O_2) saturation below 90%, forced vital capacity (FVC) less than 1.5 L, forced expiratory volume in 1 second (FEV_1) less than 1 L, and FEV_1/FVC less than 35%, the transthoracic approach is contraindicated.[2]

Transthoracic Approach to the Midthoracic Level

POSITIONING AND INCISION

The operation is performed with the patient in a lateral decubitus position with an axillary roll under the dependent axilla (Fig. 35-1). The patient's body should be extended with the kidney rest and by the tilting of the operating table. The side of approach is decided based on the location of the pathology. When possible, a right-sided approach is preferred in the middle and upper thoracic spine, because more working space is available over the spinal surface behind the azygos vein compared with that behind the aorta. The left side is preferred for the lower thoracic spine, because at this level, the liver causes the right diaphragm to rise and partially obstruct the working space. The skin incision starts from four fingerbreadths lateral to the spinous process, runs along the selected rib, and reaches anteriorly to the costochondral junction.

MUSCLE DISSECTION

The latissimus dorsi muscle is then divided in a transverse direction relative to the fibers (Fig. 35-2). In the anterior region of the opening, the anterior serratus muscle is exposed; posteriorly, the trapezius muscle can be exposed. When severing this muscle, the incision line should be as far caudal as possible to save the long thoracic nerve.

After the superficial muscle layer is divided, the second layer of muscles is exposed. According to the level of the lesion, rhomboids (superior), serratus anterior (anterior), and serratus posterior inferior (posterior) can be severed (Fig. 35-3). In cases that involve the upper thoracic level, mobilization of the scapula is required.

RIB REMOVAL

The selection of the rib to be removed is dependent on the lesion site. With lateral radiographs, the rib seen to be overlying the pathologic vertebral body can be determined. In general, an interspace of at least two levels above the level of the vertebral body involvement should be entered, and the rib below is resected.

The outer periosteum of the selected rib is incised sharply and stripped with a periosteal elevator (Fig. 35-4). On preparing the outer and superior surfaces of the rib, a small dissector is used to free the inner periosteum from the underlying pleura. A Doyen elevator is introduced to elevate the inner periosteum anteriorly from the costal junction to the angle of the rib posteriorly (Fig. 35-5). A rib cutter is used to remove the rib. To gain additional exposure of the rib posteriorly, a longitudinal incision is made along the anterior border of the paraspinal muscles to allow them to be retracted posteriorly past the rib angle.

EXPOSURE OF VERTEBRAL BODY (TRANSPLEURAL)

The thoracic cavity is opened in the bed of the resected rib. The spine is exposed by a longitudinal incision of the pleura 5 mm anterior to the rib heads.[2] The lung is retracted anteriorly, and the vertebral body is exposed with the parietal pleura covered. Underneath the parietal pleura, the rib head is seen to be in contact with the intervertebral disk. On palpation, the intervertebral disk spaces are prominent, and the segmental vessels generally cross the middle portion of the body.

A transverse incision of the parietal pleura is made along the rib head and disk space to expose the segmental vessels. In cases of a T8 body lesion, dissection starts from adjacent levels (T7 and T9). The parietal pleura overlying the segmental vessels are swept away with a monopolar coagulator (Fig. 35-6).

The segmental vessels are coagulated and divided (Fig. 35-7). The segmental vessels are dissected from the underlying vertebral body with a right-angle dissector, and hemoclips are applied to two sites, proximal and distal; the proximal side is controlled first, and later the distal side. After the hemoclips are applied to both sides, the vessel is cut and retracted. The sympathetic ganglion is removed to expose the rib head. For further exposure of the anterior

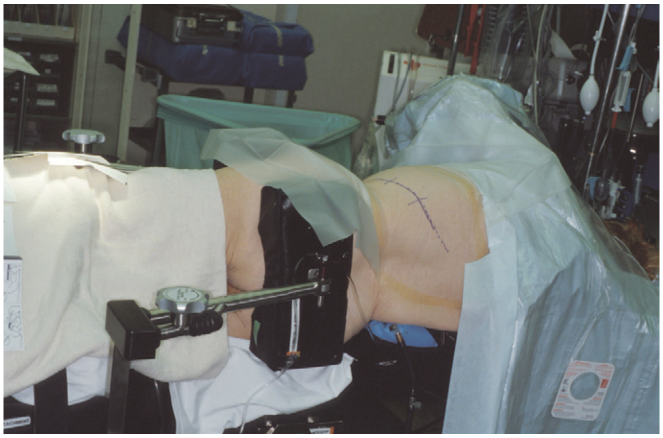

Figure 35-1 Lateral decubitus position and combination of midline vertical and transverse paraspinal incision.

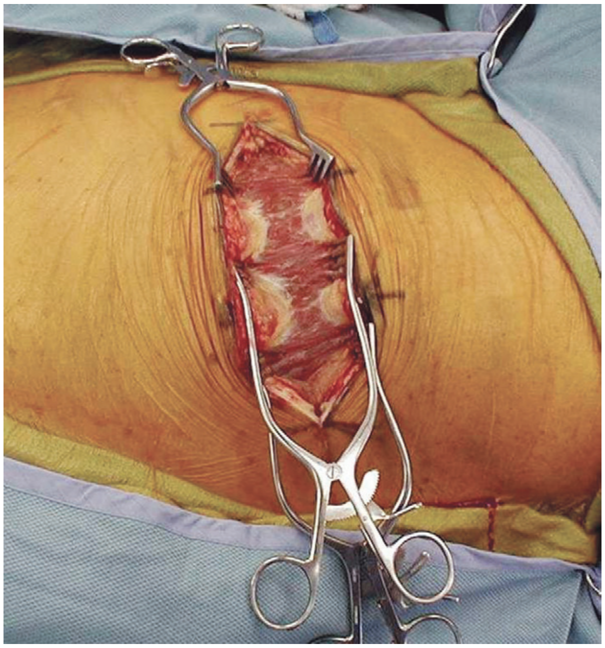

Figure 35-2 Latissimus dorsi muscle incision.

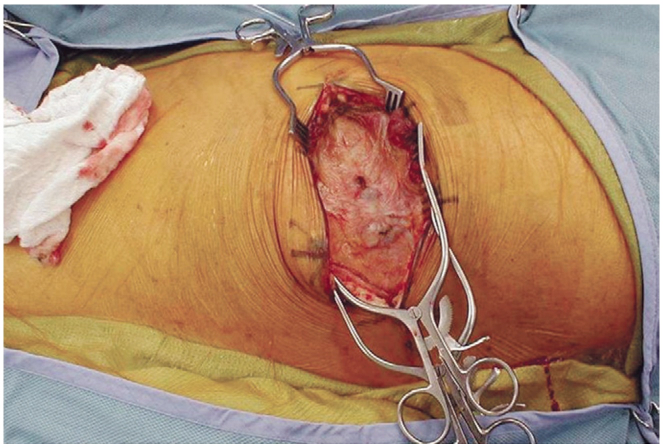

Figure 35-3 Rhomboids and serratus muscles dissection.

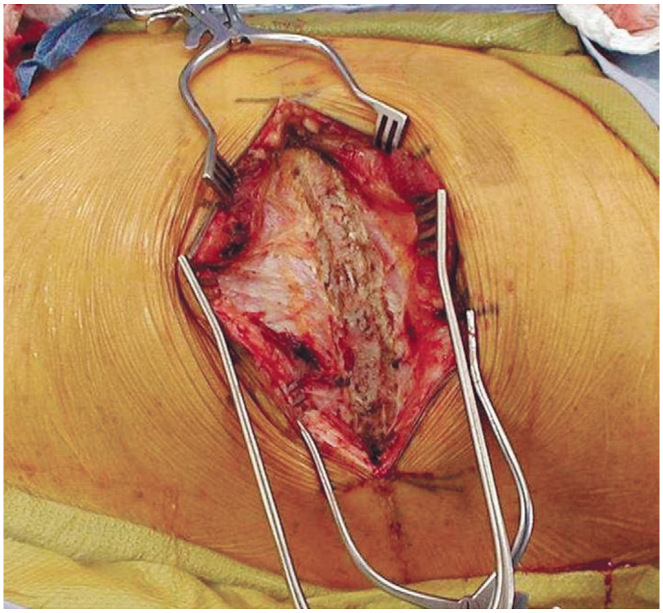

Figure 35-4 Periosteal incision of the rib.

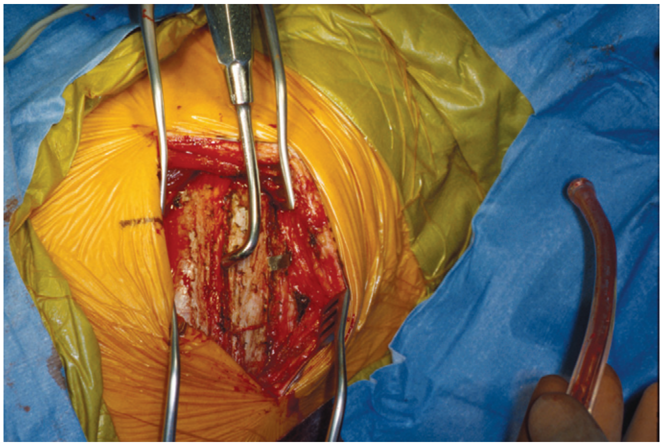

Figure 35-5 Dissection of the rib from the rib bed.

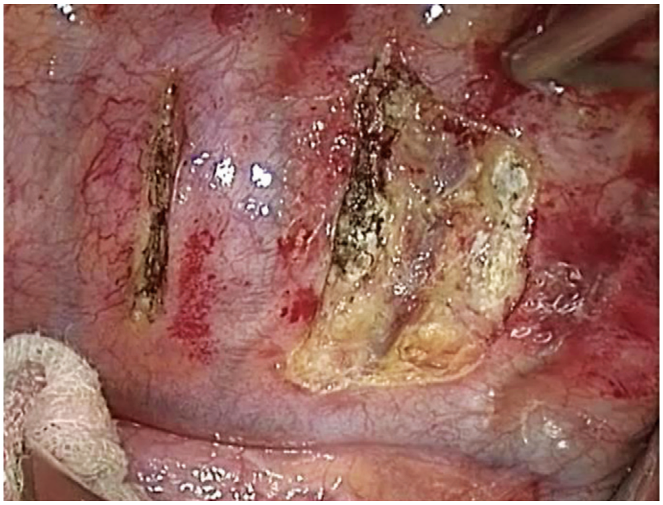

Figure 35-6 Parietal pleura dissection and exposure of the segmental vessels at T7 level.

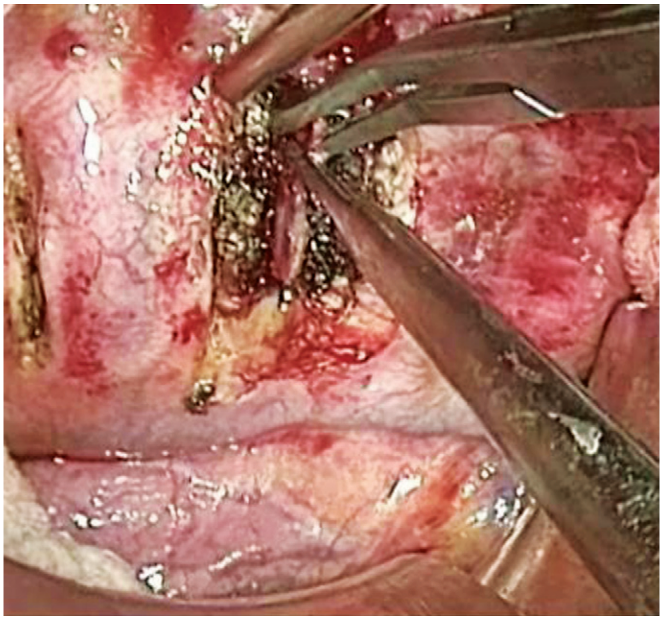

Figure 35-7 Hemoclip is applied to distal side of the segmental vessel.

portion of the vertebral body, the great vessels should be dissected. The space between the anterior longitudinal ligaments (ALLs) and great vessels is easily created by blunt dissection after the segmental vessels are disconnected. The removal of the rib head is mandatory for the exposure of the intervertebral foramen and posterior margin of the vertebral body. The rib head is drilled away, and the shell is removed with a curette. After rib head removal is complete, the costovertebral joint is exposed.

VERTEBRAL BODY RESECTION

After the parietal pleura is reflected and segmental vessels are controlled, the corpectomy begins. Adjacent disk removal is completed with an osteotome and pituitary forceps. The tumor-infiltrated vertebral body is slightly soft and friable. The resection boundary is confined with an osteotome, and an internal debulking is performed with pituitary forceps (Fig. 35-8). For the exposure of the ventral surface of the spinal cord, the posterior cortical shell of the vertebral body should be removed. When the posterior cortex is removed, great care should be taken not to injure the spinal cord.

EXPOSURE OF THE VERTEBRAL BODY (EXTRAPLEURAL)

When a patient's pulmonary function is not sustainable for one-lung ventilation, an extrapleural approach can be considered. Although this approach provides limited exposure compared with the transpleural approach, one advantage is that it can be done with lung retraction without lung collapse. After rib removal, the endothoracic fascia is incised; the parietal pleura is kept intact. The dissection is performed between the endothoracic fascia and the parietal pleura (Fig. 35-9). This dissection provides the way to the vertebral body (Fig. 35-10).

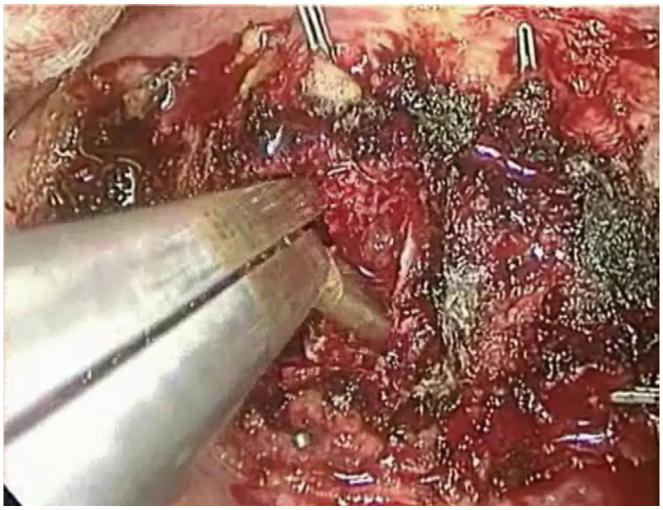

Figure 35-8 Tumor-infiltrated vertebral body is removed with chisel and pituitary forceps.

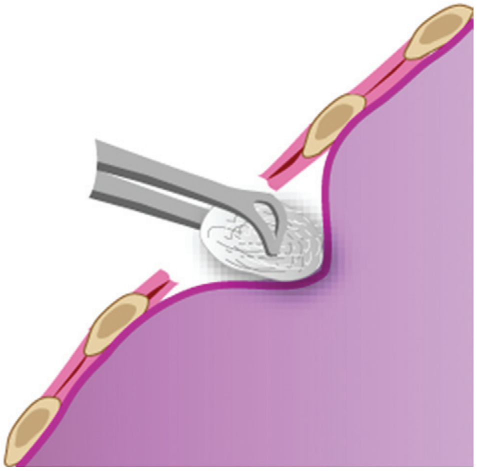

Figure 35-9 Extrapleural dissection is carefully performed from the rib bed and is continued under the adjacent rib.

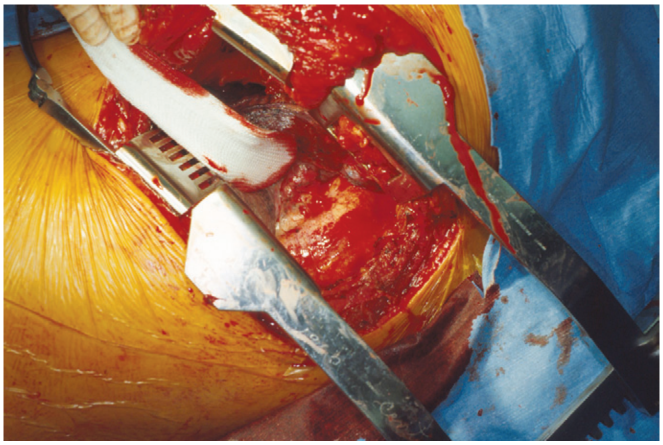

Figure 35-10 Extrapleural dissection starts from the rib bed and proceeds to the proximal rib and vertebral body.

BILATERAL SEGMENTAL VESSEL LIGATION

In a study involving dogs, the interruption of the bilateral segmental arteries at three levels, one targeting the vertebra and the other two the adjacent vertebrae, reduced the blood flow of the target vertebra to one fourth of the control value in the lower thoracic spine. This experimental result suggests that preoperative embolization at three levels, the levels of the tumor vertebra and the adjacent vertebrae above and below, may reduce intraoperative hemorrhage effectively during total en bloc spondylectomy for hypervascular spinal tumors. When the embolization fails, intraoperative ligation of the segmental vessels can lessen tumor bleeding. If the interruption of the bilateral segmental arteries is planned, the Adamkiewicz artery should be identified on preoperative angiography to be excluded from the ligation.

In the thoracic region, parietal pleural incisions are made on each vertebral body level and corresponding rib head. After the dissection of the parietal pleura, the segmental vessels are seen on the midpoint of the vertebral bodies. First, the segmental vessels on the approach side are ligated (Fig. 35-11). Great care should be taken to dissect the vessel from the tumor-infiltrated cortical surface. After vessel ligation, the interface between the aorta and vertebral body anterior surface is dissected. With traction applied to the proximal portion of the ligated segmental vessels, the great vessels are moved to the anterior side to form a potential space relative to the ALL (Fig. 35-12).

An adhesion may exist between the tumor-infiltrated vertebral body and great vessels. However, the dissection is relatively easy, because the ALL blocks ventral expansion of the tumor mass. When the great vessels are moved forward, the segmental vessels on the contralateral side are seen to wind around the lateral surface of the vertebral bodies. The exposed field is very deep. A surgical instrument such as the right-angle dissector is applied to the contralateral segmental vessels, which are cut and tied (Figs. 35-13 and 35-14). Great care should be taken not to stretch these vessels. Neurologic deficit after unilateral left-sided ligation of the T10–T12 segmental vessels occurs in 0.75% of patients.[3,4] The risk of segmental vessel ligation is minuscule provided 1) vessel ligation is unilateral, 2) ligation is done on the convexity of a scoliosis, 3) vessels are ligated at the midvertebral body level, and 4) hypotensive anesthesia is avoided.

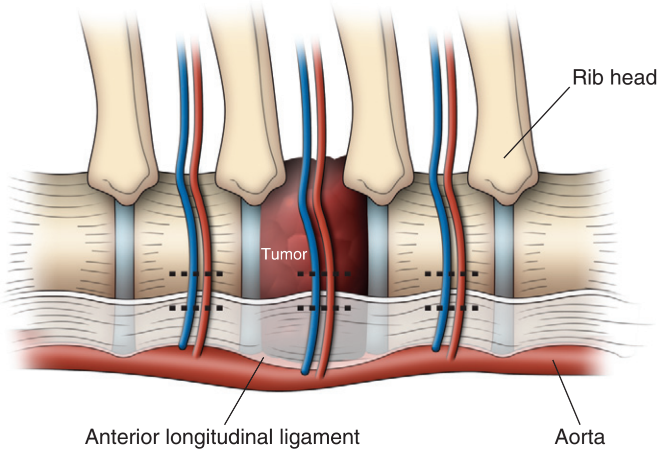

Figure 35-11 Three-level segmental vessels are selected around the tumor lesion and are dissected from the underlying vertebral body. They are ligated and cut at the point closer to the origin from the great vessel.

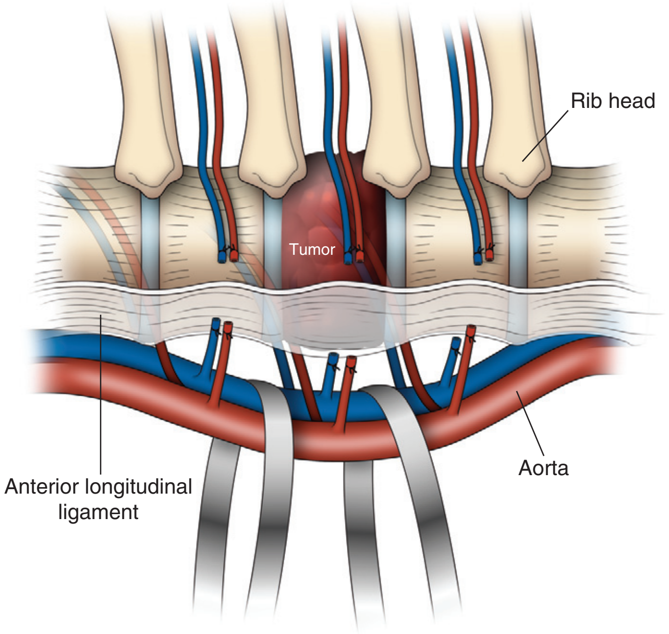

Figure 35-12 Great vessels are dissected from the vertebral body. From the left-side approach, the aorta is detached from the vertebral body first, then the vena cava is dissected. Both great vessels are retracted with a vascular loop to expose the contralateral segmental vessels.

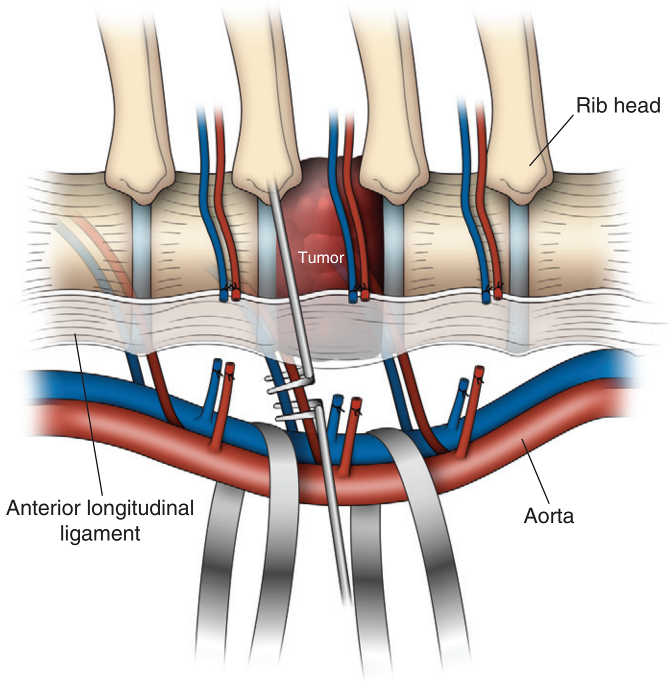

Figure 35-13 Contralateral side segmental vessels are exposed and divided. They are situated in a deeper position. Great care should be taken not to stretch the contralateral side segmental vessels.

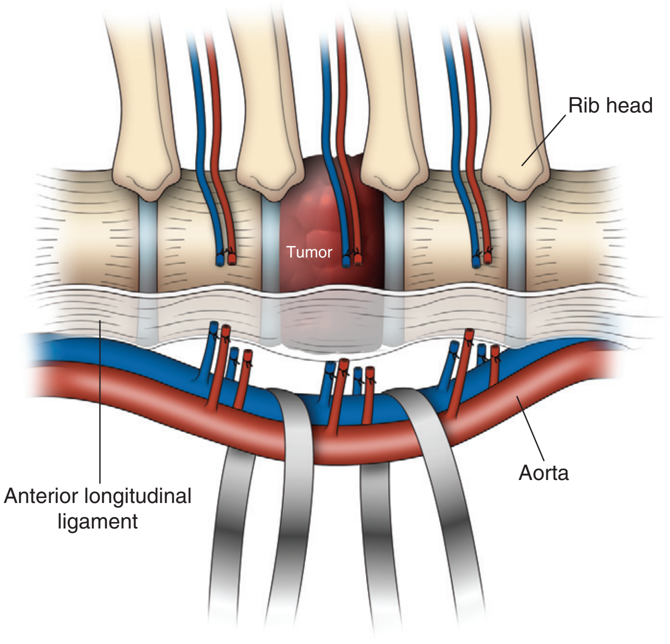

Figure 35-14 Contralateral side segmental vessels are ligated and cut. They should be controlled at the visible segment, not in the hidden segment.

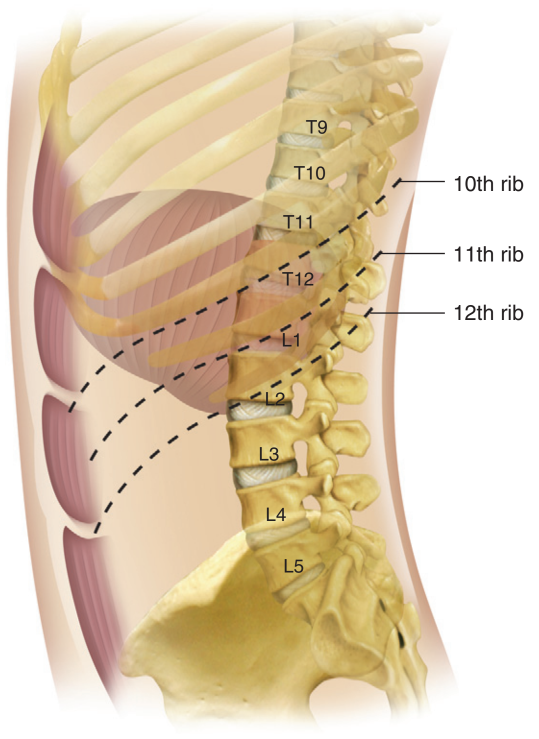

Figure 35-15 Skin incisions for the anterior approach; the incision varies according to the level of the lesions.

Anterior Approach to Thoracolumbar Junction (Transpleural-Transdiaphragmatic Approach with Tenth Rib Resection)

The exposure of the thoracolumbar junction (TLJ) can be approached through either side, but a left-sided approach is often selected, for which the patient is placed in the true lateral decubitus position with a beanbag under the flank. For the exposure of T11–T12, the resection of the ninth rib is usually best, and at T12–L1, a tenth rib thoracoabdominal approach is preferred. In this approach, long exposure of the thoracic and lumbar spines is possible from the T10 vertebral body down to L3 level. This approach involves detaching the diaphragm at its circumference.[5,6]

When the diaphragm should not be taken down, or when less exposure is needed, the twelfth rib approach is used. For L1–L2 exposure, a twelfth rib extrapleural retroperitoneal approach is recommended. The eleventh rib exposure is the highest practical, extrapleural, retroperitoneal approach for exposure of T10–L2. It avoids opening the pleural cavity and cutting the diaphragm in patients with the potential for high morbidity.

POSITIONING AND INCISION

The patient is placed in the lateral decubitus position. The skin incision begins posteriorly near the midline, follows the course of the tenth rib as far as the costal cartilage, and then continues obliquely downward on the upper abdomen, following the direction of the segmental nerves (Fig. 35-15).

The procedures are performed to expose the thoracic cavity first, followed by the exposure of the abdomen, and then the two parts are joined.

SOFT TISSUE DISSECTION

Using cautery, the incision is deepened down through the thoracic muscles, and the latissimus dorsi muscle and serratus anterior muscles are transected posteriorly (Fig. 35-16). The deep abdominal muscle layers (internal oblique and transverse muscles of the abdomen) are bluntly split and retracted to allow exposure of the upper lumbar spine retroperitonially.

RIB REMOVAL

The superficial periosteum is stripped out with cautery from the rib to the costal cartilage, and the ribs are dissected subperiosteally with a periosteal elevator and Doyen elevator. The neurovascular bundle that lies below the rib is carefully isolated and ligated.

The rib is removed using a rib cutter from the angle of the rib posteriorly to the costal cartilage anteriorly (Fig. 35-17). The pleural cavity extends over the majority of the eleventh rib and the medial portion of the twelfth rib. The endothoracic fascia and the pleura are carefully stripped from the inner surface of the rib.

The thorax is opened with the incision of the periosteal layer of the removed rib bed and the parietal pleura. Using a sponge stick, the diaphragm is kept under tension and is gradually detached from its costal insertion and posteriorly from the eleventh and twelfth ribs.

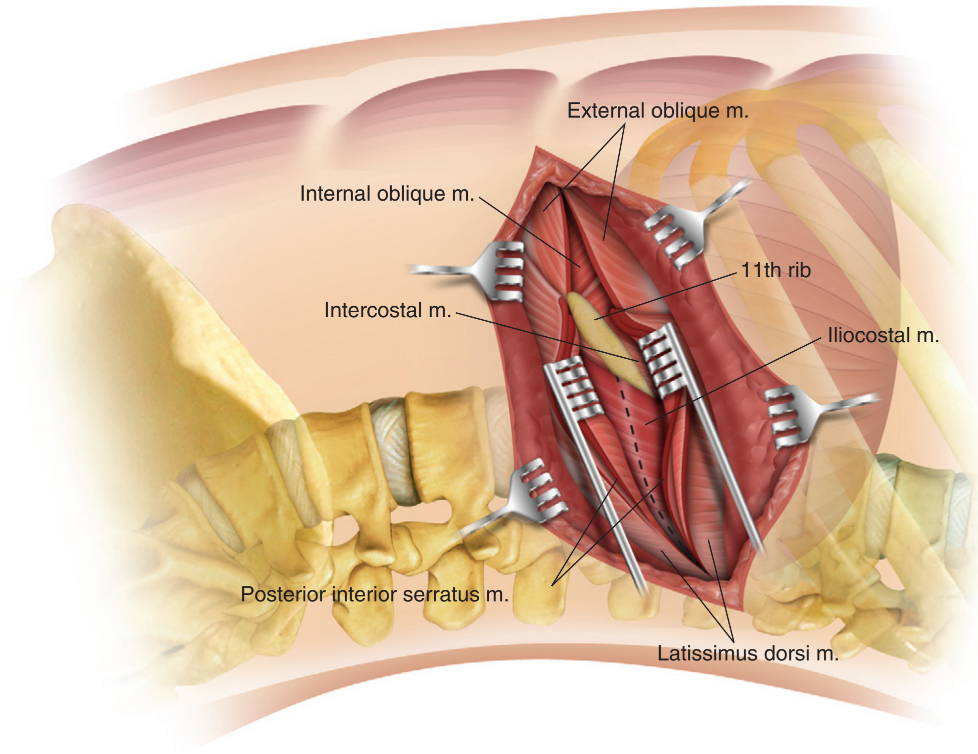

Figure 35-16 Muscle incision and dissection; the latissimus dorsi muscle and serratus anterior muscles are transected first, and the deep abdominal muscles are incised later.

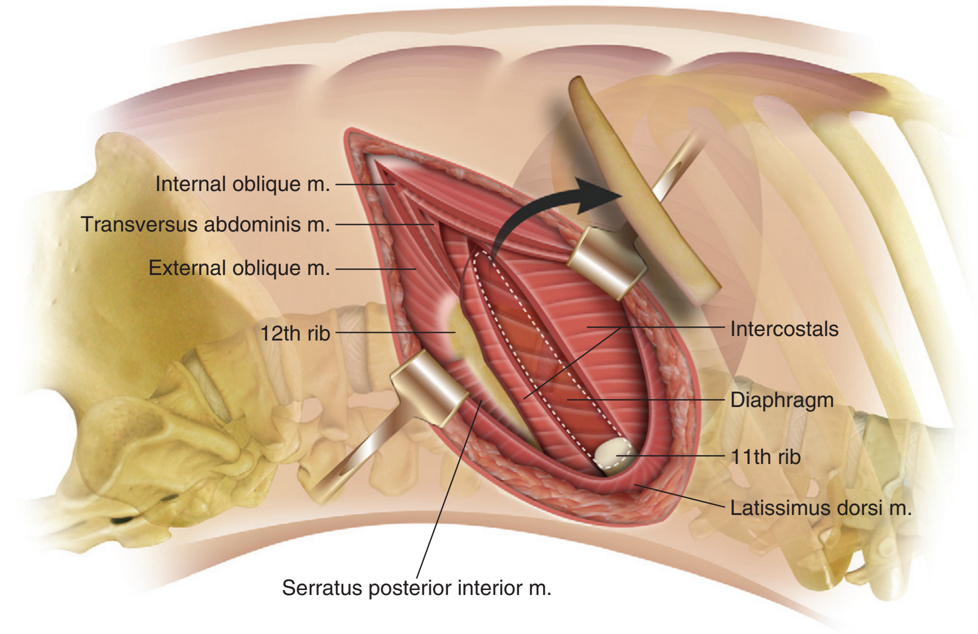

Figure 35-17 Subperiosteal dissection is made around the rib, and a short rib segment (about 10 cm) is removed from the angle of the rib to the costal cartilage.

DIAPHRAGM INCISION

For exposure of the T12–L1 vertebral body, diaphragmatic detachment is required. Anatomically, the diaphragmatic muscle fibers originate from three locations: the sternal, costal, and lumbar parts. The lumbar part arises from both the right and left crura and from the medial and lateral arcuate ligaments, the sternal part originates from two muscular slips from the dorsum of the xiphoid process,[7] and the costal part arises from the inner surfaces of the costal cartilages and adjacent portions of the bone of the last six ribs on either side. The right crus begins from the sides of the L1–L3 bodies, and the left crus begins from the sides of the L1 and L2 bodies. The medial arcuate ligament covers the upper part of the psoas major muscle, attaching from the sides of the first and second lumbar vertebrae to the tip of the L1 and L2 transverse processes. The lateral arcuate ligament covers the quadratus lumborum and attaches from the tip of the L1 transverse process and laterally to the lower border of the twelfth rib. Thus both the crura and arcuate ligaments of the diaphragm are inserted below the T12–L1 disk space, so lesions located above the T12–L1 disk can be approached from above without dividing the diaphragm. Below the T12–L1 disk space, the spine is surrounded by the diaphragmatic crura, psoas muscles, and arcuate ligaments, so injuries here require diaphragmatic detachment for adequate exposure.

The diaphragmatic incision is made from inside the chest with clear visualization under the diaphragm in the retroperitoneal space (Fig. 35-18). The incision may be extended circumferentially 1 inch from its peripheral attachment to the chest wall. For an accurate reapproximation, marker clips should be used throughout the takedown of the diaphragm (Fig. 35-19).

EXPOSURE OF EACH VERTEBRAL BODY

After the longitudinal incision of the parietal pleura, the dissection is done over the intervertebral disk space, until the base of the transverse processes is reached. The sympathetic trunk is retracted laterally (Fig. 35-20). The origins of the psoas muscles are stripped from the vertebral body. The intercostal arteries and veins are tied and ligated to allow mobilization of the major vascular trunk (Fig. 35-21). The twelfth intercostal vessels and first lumbar artery and vein may be covered by the muscular crus of the diaphragm.

For the cephalad extension of the operative field, the parietal pleura can be incised to the lower thoracic spine. In the lower thoracic spine, the aorta is located slightly to the left of the vertebral body compared with the L1 body level. For the exposure of the vertebral body at the lower thoracic level, the aorta should be mobilized to the midline.

CLOSURE

The diaphragm is reattached starting with approximation of the divided crus using a polydioxanone (PDS) No. 0 monofilament and proceeding as a continuous or interrupted suture along the periphery of the divided diaphragm to the site of the division of the costal arch (Fig. 35-22).[6] If the instrument is left on the vertebral body, the crus connection may be incomplete. The diaphragm repair is done

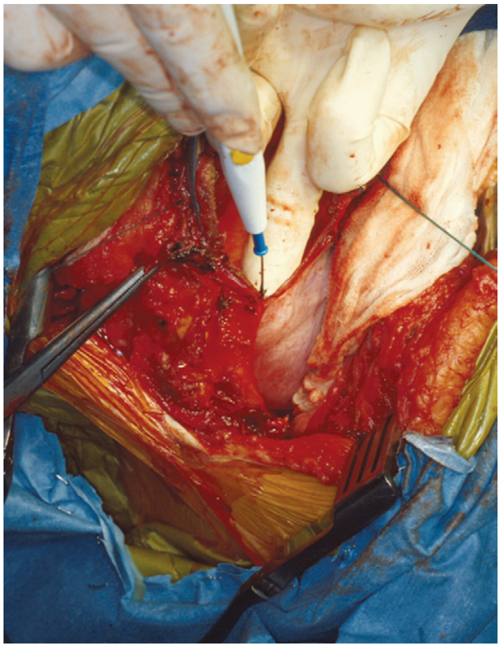

Figure 35-18 The diaphragm is incised, while a finger protects the intestinal content. For facilitated closure, the incision is made 1 inch from its peripheral attachment to the chest wall.

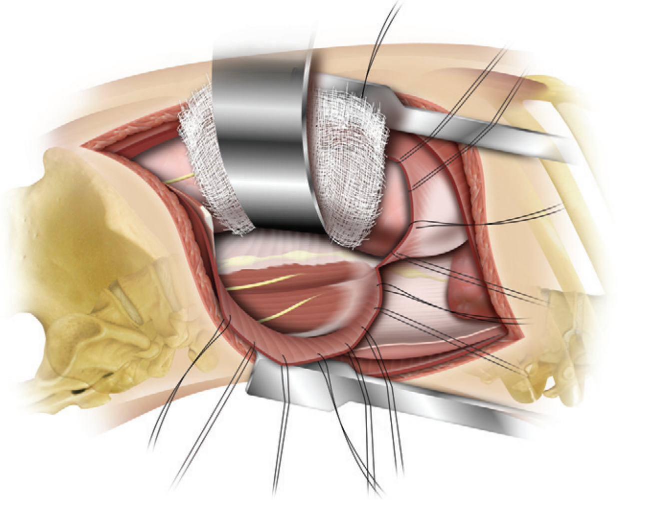

Figure 35-19 After the diaphragm incision proceeds to the vertebral body, the intestinal contents are reflected to the right side.

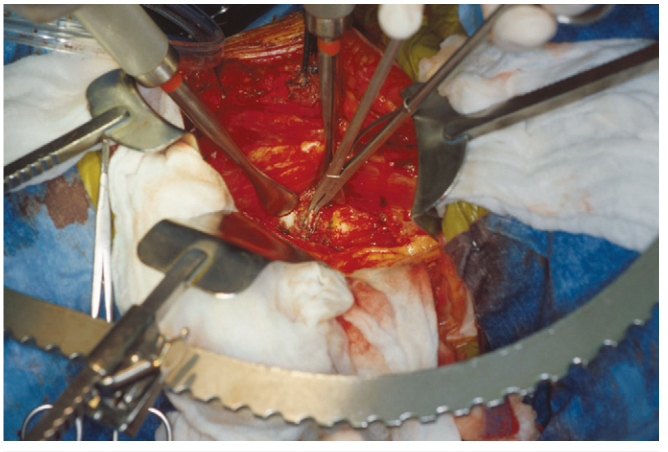

Figure 35-20 The diaphragmatic crus is cut, and retroperitoneal contents are reflected. With continual incision of the parietal pleura, enlargement of the thoracic surgical field is accomplished.

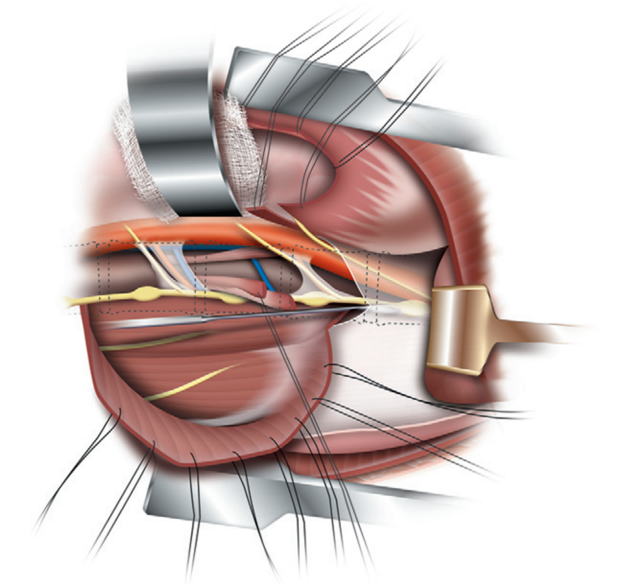

Figure 35-21 The psoas muscles are stripped from the vertebral body. The segmental arteries and veins are tied and ligated to allow mobilization of the major vascular trunk.

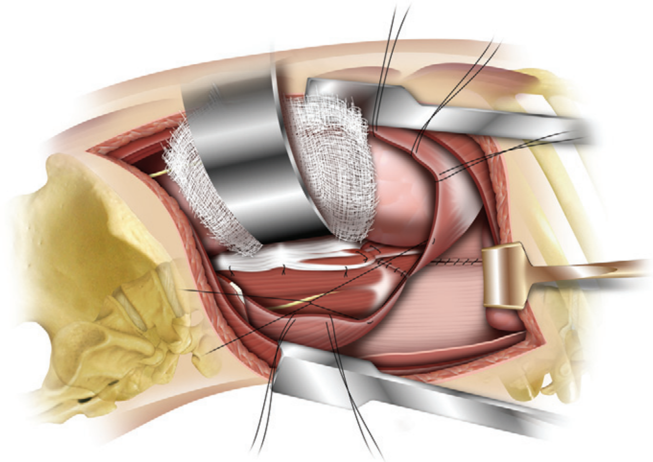

Figure 35-22 Diaphragm closure starts from the crus connection, and gradual reapproximation is done with preapplied sutures.

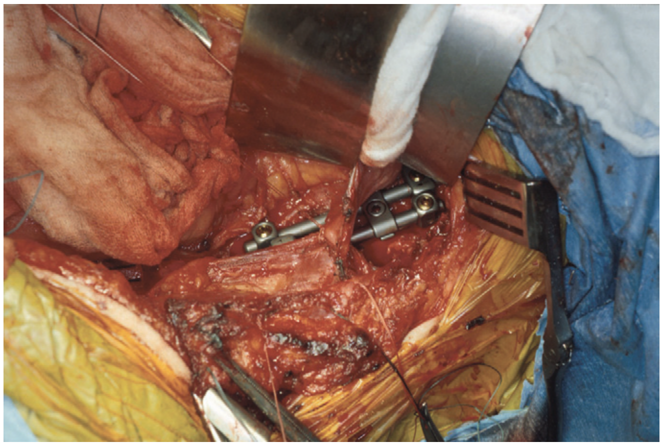

Figure 35-23 When the implant is left on the vertebral body, the diaphragm repair is done over the implant.

over the implant applied to the vertebral body (Fig. 35-23). The divided costal cartilage serves as a good landmark for closure and should be reapproximated with two No. 0 or 1 braided polyester sutures used as a figure-eight. Closure of the diaphragm is completed by additional stitches.

The abdominal muscles are then approximated anatomically with a continuous suture of PDS No. 0. Usually, two layers of closure are required, one for the transverse and internal oblique muscles and a second layer for the external oblique muscles. The chest tube is inserted in the eighth intercostal space and is passed posterolaterally. On the cephalad surface of the costal cartilage, the diaphragm and the interthoracic fascia are inserted. Inserting into the distal split of costal cartilage are the transverse abdominal fascia and the attachment for the abdominal musculature.

Case Illustration

A 53-year-old patient was diagnosed with breast cancer with L1 metastasis. Preoperative magnetic resonance imaging showed an L1 vertebral body collapse with severe dural sac compression (Fig. 35-24). Surgical treatment was done with a left-sided transpleural transdiaphragmatic approach. The diaphragm was detached, and an L1 corpectomy and dural sac decompression was completed. Then a titanium mesh graft was inserted, and an anterior screw-rod system (Kaneda device) was used for an anterior stabilization (Fig. 35-25).

Figure 35-24 L1 vertebral body collapse is seen with resultant dural sac compression.

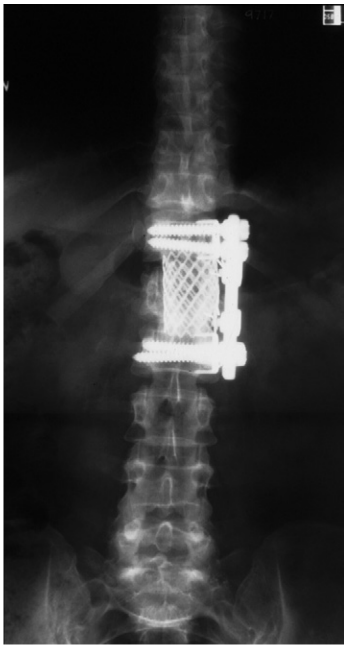

Figure 35-25 A left-side transdiaphragmatic approach was done, and anterior stabilization was performed with mesh and a Kaneda device.

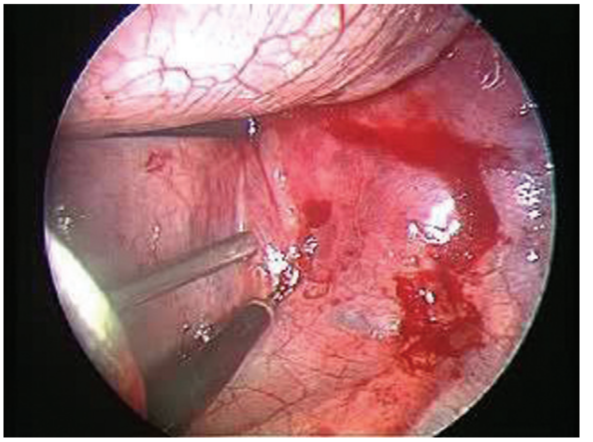

Figure 35-26 With caudal retraction of the diaphragm, the L1 vertebral body is palpated.

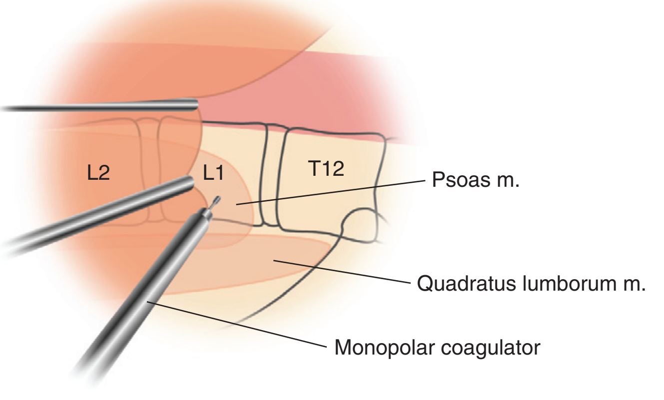

Figure 35-27 With caudal retraction of the diaphragm, the L1 vertebral body is exposed.

Transpleural-Retroperitoneal Approach (Diaphragm Detach) to the Thoracolumbar Junction

The transpleural-retriperitoneal approach begins with the entrance to the thoracic cavity via the transpleural approach. In the thoracic cavity, the retroperitoneal space is entered with a partial detachment of the diaphragm. The detached portion of the diaphragm is the 6 to 10 cm around the L1 vertebral body. If the caudal limit of the exposure is L1, the incision length may be 6 to 7 cm. If the L2 vertebral body is to be exposed, the incision length should be longer. This approach is less invasive compared with the transdiaphragmatic approach, and it can provide nice exposure of the L1 vertebral body. With use of a retractor, it can also be extended down to the L2 vertebral body. This approach is most appropriate for treatment of localized pathology (two or fewer vertebral segments).

IDENTIFICATION OF THE INSERTION POINT OF THE CRUS

The skin incision and rib removal procedure are the same as in the transdiaphragmatic approach. The pleural cavity is entered through the rib bed, and the lung is retracted cranially.

After a thoracotomy, the diaphragm is identified and gradually retracted caudally to expose the crus, and the key is to enter the pleural cavity and then identify the posterior insertion and crus of the diaphragm. The retractor holds down the diaphragm and exposes the insertion of the diaphragm on the spine (Figs. 35-26 and 35-27). Both the crural muscle and the arcuate ligament of the diaphragm are inserted below the T12–L1 disk space. With a blunt probe, the anterior aspect of the spine is identified, along with its diaphragmatic insertion and course of the aorta.

INCISION OF THE DIAPHRAGM INSERTION

The line of incision for diaphragmatic detachment is identified and marked with monopolar cautery. A semicircular incision is preferred to radial incision, because the latter is frequently associated with increased risk of diaphragmatic hernia (Figs. 35-28 and 35-29).

The incision for the diaphragm is made to run along the vertebral body and the ribs parallel to the diaphragmatic insertion and 1 to 2 cm away from it.[8,9] With a diaphragmatic opening of about 6 to 10 cm, the L2 vertebral body can be exposed. A rim of 1 cm is left on the spine to facilitate closure of the diaphragm at the end of the procedure. After the diaphragm is split, the retractors are applied into the diaphragmatic opening. The retroperitoneal fat tissue is then exposed and mobilized in an anterior-to-posterior direction along the anterior surface of the psoas muscle. The fat tissue should be separated from the peritoneum to create a plane leading down to the anterior aspect of the psoas and vertebral bodies.

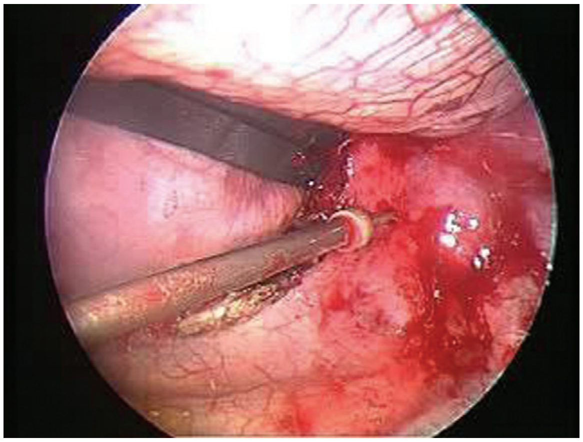

Figure 35-28 After the diaphragm is incised and retracted, the whole L1 body and half of the L2 body are exposed. The line of the incision for the diaphragm is round along the diaphragmatic insertion.

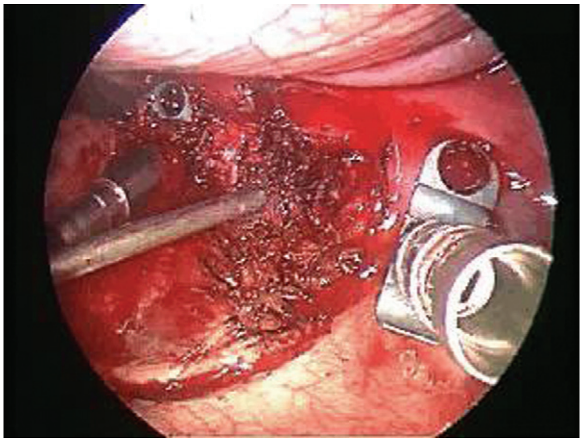

Figure 35-30 The psoas muscle is dissected carefully from the vertebral bodies, and implants are applied.

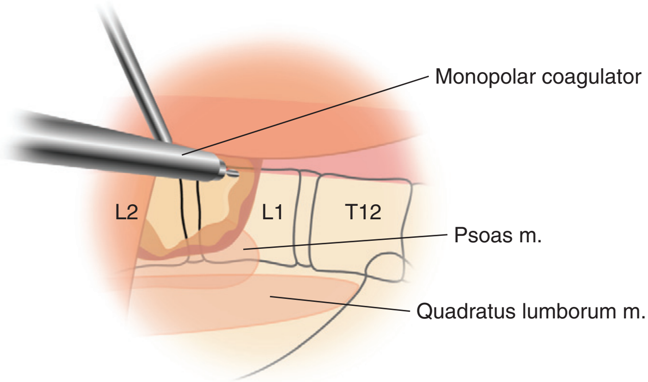

Figure 35-29 With a monopolar coagulator, the diaphragmatic insertion is detached.

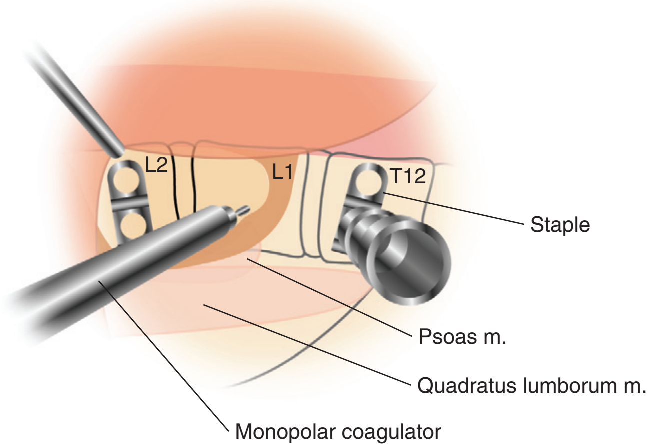

Figure 35-31 Psoas muscle dissection and instrumentation.

PSOAS MUSCLE DISSECTION

The psoas muscle with its tendinous insertions is dissected very carefully from the vertebral bodies so as not to damage the segmental blood vessels hidden underneath. The segmental vessels are then identified over the center of the vertebral body, ligated using a hemoclip or suture tie, and then divided. Compared with extensive thoracolumbar exposure with total dissection of the diaphragm in the transdiaphragmatic approach, this approach requires only minimal detachment of the diaphragm and holds the detached diaphragm down (Figs. 35-30 and 35-31).[7]

Extrapleural-Retroperitoneal Approach to Thoracolumbar Junction with Eleventh Rib Resection

The extrapleural approach is indicated if only one or two spinal segments at the TLJ need to be accessed.[10]

POSITIONING AND INCISION

The position is similar to the tenth rib approach. The skin incision line runs over the eleventh rib course and curves downward at the costal cartilage to the edge of the rectus sheath at the level of the umbilicus (see Fig. 35-15).

MUSCLE INCISION AND RIB REMOVAL

The latissimus dorsi, the serratus posterior inferior, and the external oblique are first incised. After dissection, the iliocostal muscle and the lumbocostal ligament are exposed.

Under the rib, the endothoracic fascia layer is dissected, and the anterior two thirds of the eleventh rib are removed. The pleura and the pleural cavity are under the rib bed, which has three layers: *periosteum, endothoracic fascia,* and *parietal pleura* (Fig. 35-32). The pleural cavity extends over the majority of the eleventh rib and the medial portion of the twelfth rib.

RETROPERITONEAL SPACE DISSECTION

After rib removal, the deep abdominal muscle layers (internal oblique muscle and transverse muscles of the abdomen)

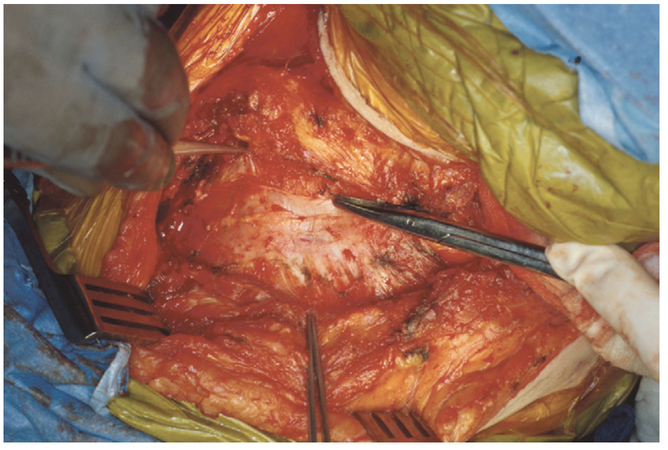

Figure 35-32 After the rib is removed, the rib bed is exposed. It is composed of three layers: periosteum, endothoracic fascia, and parietal pleura.

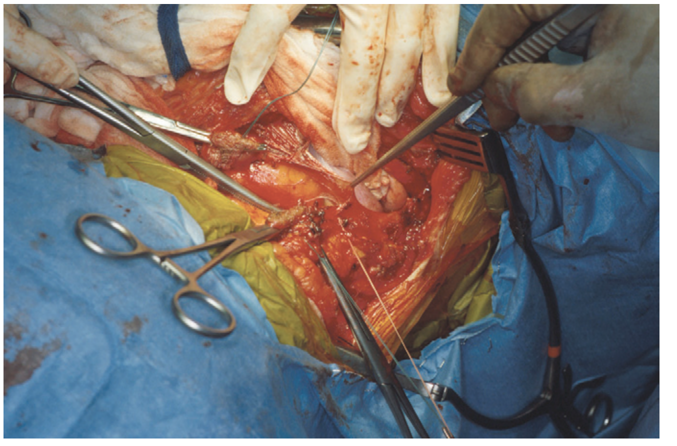

Figure 35-34 The costal cartilage is split, and the retroperitoneal fat is exposed. The fat tissue is yellow and is shown under the diaphragm.

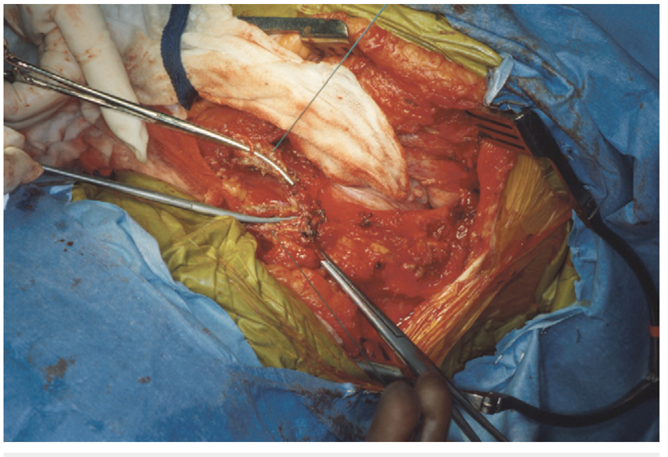

Figure 35-33 The costal cartilage is split and serves as a landmark for closure. The cartilage should be tagged.

are divided, and the peritoneum is brought into sight. Each muscle layer is divided from the tip of the eleventh rib. After the incision, preperitoneal fat tissue is seen first, and with the dissection of the fat tissue, the peritoneal membrane can be visualized.

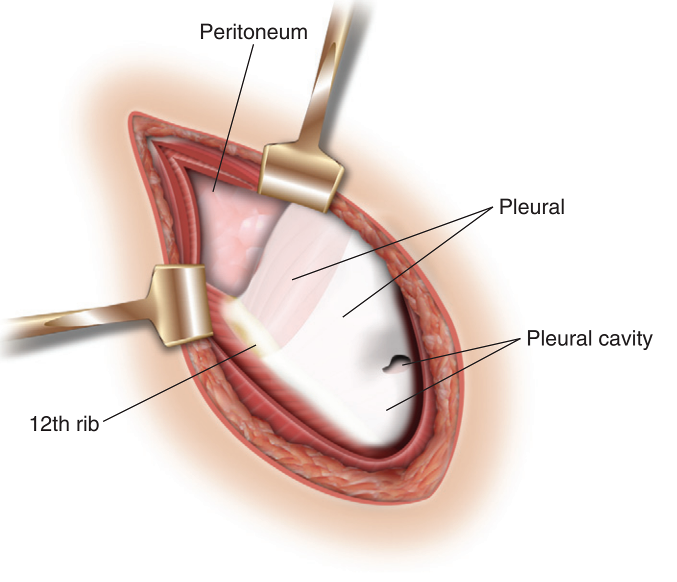

Figure 35-35 The endothoracic fascia is incised along the course of the twelfth rib. The parietal pleura and lung tissue are laid under the fascia, and the diaphragm is inserted along the twelfth rib.

COSTAL CARTILAGE SPLITTING

When the extrapleural and retroperitoneal spaces are to be communicated, the costal cartilage should be split (Fig. 35-33). The insertion of the diaphragm is into the cephalad edge of costal cartilage and adjacent rib bed; the insertion of the transversus abdominis muscle and transversalis fascia is made into the caudad portion (Fig. 35-34).

EXTRAPLEURAL SPACE DISSECTION

Careful dissection should be done under the rib bed to create extrapleural space. The endothoracic fascia is first incised, and then the parietal pleura is seen (Fig. 35-35). Blunt dissection with a cotton ball is performed between the endothoracic fascia and the parietal pleura. The dissection is begun under the proximal end of the exposed segment of the twelfth rib and is continued down to the costal cartilage and toward the vertebral body (Figs. 35-36 through 35-38). The endothoracic fascia is firmly adhered to the bony structures,[11] but gentle dissection can easily reveal the extrapleural space. If the pleural membrane is torn, an immediate suture should be done.

DIAPHRAGM RELEASE FROM THE INSERTION TO THE TWELFTH RIB

The parietal pleura is mobilized from the superior aspect of the left diaphragm and posteriorly from under the surface of the tenth and twelfth ribs and the eleventh rib stump. Posteriorly a 4- to 5-cm margin of diaphragm along the rib cage is now exposed; the diaphragm is attached to the tip of the twelfth rib. When the pleura is sufficiently pushed away from the rib, the insertion point of the diaphragm to the

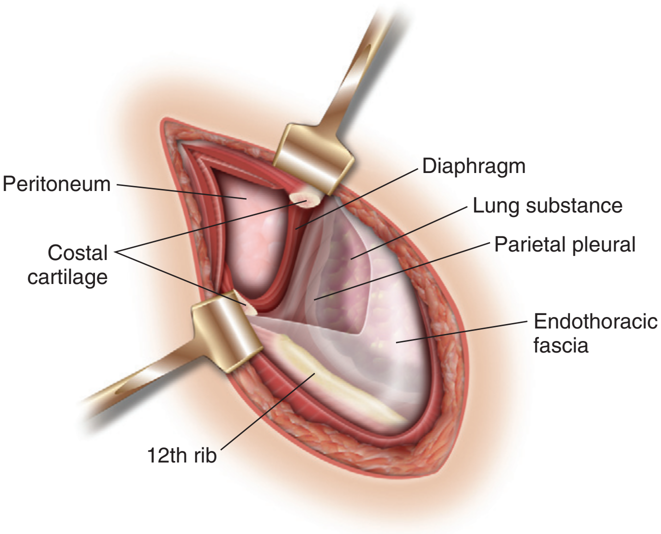

Figure 35-36 After the endothoracic fascia is opened, the parietal pleura is seen.

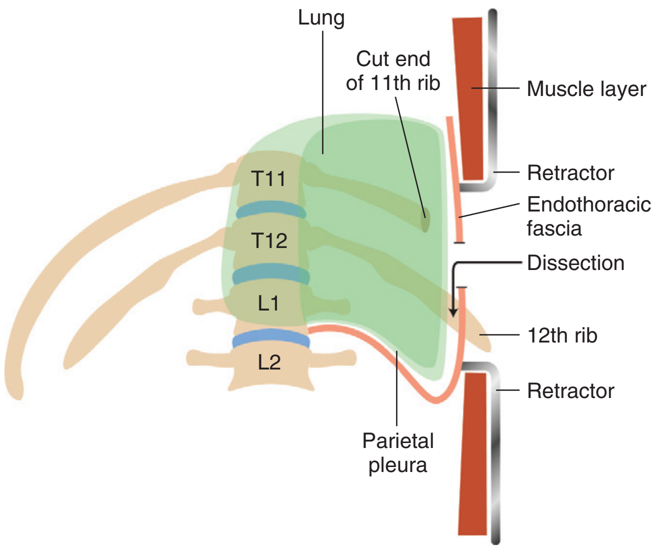

Figure 35-38 Frontal view of the dissection plane of the extrapleural space.

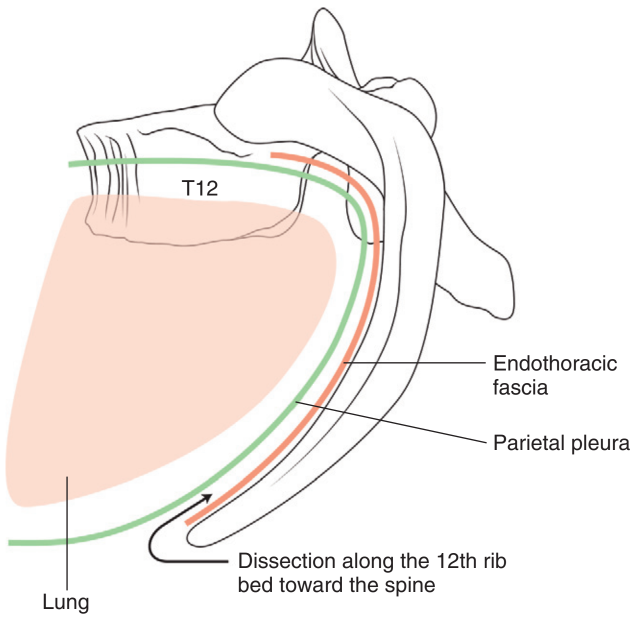

Figure 35-37 Oblique view of the dissection plane of the extrapleural space.

twelfth rib is cut off (Fig. 35-39). The diaphragm is then released from the insertion site to the rib, a maneuver that makes it easier to retract the diaphragm to the cephalad direction (Fig. 35-40).

VERTEBRAL BODY EXPOSURE

For T12–L1 exposure, the approach can be possible from under the diaphragm. After the diaphragm is released from the tip of the twelfth rib, the next tethered site is the L1 transverse process (Fig. 35-41). At the L1 transverse process, the medial and lateral lumbocostal arches of the diaphragm meet.[12] This attachment is cut. The next anchored point of the diaphragm is on the left side of the L1–L2 vertebral bodies, where the left crus is attached. The crus is divided and elevated from the vertebral bodies, leaving a portion for reattachment at closure. When the crus is detached, the diaphragm is fully freed from the bony structures. With the diaphragm retracted cephalad, the psoas and quadratus lumborum muscles are shown on its proximal origin: the psoas originates from the lateral surface of the T12–L1 vertebral body, and the quadratus lumborum is attached to the proximal end of the twelfth rib.[13] The psoas muscle is peeled off the origin portion of the vertebral body and is taken down to expose the L1–L2 vertebral body and pedicles (Fig. 35-42).

This approach is taken from under the diaphragm. The upper limit of the exposure is usually the T10–T11 disk space; additional rostral exposure is limited because of the overhang of the rib cage. The lower lumbar exposure can be varied by making the initial incision more oblique below the umbilicus or by making more of a paramedian incision.[14]

WIDENING OF VERTEBRAL BODY EXPOSURE

For extensive exposure of the lower thoracic spine, the diaphragm should be transected (Fig. 35-43). When the pleura and the peritoneum have been freed, the diaphragm is transected above the medial arcuate ligament in such a way as to permit resuture later. For the part of the diaphragm to be left over, the medial arcuate ligament—the diaphragm attachment to L1 transverse process—should be left intact.

After the diaphragm is freed from the bony insertion site, the dome is retracted to the cephalad side. The lower thoracic spine levels are exposed.

WOUND CLOSURE

The diaphragmatic crus is closed with interrupted sutures, and the diaphragm above the median arcuate ligament is then sutured in the appropriate position. Any violation of the pleura is closed with a size 0 nonabsorbable suture on a noncutting needle. The abdominal musculature is closed in layers, and the iliocostal and inferior posterior serratus muscles, as well as the latissimus dorsi, are sutured.

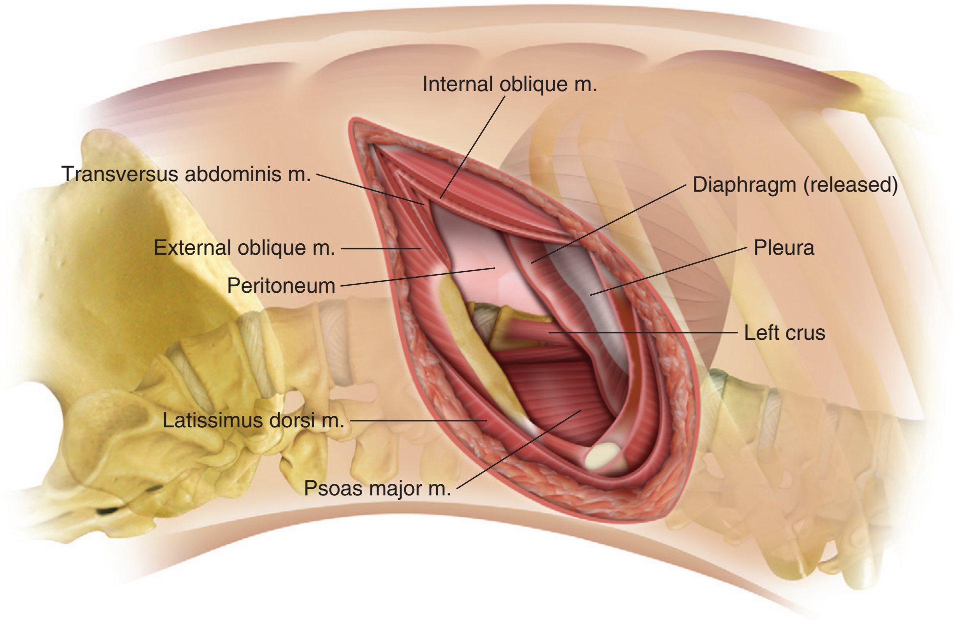

Figure 35-39 After the diaphragm detachment, the retroperitoneal space is exposed.

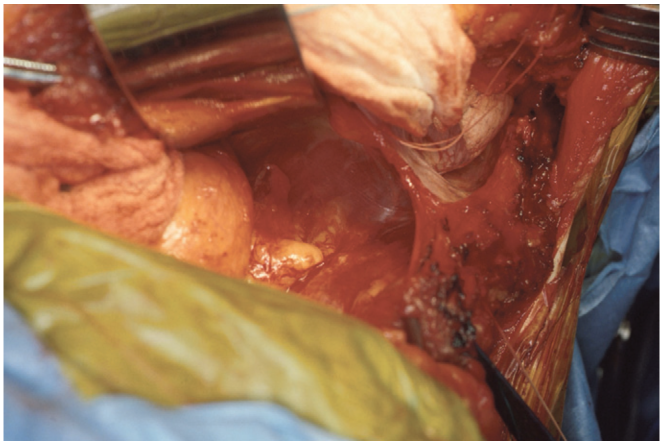

Figure 35-40 The diaphragm is seen between the thoracic cavity and retroperitoneal space.

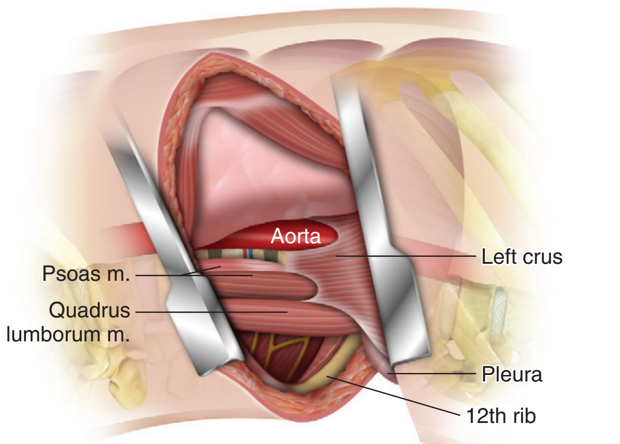

Figure 35-41 The diaphragm is tethered to the vertebral body with a crus.

The eleventh rib extrapleural approach has the advantage over the transpleural approach in that there is no need to enter the pleural cavity, so it causes few pulmonary complications. This may be preferable in elderly patients or in those with poor pulmonary function.

Minithoracotomy-Transdiaphragmatic Approach (Mini-TTA)

DIAPHRAGMATIC AND RELEVANT ANATOMY

The domelike diaphragm is firmly connected at its margins to the sternum, ribs, and spine, and it arches up into the thoracic cavity. The attachment site on the spine and on the directly adjacent ribs is different on the left and right sides and has a right (*dexter*) and left (*sinister*) crus. The diaphragm attaches to the anterior body wall much more superiorly than to the posterior body wall. Anteriorly, the diaphragm attaches to the inferior aspect of the sternum as well as to the medial aspects of the fifth, sixth, and seventh ribs via the sternal and costal portions of the diaphragm, respectively. Posteriorly, the diaphragm attaches to the lumbar spine in various locations. Along the midline, the right crus of the diaphragm envelops the esophageal hiatus then extends caudally to the right of the aorta. The left crus of the diaphragm extends caudally to the left of the aorta, and the right and left crus connect to each other via the median arcuate ligament to form the aortic hiatus. Just lateral to that, the lumbar portion of the diaphragm attaches to the posterior body wall via the medial arcuate ligaments. The lumbocostal triangle of the diaphragm, formed from ligamentous extensions of the lumbar and costal portions of the diaphragm, attaches to the posterolateral body wall

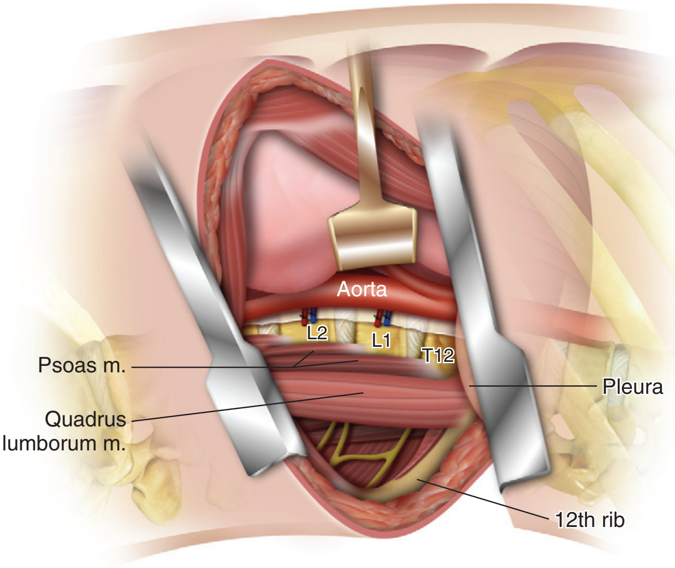

Figure 35-42 After the crus and psoas muscle are detached, the vertebral body is exposed.

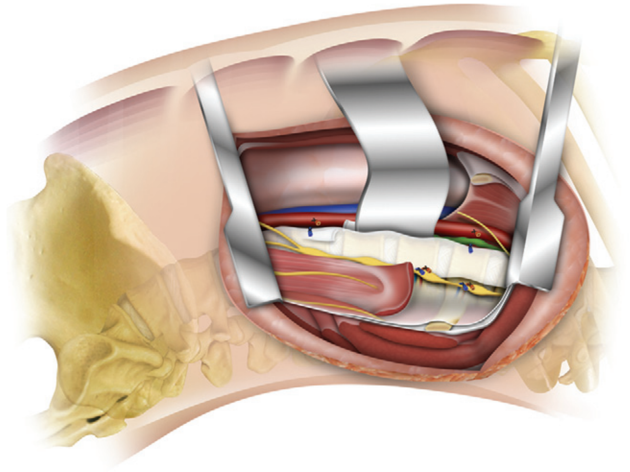

Figure 35-43 For extensive exposure of the vertebral body, the diaphragm should be divided and left lying over the L1 transverse process.

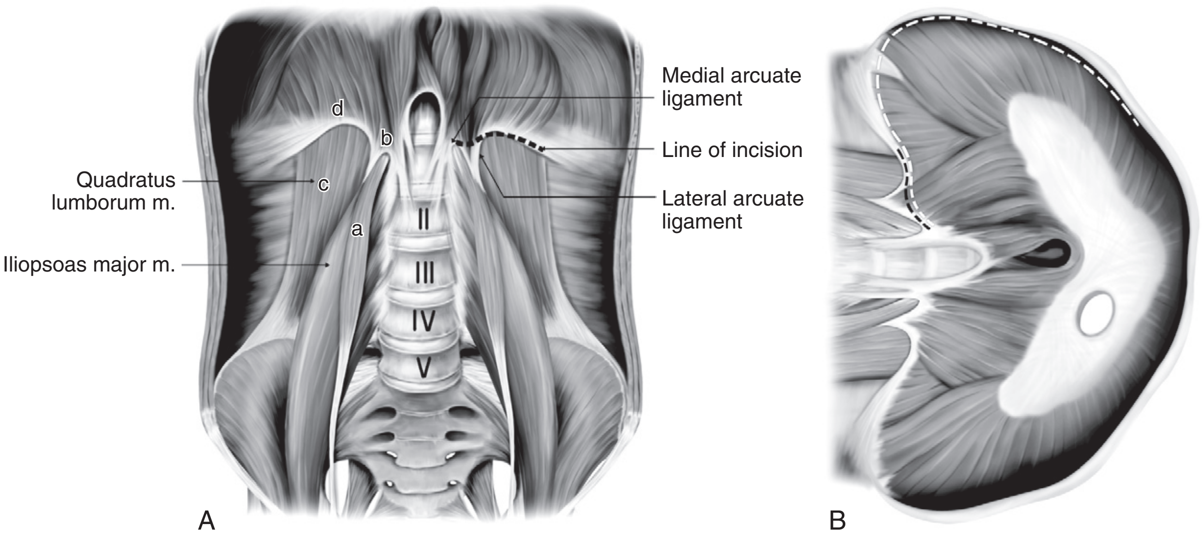

Figure 35-44 **A,** View of the diaphragm from below shows the diaphragm and the anatomic conditions at the thoracolumbar junction (TLJ). The course of the incision (*black dotted line*) runs parallel to the attachment of the diaphragm (II-III), vertebral bodies of L2, L3. Anatomic features around the diaphragm: a, iliopsoas muscle; b, medial arcuate ligament of the diaphragm; c, quadratus lumborum muscle; d, lateral arcuate ligament of the diaphragm (II-V), vertebral bodies of L2 through L5. **B,** Comparison of muscle dissection of approaches: muscle dissection line of mini-TTA technique (*black dotted line*); muscle dissection line of thoracoabdominal approach (*white dotted line*).

via the lateral arcuate ligament. The medial and lateral arcuate ligaments generally attach to the transverse process of L2 and occasionally to the transverse process of L3 (Fig. 35-44).[15]

The iliopsoas muscle lies just lateral to the lumbar spine and passes just under the medial arcuate ligament of the diaphragm. The quadratus lumborum muscle is lateral to the iliopsoas muscle and passes under the lateral arcuate ligament of the diaphragm. The sympathetic trunk runs lateral to the right and left crus of the diaphragm on either side, just medial to the iliopsoas muscle, lying along the ventral aspect of the lumbar spine (see Fig. 35-44).

The right crus originates from the sides of the L1–L3 bodies, and the left crus originates from the sides of the L1 and L2 bodies. The medial arcuate ligament covers the upper part of the psoas major muscle, attaching from the sides of the first and second lumbar vertebrae to the tip of the L1 and L2 transverse processes. The lateral arcuate ligament covers the quadratus lumborum and attaches from the tip of the L1 transverse process laterally to the lower border of the twelfth rib. Thus both the crura and arcuate ligaments of the diaphragm are inserted below the T12–L1 disk space.

As a result, lesions located above the T12–L1 disk can be approached from above without dividing the diaphragm.

Below or at the T12–L1 disk space, the spine is surrounded by the diaphragmatic crura, psoas muscles, and arcuate ligaments, so injuries here require diaphragmatic detachment for adequate exposure.[8]

ANESTHESIA

Unlike thoracoscopic procedures, mini-TTA does not require double-lumen endotracheal intubation.

POSITIONING

The patient is placed in the lateral decubitus position over an inflatable beanbag, with an axillary roll and padding of all bony prominences, and is then fixed with a four-point support at the pubic symphysis, sacrum, scapula, and upper arm (Fig. 35-45). The patient must remain in the true lateral position with the coronal axis perpendicular to the floor at all times to maintain accurate surgeon orientation for spinal decompression or instrumentation. The hip is flexed to relax the psoas muscle, and the operation table is flexed with the apex at the TLJ to improve operative field visualization. Before starting the operation, the position and free tilt of the C-arm should be checked.

TECHNIQUE

Under direct fluoroscopic guidance, the target-fractured vertebra is projected onto the skin level, and the borders of the fractured vertebra are marked on the skin. The skin incision is centered over the eleventh rib and extends posteriorly to the posterior axillary line and anteriorly to the costal cartilage of the eleventh rib (average skin incision is 6 cm; see Fig. 35-45). After the skin and subcutaneous tissue are incised, muscle dissection and meticulous hemostasis should be obtained with bipolar electrocautery**.** The eleventh rib is then exposed subperiosteally from the cartilaginous tip to the posterior margin of the skin incision, and the intercostal vein, artery, and nerve are gently dissected underneath the rib (Fig. 35-46). Single posterior osteotomy of the eleventh rib is cut on one side and reflected downward for preservation and later for reconstruction (Fig. 35-47). The parietal pleura is divided parallel to the rib direction, and the inferior lobe of the lung is retracted

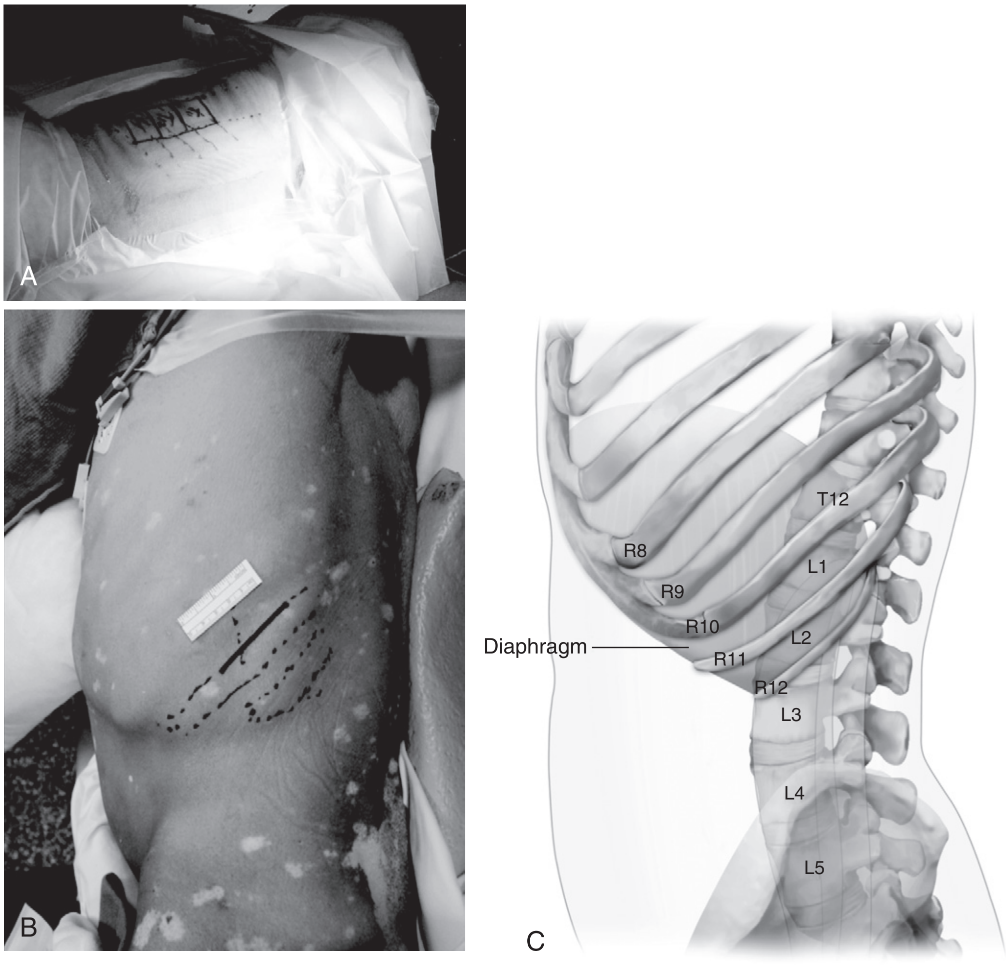

Figure 35-45 **A,** The patient is placed in the lateral decubitus position over an inflatable beanbag with an axillary roll and padding of all bony prominences. The patient is fixed with a four-point support at the pubic symphysis, sacrum, scapula, and upper arm. **B,** Operative technique: planned skin incision along the eleventh rib for exposure of the L1 vertebral body. **C,** Relation of ribs, spinal body, and diaphragm (R9 through R12: ninth through twelfth ribs).

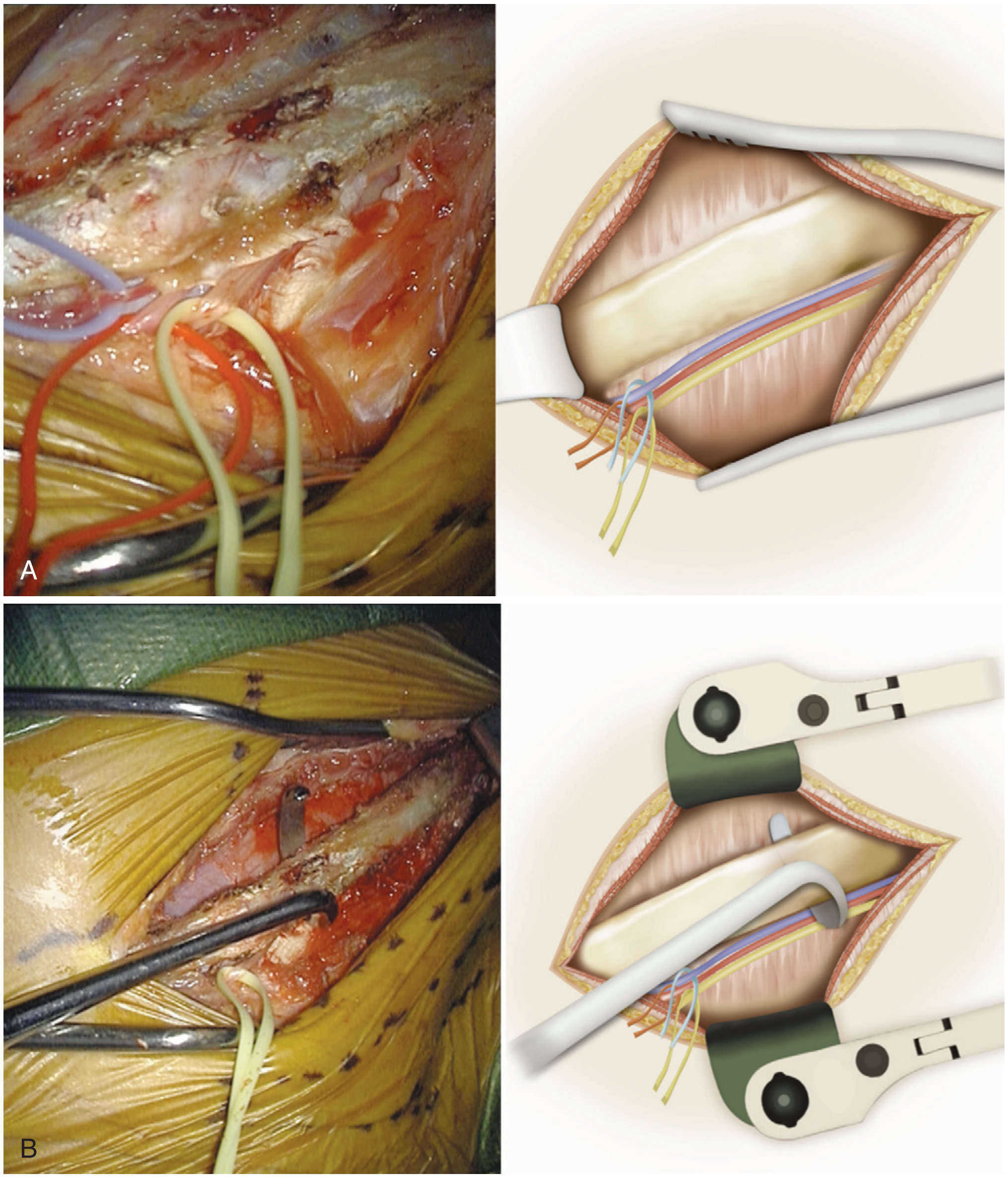

Figure 35-46 Subperiosteal dissection of the eleventh rib and gentle exposure of the intercostal vein (*purple*), artery (*red*), and nerve (*yellow*), all of which should be preserved.

superiorly with wet lap and blade retractors. At this stage, the lateral recess convexity of the diaphragm becomes exposed, and the diaphragm can then easily be visualized (Fig. 35-48).

PREVERTEBRAL DISSECTION AND DIAPHRAGM DETACHMENT

To expose the TLJ with mini-TTA, we have been able to reduce to a minimum the previous total detachment of the diaphragmatic insertion performed in the thoracoabdominal procedure. With blunt dissection, the anterior aspect of the spine, along with its diaphragmatic insertion and course of the aorta, are identified.

The line of incision for the diaphragmatic detachment is identified and marked with monopolar cautery. The medial arcuate ligament of the diaphragm should be retracted caudally to allow easy visualization of the lateral arcuate ligament of the diaphragm. Next, the attachment of the left medial and lateral arcuate ligaments to the transverse process of L2 is divided, allowing substantially greater inferior retraction of the diaphragm. Great care must be taken to stay a safe distance from the perivascular layers of the abdominal aorta.

After the diaphragm has been split, the retractor is now placed into the diaphragmatic opening and is pushed downward to expose as low as the superior end plate of L3. Retroperitoneal fat and the peritoneal sac are exposed and mobilized in an anterior-to-posterior direction along the psoas muscle to L1 or L2 level to avoid injury to the lumbar spinal roots. This will generally allow operative exposure as far caudally as the top of L3. The psoas muscle with its tendinous insertions is dissected carefully from the vertebral bodies, avoiding any damage to the segmental vessels

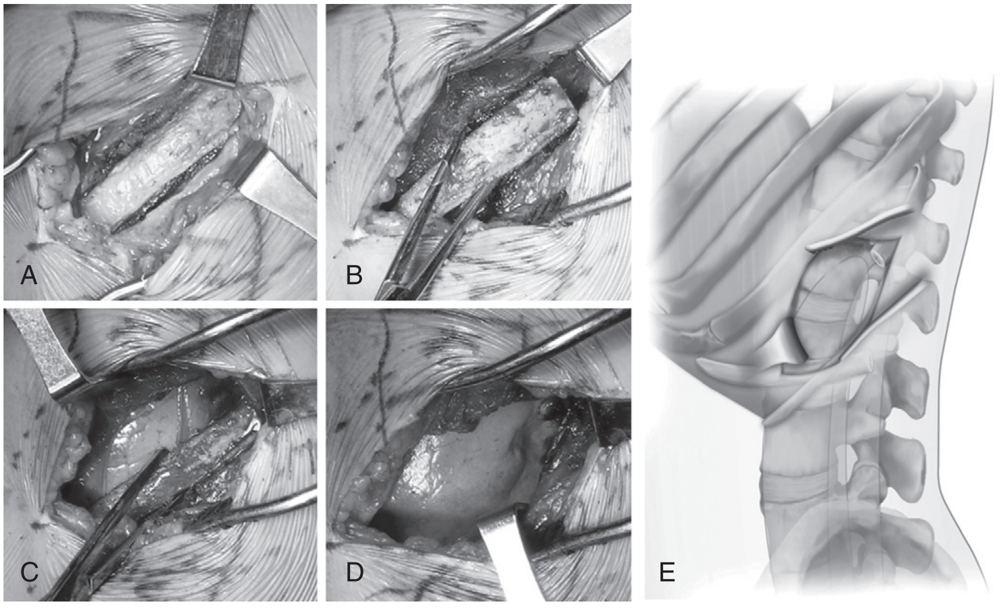

Figure 35-47 **A,** Rib is exposed subperiosteally from the cartilaginous tip to the posterior margin of the skin incision, and the intercostal vein, artery, and nerve are gently dissected underneath the rib. **B,** Cut one side of rib. **C,** Rib reflected downward for preservation. **D,** The parietal pleura is located. It should be divided, and the lung should be retracted superiorly. **E,** The eleventh rib is reflected to the twelfth rib, and the cut eleventh rib and dissected diaphragm are retracted together downward. The L2 body is then well exposed.

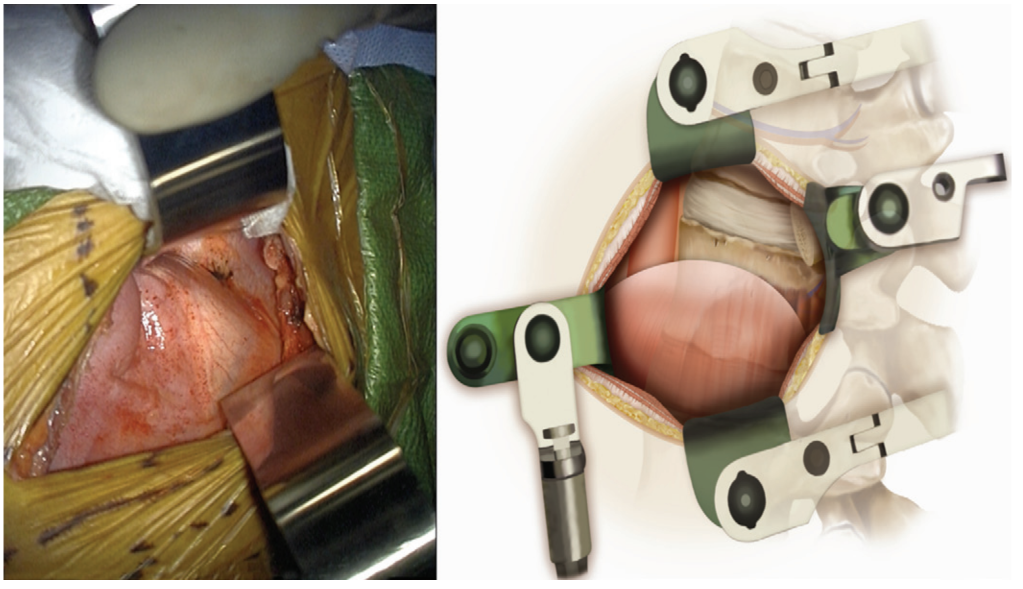

Figure 35-48 Operative technique: visualization of the diaphragm after retraction of parietal pleura and lung.

hidden underneath (Fig. 35-49). A 4- to 6-cm detachment of the diaphragm is usually sufficient for the instrumentation of the L1 vertebra, but this must be lengthened to 8 to 10 cm for the instrumentation of L2.

To get a proper operational view and field, we applied long cervical or narrow lumbar retraction blades. The surgeon may then expose the desired vertebral bodies and proceed with decompression or corpectomy and stabilization as indicated. Intraoperative C-arm radiographs should be used for localization and instrumentation.

CORPECTOMY AND DECOMPRESSION OF THE SPINAL CANAL

The extent of the planned corpectomy is defined with an osteotome, and the disk spaces are opened to define the borders. Trauma or tumor and infections can obscure normal anatomic landmarks, although surgical microscopes provide excellent visualization.

After resection of the intervertebral disks, fractured vertebral fragments are removed carefully. Resection close to

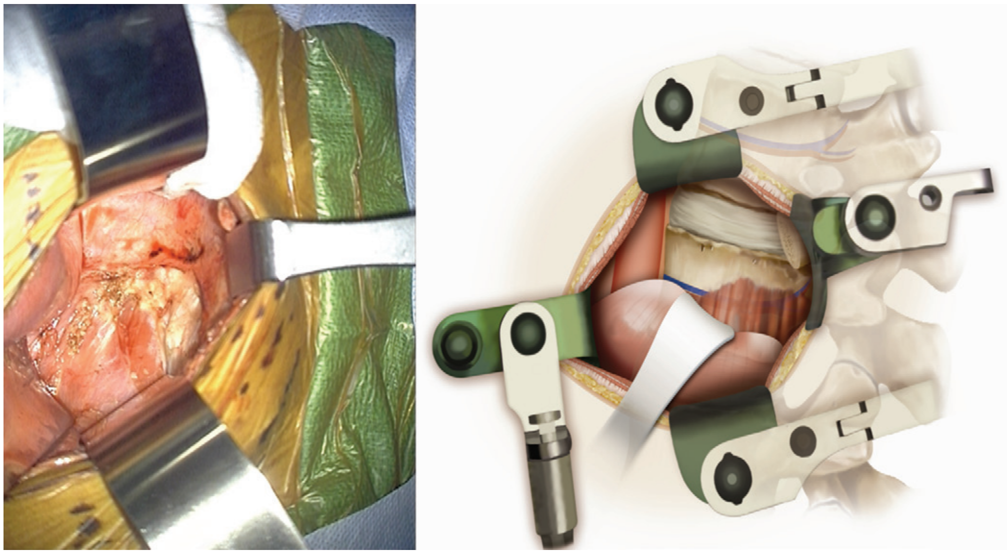

Figure 35-49 Operative technique. Inferior retraction of diaphragm after division of lateral and medial arcuate ligaments. Psoas muscle is exposed with resection and retraction of diaphragm.

the spinal canal is facilitated by the use of high-speed burrs. If decompression of the spinal canal is necessary, the lower border of the pedicle should first be identified with a blunt hook. The base of the pedicle is then resected in a cranial direction with a Kerrison rongeur, and the dural sac is identified. Finally, fragments occupying the posterior spinal canal are removed.

BONE GRAFTING, CAGE PLACEMENT, AND INSTRUMENTATION

The preparation of the graft bed is completed by aggressive preparation of the adjacent end plates and complete removal of all soft tissue. The length and depth of the bone graft/spacer required are measured with a caliper, with titanium mesh cages and expandable titanium cages used in most cases. The graft or cage is mounted on the graft holder and is inserted through the working incision. It is best to place the graft/cage under distraction and, with the distractible titanium cages, additional reduction can be achieved by further increasing the height of the cage within the graft site. In cases of fracture and dislocation, combination posterior instrumentation is performed (Fig. 35-50).

CLOSURE

Smaller incisions of the diaphragm (less than 4 cm) close without any approximating sutures. In cases when incision of the diaphragm is more than 4 cm, the opening in the diaphragm is closed with suturing. During closure, the medial and lateral arcuate ligaments can be reattached to the posterior body wall.

Subsequently, the thoracic cavity is irrigated, and a single chest tube is inserted. The two edges of the eleventh ribs are reapproximated with No. 1 nylon suture after a small hole is made by a drill. The muscle, subcutaneous layer, and skin are separately adapted by running sutures.

POSTOPERATIVE CARE

Anteroposterior and lateral radiographs of the target area are obtained postoperatively. The chest tubes are usually removed on the second or third postoperative day, and mobilization and ventilation training are started on the first postoperative day.

COMPLICATION RATES

Transient intercostal neuralgia and pleural effusion can be noted. Most patients had the chest tube removed within 2 to 3 days, and no major complications—such as vascular injuries or neurologic deteriorations—were reported, and no complications were encountered as a result of diaphragmatic detachment.

ADVANTAGES OF MINI-TTA VERSUS TRADITIONAL THORACOABDOMINAL APPROACH

The primary difference between an open thoracoabdominal approach and the mini-TTA technique is in the size of the incision and limiting the abdominal muscle splitting of the three layers (i.e., the external, internal, and external oblique muscles in the thoracoabdominal retroperitoneal dissection). The mini-TTA incision is typically 5 to 7 cm in length, but incisions for a standard thoracoabdominal approach are generally twice that length. Avoiding the more extensive incision and dissection may result in shorter recovery times, decreased postoperative pain, and decreased incidence of postoperative ileus. Furthermore, mini-TTA does not involve dissection of the diaphragmatic muscle proper, because only the medial and lateral arcuate ligaments are detached to expose the iliopsoas and quadratus lumborum muscles. Finally, given the smaller incision and dissection, less blood loss and soft-tissue trauma, and subsequent closure, this approach should ultimately be faster than the traditional thoracoabdominal approach (Fig. 35-51).

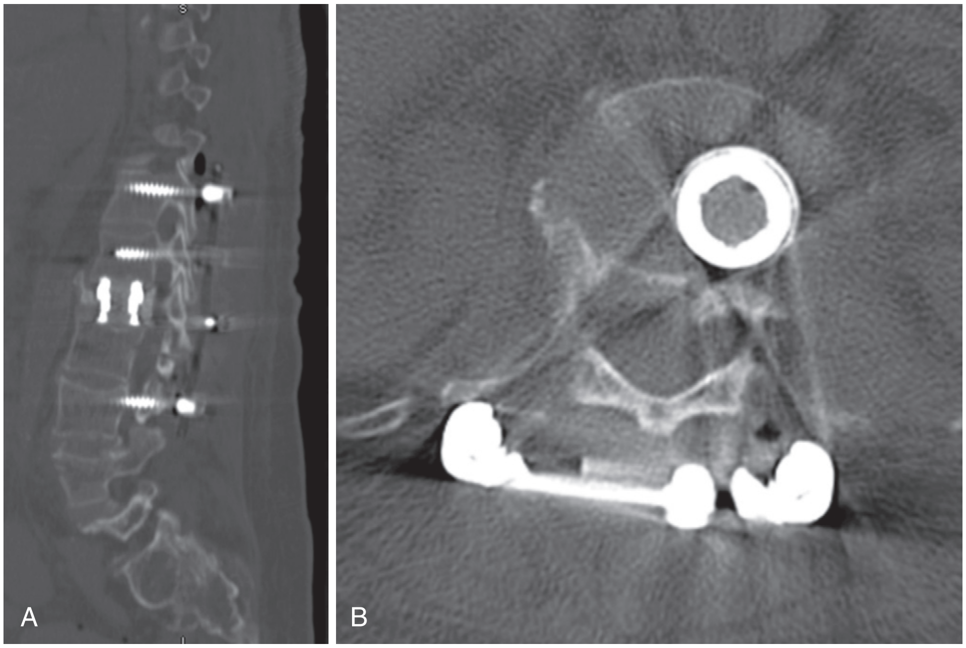

Figure 35-50 Postoperative sagittal (**A**) and axial (**B**) computed tomographic images. Combined anterior and posterior stabilization was performed for burst fracture. Corpectomy for L1 vertebral body was completed, and vertebral body was replaced with an expandable cage and bone graft via mini–thoracotomy-transdiaphragmatic approach.

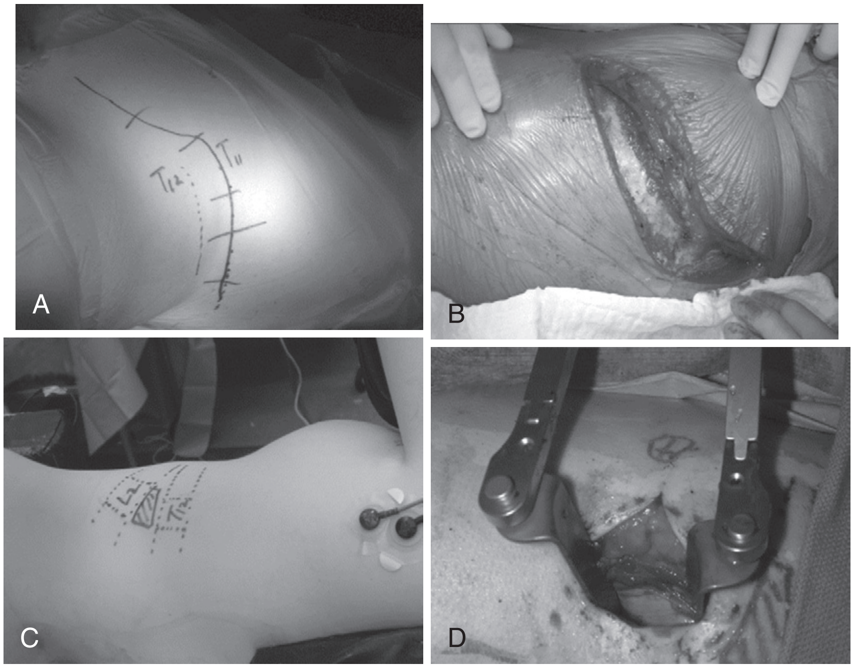

Figure 35-51 **A** and **B,** Planned incision and exposure of thoracoabdominal approach. **C** and **D,** Planned incision and exposure of mini–thoracotomy-transdiaphragmatic approach.

Open thoracoabdominal approaches for corpectomy in the thoracic or lumbar spine may cause significant pain from a large wound field, especially intercostal neuralgia and postthoracotomy pain.[16] Mini-TTA allows exposure from T10 to L3 for the purpose of corpectomy or decompression and stabilization for thoracolumbar burst fractures, tumors, infections, and deformity correction. Avoiding retroperitoneal incision and dissection is likely to prevent the morbidity associated with the traditional thoracoabdominal approach, including damage to posterior segment nerves with resulting neuralgia and pain syndromes and abdominal wall hernia secondary to T11–T12 intercostal denervation nerve injury or weakening or muscle atrophy (Fig. 35-52).

Other articles indicate the disadvantages of traditional thoracoabdominal approaches. Lin and colleagues[17] introduced the modified miniopen anterior spine surgery (MOASS) and evaluated the feasibility, effectiveness, and

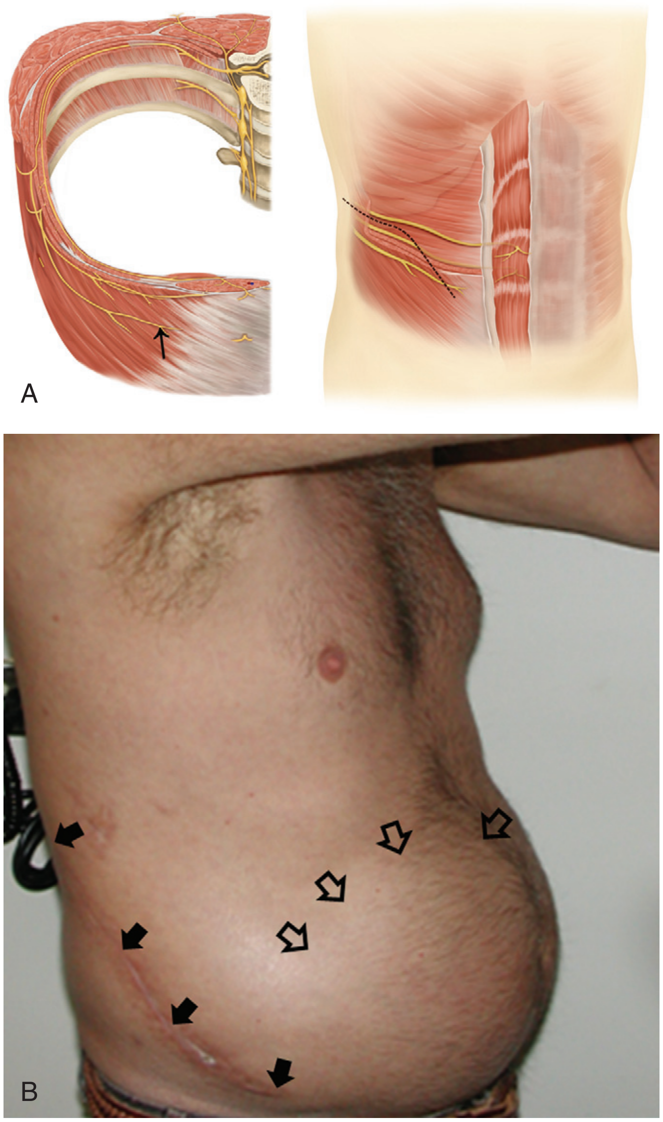

Figure 35-52 **A,** *Left:* The three muscular layers of the abdominal wall—from superficial to deep: external oblique, internal oblique, and transversus abdominis—and the location of intercostal nerve between the internal oblique and transversus abdominis muscles (*arrow*) are shown. *Right:* The typical location of incision for a conventional thoracoabdominal approach (*dotted line*). **B,** The postoperative scar (*solid arrows*) and postoperative flank bulge (*open arrows*) in a patient after an open thoracoabdominal approach to the thoracolumbar junction.

safety of this technique for the treatment of various anterior lumbar diseases. In their study, this minimally invasive technique was shown to be superior to conventional ones; patients benefit from decreased postoperative pain, shorter hospital stays, and earlier returns to work.

Surgically approaching the TLJ by mini-TTA offers several advantages over thoracoabdominal procedures, including reduced pain via a minimally invasive approach to the normal structure, a better cosmetic effect, lower perioperative morbidity, and an earlier return to normal activity. The relative differences between traditional open thoracoabdominal approaches and mini-TTA are summarized in Table 35-1.[18]

ADVANTAGES OF MINI-TTA VERSUS THORACOSCOPIC SURGERY

Familiar Three-Dimensional View

In the aspect of decreasing morbidity, thoracoscopic approaches may have some advantage compared with both the traditional thoracoabdominal and mini-TTA. However, thoracoscopic procedures are unfamiliar to many spine surgeons, and mastery demands a long learning curve. In addition, thoracoscopic views are two dimensional, so even an expert may have trouble with disorientation in relation to the anatomic topography because of the magnification and the lack of physical verification by the surgeon. Taken together, these factors may lead to serious complications.

Although thoracoscopic approaches have been shown to reduce operation-related complications, one prospective study compared open thoracotomy with thoracoscopy and showed equal incidence and intensity of persistent post-thoracotomy pain.[19] Kossmann reported that because these thoracoscopic procedures may be unfamiliar to the surgeon, they may result in an extended operation time compared with open procedures on the spine.[20] As a result, thoracoscopic interventions, when performed by less experienced surgeons, may become even more harmful to the patient than open procedures.

The thoracoscopic approach still reduces access morbidity, but mini-TTA provides a familiar, direct, three-dimensional view of the spine, which is particularly helpful and safe for the preparation of vessels, nerves, and visceral structures. Under direct view by surgical microscope with high magnification and superior light source, the management of vascular complications is quicker and easier compared with thoracoscopic procedures, which frequently have to be converted into open procedures in such cases.[12,21]

WHOLE-LUNG VENTILATION

In trauma cases, most spinal injuries that involve the TLJ are significant and multiple. Because the lung is very close by, these patients often have pulmonary problems such as lung contusion, hemothorax, and pneumothorax. Of course, such patients should be stabilized before the surgery, but when a thoracoscopic surgery is planned, the patient should be placed on one-lung ventilation during surgery to minimize risk to those with lung damage. Conversely, surgery by mini-TTA does not require one-lung ventilation anesthesia, so a double-lumen endotracheal intubation is unnecessary, thus anesthesia times are shortened without compromising lung function.

SIMPLICITY IN EQUIPMENT AND ASSISTANCE

Performance of thoracoscopic surgery comes with many requirements. In addition to the skill set necessary to perform a thoracoscopy, the surgeon will need a significant amount of equipment that includes a thoracoscope set, a set of thoracoscopic spinal instruments, monitors, and a recording device. A well-trained assistant is also required. Compare this with mini-TTA, which requires only standard equipment.

In some articles, because of the small incisions for a mini-TTA, modified retractors were used in surgery. Kossmann

Table 35-1 Relative Differences between Traditional Open Thoracoabdominal Approaches and the Mini–thoracotomy-Transdiaphragmatic Approach (Mini-TTA)

	Traditional Thoracoabdominal Thoracotomy	Mini-TTA
Exposure	Extensile exposure, direct access to 7 to 9 disks possible from T10	Exposure limited by small incision, direct access limited to 4 to 5 disks (from T10 to top of L3)
Learning curve	Short: technique familiar to most spine and thoracic surgeons	Relatively short: an extension of the open approach (The surgeon should be familiar with the technique before working through a smaller incision.)
Rib resection	Extends beyond T11 rib resection thoracotomy; involves three layers of abdominal muscle splitting	Usually 4 to 6 cm
Muscle dissection	Significant chest and abdominal wall dissection	No retroperitoneal abdominal muscle splitting with rib sparing
Operative time	Long incision and larger muscle dissection, closing time is longer	Relatively short incision, minimal diaphragmatic dissection, and no muscle opening (shorter operative time)
Hemostasis	Blood loss from larger diaphragm detachment with three-muscle-layer–splitting procedure	Less blood loss
Pulmonary function test	Transiently decreased secondary to T11 rib resection	Less severe as a result of rib sparing
Chest tube duration	About 3 to 4 postoperative days	About 1 to 2 postoperative days
Hospital stay	4 to 6 days	2 to 3 days

and colleagues[20] published an article about minimally invasive reconstruction surgery using a retractor system (SynFrame, Synthes, Inc., West Chester, PA). Surgeons can achieve a sufficient surgical field with long cervical or narrow lumbar retraction blades—equipment already very familiar to spine surgeons. With these simple retractors, surgeons can perform operations that included decompressive corpectomy and instrumentations.

LOW RATE OF SURGERY-INDUCED RIB INTERCOSTAL NEURALGIA

With mini-TTA procedures, reconstruction of a single, posteriorly osteotomied and resected rib is very simple. The intercostal nerve, artery, and vein are dissected and protected initially, and the rib is cut using a single posterior osteotomy and is reflected downward for preservation. At closure, the two edges of the eleventh rib are reapproximated with No. 1 nylon suture, after a small hole is made in the rib by a drill. With this technique, complication rates for the rib cage are relatively low. However, in thoracoabdominal approaches, the intercostal space is dissected; and at closure, areas above and below the T10 resected rib T11 are reapproximated together, resulting in a high risk of intercostal nerve injury at the reapproximated ribs.

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36 Surgical Stabilization Techniques for Thoracolumbar Fractures

NADER S. DAHDALEH, STEPHANUS VILJOEN, ANDREW J. GROSSBACH, and PATRICK W. HITCHON

Classifications of Spinal Fractures

HISTORICAL REVIEW

The classification, management, surgical approaches, and stabilization techniques for thoracolumbar fractures have been undergoing continuous evolution over the past few decades. Appropriate classification of these fractures is the first step toward successful treatment, so a comprehensive classification system should facilitate the selection of the appropriate approach and surgical technique for fractures that require surgical stabilization.

Boehler[1] was the first to attempt to classify thoracolumbar spine fractures in 1929. In 1963 Holdsworth[2] introduced the two-column theory of spinal stability. In 1978 White and Panjabi[3] defined *clinical instability* as the inability of the spine under physiologic loads to maintain relationships between vertebrae such that there is neither acute nor subsequent neurologic injury, deformity, or pain.

The three-column theory of the spine was introduced by Francis Denis[4] in 1983. He added a third, or middle, column to Holdsworth's two-column model. According to Denis, the *anterior column* of the spine included the anterior longitudinal ligament (ALL) and the anterior half of the vertebral body, annulus, and disk. The *middle column* included the posterior half of the vertebral body, annulus, and disk in addition to the posterior longitudinal ligament (PLL). The *posterior column* incorporated the neural arch, facets, and the posterior ligamentous complex (PLC), consisting of the supraspinal and interspinal ligaments, ligamentum flavum, and facet capsules (Fig. 36-1). The importance of the middle column had become evident, because it was necessary to disrupt the middle column with the anterior or posterior columns for dislocation to occur. Denis defined stability based on the integrity of two of the three columns. His classification included four groups: 1) *compression fractures* resulting from failure of the anterior column under compression, 2) *burst fractures* resulting from failure of the anterior and middle columns secondary to fractures of the vertebral body under axial load, 3) *flexion-distraction injuries* secondary to failure of the posterior and middle columns, and 4) *fracture-dislocations* resulting from failure of all three columns. This classification stood the test of time, because it was simple to apply and in a way simplified management, because most anterior column injuries are treated conservatively or nonsurgically with bracing, and almost all three-column injuries are treated with surgical stabilization. Two-column injuries are still a topic of debate; however, in the presence of a neurologic deficit or severe deformity, surgical stabilization is required.

In 1989, Magerl and colleagues[5] introduced the Association for the Study of Internal Fixation—*Arbeitsgemeinschaft für Osteosynthesenfragen,* or AO—classification system. This was based on a 10-year review of 1445 thoracolumbar fractures that recognized three main fracture types: compression fracture (type A), distraction (type B), and fracture-dislocation (type C). Subdivisions were created according to the severity of the fractures. This detailed and descriptive classification system resulted in 53 fracture patterns, with A1 being the least severe and C3 the most severe.

The Load-Sharing Classification was introduced by McCormack and colleagues[6] in 1994. The classification was derived from the analysis of failures of thoracolumbar spine fractures treated with transpedicular short-segment arthrodesis. According to their classification, fractures were graded according to the degree of comminution of the body, apposition of the fracture fragments, and deformity. A point system was applied to each fracture, from 3 to 9, with a higher number indicative of increased severity. Fractures with a score greater than 7 had a high risk of short-segment fixation failure. This algorithm was intended to aid in deciding whether to use short-segment arthrodesis and/or anterior column graft support. The classification was validated biomechanically in vitro.

In 2005, the Spine Trauma Study Group introduced the Thoracolumbar Injury Severity Score (TLISS) as a new classification system.[7,8] The system was based on three injury characteristics: 1) mechanism of injury, 2) neurologic status, and 3) the integrity of the PLC. This classification system was eventually modified to become the Thoracolumbar Injury Classification and Severity Scale (TLICSS).[9] As for the morphology of injury, compression injuries are assigned 1 point; burst fractures and compression fractures with coronal plane deformity greater than 15 degrees score 2 points; translational or rotational injuries score 3 points; and distraction injuries, being the most unstable, receive 4 points. Scoring the severity of neurologic injury is based on a five-category system. Patients with an intact neurologic exam receive 0 points. In the presence of nerve root injury or complete spinal cord injury, the fracture scores 2 points. Patients with an incomplete spinal cord injury or cauda equina syndrome are given 3 points.

Assessing the integrity of the PLC can be accomplished clinically by the presence of a palpable interspinous gap, separation of the spinous processes on plain radiographs, or with the use of magnetic resonance imaging (MRI). Patients with an intact PLC receive 0 points. Those in whom the integrity of the PLC is indeterminate receive 2 points, and those with confirmed injury receive 3 points. If the injury involves multiple levels, the most severe level is scored. If more than one mechanism involves the same level, the score should represent the summation of mechanisms. The total TLICSS score reflects the severity of the injury and helps guide treatment. Patients with a score of 3 or less are treated nonoperatively. Those with scores of 5 or above are treated by surgical stabilization. Lastly, patients who score 4 points fall into the indeterminate category, and treatment is according to surgeon preference. Moreover, Lenarz and colleagues[10] showed that the interobserver reliability of the TLICSS score was comparable with the Denis and AO systems.

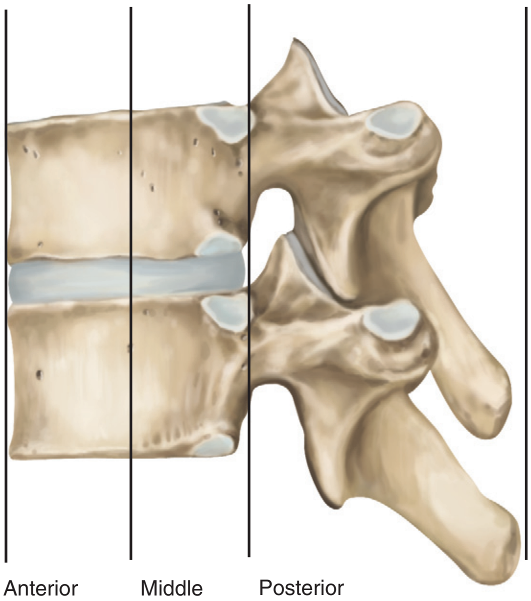

Figure 36-1 The three columns of the spine in accordance with Denis.

THE IOWA CLASSIFICATION SYSTEM AND ALGORITHM

Recognizing the schemes and classification systems described above, and based on data collected prospectively on 300 thoracolumbar fractures, a simple classification and algorithm for thoracolumbar spine fractures was developed (Fig. 36-2). This algorithm is based on three criteria: 1) clinical, 2) biomechanical, and 3) radiographic. The *clinical criteria* address the presence or absence of pain or neurologic deficit. *Biomechanical criteria* describe the involvement of one, two, or three columns. *Radiographic criteria* address the degree of kyphosis, canal compromise, and the integrity of the PLC.

Surgical decompression and stabilization is recommended for those patients with neurologic deficit. Surgery for stabilization is also recommended for those who suffer from persistent pain despite bracing, and in spite of a normal neurologic exam, and cannot be mobilized satisfactorily. In patients with a normal neurologic exam, the biomechanical criteria are then used to address the Denis three-column involvement with the use of plain radiographs and computed tomography (CT) scans. In the presence of three-column injuries—such as a fracture–dislocations or flexion-distraction injuries, which are inherently unstable—patients are operated upon acutely. Patients with a single-column fracture (i.e., a wedge compression fracture) are treated nonoperatively with bracing. With two-column injury, such as burst fractures, the integrity of the PLC is assessed with MRI. Disruption of the PLC on MRI would render a burst fracture unstable; hence it would qualify the patient for stabilization. Clinical experience also suggests that older patients (>60 years) are more likely to fail with nonoperative treatment, necessitating surgical intervention.

Stabilization Techniques

ANTEROLATERAL APPROACH TO THE THORACOLUMBAR SPINE (T11–L4)

The anterior or anterolateral approach is undertaken when the spinal canal is compromised from fracture, tumor, or

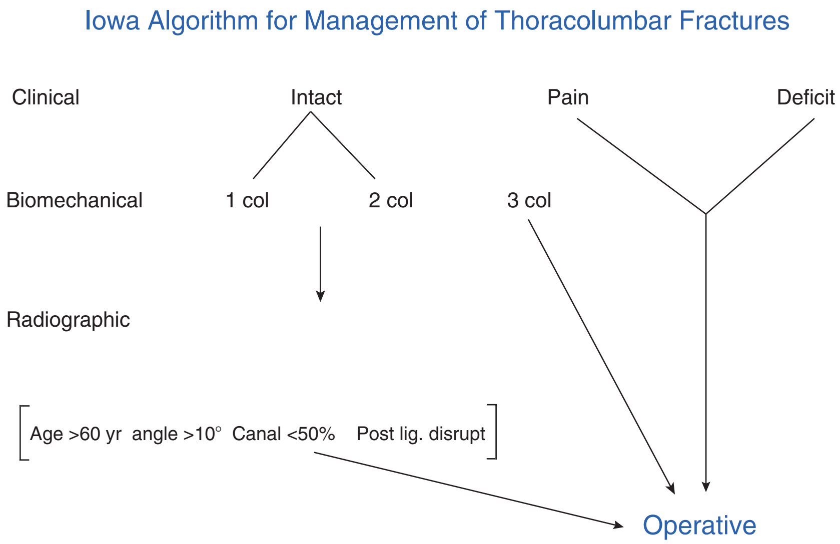

Figure 36-2 The Iowa algorithm for the management of thoracolumbar fractures. *col,* column; *Post lig. disrupt,* posterior ligament disruption.

infection. Under such circumstances it is difficult or impossible to decompress the cord and proceed with anterior grafting or stabilization through a midline posterior approach. Reconstruction of the anterior two columns is achieved by thoracotomy in the thoracic spine[4] and through a flank retroperitoneal approach in the thoracolumbar or lumbar spine.[11-14]

Patients are placed in the lateral decubitus position with the left side up (Figs. 36-3 and 36-4). The approach is through the left side, on the same side as the abdominal aorta, which is less likely to be injured than the inferior vena cava. The patient is positioned with the flank over the break in the table. The operating table is flexed, opening up the left flank yet keeping the thoracolumbar spine fairly straight. The patient is immobilized on a beanbag supplemented with adhesive tape. The upper knee is slightly bent, and the knees, heels, and ankles are also padded. Wide adhesive tape is used to strap the patient to the operating table, and it is placed across the greater trochanter in a fashion that

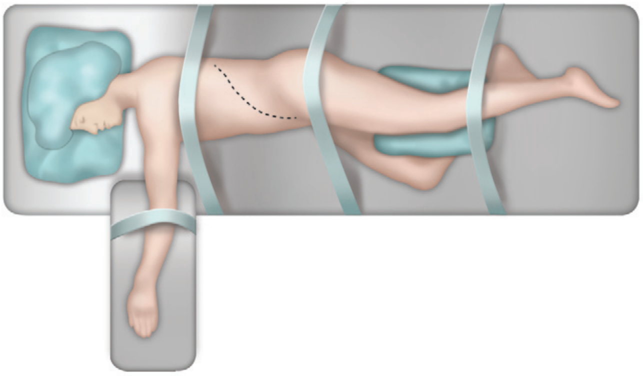

Figure 36-3 For the antrolateral approach, the patient is placed in a decubitus position with the left side up. A beanbag is helpful, but not necessary, as long as the patient is well padded and taped in position to allow tilting the table. The table is broken at the flank to open up the rib to the iliac crest space and facilitate exposure. The location of the incision, usually about 6 inches long, is determined using anteroposterior fluoroscopy.

Figure 36-4 Taping the patient to the table is a must to allow tilting of the patient in the anteroposterior plane. Repetitive fluoroscopy is used to direct the exposure and placement of hardware.

allows exposure of the iliac crest, should bone harvesting be required. Pneumatic compression stockings are placed to reduce the incidence of deep venous thrombosis (DVT), and a warming blanket is placed over the lower extremities and torso to maintain body heat during the procedure.

The fracture is confirmed using anteroposterior (AP) and lateral fluoroscopy. For T11, T12, and L1, it is necessary to enter the chest cavity. The left lung is deflated while ventilating the right lung through a double-lumen endotracheal tube. Through a 6-inch incision, the chest is entered, and the spine is visualized. Exposure may be facilitated by resection or by shingling of one or two ribs. Periosteal elevators and rib-resection instruments help prevent injury to the intercostal bundle. The incision should stop short of the lateral edge of the paraspinal muscles.

The exposed segmental intercostal arteries and veins may need to be ligated for the decompression and screw application. When necessary, the ligation should be performed as far from the neural foramina as possible; this should allow adequate blood flow to the spinal cord and conus through collaterals. Commonly, the intercostal arteries between T9 and L2 on the left give rise to the artery radiculomedullaris magna, or the artery of Adamkiewicz, the largest spinal branch to supply the lower thoracic cord and lumbar enlargement. To avoid spinal cord ischemia or infarction, ligation of these intercostal vessels should be undertaken sparingly and only when absolutely necessary.

For L2 through L4, the chest cavity can be avoided by making the incision between the costal margin and the iliac crest and by remaining in the retroperitoneal space, below the diaphragm. A 6-inch curvilinear incision is extended posteriorly from the lateral border of the rectus sheath parallel to the rib cage. Lower incisions that do not overlie the rib cage are carried through the layers of the abdominal wall down to the transversalis fascia. The latter is retracted anteriorly, and through it, the surgeon can visualize the kidney and ureter. The spleen is located above the kidney and may be seen or palpated. Blunt dissection is used to define the space behind the transversalis fascia, and it is carried down (posteriorly) to the psoas muscle.

Table-mounted self-retaining retractors can then be used to retract the psoas muscle posteriorly, the diaphragm and ribs superiorly, and the kidney and abdominal contents anteriorly. Extra care must be exercised in retracting the spleen to protect it from laceration. Using electrocautery, the psoas muscle is incised at its attachment to the vertebral bodies and is retracted farther posteriorly to expose the pedicles and neural foramina of the fractured and adjacent vertebrae to be instrumented.

Under magnification, either by loupe or microscope, the intervertebral disks adjacent to the fractured body are then excised. A corpectomy of the fractured body is performed using rongeurs and chisels, and the bone is saved for fusion (Fig. 36-5). An air drill may sometimes be necessary but is less desirable, because the bone dust is hard to retrieve. The decompression of the canal extends across to the opposite side of the canal, until the contralateral pedicle is palpated (Fig. 36-6). The dura can be felt with a Penfield dissector and can sometimes be inspected with a small laryngeal mirror. The corpectomy must be large enough to accommodate a graft with a large footprint to avoid telescoping into the adjacent bodies, and adjacent end plates are kept

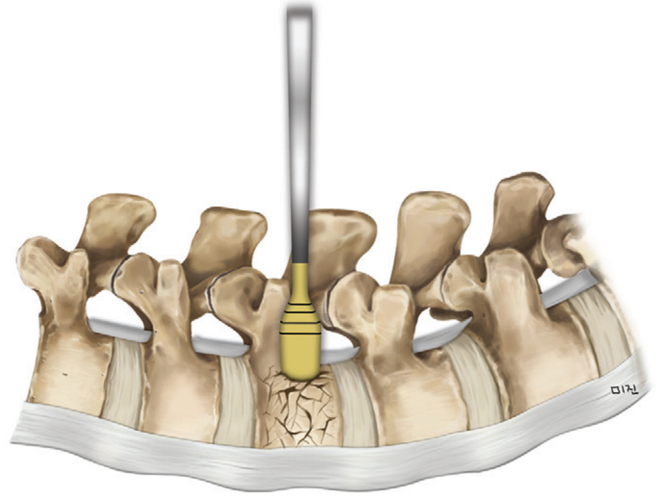

Figure 36-5 Corpectomy and decompression is performed with chisels and curettes, and the bone is harvested for the fusion. The anterior longitudinal ligament is preserved, and the canal is decompressed. The posterior longitudinal ligament is generally disrupted, and if necessary, it is decompressed as long as decompression of the canal is achieved.

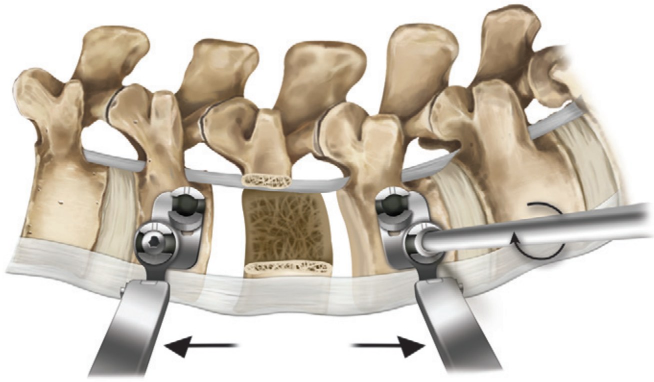

Figure 36-7 Fixed-head screws are inserted parallel to the end plates and with a triangulated trajectory about 10 degrees from the vertical.

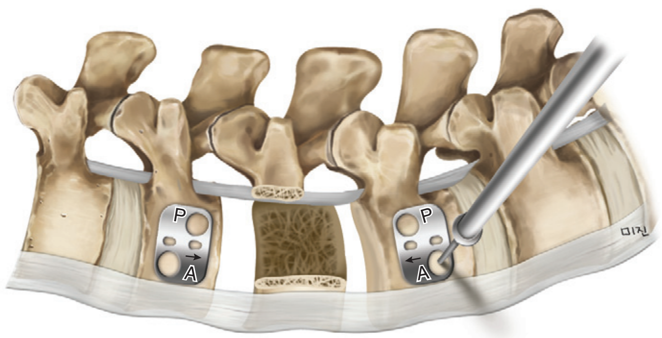

Figure 36-6 Once the decompression is achieved, and the rostral and caudal disks are removed, lateral plates of appropriate size are applied to the rostral and caudal bodies, pilot holes are made through the plates, and the trajectories are partially undertapped. Generally, 6 mm diameter screws are used, and thus a 5 mm tap suffices.

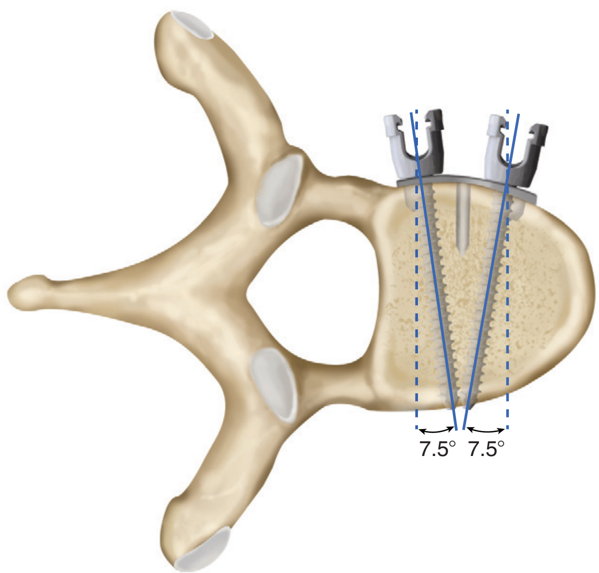

Figure 36-8 If entry points and trajectories are selected properly, the screws will not meet. The length of each screw is selected for bicortical engagement.

intact to provide rigid apposition to the graft and to minimize subsidence.

Once the decompression is achieved and confirmed, 6-mm bicortical screws are placed through lateral plates above and below the corpectomy (Fig. 36-7). The entry point for the screws is usually 5 to 10 mm from the floor of the canal and the adjacent end plate, with a triangulated trajectory of about 10 degrees away from the spinal canal (Fig. 36-8). The length of the screws is estimated from the AP plain films or CT scan to ensure bicortical engagement, and the trajectory is monitored with fluoroscopy. While the bone screws above and below are distracted, a graft is impacted into the corpectomy defect (Fig. 36-9). Our preferred graft material is the stackable graft of carbon fiber reinforced polymer (CFRP; DePuy Spine, Raynham, MA). The graft is packed with the patient's own bone supplemented with allograft.

In addition to distracting the end plates above and below the decompression, correction of angulation is also achieved through ventral compression posteriorly applied on the gibbous side. The graft is impacted into the corpectomy defect and is made to lie in the center of that defect on AP fluoroscopy. Once implanted it is necessary to confirm its location in the sagittal plane using lateral fluoroscopy; if the graft is tilted into the canal, it needs to be withdrawn and reinserted parallel to the canal.

Once spinal alignment is achieved, rods are applied onto the screws, and nuts are tightened at one end. At least one transverse connector is applied between the two rods. Using the transverse connector as an anchor, under compression, the second set of set screws is tightened on the rods (Fig. 36-10). This step often requires an extra set of hands. Once the position of the graft is confirmed (Fig. 36-11), additional morcellized bone graft is placed in

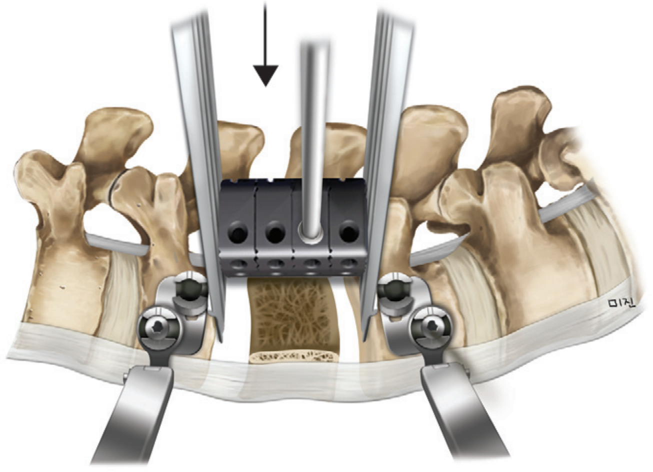

Figure 36-9 A stackable cage of carbon fiber reinforced polymer (CFRP; DePuy Spine, Raynham, MA) or other materials is impacted into place using the sled guides. It is important to select the graft length to correct the kyphotic deformity and avoid impacting it into the bodies above or below. The cage is packed with autologous bone augmented with allograft. Distraction can be applied rostrally and caudally by way of the bicortical screws to facilitate graft insertion; however, excessive distraction can loosen the screws.

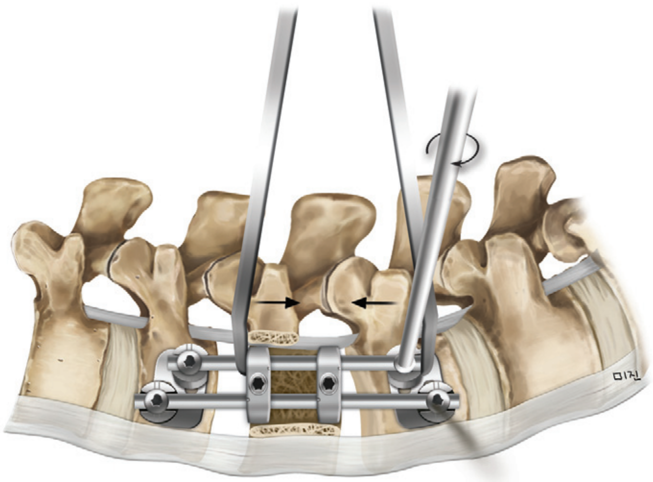

Figure 36-10 Once the graft position is confirmed with lateral fluoroscopy, lateral instrumentation is applied. Set screws are tightened on the rods on one end, and one or two transverse connectors are applied and tightened. Using the transverse connector as an anchor, set screws at the other end of the rods are tightened under compression.

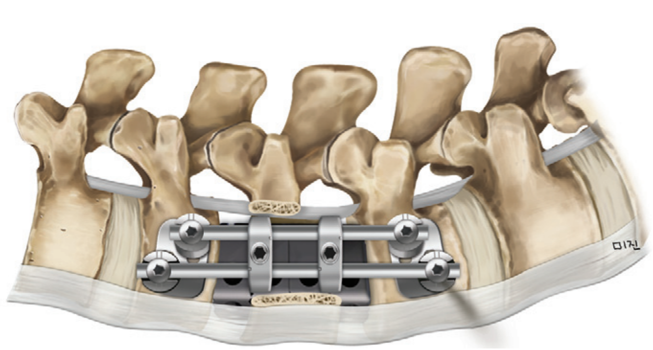

Figure 36-11 Once the construct is checked in both AP and lateral planes, additional bone graft is inserted in and around the construct.

and around the implant, and the construct is covered with Gelfoam.

If the chest has been entered, a 28- to 32-Fr chest tube is inserted into the chest cavity. A purse-string suture is usually sufficient to close the diaphragm close to the spine. The chest tube should exit in the anterior to midaxillary line, so the patient will not lie on the tube. Hemovac drains are placed adjacent to the hardware and are brought out anteriorly. Removal of the drain can thus be accomplished without uncovering the entire fresh wound. The drains are secured at their point of exit with nonabsorbable suture, and the wound is closed in layers. Prophylactic antibiotics are usually maintained while the chest tubes are in place. The tubes are placed on −10 to −20 cm of water suction, and they are removed once the output from them is less than 150 to 250 mL per day, and no air leak is present. Postoperatively, patients are maintained on incentive spirometry and chest physiotherapy. Pulse oximetry is routinely checked, and adequate pain management is critical to prevent postoperative atelectasis and possible pneumonia.

This approach has been used in 58 thoracolumbar burst fractures from T12 to L4 (Fig. 36-12).[12] All were approached through the left side. Anterior column reconstruction was performed with allograft in 30, and the rest were done with CFRP impacted with autograft and/or allograft. The anterolateral approach alone was sufficient in 52 cases. One case required contemporaneous posterior instrumentation, and five required delayed posterior instrumentation. Owing to the small size of S1, and the obstruction by the iliac crest, it is difficult if not impossible to place a lateral implant that spans L4 to S1; thus L5 burst fractures are often treated nonoperatively or through a posterior approach. If anterior decompression involves two levels of the thoracolumbar spine (T11–L4), or in the case of older patients with osteoporosis who are overweight, or when the posterior column is also involved, supplementary posterior instrumentation may be necessary. Anterior and posterior instrumentation can be staged, or it may be incorporated in a single procedure when disruption of the posterior column is definite.

POSTEROLATERAL TRANSPEDICULAR APPROACH WITH VERTEBRAL BODY RECONSTRUCTION

When neurologic deficit is present and/or severe comminution of the vertebral body, reconstruction of the vertebral body through a dorsolateral transpedicular approach and placement of an expandable cage can be accomplished, provided it is long enough.[15-20] Pedicle screws are placed two or three levels above and below the fracture. Where instability exists, a temporary rod is placed contralateral to the transpedicular decompression. Complete exposure to the tip of the ipsilateral transverse process is necessary, with removal of the inferior and superior facets and pedicle. Corpectomy of the fractured vertebral body is performed from the caudal end plate of the body rostrally to the rostral end plate of the caudal adjacent body. This is accomplished with rongeurs and an electric drill, and the canal is decompressed.

Cancellous bone and any retropulsed bony fragments are removed and soaked in bacitracin to be used later for grafting. The exiting nerve roots are identified and protected. A

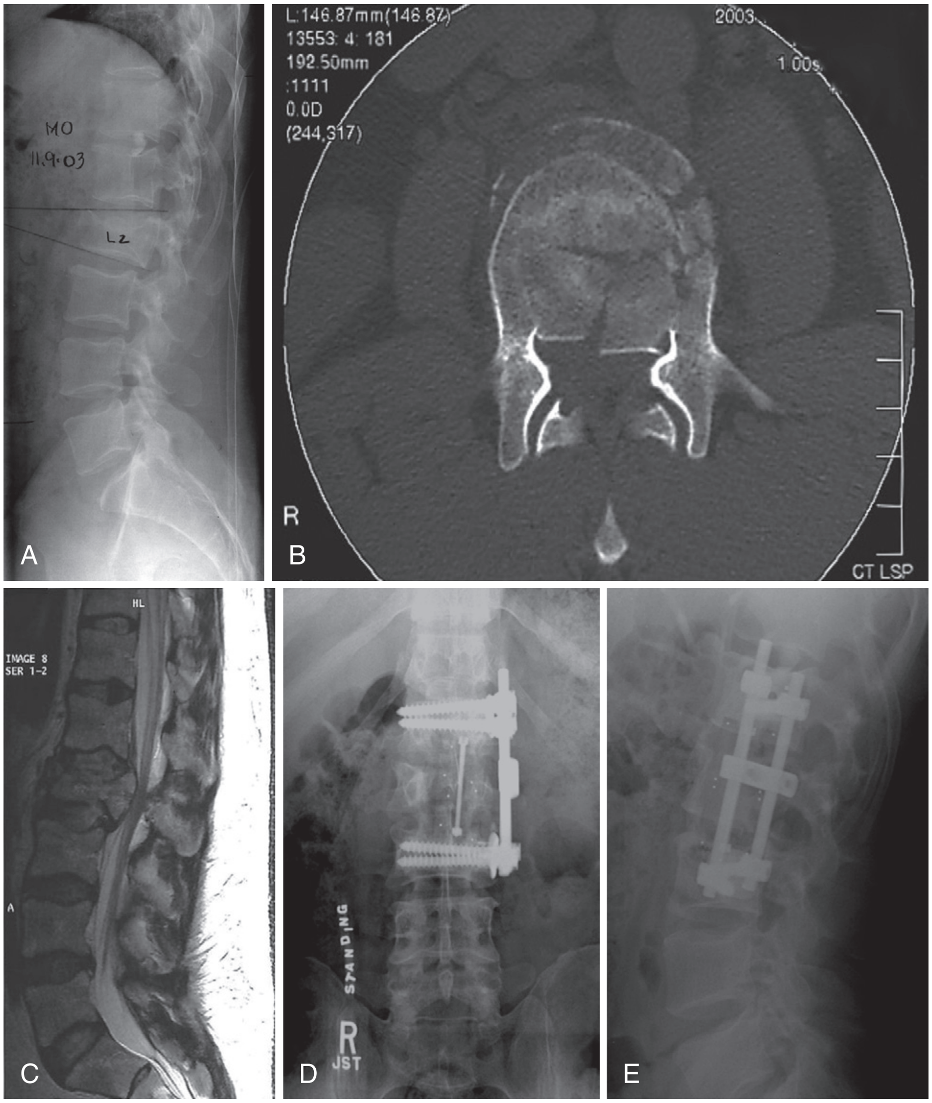

Figure 36-12 A 45-year-old patient who fell from horse came to medical attention with leg paresthesias and hesitancy but no motor weakness. A plain lateral film (**A**), axial CT (**B**), and MRI (**C**) show the burst fracture with retroplused bone into the canal. Two years later, the patient skis and snowboards without restriction. Anteroposterior (**D**) and lateral radiographs (**E**) show good alignment with the CFRP cage in place.

corpectomy is made sufficient to accommodate an expandable cage with the largest footplate to prevent subsidence. The cord, or conus, is not retracted; rather it is carefully decompressed with reversed curettes. Once decompression is accomplished, the expandable cage is inserted between the exiting nerve roots. To prevent telescoping of the graft into the adjacent vertebral bodies, the cage with the largest footplate is selected. Using lateral fluoroscopy, the sagittal placement of the cage is adjusted. AP fluoroscopy confirms the adequacy of cage placement in the coronal plane. The corpectomy has to be sufficient to place the graft as close to midline as possible and for best biomechanical advantage. The cage is prepacked with auto and allograft, and additional bone is placed around the cage.

Posterior instrumentation is applied using pedicle screws supplemented with hooks if deemed necessary. The wound is closed in layers. Suction drainage is used and is removed 1 to 2 days postoperatively, when drainage drops below 50 mL per shift. Mobilization is initiated as soon as allowable with thoracolumbar bracing, generally for 3 months, and sequential radiographs are obtained. This approach was undertaken in the patient shown in Figure 36-13.

POSTERIOR MINIMALLY INVASIVE TECHNIQUES

Percutaneous fixation of thoracolumbar fractures has been gaining popularity in the past decade.[21] For the stabilization of a variety of thoracolumbar fractures, pedicle screws can be placed percutaneously under fluoroscopic guidance with minimal muscle dissection.[21-28] This technique has been adopted in the fixation of compression fractures, burst fractures, flexion-distraction, and extension injuries. The goal of percutaneous instrumentation is the provision of internal stability sufficient to achieve osseous union. The main advantages of percutaneous surgery are reductions of 1) soft tissue dissection and trauma, 2) intraoperative blood

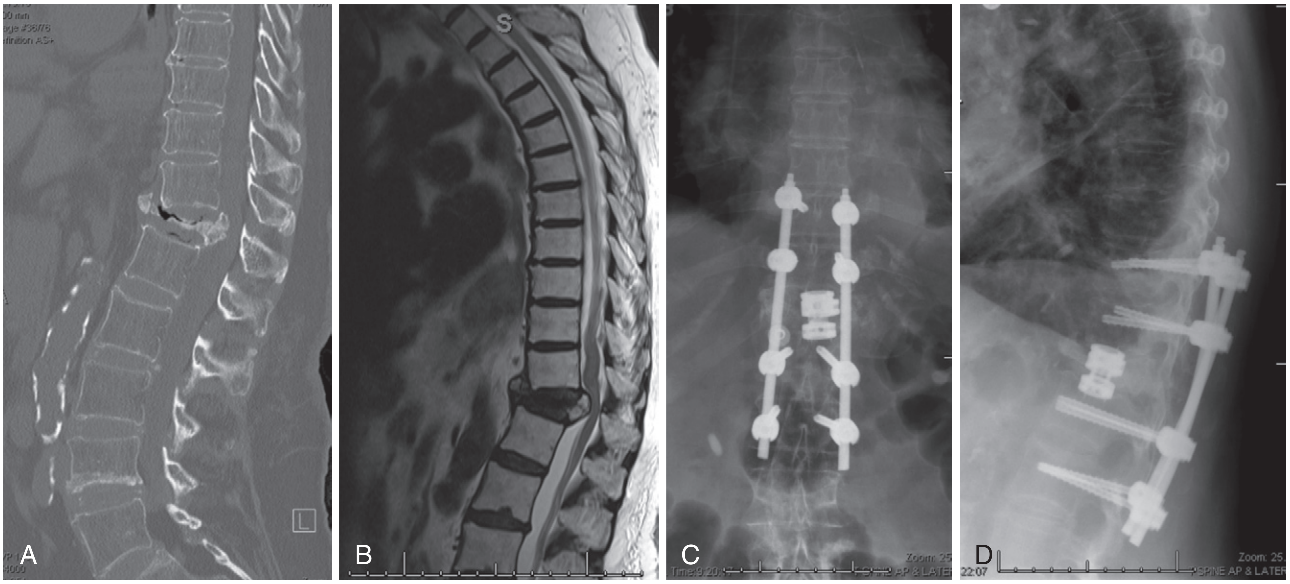

Figure 36-13 An 80-year-old woman reported difficulty ambulating for 4 months and decreased sensation in her legs for the same period of time. She came to her family physician with numbness in her feet but no history of distinct trauma. **A** and **B** show the sagittal CT and T2-weighted magnetic resonance imaging demonstrating a burst fracture of T12 with retropulsion of bone into the canal. The patient underwent percutaneous placement of the T10–L2 pedicle screws. The expandable cage was placed though a 21-mm spotlight working channel (DePuy Spine) without sacrificing a nerve root. Postoperative plain films (**C** and **D**) show the pedicle screws at T10–L2 with an expandable cage in place.

loss, 3) operative time, and 4) infection rates.[29] These considerations are important when treating high-risk and compromised patients, as in multitrauma casualties.

Percutaneous pedicle screw fixation can be used as the sole treatment option in patients who have no neurologic deficits and do not need anterior column reconstruction. It can also be used as an adjunct treatment method to reestablish the posterior tension band in cases where the anterior column is reconstructed through an anterolateral-retroperitoneal or transthoracic approach (Fig. 36-14).

Screw Placement

To facilitate fluoroscopy and replicate the normal thoracolumbar curvature, the patient is preferably placed prone on the Mizuho OSI spinal table (Mizuho, Tokyo). During the turning process, complete spinal precautions are maintained, and the patient is log-rolled. In cases of instability, neurologic reassessment after turning is recommended. For fractures at and above the level of the conus medullaris, we usually use neural monitoring with somatosensory evoked potentials (SSEPs).

After identifying and confirming the level of the fracture using lateral fluoroscopy, the AP view is used to identify the pedicles of interest. A good AP image would show a midline spinous process and a well-demarcated superior end plate above the pedicles of interest. A small 1 to 2 cm incision is marked lateral to the lateral border of the pedicle. The skin incision is made after infiltration with local anesthetic, and the dorsolumbar fascia is incised with a Mayo scissors.

Using AP fluoroscopy, the Jamshidi needle is introduced until bone is encountered. The entry point is in the upper outer quadrant of the pedicle (Fig. 36-15, *A*). The needle is introduced parallel to the disk space and is triangulated relative to the sagittal plane. Triangulation varies with the level and the long axis of the pedicle as measured from the axial CT scan. At the thoracolumbar junction, triangulation can be as little as 5 degrees, increasing to as much as 30 degrees toward the top of the thoracic spine and the bottom of the lumbar spine. The tip of the needle should not violate the medial border of the pedicle. Once it is within the body and past the pedicle, a K-wire is then introduced through the Jamshidi needle (see Fig. 36-15, *A*), and it acts as a guide for all subsequent instruments, including the pedicle screw. Thus it is necessary to keep the guidewire in place, without inadvertently withdrawing it or advancing it into the retroperitoneum, with potentially serious complications. The Jamshidi needle is withdrawn, and the K-wire is kept in place.

A dilator is advanced along the guidewire, followed by a cannulated awl to penetrate the cortical bone at the point of entry. The awl is withdrawn, and an appropriately sized cannulated tap is introduced through the K-wire and is used to create the path for the screw in a direction parallel to the end plate. Only the pedicle is tapped, with only the tip of the tap making it into the body (see Fig. 36-15, *B*). Undertapping the pedicle is advised for a more snug fit of the screw. The trajectory of the guidewire must be maintained such that it is not transected or bent by the tap or screw. The tap is withdrawn, and a cannulated screw, the diameter and length of which are based on the CT images, is introduced on the K-wire (see Fig. 36-15, *C*). Diameters vary from 5 to 7 mm, and lengths are generally 45 to 55 mm. It is important to maintain the trajectory of the screw such that it is congruent with the wire. Should the trajectory of the screw intersect the wire, the latter would be severed, leaving a portion of it in the body. The K-wire is then removed. Depending on the fracture type and the degree of instability, one (compression fractures) to two

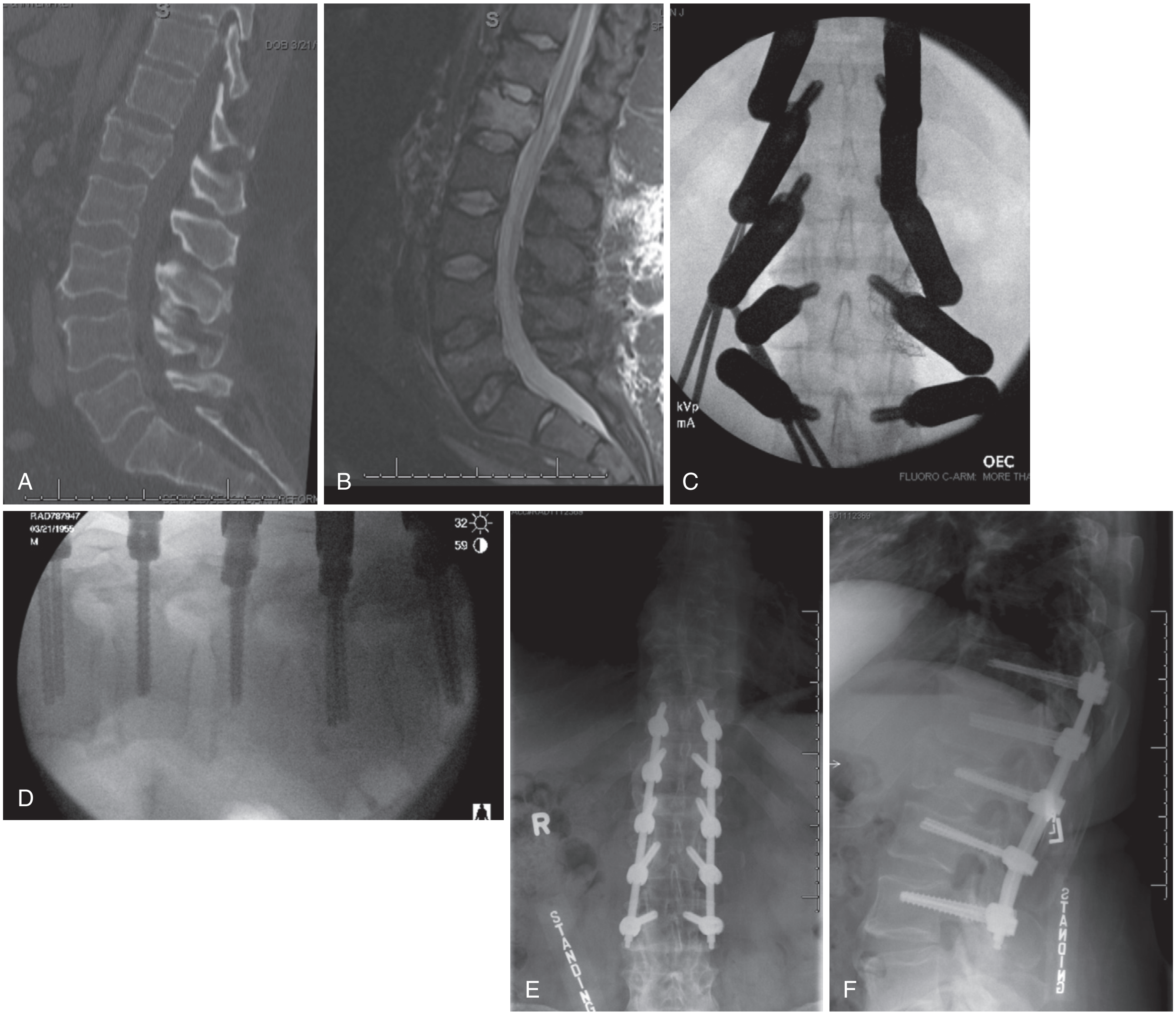

Figure 36-14 This 55-year-old man fell off a deer-hunting tree stand and landed on his back in severe pain. On admission he complained of numbness and displayed 4/5 motor strength in his legs. **A,** Computed tomography scan shows a bust fracture of L1 with minimal canal compromise. **B,** Short T1 inversion recovery magnetic resonance imaging shows the fracture without disruption of the posterior elements. Contusion of the conus is noted. Because the patient needed stabilization without decompression, percutaneous pedicle screws were inserted as shown on fluoroscopic anteroposterior (AP) (**C**) and lateral (**D**) views. When seen 11 months later, the patient's only deficit was weakness of his right dorsiflexors; gait was normal. AP (**E**) and lateral (**F**) views show normal spinal alignment with the hardware intact.

levels (fracture-dislocation) rostral and caudal to the fracture are instrumented.

Rod Insertion

Using a compass or similar device recommended by the manufacturer of choice, the proposed length of the intended rod is measured. After contouring the rod to the spine—lordotic for lumbar, straight for thoracolumbar, and kyphotic for thoracic spine—the rod is attached to the introducer. The rod is introduced subfascially, rostrally, or caudally and is advanced through the slots of the pedicle screws (see Fig. 36-15, *D*). Set screws are then inserted, and they are screwed and tightened under compression, while holding the rod in the inserter to prevent the rod from flipping from a lordotic to a kyphotic position. Final tightening is performed with the antitorque device in place to prevent rod rotation in the coronal plane.

We usually obtain an intraoperative multiplanar image to verify appropriate screw placement in three dimensions without medial or lateral violation of the pedicle. After that, the screw holders are removed or the extended tabs are broken off. The fascia is approximated with 2-0 or 3-0 absorbable suture, and the skin is closed with subcuticular absorbable suture. Tissue adhesive covers the suture line. After surgery, patients are mobilized in a thoracolumbar brace. We have been successful in using this technique in 28 patients, none of whom had any complications. These included 8 burst fractures, 10 flexion-distraction injuries, 7 extension fractures, 2 fracture-dislocations, and 1 compression fracture.

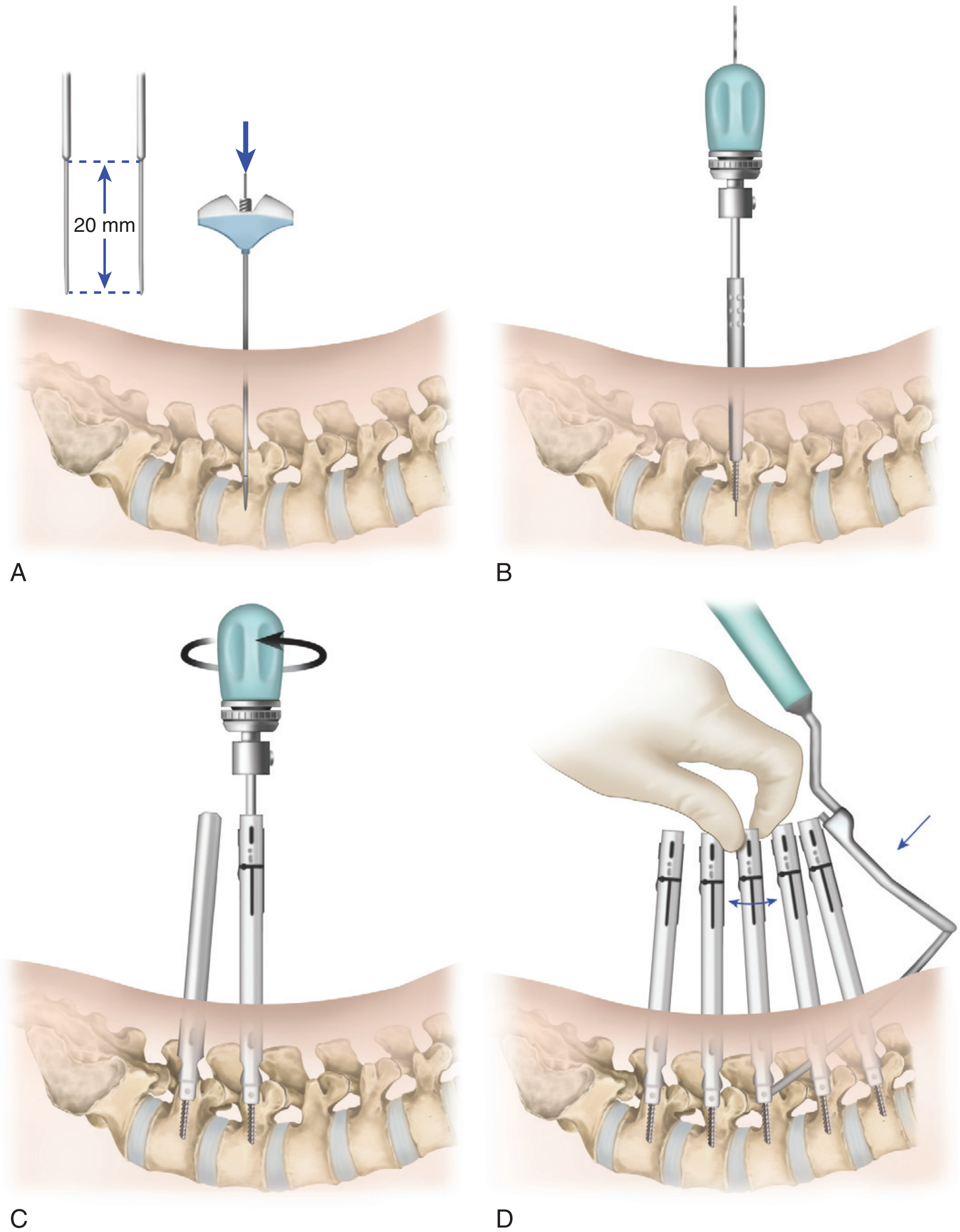

Figure 36-15 Steps for percutaneous pedicle screw placement. **A,** Percutaneous introduction of the Jamshidi needle through the pedicle and into the body. The K-wire generally extends 1 to 2 cm distal to the tip of the Jamshidi needle. **B,** Introduction of the tap on the K-wire. **C,** Pedicle screws are advanced on the K-wires. **D,** Subfascial advancement of the rod through the screw-head slots.

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37 Anterior Retroperitoneal Approach to the Lumbar Spine

REX A.W. MARCO

Overview

Anterior lumbar spinal surgery has been performed in various forms for decades.[1-3] Müller[1] described an anterior approach to the lumbar spine as early as 1906, and the anterior approach was later popularized by Hodgson[2] for the treatment of spinal tuberculosis. In 1948, Lane[3] described a transperitoneal approach specifically designed for anterior lumbar diskectomy and fusion. That approach, however, requires opening the peritoneum and mobilizing the bowel. Harmon[4] later described a modification through the retroperitoneum that enables the operator to access the lumbar spine without intentionally violating the peritoneum.

The desire to access the anterior elements of the lumbar spine has increased because of the possibility of improving fusion rates and gaining better sagittal balance with the application of anterior interbody devices. Classically, the retroperitoneal approach is performed through an incision through the abdominal wall. The incision may be paramedian, midline, or Pfannenstiel. Although the Pfannenstiel incision is the most cosmetic, it is nonextensible and is therefore used for single-level access to L5–S1 alone. In recent years, minimally invasive techniques have been developed that have included laparoscopic and mini–open approaches; however, these techniques are technically challenging, and they have not decreased many of the unwanted complications, nor have they consistently provided significant benefits over open techniques. Because of the perceived benefits of the interbody fusion, however, the search for safer techniques to gain access to the anterior vertebral elements continues.

The latest technique gains exposure via a less invasive lateral approach through the retroperitoneal fat and psoas major muscle.[5] This approach, may circumvent some of the potential complications encountered in the anterior transperitoneal approach, such as visceral, vascular, and ureteral injury and sexual dysfunction in males. Additionally, it can be very useful in revision surgery of the upper lumbar spine to avoid previously operated tissue.

This chapter describes the various retroperitoneal approaches to the lumbar spine and its junctions, using both open and minimally invasive surgical (MIS) techniques.

Anatomy Review

Understanding the classic anatomy is the basis for performing these techniques, but that alone is not sufficient preparation. Evaluating the patient-specific anatomy and potential anatomic variants is absolutely critical to performing these techniques safely.

The open anterior surgical dissection is performed through the anterior abdominal wall, which consists of the skin, subcutaneous fat, Scarpa fascia, rectus abdominis muscle, transversalis fascia, and preperitoneal fat. The linea alba is the fascial condensation encountered at the midline, between the left and right rectus abdominis muscles. The lateral musculature, from superficial to deep, includes the external oblique, internal oblique, and transversus abdominis muscles (Fig. 37-1).

The umbilicus is generally located at the L3–L4 disk space; the L4–L5 disk space is often located at the level of the iliac crests (Fig. 37-2). Access to L4–L5 and L5–S1 can be gained through an incision from the umbilicus to the pubic symphysis. Access to the upper lumbar disks requires extending the incision proximal to the umbilicus.

The abdominal vault is encountered deep to the abdominal wall, and it houses the peritoneum and the intraperitoneal contents. Posterior to the peritoneum are the retroperitoneal structures. The aorta generally bifurcates into the common iliac arteries at the L4–L5 disk level and into the inferior vena cava bifurcates at the L5 body level. The vena cava is most commonly posterior and to the right of the aorta, and the iliolumbar vein usually drains into the common iliac vein at the level of the L5 vertebral body. The ascending lumbar vein may be present as a branch off the iliolumbar system or as a separate vein that arises directly off of the common iliac vein.[6] The middle sacral vessels run anteriorly along the lowest lumbar vertebra and the sacrum (Fig. 37-3). It is extremely important to review the patient-specific vascular anatomy to determine whether any variation is present that could preclude a safe surgical approach, specifically when access to the L4–L5 level is required.

The psoas muscles run bilaterally along the lateral borders of the lumbar spine, and the ureters lie on the anterior psoas and cross over the common iliac vessels at the level of the sacroiliac joint. The sympathetic trunk runs along the lateral borders of the lumbar vertebral bodies

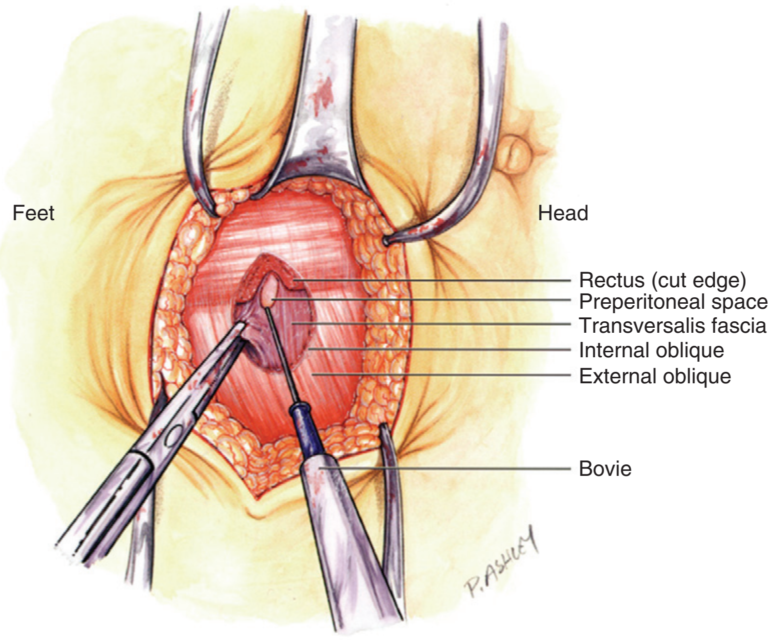

Figure 37-1 Paramedian approach demonstrates the muscular anatomy of the anterior abdomen.

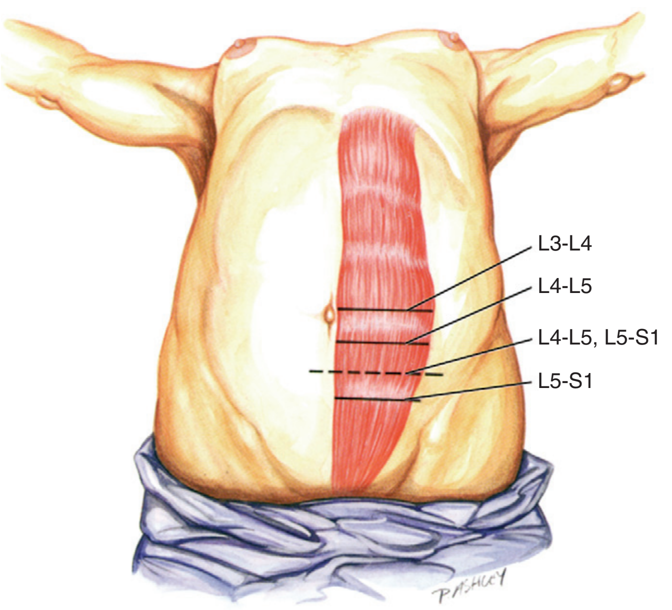

Figure 37-2 Lumbar disk levels with respect to surface anatomy of the abdomen.

(Fig. 37-4), generally located directly on or near the medial origin of the psoas. The sympathetic trunk is often well fixed to the disk by a very dense, fascialike connective tissue layer at L2–L3, L3–L4, and L4–L5 disk levels, and it is slightly separated from the bony surfaces of the vertebral bodies. Caudad, the sympathetic chain commonly runs vertically to pass beneath the common iliac vein and artery.[7] Injury to the sympathetic trunk blocks normal vasoconstriction of the extremity vasculature, which can result in temperature discrepancies in the lower extremities. The extremity on the affected side will feel warmer as a result of unopposed vasodilation. Nursing staff will often report that the contralateral extremity is cold.

The superior hypogastric plexus is an extension of the aortic plexus lying in the extraperitoneal connective tissue anterior to the distal aorta and aortic bifurcation. It usually drapes over the L5–S1 disk space as a "leash" of fibers, but it can be present as a single trunk or as parallel strands.[8] Generally, it is located just left of midline before dividing into left and right hypogastric nerves. This plexus mediates contraction of the internal vesicular sphincter during normal ejaculation. Failure of the vesicular sphincter to contract during ejaculation causes retrograde flow of semen into the bladder, a complication known to occur in up to 20% of anterior cases.[8] Retrograde ejaculation may cause infertility in men who have undergone anterior lumbar surgery.

The cisterna chyli is a dilated sac at the end of the thoracic duct that acts as a conduit for lymph from the intestinal tract and lumbar trunks. It is most commonly located on the anterior aspect of the first and second lumbar vertebral bodies just posterior to the aorta and adjacent to the right crus of the diaphragm.[9] Damage to the cisterna chyli can occur with anterior approaches to the upper lumbar and lower thoracic spine. Traumatic injury to the cisterna chyli or thoracic duct within the abdomen can lead to chyloperitoneum, and an injury at a thoracic level can lead to chylothorax. If injury occurs, conservative treatment should be instituted, such as thoracentesis, bowel rest and/or tube drainage, parenteral nutrition, and a restricted-fat diet. If drainage persists, exploration may be required to ligate ducts. Intraoperative discovery of an injury can be treated with ligation or repair; however, ligation of the ducts can lead to lymphedema of the extremities.

Retroperitoneal access to the lumbar spine from the lateral approach is performed through the lateral abdominal wall (i.e., the external and internal oblique and transversus abdominis musculature), the retroperitoneal fat, and the psoas muscle. The superior edge of the iliac crest limits the potential exposure of the inferior lumbar levels. During

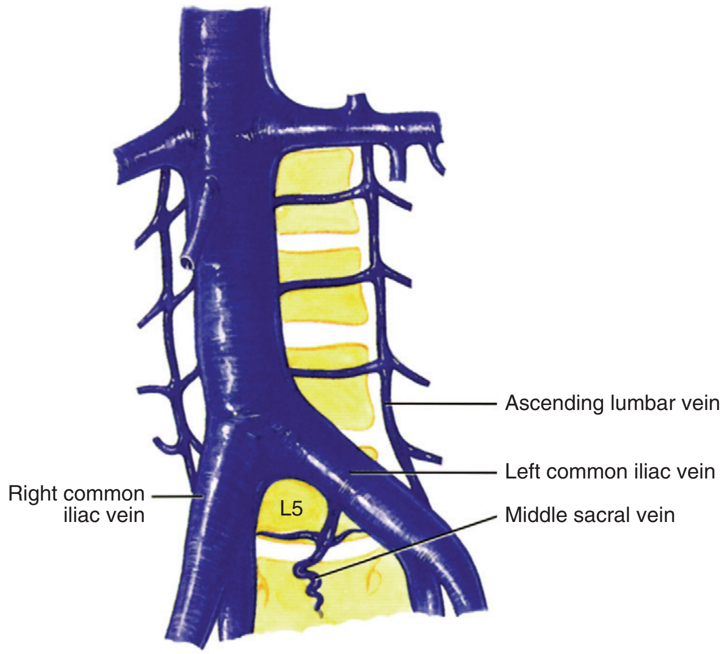

Figure 37-3 Venous anatomy in the lumbar region. The inferior vena cava is shown bifurcating at the level of the L5 body. Ascending lumbar veins are visualized arising from the common iliac veins bilaterally, and the middle sacral vein is shown crossing the L5–S1 disk. (*The iliolumbar vein is not shown.*)

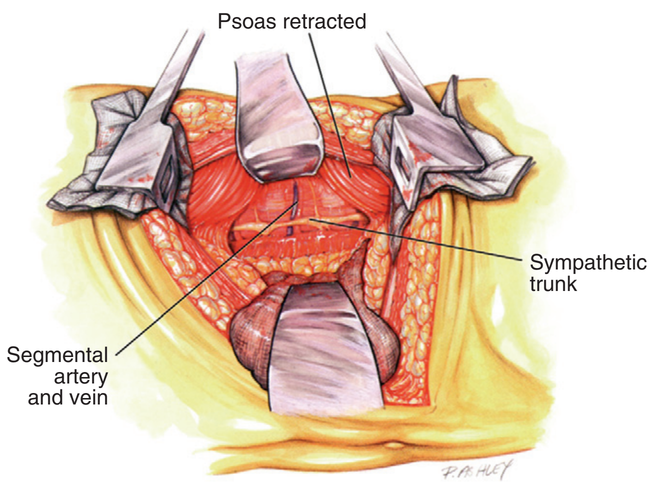

Figure 37-4 Retraction of the psoas allows visualization of the sympathetic trunk on the lateral borders of the lumbar vertebral bodies.

open dissection anterior to the psoas, the surgeon must again be aware of the location of the ureters overlying the psoas and the sympathetic trunk on the lateral borders of the lumbar vertebral bodies.

During the direct lateral approach, the lumbar plexus anatomy must be carefully considered. The anterior rami of the L1–L4 nerves coalesce within the psoas muscle to form this plexus, which gives rise to the iliohypogastric (T12–L1), ilioinguinal (L1), genitofemoral (L1–L2), lateral femoral cutaneous (L2–L3), obturator (L2–L4), and femoral nerves (L2–L4). All but the genitofemoral nerve pass through the posterior portion of the psoas before exiting. The genitofemoral nerve travels within the psoas in a posterior-to-anterior direction between L3 and L4, exiting the anterior aspect of the psoas then traveling along its anterior aspect.[10] Nerve injuries can occur during the transpsoas dissection, leading to significant thigh and groin numbness and weakness of the iliopsoas and quadriceps muscles.

General Indications

- Interbody fusion
- Spondylolisthesis correction
- Pseudarthrosis management
- Deformity correction
- Fracture
- Tumor
- Infection

ANTERIOR APPROACH

- L5–S1 pathology
- L4–L5 more difficult because of the presence of great vessels

THORACOABDOMINAL/FLANK APPROACH

- Extensile approach to thoracic and lumbar spine (may require rib resection and division of diaphragm)
- Good for deformity correction (Lenke 5 curves)
- Prior anterior surgery

DIRECT LATERAL (MINIMALLY INVASIVE) APPROACH

- T12–L5 pathology (can be used for thoracic levels as well)
- Good for adjacent segment syndrome

Contraindications

ANTERIOR APPROACH

- Previous anterior surgery is a relative contraindication, especially at L4–L5.
- Morbid obesity precludes this approach.

THORACOABDOMINAL/FLANK APPROACH

- Prior retroperitoneal surgery is a relative contraindication.

DIRECT LATERAL (MINIMALLY INVASIVE) APPROACH

- High-grade spondylolisthesis
- L5–S1 level pathology
- Prior retroperitoneal surgery

Operative Technique

EQUIPMENT/ASSISTANCE

Anterior Approach

- Access surgeon
- Abdominal retractors
- Radiolucent table
- C-arm fluoroscopy
- Foley catheter
- Kocher clamps
- Richardson retractors
- Deaver retractors
- Crock retractors
- Steinmann pins
- Cobb elevators
- Pituitary rongeurs
- Long-handled scapel
- Angled curettes

Thoracoabdominal/Flank Approach

- Beanbag
- Axillary roll
- Foam padding
- C-arm fluoroscopy
- Access surgeon for thoracoabdominal exposure (if the thoracic cavity is to be entered)
- Rib dissector
- Rib spreader
- Rib cutter
- Chest tube

Direct Lateral (Minimally Invasive) Approach

- Radiolucent table
- C-arm fluoroscopy
- Axillary roll
- Foam padding
- Large Tegaderm dressings (two each)
- Four-inch tape
- Neurophysiologic monitoring (electromyelogram [EMG])
- Cobb elevators
- Pituitary rongeurs
- Long-handled scapel
- Angled curettes
- Rasps

Patient Positioning

ANTERIOR APPROACH (Fig. 37-5)

- Place a Foley catheter.
- Position the patient supine on a radiolucent table.
- Place a roll under the small of the patient's back when going to L5–S1 with a bend in the small of the back near the iliac wings.
- Arms are extended on arm boards in the cross position.
- Trendelenburg position is used, especially for patients with significant pannus.

THORACOABDOMINAL/FLANK AND DIRECT LATERAL APPROACHES (Fig. 37-6)

- The patient is placed in the lateral decubitus position with greater trochanters at the level of the table break.
- Hips and knees are flexed to relax the psoas muscle.

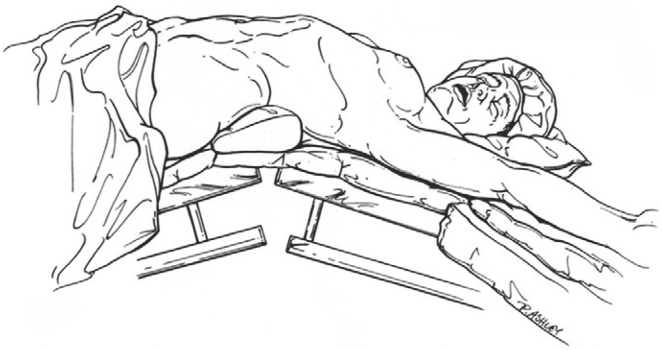

Figure 37-5 Positioning of the patient for access to L5–S1. A roll has been placed in the small of the back, and the table is broken to improve accessibility to the L5–S1 disk.

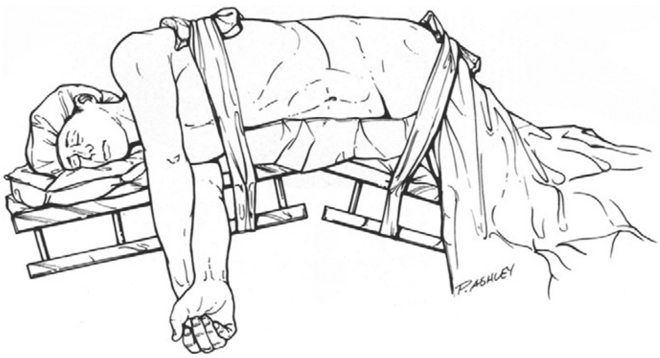

Figure 37-6 Positioning of the patient in the lateral position. The operating table is flexed to increase the distance between the last rib and iliac crest to gain greater access. Perfect lateral positioning is critical when using direct, lateral, minimally invasive approaches.

- The operating table is flexed at the apex of T12 to increase the space between the last rib and the ilium.
- Large Tegaderm dressings are placed over the lateral aspect of the chest wall and axilla and over the greater trochanter to protect the skin. Four-inch tape is then placed across the chest and greater trochanter to secure the patient to the bed in a perfect lateral position.
- Bony prominences and the peroneal nerve are well padded.
- It is absolutely critical that the patient be positioned perfectly lateral; obtaining a perfect anteroposterior (AP) view facilitates perfect lateral positioning.

Dissection

ANTERIOR APPROACH

A general or vascular surgeon is routinely used for the anterior retroperitoneal approach. A surgeon with such training and familiarity with the anterior approach to the lumbar spine can provide the most efficient and safest approach. The access surgeon remains in the case during the remainder of the procedure to assist the spine surgeon, repair any injured structures, and perform meticulous closure of the abdominal wall. This is highly recommended, especially during revision cases.

Either a paramedian or midline approach may be used. For a single-level L5–S1 surgery, the Pfannenstiel approach may be used for better cosmesis. The incision is curvilinear and is placed within the skin crease approximately 1 cm above the pubic symphysis. Care must be taken not to injure the inferior epigastric vessels, which course superiorly between the abdominal wall muscles and the transversalis fascia in a medial-to-lateral direction. We prefer the midline approach, because it is extensible, it creates a central working portal that allows a more uniform diskectomy, and it facilitates placement of the interbody graft in the midline.

The umbilicus is generally located at the L3–L4 disk space. The incision is placed in the midline with reference to the umbilicus. A scapel is used for the skin incision, and electrocautery is used through the subcutaneous tissues. The linea alba is identified and is incised with electrocautery, and Kocher clamps are placed on the fascial borders to assist with elevating the abdominal wall from the underlying peritoneum. The rectus abdominis muscles are retracted laterally, and the peritoneum is visualized within the abdomen. The peritoneum is then gently mobilized by hand, from left to right, to expose the retroperitoneal structures and the lumbosacral spine. For access to the L5–S1 disk, the bifurcations of the great vessels are identified and gently mobilized using peanut sponges. The middle sacral vessels are identified and are either tied off or clipped. Electrocautery is no longer used, because it may cause thermal injury to the nearby superior hypogastric plexus, which may lead to retrograde ejaculation.

Various retractors and techniques may be used to create the working portal. Crock retractors are recommended by some, but our preferred technique uses two Steinmann pins inserted into the lateral L5 vertebral body parallel to the L5–S1 disk space; the pins retract the vessels laterally. Once inserted, Steinmann pins do not need to be held, and retracted tissue cannot slip under the pins, as it can with a handheld retractor. During placement of the pins, extreme caution and control must be maintained to avoid vascular injury. After placement of the pins, a localizing radiograph is taken with C-arm fluoroscopy to confirm the level before diskectomy, after which diskectomy ensues.

The disk space preparation and diskectomy are performed with a scapel, Cobb elevator, pituitary rongeur, and curettes. The interbody is then placed, and radiographs are taken to confirm proper placement. The pins are then removed, and proper hemostasis is confirmed. For access to the L4–L5 disk, dissection proceeds from the lateral aspect of the lumbar spine from the left. The iliolumbar and ascending lumbar vessels are identified and sacrificed; failure to control these vessels can lead to significant hemorrhage that may be difficult to control. Peanut sponges are used, and blunt dissection of the artery is performed from left to right; arteriosclerosis of the vessels may significantly limit the ability to mobilize the vessels and visualize the spine.

Once the L4–L5 disk is identified, a No. 15 blade scapel is used to perform the annulotomy. The diskectomy and placement of the interbody is then performed as previously described. Once the interbody has been placed, the retractors are removed, and the peritoneum is inspected to confirm that it has not been violated. If the peritoneum has been violated, it is repaired with fine absorbable suture to prevent herniation of the bowel through the defect.

When operating on revision cases or infected tissues, the surgeon must consider the degree of scar tissue, and pathologic anatomy can be significant. In cases of diskitis or osteomyelitis, it may be prudent to leave the inflamed tissue and the anterior longitudinal ligament intact. Dissection through this plane may lead to vascular injury, specifically at the L4–L5 level and above, owing to the placement of the iliolumbar and ascending lumbar veins.

THORACOABDOMINAL/FLANK APPROACH

In general, a left-sided approach is made because of the anatomy of the great vessels and the liver. However, preoperative scans must be carefully evaluated to determine whether specific patient anatomy and/or pathology warrant a right-sided approach instead. C-arm fluoroscopy is used to determine the appropriate levels, ensure perfect lateral positioning, and mark out the planned approach before incision. Beginning at the lateral border of the rectus abdominis muscle, an oblique incision is made that extends proximally. If exposure above L1 is required, it may be necessary to resect a rib. In this case, the skin incision is centered over the rib to be resected.

The skin incision is made with a scapel, and electrocautery is used to further the dissection through the subcutaneous tissues. The oblique abdominal musculature is divided with electrocautery, and the preperitoneal fat is identified.

The thoracic dissection proceeds between the ribs, dividing the intercostal musculature as well as the overlying latissimus dorsi muscle if necessary. Care is taken to preserve the neurovascular bundle that runs beneath the ribs. A tenth rib thoracotomy is most commonly used for this approach, and it is useful to split the cartilaginous tip at the distal end of the tenth rib; doing so facilitates the localization of the retroperitoneal plane. The rib is dissected subperiosteally using a rib dissector, and the rib may either be transected or disarticulated; our preferred method is to transect the rib near its base using a rib cutter. The resected rib may subsequently be used as local bone graft if necessary.

The undersurface of the diaphragm and the peritoneum and its contents are then visualized. If access to the thoracic cavity is required, the pleura is divided, and the lung is gently mobilized away from the diaphragm. The diaphragm is divided back to the medial crus, leaving a 2-cm cuff laterally; placing stay sutures in the divided muscle facilitates later repair. Rib spreaders are inserted, and the lung is retracted anteriorly. The ureter overlying the psoas muscle is identified and retracted anteriorly with the peritoneum. Distal exposure is achieved by gently mobilizing the peritoneum anteriorly. The aorta and its bifurcation are identified at L4–L5, and the iliolumbar vein is identified and ligated early if necessary. The ureter overlying the psoas muscle is identified and retracted anteriorly with the peritoneum, and the psoas is retracted to expose the lateral borders of the vertebral bodies, with care taken not to injure the sympathetic trunk.

An intraoperative radiograph confirms the appropriate levels are exposed. The segmental vessels overlying the appropriate vertebral bodies are dissected with a right-angle clamp, tied off, and ligated. Further rib resection may be performed if additional exposure of the vertebral body is required.

At the conclusion of the surgery, the retractors are removed, and the peritoneal cavity and its contents are inspected. Any defects in the peritoneum are closed with fine absorbable suture, and a chest tube is placed if the dissection entered the pleural cavity. The chest tube is placed to 20 cm Hg of continuous wall suction; it can be removed when there is no air leak, and the output is less than 30 to 50 mL per shift.

Injuries to the bowel or ureters require intraoperative consultation with a general surgeon or urologist for proper repair and management. Meticulous closure is then performed in layers.

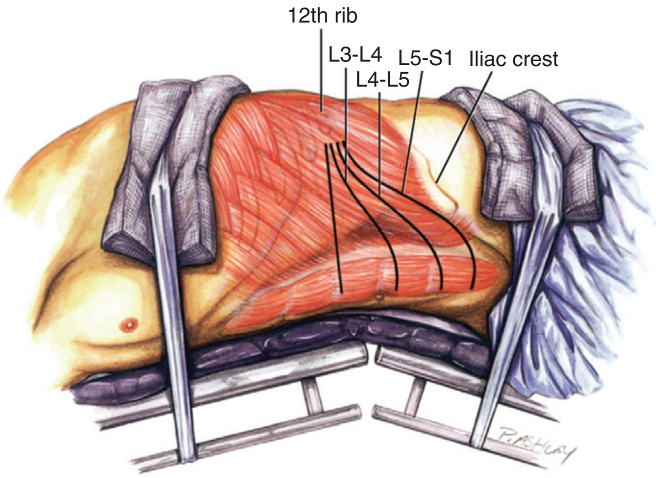

Figure 37-7 Surface anatomy in the lateral position and the corresponding disk levels.

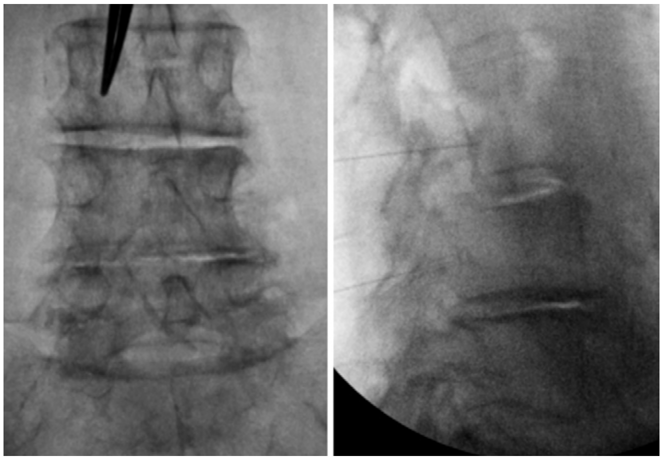

Figure 37-8 Anteroposterior (AP) and lateral views of the lumbar spine demonstrate perpendicular alignment of the end plates (*arrows*) to ensure a true AP view.

DIRECT LATERAL (MINIMALLY INVASIVE) APPROACH

The key to the direct lateral approach is to position the patient perfectly lateral so as to obtain perfect lateral radiographs. Improper positioning and poor radiographs can be misleading and can lead to severe complications, such as neurovascular or visceral injury, which can result in serious morbidities and death. Strict adherence to proper patient positioning to obtain perfect lateral radiographs is absolutely critical.

After induction of anesthesia, the patient is placed on the table in the lateral decubitus position such that the break in the table may be applied to increase the distance between the lowest rib and the iliac crest (Fig. 37-7). The greater trochanters should be at the level of the break in the table. Care must be taken to ensure that the C-arm machine can be mobilized into position to obtain the necessary AP and lateral views. The patient's hips and knees are slightly flexed, the patient is well padded, and an axillary roll is put into position. Large Tegaderm patches are applied to the patient over the greater trochanter and the lateral aspect of the upper thorax to serve as a protective barrier to subsequent taping. The patient is provisionally taped to the bed at the hips, and proper positioning is once again confirmed on fluoroscopy. The vertebral bodies above and below the intervertebral disk of interest are visualized in an AP view first.

Next, the end plates are visualized, and adjustments are made to the bed position relative to the C-arm so that the end plates are perpendicular to the C-arm (Fig. 37-8). Once the perfect AP view has been obtained, the C-arm is rotated 90 degrees to obtain the perfect lateral shot. Placing the bed in varying degrees of Trendelenburg position may be necessary to perfect the lateral view. The patient is then taped in position and firmly secured to the table, and four-inch tape is applied to the lower extremities, starting from the table and going over the greater trochanter down along the padded portion of the lateral thigh, around the undersurface of the table at the level of the patient's feet, back up over the lateral padded calf and knee, and back to the table.

This creates a crossing configuration that secures the pelvis and extremities firmly. The chest is secured with tape placed across the lateral chest just below the axilla.

A 2-cm incision is made with the scapel at the second mark, and the surgeon's finger is inserted anteriorly through the muscles. Blunt dissecting scissors are used to help facilitate entry into the retroperitoneal fat, and the finger is used to sweep the peritoneal contents anteriorly and then to palpate the psoas muscle. The finger is then directed up toward the ceiling, aiming for the mark made for the direct lateral incision. An incision is then made at the direct lateral location, and a dilator is introduced into the direct lateral incision. The dilator is safely guided through the retroperitoneal fat to the psoas muscle using the index finger from the posterolateral incision.

The safe zones with respect to the lumbar plexus as described by Moro and colleagues[10] should be observed. EMG monitoring is used to determine whether safe passage through the psoas muscle can be achieved with respect to the lumbar plexus. If EMG activity is noted below the acceptable threshold (10 mA), the dilator should be repositioned. This is done properly by pulling the dilator back out of the psoas muscle and creating a new starting point, rather than simply translating the dilator within the psoas to an alternate position, which causes traction pressure on the muscle and adjacent nerves and may cause hemorrhage. If multiple attempts to reposition the dilating probe to a safe location are unsuccessful, the technique should be abandoned.

Once an acceptable position has been obtained, the dilator is pinned into place with a K-wire, and additional dilators are placed over the initial dilator to widen the dissection. The insertion depth of the dilators is measured, and the retractor system is then placed into position. Radiographs are taken to confirm appropriate positioning of the retractor over the disk, and the dilating trocars are removed. Using an EMG probe, the tissue at the base of the retractors is then probed to confirm that the nerves are free and clear from the dissection. Once this is confirmed, a No. 15 blade scapel is used to make the annulotomy. The diskectomy is then performed using the Cobbs, curettes, rasps, and rongeurs.

Once the interbody has been placed, and proper positioning has been confirmed on both AP and lateral views, the retractors are slowly removed. Hemostasis is achieved with bipolar electrocautery if necessary.

Postoperative Care

- Early mobilization is beneficial.
- A clear liquid diet is offered until evidence of bowel function returns.
- Intravenous antibiotics are given for 24 hours postoperatively.
- Mechanical deep venous thrombosis prophylaxis is initiated with stockings and pneumatic compression devices.
- Foley use is discontinued once the patient is mobile and bowel function has returned.

Potential Complications

- Vascular
  Veins more often than arteries
  Middle sacral, ascending lumbar, iliolumbar
- Gastrointestinal
  Ileus
  Peritoneum perforation
  Bowel perforation
  Bowel herniation
- Urogenital
  Urotomy/transection of ureter
  Bladder perforation
  Kidney injury
- Respiratory
  Atelectasis
  Pneumothorax
- Lymphatic
  Cisterna chyli/thoracic duct injury
- Neurologic
  Sympathetic trunk
  Lumbar plexus injury
  - Genitofemoral nerve
  - Femoral nerve
- Infectious

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38 Posterior and Posterolateral Approaches to the Lumbar Spine

BRIAN KWON

Overview

The posterior approach is undoubtedly the most utilized approach in all of spine surgery. It remains the workhorse for exposure of the entire spine, from occiput to sacrum, during minimally invasive and deformity operations alike. In the lumbar and thoracic spine, the posterior approach and its variations provide exposure of the anterior vertebral bodies as has been described in tumor,[1] trauma, and deformity surgeries.[2] Thus it is with utmost importance that a spine surgeon develop acumen with the posterior approach.

In the lumbar spine, with the exception of the L5–S1 segment, the likeness of the dorsal elements lends itself to similarities and potential confusion during surgery. Precise marking of laminae and a thorough understanding of dorsal surface anatomy is critical to avoid surgery on unintended levels. This requires intraoperative interpretation of imaging studies and visible anatomic landmarks that have been indelibly marked with a radiolucent marker; adequate planning and study of preoperative imaging is critical at this step.

Good subperiosteal exposure of the spinous processes and laminae is the important next step, but irregularities in the shapes of the dorsal elements can create difficulties of their own. Spondylotic bone, body habitus, and excess bleeding can all obscure visualization. Exposure for a direct midline or paramedian approach requires differing entry points and muscle planes. Also, whether intertransverse process fusion technique will be used dictates the amount of lateral muscle stripping required.

Finally, wound closure is perhaps as important, if not more so, than exposure. Because of the dorsal skin incision, often close to the perineum, watertight wound closure remains a critical yet sometimes overlooked last step of posterior spinal surgery. Although few complications occur as a result of the posterior exposure per se, it is assumed that some infections and wound dehiscence occur because of poor exposure and closure.

Anatomy

The dorsal skin anatomy is straightforward, and skin incisions can be planned according to surface landmarks (Fig. 38-1). Midline can easily be palpated, even in obese patients, using spinous processes (SPs). In the extremely obese, the thoracic SP or the sacrum/coccyx can be palpated. If using the paramedian approach, the recommendation is two fingerbreadths, or 2.5 to 3.0 cm, lateral to midline. The dorsoventral landmarks become more difficult, especially in obese patients. The iliac crests typically localize to L4–L5, although body habitus will often skew this landmark cephalad and will direct a surgeon toward L3–L4 (Fig. 38-2). If any concern exists, I use the inner bore of a 20-gauge spinal needle and localize using a lateral radiograph (Fig. 38-3).

Deep to the skin, the relevant anatomy includes subcutaneous fat, the Scarpa layer, and fascia. The Scarpa layer should be preserved with the intent to use it as an added layer during closure. Note that once the lumbodorsal fascia is reached, the perforating vessels will emerge. Midline should be easily palpable using SPs and the supraspinous ligament (Fig. 38-4). The paraspinal muscles—the multifidus, longissimus, and iliocostalis—occupy the space flanking the SPs and laminae and extend to the transverse processes (TPs; Fig. 38-5).

Short *intersegmental muscles,* the interspinalis and intertransversarii medialis, originate at a caudal vertebra and insert on the adjacent vertebra. The short *polysegmental muscles,* the multifidus and lumbar erector spinae, span two to five vertebral levels. The multifidus is the most medial and is also the largest of the paraspinal muscles. Lateral to the multifidus lies the lumbar erector spinae, made up of the longissimus and the iliocostalis lumborum. Each muscle has thoracic and lumbar fascicles that originate on the mamillary and transverse processes and insert on the medial aspect of the posterior superior iliac spine.

The Wiltse paraspinal approach exploits the interval between the multifidus and longissimus. This plane can be palpated after the lumbodorsal fascia is split, and segmental vascular and neural structures are often encountered here. The segmental dorsal ramus must be found and followed into the foramen of interest (Fig. 38-6), but note that it branches directly off the exiting nerve root, so it should be handled gently.

The relevant bony anatomy includes the SP, lamina, facet joint, and TP. Good subperiosteal dissection requires thorough understanding of the irregularities in lumbar anatomy. This includes understanding the depth and location of interspaces and the spatial relationships in between. From the perspective of the surgeon, the laminae will be found slightly cephalad in relation to the SP (Fig. 38-7). More cephalad and lateral on the lamina, the pars interarticularis and then the facet joint are encountered. Especially when using cautery, keep in mind that direct ventral

Figure 38-1 Dorsal view of back with drawing of spine and pelvis.

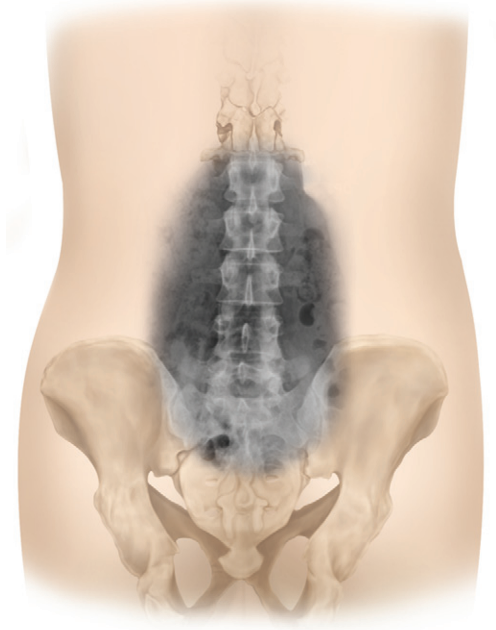

Figure 38-2 Anteroposterior radiograph with soft tissue drawn on the outside.

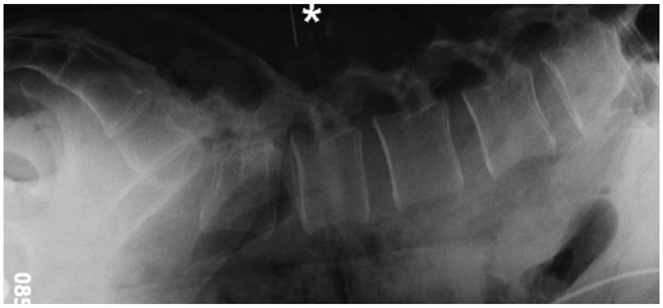

Figure 38-3 Radiograph of a spinal needle (*asterisk*).

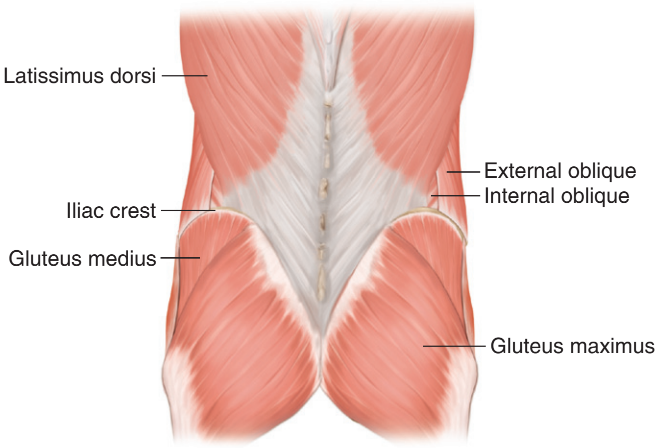

Figure 38-4 Midline structures of the lumbar spine.

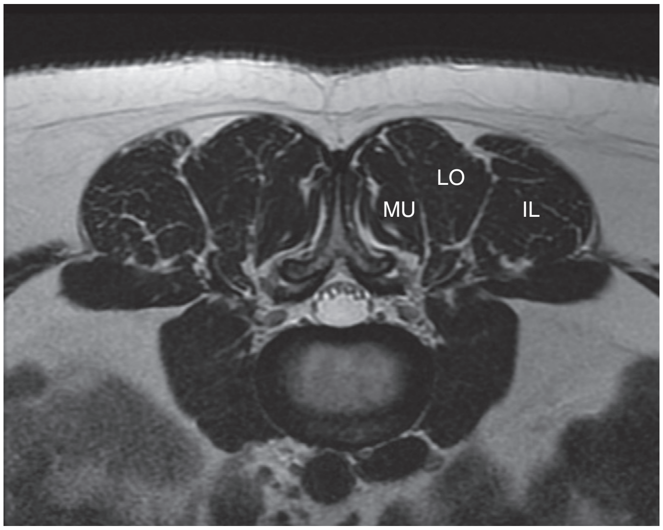

Figure 38-5 Magnetic resonance image (MRI) shows paraspinal muscles. *IL,* Iliocostalis; *LO,* longissimus; *MU,* multifidus.

dissection caudal to the lamina may lead to violation of the interspace, particularly at the lumbosacral junction at L5–S1. The facet joint capsules must be preserved, unless a fusion at that level is planned. A clear plane of attachment of paraspinal muscles on the facet capsules can be effectively dissected (Fig. 38-8). Coursing laterally, the accessory process—a typical pedicle screw entry point—is still seen, which then leads directly to the TP. Lateral dissection of the musculature out to the tips of the TPs then creates the posterior gutter for graft placement. The intertransverse membrane attaches from one TP to the next and should not be violated; it supports the fusion bed (Fig. 38-9).

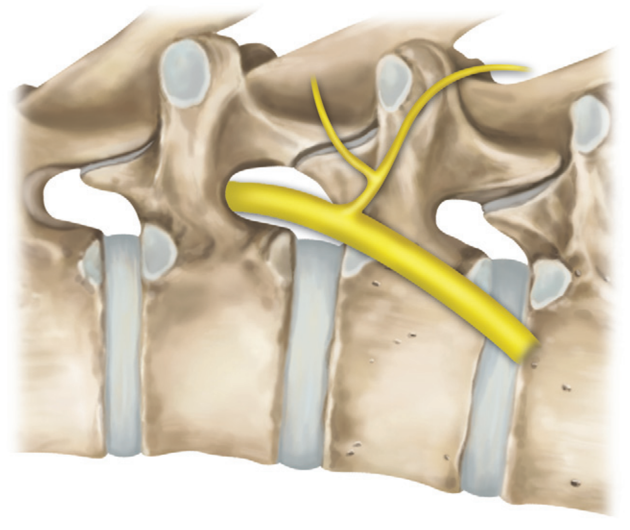

Figure 38-6 Lateral view into the foramen shows the dorsal ramus of a nerve root branching off just after the nerve root exits.

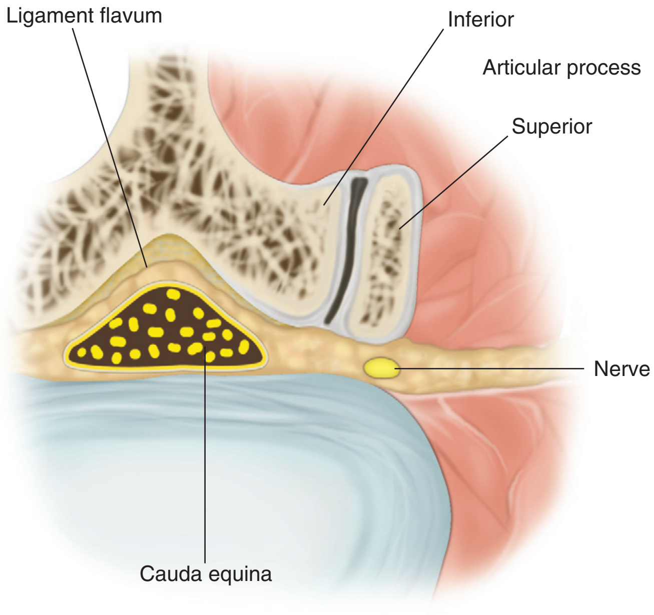

Figure 38-8 Facet capsule and overlying muscles *(asterisk)*.

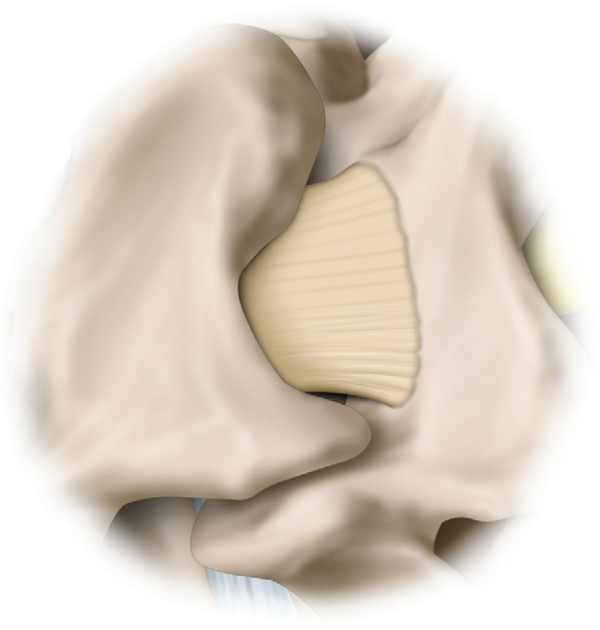

Figure 38-7 Bird's-eye view onto the spinous process and lamina.

Indications/Contraindications

INDICATIONS

- Posterior surgery (diskectomy/laminectomy, posterior fusion, posterior interbody fusion)
- Symptomatic radiculopathy from disk herniation (paracentral and far lateral) or spinal stenosis
- Instability as a result of spondylolisthesis, trauma, or tumor

CONTRAINDICATIONS

- Active infection of a dorsal compartment on or near operative site
- Previous or planned radiation therapy

Patient Positioning

- Patients are positioned prone using a variety of tables and padding options.
- The key components include maximizing equal weight distribution, minimizing abdominal compression, and ensuring face and eye protection.
- The surgeon must be keenly aware of the pitfalls of the prolonged prone position. Skin breakdown, facial and airway swelling, and muscle injury (myositis) are all possible complications, and all patients should be positioned with these issues in mind.
- For decompression procedures, reducing lordosis by placing patients in a knee-chest position and placing the hips into flexion will aid in opening interspaces (Fig. 38-10).
- If fusion is considered or planned, the hips and legs should be extended to achieve lordosis in the lumbar spine (Fig. 38-11).
- The abdomen and male genitalia should be checked to ensure they are free from compression.
- The chest is a major weight-bearing location. Ensure that no compression is placed on the anterior neck, particularly with large-breasted women. Proper chest positioning will also aid in positioning the patient's arms, which should be well padded. Upper extremity brachial plexus injuries have been reported and observed at one institution.[3]
- Head positioning is critical and should be a coordinated effort between surgical and anesthesia teams. Skin

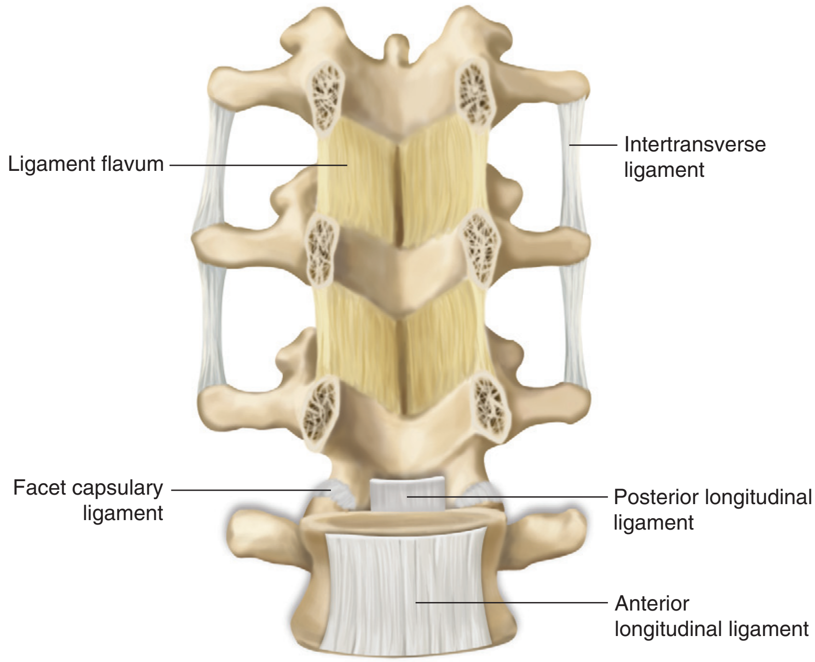

Figure 38-9 Intertransverse ligament of the lumbar spine.

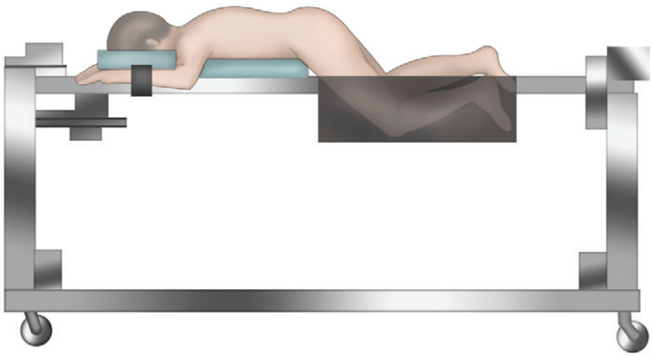

Figure 38-10 Jackson table with sling to minimize lumbar lordosis during decompression procedures.

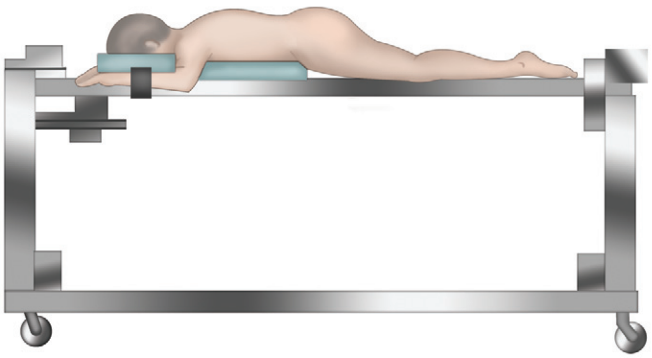

Figure 38-11 Jackson table with flat plate extends hips, which restores lumbar lordosis for fusion procedures.

breakdown on the forehead, chin, and nose is disfiguring and alarming to patients. Although most such injuries heal uneventfully, the tip of the nose may not.[4]

- Postoperative blindness is devastating and should be safeguarded against at all costs, particularly if long operative times are anticipated. Several reports list prone head position as a risk factor.[5]

Operative Technique

- The standard technique of exposure can be modified to surgeon and institutional preferences.
- For minimally invasive operations, preincision imaging can be helpful (see Fig. 38-3).
- A preincision "time-out" should be performed in which the correct procedure, site and side, patient, and imaging studies are examined and confirmed by the surgical team.[6]
- A subcutaneous injection of dilute epinephrine before incision is helpful. Once the skin incision has been made, careful dissection using cautery is recommended for hemostasis, particularly of the subdermal vascular layer.
- Dissection should be meticulous, and hemostasis should be a priority. Bleeding skin edges and perforating vessels can contribute to significant blood loss that will obscure the surgical field throughout the case.
- Create a deliberate incision through the layer of Scarpa fascia to aid in closure.
- The lumbodorsal fascia can be split on either side or in the middle of the SPs, where the supraspinous ligament is encountered.
- The paraspinal muscles can then be dissected off the SP, lamina, and pars interarticularis.

- For decompression alone, the pars interarticularis is the critical landmark to visualize to ensure that overzealous pars resection does not occur.
- If the procedure is a lumbar fusion, dissection should continue laterally and ventrally until TPs and the intertransverse membrane are exposed.
- Once exposure is completed, the next critical step for the surgeon is to confirm the levels to be operated on; with the exception of L5–S1, every other vertebral segment looks similar, if not identical.
- Appropriate marking of levels is critical.
- Several landmarks—SP, lamina, TP—and marking tools can be used.
- The next critical step is radiographic confirmation. The surgeon must verify that the landmark used has been securely marked and that the image confirms that location and level.
- Most pitfalls occur during translation of the image back into the anatomic location and levels marked.
- Once confirmed, the landmark should be indelibly marked.[6]
- Spine surgery performed at unintended levels has been a visible complication in today's medicolegal environment. It is considered avoidable and almost entirely the surgeon's responsibility.

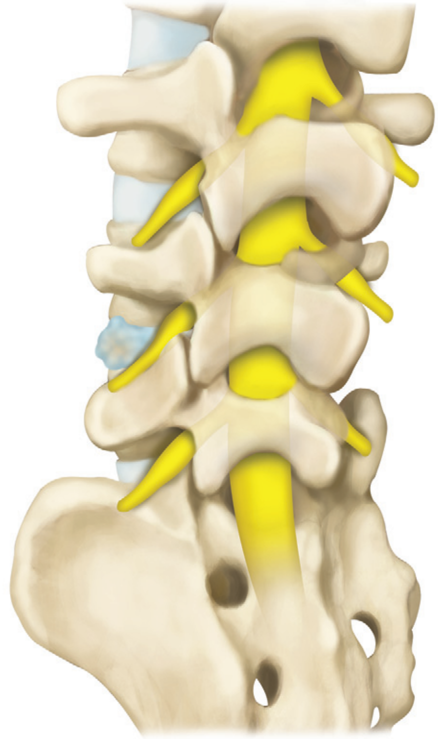

Figure 38-12 Oblique look at disk space shows location of far-lateral disk herniation.

WILTSE'S APPROACH

- Dr. Leon Wiltse described the posterolateral muscle-splitting approach in 1963.
- Its most common indication is far-lateral disk and nerve root decompression.
- The approach exploits the plane between the multifidus and longissimus muscles.
- It avoids detachment of midline structures and disruption of the supraspinous and interspinous ligaments, and it allows for easy access to the lateral and posterolateral compartments of the lumbar spine.
- The skin incision recommended is 2.5 to 3.0 cm lateral to midline.
- The lumbodorsal fascia is split longitudinally; typically, this plane is easier to palpate than to visualize.
- Blunt dissection easily finds the facet joint, which then leads to the TP.
- Retractors can be placed here, and the level can be marked using the TP or facet joint as a point of reference.
- To find the disk, the caudal TP, such as the L5 TP for far-lateral L4–L5 herniated nucleus pulposus, should be used as an anatomic landmark (Fig. 38-12). This will then mark the dorsoventral location of the intertransverse membrane.
- Coursing cephalad the facet joint, the pars interarticularis is encountered.
- At this point, the dorsal ramus should be found and dissected (see Fig. 38-6).
- The intertransverse membrane can be dissected free from surrounding bony attachments.
- Because of the proximity of the venous plexus, blunt dissection and bipolar cautery should be used.
- The facet joint and pars interarticularis will be removed from the lateral aspect to get access medially into the disk and canal.
- The far-lateral herniation is encountered cephalad to the pedicle and should be decompressed as far cephalad as the nerve root to ensure no free fragments or cephalad compression remains.
- Care must be taken not to injure the dorsal root ganglion.

ANTERIOR COLUMN SURGERY

In the lumbar spine, access to the vertebral bodies has been described for use in trauma, tumor, and deformity surgery (Fig. 38-13). Tomita[1] described an all-posterior vertebral body resection technique. The salient steps include removal of all dorsal elements, including pedicles, followed by careful dissection ventrally along lateral vertebral body walls until circumferential release has been performed. Similar dissection technique is used during trauma and deformity surgery.

Typically, dorsal elements are removed, leaving the pedicles (Fig. 38-14). Excellent dissection and isolation of both nerve roots and cephalad and caudal disks is imperative. The lateral pedicle walls are a useful guide to finding the lateral vertebral body wall, where blunt dissection can be used to separate soft-tissue attachments from bone. Maintaining hemostasis is critical, because much of the bony work that follows can lead to brisk blood loss. Removal of vertebral bodies requires release from disks and soft tissues. The thecal sac and nerve roots should be carefully retracted to remove the vertebral body, either whole or in fragments. Reconstruction is done based on indication and patient needs.

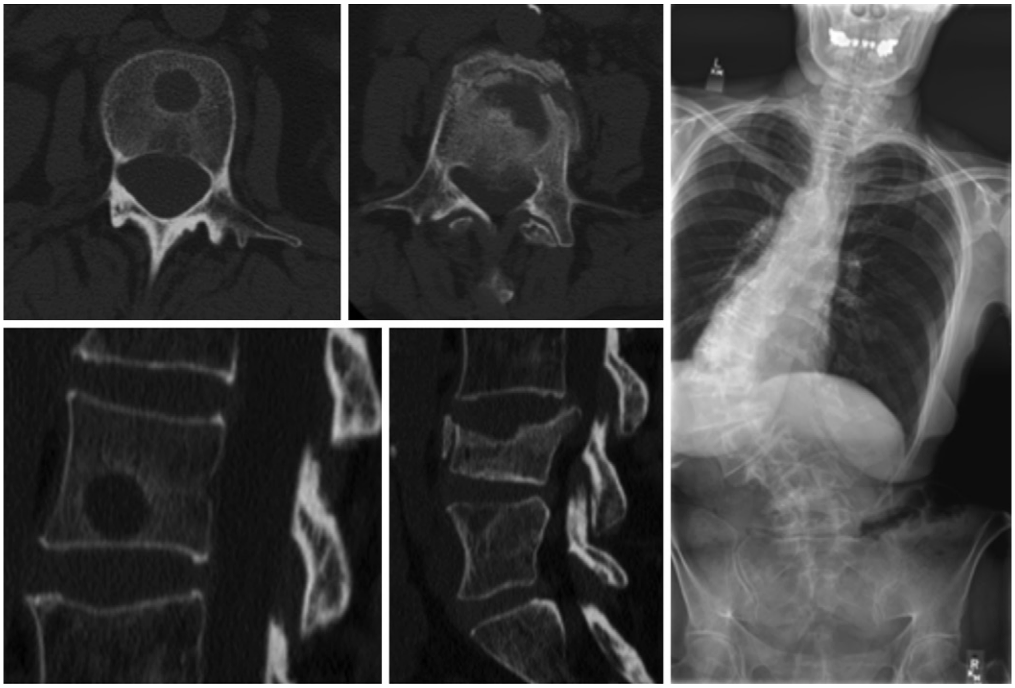

Figure 38-13 Images of tumor, trauma, and deformity.

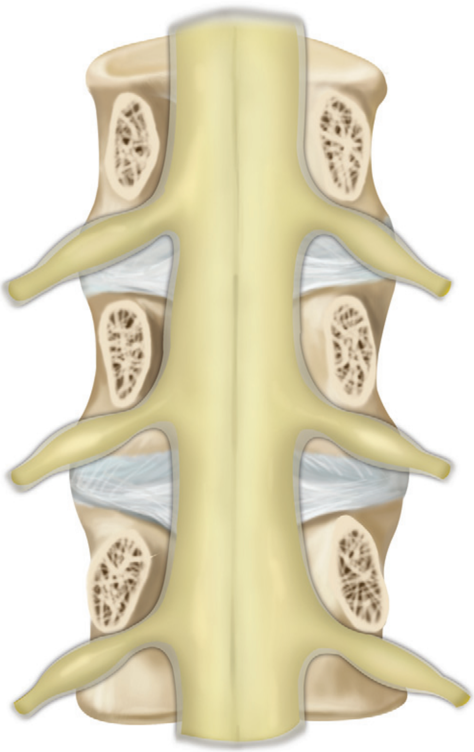

Figure 38-14 Pedicles with posterior elements removed.

SPECIAL CONSIDERATIONS AT L5–S1

- The lumbosacral junction has several special considerations that include a wide interspace, transitional vertebrae, and spina bifida occulta.
- The wide interspace will be encountered more often in younger patients with tall, well-hydrated disks.
- At risk here is the thecal sac, which can be injured during dissection and may lead to persistent cerebrospinal fluid (CSF) injury.
- Transitional vertebrae are seen in up to 36% of individuals, and 6% have six lumbar vertebrae. This can lead to a miscount to the right vertebral level for surgery.[7]
- It may be necessary to have a radiologist review magnetic resonance imaging and radiographic images preoperatively and confirm intraoperative marking images.
- Although uncommon, spina bifida occulta should be considered on every preoperative posteroanterior image to prevent thecal sac injury during routine dissection at or near the lumbosacral junction.

Closure

- Although developing acumen with posterior exposure of the spine is critical, wound closure is perhaps as important.
- The dorsal incision remains in a precarious position in the postoperative patient.
- A prolonged supine position demands the patient lie on the incision, which leads to inevitable perspiration and maceration of wound edges.
- The caudal edge of the lumbar incision is, by definition, near the perineum, where toileting and hygiene must be considered.
- In postlaminectomy cases, a subfascial drain can be used.
- No definite evidence suggests that postoperative drainage improves wound healing or minimizes hematoma formation or blood loss, although this makes sense intuitively.[8]
- The lumbar fascia is considered the primary mechanical and physical barrier to ingress and egress of fluid from the operative site.

- Watertight closure of lumbar fascia is paramount. I close the cephalad and caudal extents of the wound first to ensure those extreme ends close tightly.
- Once the lumbodorsal fascia has been closed, copious irrigation should be used once more to make certain skin flora is irrigated out of the surgical site.
- The Scarpa fascia is identified during exposure, typically as a robust and distinct layer that can be closed much the same as any other fascial layer. It provides one more barrier but adds little extra time to wound closure.
- Finally, skin closure and adequate dressing material complete the surgical dissection and the procedure.

Complications

Few complications are directly attributable or unique to the posterior approach, but they include excessive blood loss, infection, epidural hematoma, wrong-level surgery, and blindness. In addition, excessive blood loss can occur from posterior surgery at every step from exposure to closure. The major vascular contributions come from the subdermal vascular plexus, perforating segmental arteries, muscle, bone, and epidural venous plexus. Careful attention to vascular structures and meticulous hemostasis is necessary.

Wound infection from posterior surgery has an incidence of 1.0% to 12.0%. Operative factors include prolonged blood loss, long operative times, and revision surgery. Patient factors include obesity, smoking status, diabetes, and immune status.[9] Both types of factors can sometimes be controlled to a small degree, but many times they cannot. Treatment for wound infections often involves serial débridement followed by closure. Mok and colleagues[10] analyzed clinical outcomes using the SF-36 Physical Component Score (PCS) in patients who developed deep wound infection after instrumented lumbar fusion and were treated immediately with irrigation and débridement. If the infection was acute, the hardware was maintained. Outcome in infected patients was compared with those of a matched cohort, and no significant differences in PCS were found.

Epidural hematoma in the postoperative patient is a common radiologic finding. Cauda equina syndrome (CES) has an incidence of 1 to 2 per 1000 surgeries, yet because of its devastating sequelae, careful attention must be paid to patients' complaints. Sokolowski and colleagues[11] prospectively obtained preoperative and immediate postoperative MRI on 50 patients and found 58% showed epidural hematoma that caused thecal sac compression beyond its preoperative measurements. None had evidence of CES. Additionally, the hematoma extended to an average of 1.9 levels when 1.4 levels on average were operated on. Significant factors included age older than 60 years, multilevel surgery, and abnormal international normalized ratio values.

Wrong-level surgery has become visible since the Institute of Medicine published their landmark work "To Err Is Human: Building a Safer Health System." Since then, U.S. spine societies have adopted guidelines to avoid wrong-level surgery, the incidence of which may be as high as 8%; in a recent surgeon's survey, 50% of all respondents reported performing or nearly performing a wrong-site operation. The prevalence was estimated to be 1 in 3110 surgeries, and 17% led to legal action or monetary settlement to the patient.[6]

Postoperative visual loss (POVL) is a devastating injury that occurs at an incidence no higher than 1 per 1000. The differential diagnosis includes ischemic optic neuropathy (ION), central retinal artery occlusion, and cortical blindness. ION is most often associated with prone positioning. Risk factors include male gender, surgery longer than 5 hours, and blood loss greater than 1 L. Urgent ophthalmologic examination is necessary to differentiate ION from other forms of POVL. Blindness is often permanent.[5]

Conclusion

The posterior approach is the most utilitarian and necessary approach used in spinal surgery. Good technical execution of the approach is necessary for all spine surgeons, and a thorough understanding of both bony and soft-tissue anatomy is necessary to perform it well. Good prone positioning protects the patient and makes decompression more effective, and thorough care and attention should be paid to the marking process to ensure that surgery is performed at the correct site and side. With repetition and attention, the technique will become routine, and ultimate comfort with the approach can be achieved.

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39 Surgical Approaches to Lumbar Fractures

TIFFANY GRACE PERRY, JENNIFER ORNING, and SIVAKUMAR JAIKUMAR

Overview

Because of the biomechanical features of the region, the most common site of injury in the lower spine is the thoracolumbar junction. The thoracic spine is stabilized by the rib cage, which results in a transition point at T12–L1. The lumbar spine also transitions from the kyphotic thoracic spine to the lordotic lower lumbar spine, which increases the potential stress on the upper lumbar region. Fractures of the lower lumbar spine are less common because of the significant size of the vertebral bodies.

The most common cause of spinal cord injury in the United States is motor vehicle accidents, which account for about 40%, and the second most common is falls, which represent another 28%. Other causes include violence and sports-related injuries.[1,2] Traumatic fractures of the lumbar spine can result in a spectrum of neurologic injuries, presenting with no symptoms at all or with complete bilateral lower extremity paraplegia with loss of bowel and bladder function. The extent of the injury—including the radiographic features, neurologic symptoms, and the acuity of the fracture—all contribute to the management of the fracture.

Classification of Lumbar Fractures

Fractures of the spine may be labeled as either *stable* or *unstable.* In 1970, Holdsworth[3] introduced the *two-column model* that comprises an anterior and a posterior column. The *anterior column* is composed of the anterior longitudinal ligament (ALL), vertebral body, and posterior longitudinal ligament (PLL); the *posterior column* is composed of the laminae, transverse processes, spinous process, and interspinous ligament (ISL). Violation of both columns denotes instability.

In 1983, Denis proposed the *three-column model,* which comprises an anterior, middle, and posterior column.[4] The *anterior column* is the ALL and anterior two thirds of the vertebral body and disk; the *middle column* is the PLL and posterior third of the vertebral body and disk. The *posterior column* includes the pedicles, laminae, spinous process, ISL, facets, and transverse processes. A fracture is considered unstable when two of the three columns have been violated.

Types of Fractures

A *compression fracture* usually involves an axial load, sometimes with a flexion component that causes violation of the anterior column. It may extend into the middle column but usually does not violate the posterior cortex of the vertebral body.[5] These fractures are commonly managed nonoperatively and may or may not require external orthosis.

A *burst fracture* also usually involves an axial load with resultant compromise of the anterior and middle columns. These may be managed nonoperatively, or they may require surgical intervention for stabilization.

A *Chance fracture* is a complex fracture that involves a flexion component of injury in the anterior column with an associated distraction injury in the middle and posterior columns.[5] The fracture may extend through the bony vertebral body or through the disk anteriorly and through the lamina or the facets posteriorly. Chance fractures are destabilizing injuries that usually require operative intervention.

A fracture-dislocation is a high-energy injury to the spine that involves not only violation of all three columns with associated ligamentous injury but also a translation or dislocation of the fractured parts. These fractures are most commonly associated with spinal cord or nerve root injury and therefore require operative stabilization.[5]

Radiographic Evaluation of Fractures

Plain radiographs are less likely to be the modality used to initially evaluate a fracture, given the availability of computerized tomography (CT) in the setting of trauma. A set of anteroposterior (AP) and lateral radiographs gives the surgeon the opportunity to better assess a fracture with respect to the coronal and sagittal curvature of the spine. The posterior elements, including the pedicles and lamina, are more difficult to assess on plain radiographs. However, vertebral body abnormalities, such as compression fractures, may be readily noticed on plain radiographs, and consideration of the overall anatomic relationships in the spine can be obtained from three-foot standing or lateral/AP films. Neglecting to evaluate preoperative and postoperative alignment can lead to postoperative complications in the long term (Figs. 39-1 and 39-2).

Figure 39-1 Plain anteroposterior radiograph of an L1 burst fracture, with fracture through the right pedicle.

Figure 39-3 Sagittal computed tomography of an L3 vertically oriented burst fracture with retropulsion of bony elements into the canal.

Figure 39-2 Plain lateral radiograph of an L1 burst fracture.

Figure 39-4 Axial computed tomography of L3 burst fracture with the fracture extending into the right pedicle.

CT is a better modality to evaluate the fine cuts of the fractures and the anatomic parts of the affected vertebrae. It also can help assess the extent to which retropulsion, listhesis, or violation of the pedicles and facets has occurred. The CT axial cuts are reconstructed to sagittal and coronal orientations to enable the surgeon to evaluate all three planes of the fracture (Figs. 39-3 and 39-4).[5]

Magnetic resonance imaging (MRI) is also frequently used to assess injury to the soft-tissue structures, such as the nerve roots, thecal sac, and ligaments. The T2-weighted fast spin-echo (TSE) and fluid-attenuated inversion recovery (FLAIR) images are used to assess vertebral body marrow edema. The gradient-echo T2-weighted sequence can best outline the vertebral body, ligamentous (ALL, PLL, ISL), and thecal sac anatomy.[5] MRI is the most useful modality to examine the extent of the injury to the nerve roots (foraminal stenosis), ligamentous injury (ALL, PLL, ISL), and facet and disk joint violation. If an MRI were to show extensive ligamentous injury, the threshold for operative intervention might be lowered.

CT is better utilized to evaluate the bony fracture itself, including extent of canal compromise, violation of the vertebral elements, and often the mechanism of injury (compression, distraction, dislocation; Fig. 39-5).

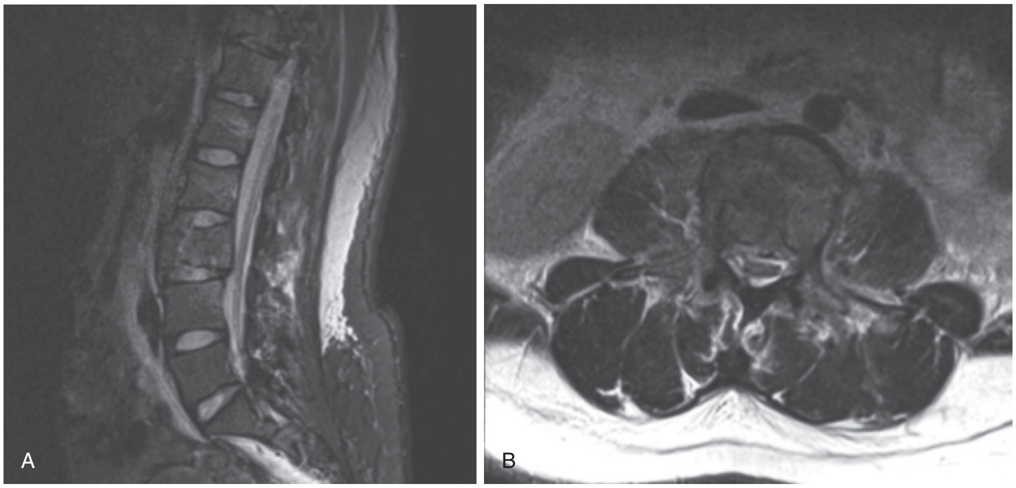

Figure 39-5 Magnetic resonance imaging of the lumbar spine depicting an L3 burst fracture with some impingement on the thecal sac in the sagittal (**A**) and axial (**B**) planes.

Indications for Surgery

NEUROLOGIC INJURY

Acute lumbar fractures with associated neurologic deficits in the setting of spinal trauma are usually indications for urgent surgical intervention. In the lumbar spine, the deficits with which the patient might present depend on the level and extent of the fracture. The conus medullaris could be injured at the upper lumbar levels (L1 and L2). The cauda equina centrally and nerve roots at the neural foramen may be injured, which is a concern for fractures below the level of L3. A thorough neurologic examination is pertinent to assess the urgency of surgical intervention.

In 1992, the American Spinal Injury Association (ASIA) introduced a universal classification system for spinal cord injury to aid in assessment and definition of extent of injury. If the patient has a *complete* spinal cord injury (ASIA class A), defined as no motor or sensory function below the level of the injury, operative intervention might be considered on a less emergent basis, because the prognosis for a complete injury is dismal. The ASIA scale is used not only for the initial trauma assessment of spinal cord injury, but also in the follow-up of patients after medical or surgical intervention.[6]

RADIOGRAPHIC ANALYSIS

Another indication for operative stabilization is an unstable fracture assessed as such by radiographic evaluation. The extent of canal compromise on computed tomography (CT) or MRI is more important in the cervical and thoracic spine than in the lumbar spine with respect to the extent of neurologic injury.[7] The amount of compression of the vertebral body and focal kyphotic angulation are not necessarily indicative of posterior ligamentous complex instability in the thoracolumbar region.[8] CT is the best modality to evaluate the extent of bony injury to the anatomic columns; the axial cuts are beneficial to measure the width and length of the pedicle screws to be used in preparation for surgical stabilization. The ligamentous injury and canal compromise evaluated on MRI may also help in the decision-making process for surgery.

Evaluation for Surgical Approach

In trauma, several considerations weigh into the decision as to which surgical approach to use. A patient with a lower body mass index is easier in general for positioning prone, lateral, or anterior. Operative positioning can be affected by other injuries, such as an open abdomen from exploratory laparotomy, external fixation devices on upper and lower extremities, and pulmonary injuries from trauma.

Positioning patients for anterior approaches is easiest and safest in the setting of trauma with an unstable spine injury. However, anterior approaches are commonly used as adjuncts for stabilization rather than as the sole or primary approach. Posterior approaches involve prone positioning, usually on a Wilson frame or Jackson table.

Sometimes other injuries associated with the trauma make positioning challenging. Associated hip, pelvic, or long bone injuries to the upper or lower extremities may also add a confounding variable to positioning.

Patients who have undergone prior spine surgeries may require special consideration in operative preparation. Someone who has existing instrumentation might require removal of the hardware or extension of the construct. These factors all play an important role in the decision-making process for surgical approaches in the setting of management of spine trauma.

APPROACH SURGEON

When considering anterior approaches to the lumbar or sacral spine, many surgeons will consider using a vascular or general surgeon as an “approach surgeon” to assist with navigating areas familiar to those specialties. One of the complications that can occur with these approaches is damage to the lower aorta, common iliac vessels, inferior vena cava (IVC), iliolumbar vein, or middle sacral artery.[9] The aortic bifurcation is usually at the L4 vertebral level, but this can vary with sacralization of the L5 vertebral body or with lumbarization of S1. Overall, 67% to 84% of patients in some studies had the standard level of bifurcation.[10] The level of the IVC formation and relation of the great vessels to the vertebral bodies themselves can also vary.[11] Venous injuries are reported from 2.9% to 15.6% of cases, and arterial injuries are even less common.[12,13] Such vessel injuries may be more common when the patient has had prior abdominal or vascular surgery and in the presence of osteomyelitis, spondylolisthesis, or anterior osteophyte formation. Careful preoperative imaging and preparation is necessary to minimize the risk of vascular injury.

Injury to the retroperitoneal and extraperitoneal organs can also be a cause of significant postoperative morbidity. Bowel and bladder injury are known but uncommon complications of anterior approaches.[13,14] Damage to the sympathetic plexus can also lead to retrograde ejaculation, possibly increased with transperitoneal versus retroperitoneal approaches.[15]

Because of these multiple considerations, it can be helpful to the spine surgeon to have another surgeon access the abdomen. However, the literature varies on the short- and long-term morbidity and mortality difference when comparing approaches with and without an approach surgeon.[16] Many studies show similar results in the hands of spine surgeons, as long as they are experienced.[17-19]

Adjuncts to Surgical Intervention

FLUOROSCOPY AND SPINAL NAVIGATION

In addition to neurologic monitoring and appropriate preoperative and postoperative imaging, intraoperative navigation has been noted as an emerging and ever more useful tool. The option to use anatomic landmarks and operative anatomy still exists and offers advantages of reduced radiation exposure, lower costs for the institution and surgeon, and possible reduced operative times. Recently, three-dimensional (3D) fluoroscopy and intraoperative CT (iCT) have been discovered as beneficial adjuncts to spinal surgery and instrumentation. 3D fluoroscopy is reportedly more accurate than the two-dimensional (2D) imaging of the past.[20] In addition, many studies indicate that iCT is useful in appropriate pedicle screw placement over 2D and 3D fluoroscopy,[21] especially in abnormal spine configurations, such as after trauma and with lumbar fractures.[22] Some analyses have yielded lower complication rates with navigation, although they also report possible increased utility in the thoracic compared with the lumbar spine.[23]

NEUROMONITORING

Somatosensory-evoked potentials (SSEPs), motor-evoked potentials (MEPs), and electromyography (EMG) may also be used in the surgical approach to the upper lumbar spine rostral to the cauda equina. The utility of SSEPs to monitor the cauda equina and nerve roots during the placement of posterior instrumentation remains controversial.[24] Below L2, the surgeon might opt to only use SSEPs and EMG during the procedure. If MEPs are monitored, anesthesia will not be able to use paralytics; this can make the muscular dissection difficult, especially in larger patients.

Surgical Approaches for Location of Injury

UPPER LUMBAR FRACTURES: L1, L2, AND L3

Posterior Approach

Upper lumbar fractures of L1 and L2 may be stabilized from a posterior approach alone with the use of pedicle screw fixation. In the setting of an unstable fracture with preservation of vertebral body anatomy and spinal alignment, one option is to stabilize the spine posteriorly with instrumentation, allowing the fractured vertebral body to heal over time. If the patient fails either with subsequent kyphotic deformity or nonunion, a lateral approach may be used in the future.

Baseline neuromonitoring signals are obtained in the supine position. The patient is positioned prone on the Wilson frame or Jackson table with hip pads, thigh pads, and a leg board for the feet. All pressure points are padded, and prone neuromonitoring potentials are obtained. Fluoroscopy or intraoperative navigation is used to confirm appropriate positioning and alignment before incision.

Incision is made along the midline of the spine, using subperiosteal dissection with monopolar cautery or a Cobb dissector and Hipp's sponges to dissect laterally to the transverse processes of the vertebrae. When adequate exposure of the appropriate levels is confirmed via fluoroscopy, the pedicle screw entry pilot holes are made with a high-speed drill. Pedicle markers may be used at each level to ensure appropriate starting points and initial trajectories. The lumbar entry sites may be placed just superomedial to the transverse process at each level. In the lower thoracic spine, the pedicle screw entry site is just at the inferolateral portion of the superior facet at each level.

Once the entry sites are defined, the curved pedicle probe is used to create the trajectory for the screw to the desired screw length. The ball-tip probe is used to palpate the four quadrants to ensure no violation occurs. The tap is used to prepare the hole for the screw, and the hold is probed once more in all four quadrants. The screw may then be placed into the pedicle, and fluoroscopy may be used to confirm appropriate screw placement.

The level of the fracture may or may not accommodate screws. If the pedicle is fractured, a screw should only cautiously be placed at that level, given the possibility of splaying the fractured bone, which can cause canal impingement laterally or neuroforaminal impingement. If the surgeon is unable to place a pedicle screw at a level adjacent to the fracture, the construct could be extended to another level, or hooks or laminar screws could be used.

After pedicle screws are in place, attention is turned to the extent of decompression needed, if any. For fractures that require decompression of the spinal canal or neuroforamen, one or more of the following techniques may be performed from a posterior approach:

1. When canal compromise with bony fragments is significant, but the PLL appears to be intact on imaging (MRI), gentle distraction during fixation can assist ligamentotaxis. However, overdistraction can further disrupt the facet and an already unstable spine, causing increased stress on the fractured level.

2. Another option for posterior decompression is a multilevel laminectomy, taking care to avoid a sagittal bowstring effect (migration of the cord dorsally) with the decompression, especially at the level of the conus.
3. Finally, a transpedicular decompression may be performed as follows:
   - After exposure of the posterior elements and placement of the screws at the appropriate levels, with the exception of the level of the fracture, a laminectomy is performed at the level of the fracture. An osteotome or high-speed drill is used to completely resect the facet on one or both sides of the fractured vertebrae.
   - With the pedicle exposed, using either Leksell rongures or a high-speed drill, the pedicle is completely resected to facilitate exposure of the anterior portion of the canal.
   - Epstein curettes are then gently placed between the thecal sac and the PLL, using the mallet to complete the decompression. A dural or Penfield No. 4 dissector may be used to palpate the posterior portion of the fractured level to ensure that the decompression is adequate.
   - Once adequate decompression has occurred, the rods are cut and fashioned appropriately and are secured in place using set screws. If a laminectomy was performed at the level of the fracture, a crosslink may be desirable to establish increased pull-out strength of the pedicle screws and to prevent a parallelogram effect on the construct.

Construct design and length is important in the isolated posterior approach. The posterior instrumentation and fusion will restore a tension band but could also place undue stress on adjacent levels and result in regional deformities (flat back syndrome, kyphotic angulation juxtaposed to the construct). The construct length must be carefully considered so as not to end a long construct at transition points or at other levels with increased regional stress (e.g., at the apex of a kyphotic curve, cranially at T12, caudally at L1, at levels with nonoperative fractures).

Posterior Approach with Anterior Column Stabilization

Another option from the posterior approach is stabilization of the anterior column via a transpedicular corpectomy. The caveat to the transpedicular corpectomy in the lumbar spine is that the nerve roots that may be sacrificed in the thoracic spine may not be sacrificed in the lumbar spine. In fact, care must also be taken in the upper lumbar spine not to injure the conus medullaris by impinging upon the thecal sac during positioning of the interbody cage (Fig. 39-6).

Lateral Retroperitoneal Approach

Access to L1 through L4 burst fractures can be performed via a lateral retroperitoneal approach. A left-sided approach is favored to avoid the inferior portion of the liver and the IVC. L4 and L5 may be difficult to access because of the iliac artery and vein.

The patient is positioned on a flat-top table with the left side up; using either a beanbag or gel rolls, pressure point areas are adequately padded. Baseline intraoperative neuromonitoring signals are obtained before positioning the patient and after positioning is finalized to ensure stable signals.

For access to L1 and L2, a lateral transverse incision is made just above the appropriate ribs (tenth, eleventh, or twelfth). A subperiosteal dissection is performed along the rib anteriorly, and the pleural cavity is entered, taking care to identify the diaphragm and parietal pleura. The peritoneum is then identified and dissected from the inferior portion of the diaphragm. The retroperitoneal space is entered bluntly using Metzenbaum scissors or finger dissection. The diaphragmatic attachments are divided along the periphery, carefully using sutures to demarcate the borders to facilitate the repair at the end of the procedure. The self-retaining retractor is placed at this time.

The psoas muscle is identified and split vertically along the muscle fibers, taking care to preserve the genitofemoral nerve and segmental arteries. The fractured vertebral body is exposed, and the superior and inferior disks are identified, as are the appropriate inferior and superior portions of the adjacent vertebral bodies. The diskectomies should be performed first, preserving the margins of the extent of the corpectomy of the fractured level. Using a 15 blade on a long handle, the annulus is incised along the superior and inferior end plates, and the nucleus pulposus is removed using a combination of Kerrison and pituitary rongeurs. After both disks are removed, the corpectomy is performed using large pituitary rongeurs, curettes, or a high-speed drill; a thin rim of bone is preserved anteriorly to protect the aorta and posteriorly to protect the spinal canal. The bony fragments that penetrate the spinal canal should be carefully and adequately removed, and these bone fragments are retained for the autograft and fusion.

The decompressed site of the corpectomy is now ready for the interbody graft. Expandable cages, stacked cages, and titanium mesh cages are available options. Other options for interbody grafts include fibular or tibial strut cadaveric bone. Care must be taken to ensure that the fractured level is not overdistracted, especially using expandable cages. Placement of the interbody struts or cages should be performed with fluoroscopy, and lateral plating or rod systems may be used to secure the construct in place. Intraoperative fluoroscopy should also be used to ensure appropriate screw length across the width of the vertebral body (Fig. 39-7).

LOWER LUMBAR FRACTURES: L4 AND L5

Posterior

Fractures of L4 and L5 may be stabilized from a posterior approach to the posterior column or to the anterior and posterior columns. For fractures of the lower lumbar spine, extension of the construct to the sacrum and ilium must be considered in the preoperative surgical plan.

In the setting of an unstable fracture with adequate anterior bone and minimal angulation, the fractured segment may be stabilized from a posterior approach alone. If kyphotic angulation, significant vertebral body height loss, or a three-column injury is present, anterior and posterior column stabilization might provide more stability to the construct.

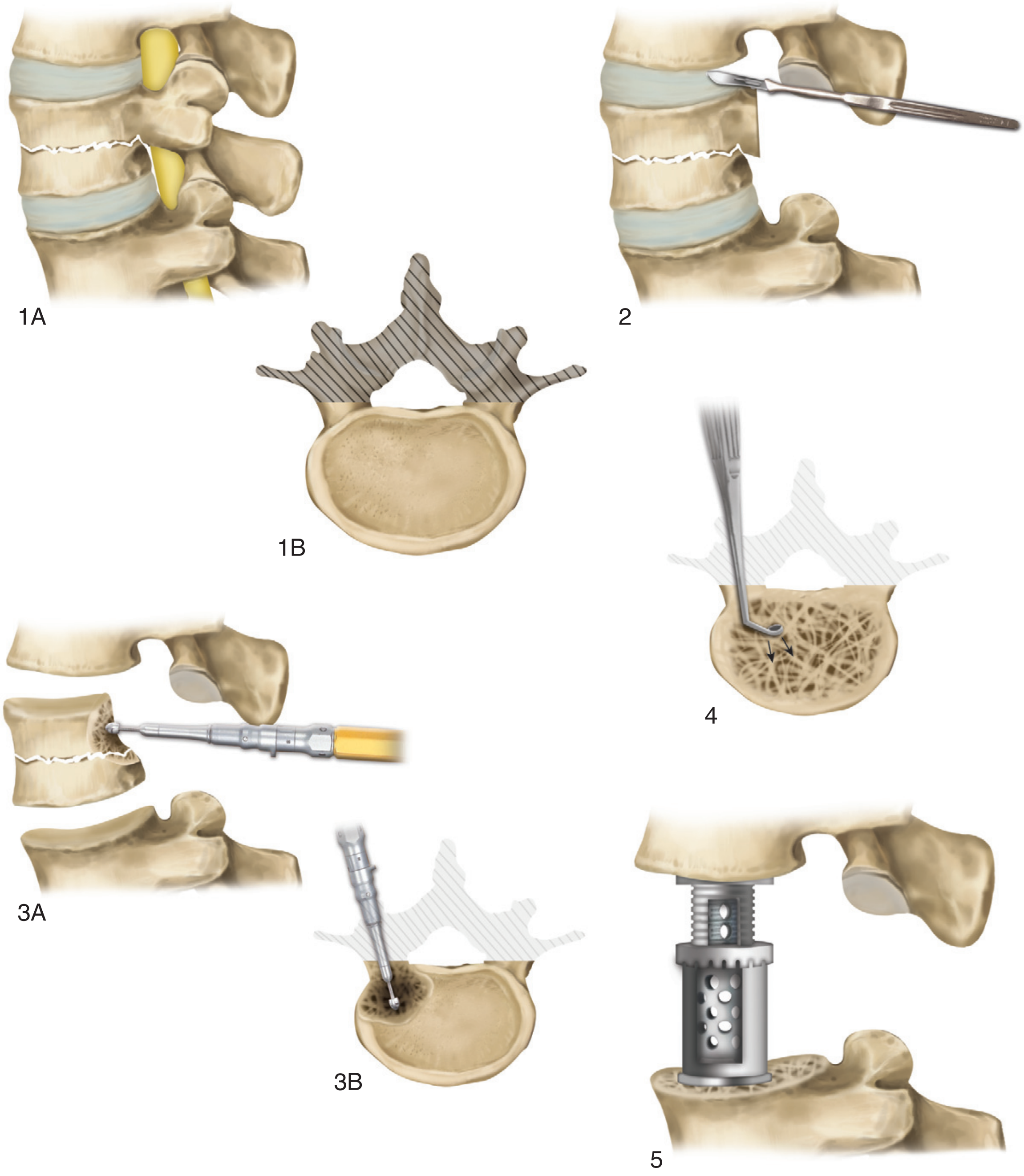

Figure 39-6 1, Laminectomy is performed with removal of posterior elements, including bilateral facetectomies (**A,** sagittal; **B,** axial) and removal of the pedicles flush with the vertebral body. 2, Diskectomy is completed at the interspace above and below the fracture. 3, The high-speed matchstick drill may be used to enter the vertebral body in the trajectory of the pedicle to begin the corpectomy (**A,** sagittal; **B**, axial). 4, Epstein curettes may be used to complete the corpectomy. 5, After corpectomy is completed, the strut graft or cage may be placed to seed the graft into the end plate on either side.

If the patient has any neurologic deficits that may be attributable to the level of the injury, a wide laminectomy and foraminotomy is performed at any levels of concern.

Procedure

Baseline neuromonitoring signals are obtained in the supine position. The patient is positioned prone on a radiolucent table. All pressure points are padded, and prone neuromonitoring potentials are obtained.

Incision is made along the midline of the spine, using subperiosteal dissection as described above. When adequate exposure of the appropriate levels is confirmed via fluoroscopy, the pedicle screw entry pilot holes are made with a high-speed drill at the levels of instrumentation. Pedicle screw holes are tapped, and screws are placed as previously described. If the distal extent of the construct is to be taken to the sacrum, the pilot holes for these are made on the medial aspect of the sacral ala, just lateral to the articular process of S1.

A decompression may be performed at this time as needed, if concern for canal compromise or neural injury

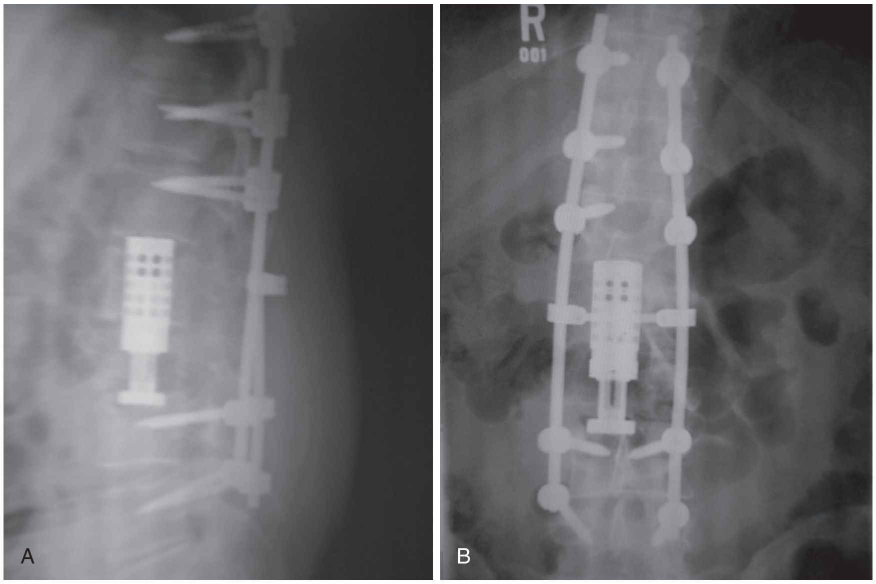

Figure 39-7 Plain radiographs of L2 and L3 posterior transpedicular corpectomies with placement of an expandable cage.

is present. The rods are then fashioned appropriately, and the construct is locked into final position.

Lower lumbar fractures may necessitate constructs that extend distally to the sacrum or the iliacs. These constructs are further discussed in Chapter 50 with regard to the biomechanical considerations of the lumbosacral junction.

Intraoperative Complications

Management of complications is the key to decreasing morbidity of spine trauma. Neuromonitoring is more commonly used today than in the past, especially in the cervical and thoracic spine. Loss of SSEPs and/or MEPs during a case necessitates immediate investigation, not only from the neurotechnician but also from the anesthesiologist and the surgeon. In the process of reducing a fracture or dislocation, a traumatic disk herniation or anterior epidural hematoma could ensue that causes loss of MEPs and prompts an emergent explorative laminectomy. Monitoring signals are also dependent upon mean arterial pressures (MAPs) and are quite sensitive to MAP changes intraoperatively. EMG may also be monitored for the purpose of stimulation of the pedicle taps and screws to ensure accurate placement with no violation of the cortex medially to the canal or inferiorly to the neuroforamen. Neuromonitoring may also be affected by vascular supply; for example, retraction of the iliac arteries for anterior lumbar interbody fusion exposure could affect the SSEPs that lateralize to the side of the associated vascular compromise.

Recovery and Rehabilitation

In the immediate postoperative period, pain control is key to facilitating the patient's willingness to mobilize. Physical therapy, occupational therapy, and rehabilitation services are useful adjuncts to initiating recovery. Use of external orthoses in the postoperative period varies among surgeons; some believe bracing affords no extra support and opt not to use braces. Other roles of bracing are as a biomechanical adjunct to the fusion construct, as a comforting stabilizer for the patient, or as a reminder to the patient of his or her limitations in recovery.

Summary

Traumatic lumbar fractures have unique considerations for radiologic assessment, neurologic injury, and acutely deformed anatomy compared with degenerative or chronic deformity. The notion of stability becomes paramount in determining the need for surgical intervention and timing of surgery. Many other factors, such as ability to position prone, other systemic injuries, and external fixators, become issues to take into account. The pathology and mechanism of injury become key factors in deciding which of the previously described approaches is appropriate for the patient and for the lumbar fracture at hand. Overall, this area poses specialized challenges for the spinal surgeon that can be overcome with the proper knowledge of anatomy, utilization of constructive tools, and technical skill.

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40 Surgical Decompression and Stabilization for Lumbar Lesions: Osteomyelitis and Tumors

JARED FRIDLEY, JAI-JOON SHIM, and IBRAHIM OMEIS

Overview

Surgical management of neoplastic and infectious lesions of the lumbar spine involves extensive preoperative planning to ensure proper patient selection and operative approach. Despite the differences in patient selection criteria, preoperative workup, and adjuvant treatments, the choice of operative approach for either an infectious or neoplastic lesion of the lumbar spine is often the same.

Infection of the lumbar spine is more often than not a nonsurgical disease. Patients with osteomyelitis and/or diskitis can usually be treated nonoperatively with antibiotics. When the organism in question is unknown, body fluid cultures are obtained; if results are negative, a biopsy guided by computed tomography (CT) can often obviate the need for open intervention. Indications for surgical intervention include 1) compression of the conus medullaris or nerve roots, causing neurologic deficits; 2) lesional involvement of at least two spinal columns; 3) significant (≥25 degrees) kyphotic deformity; 4) failure of medical therapy to cure the infection and radiologic evidence of persistent spinal disease; 5) failure to identify the organism causing the infection; and 6) intractable pain secondary to mechanical instability or ongoing infection.

Neoplasms in the lumbar spine can be divided into *primary lesions* or *secondary metastases*. Metastases are by far the most common tumors of the lumbar spine,[1] although the vast majority of symptomatic spinal metastases occur in the thoracic spine.[2] Most spinal metastases originate from and involve the vertebral body; only rarely do they solely affect the posterior spinal elements. Lung, breast, and prostate cancer are the most common metastatic tumors found in the spine.[3] Other secondary tumors often seen include lymphoma, renal cell carcinoma, and multiple myeloma. Surgery is indicated for patients with tumor causing progressive neurologic deterioration, spinal instability, or significant deformity. It is also indicated when the tumor type is unknown, or when it is known but is radiation resistant.

Surgery for metastatic disease is often palliative, but it can help maintain or improve neurologic function in affected patients. It is often supplemented with radiation therapy in the form of radiosurgery. In patients who have primary tumors of the lumbar spine, it is possible to achieve a cure through en bloc resection of the neoplasm when technically feasible. Depending on the extent of tumor involvement, surgery may entail a complete spondylectomy or resection of only a portion of the involved bone.

Preoperative Preparation

In patients with either tumor or infection of the lumbar spine, proper preoperative laboratory and radiologic diagnostic tests must be run for surgical intervention to take place. For both pathologies, magnetic resonance imaging (MRI) of the lumbar spine, both with and without contrast, is ideal to visualize the pathology in question and to discern any involvement of adjacent tissues; CT of the lumbar spine is useful to determine bony quality. In cases of infection and neoplasm, the degree of bone destruction helps dictate the extent of instrumentation needed.

Patients with osteomyelitis often have adjacent involvement of the disks and/or end plates. This can help to radiologically differentiate between infection and neoplasm when the diagnosis is in question, because tumor typically does not affect the end plates and disks. Epidural abscesses are sometimes associated with osteomyelitis. If present, the abscess is usually anterior to the thecal sac. Although patients with anterior pathology often require anterior approaches, it is often possible to approach anterior epidural abscess through a posterior approach with retraction of the thecal sac and nerve roots.

In patients with suspected neoplasm, a systemic workup and imaging survey is indicated to help determine whether the pathology is metastatic. CT of the chest, abdomen, and pelvis should be performed in these patients, with and without contrast. If any lesions are identified on imaging anywhere in the body other than the spine, and these are technically accessible using CT-guided biopsy, they should be targeted to obtain tissue for diagnosis before open surgical intervention. Knowing the type of tumor will help determine whether surgery, radiation, or chemotherapy will be the best treatment. In patients with metastatic spine lesions, surgery is often palliative and is usually reserved for single-level or multiple, contiguous-level tumor involvement causing compression of neurologic elements. Surgical resection of the tumor with supplemental instrumentation can improve overall patient neurologic function and quality of life.[4]

Patients with osteomyelitis are usually treated with antibiotics, either alone or in combination with surgery. In patients who require surgical intervention but do not have an identified offending organism, it is important that antibiotics be withheld before surgery; intraoperative cultures can be negative if the patient has been receiving antibiotics. After cultures have been obtained, empiric antibiotics can be administered until pathogen speciation is completed. In patients with osteomyelitis or neoplasm, treatment by a multidisciplinary team that includes infectious disease specialists or oncology/radiation specialists is important as part of a comprehensive treatment plan.

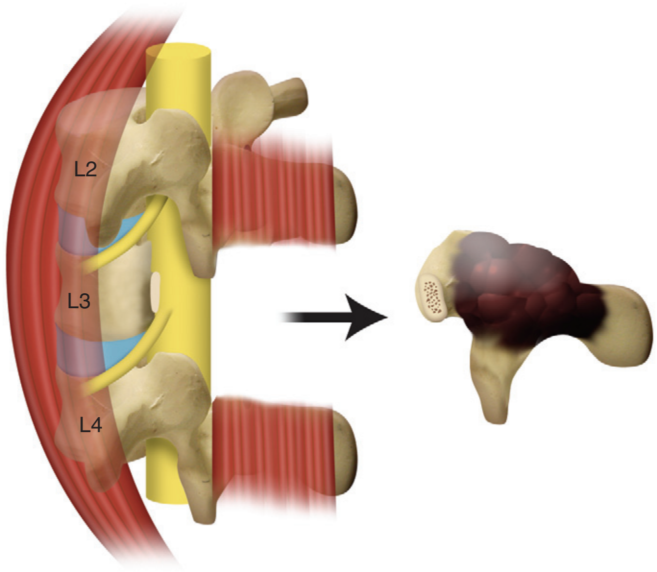

Figure 40-1 Illustration shows the resection of a tumor that involves the posterior elements at L3. After a standard midline approach to the lumbar spine, the involved spinous process, lamina, pedicles and facets are removed en bloc.

Posterior Approaches

LAMINECTOMY

Although rare, tumor and infection can arise solely in the posterior elements of the vertebrae. If confined to the laminae and facets, tumor can often be resected from a posterior approach. In these cases, patients are placed prone on a Jackson table with the patient's arms outstretched above the head superiorly. Following fluoroscopic localization of the involved level, a midline incision is centered at the level of the pathology and is carried down through the subcutaneous tissues to the dorsal lumbosacral fascia. A midline incision is made through the fascia down to the spinous process, and subperiosteal dissection is carried out using monopolar cautery and Cobb retractors. Care must be taken to avoid excessive muscle retraction laterally, because this can cause injury to the dorsal ramus of the spinal nerve, which can potentially lead to spinal muscle atrophy. By staying in the subperiosteal plane, bleeding is minimized. Dissection is carried laterally to the extent needed, out to the transverse processes if necessary. Depending on the extent of tumor involvement, either a standard laminectomy or some variant thereof can then be performed using a high-speed drill, rongeurs, curettes, and Kerrison punches (Fig. 40-1). Any surrounding soft-tissue mass can be removed at the same time. If involvement of the facet joints is extensive, posterolateral instrumentation and fusion are performed. In the case of epidural abscess causing nerve root or thecal sac compression, a hemilaminectomy often allows sufficient access for evacuation of the abscess.

LATERAL TRANSPEDICULAR-EXTRACAVITARY APPROACH

The transpedicular-extracavitary approach (TECA) to the lumbar spine allows access to the posterolateral and anterolateral aspects of the thecal sac and to the vertebral body, in case a corpectomy is planned. Special attention is required when approaching the L4 or L5 levels; this usually requires dissection of the lumbar plexus off the iliopsoas muscle, and it risks injury to important nerves. This approach is an alternative to the retroperitoneal approaches and does not require an abdominal or flank incision. Approaching posteriorly through this avenue allows decompression of the thecal sac, corpectomy, and both anterior and posterior instrumentation (360-degree stabilization). All of this can be performed through one incision and in one sitting. This approach also allows a greater lateral exposure, which can be especially useful in the case of tumor extension into the paraspinal soft tissues.

The patient is placed prone on a Jackson table or on chest and hip bolsters with outstretched arms. A midline incision is made that extends two to three levels above and below the level of interest. Dissection is carried down through the subcutaneous tissues to the dorsal fascia. A midline incision is made through the fascia down to the spinous process, and subperiosteal dissection is carried out using monopolar cautery and Cobb retractors. Dissection is carried laterally to expose the transverse processes (Fig. 40-2). Then, laminectomies are performed over the level of interest and at least one level above and below.

After decompressing the thecal sac, pedicle screws are placed at the levels above and below the vertebrectomy site to encompass at least three segments above and below. To include three segments below the vertebrectomy, the instrumentation may need to be extended to include the ilium. Once pedicle screws are placed, the process of vertebrectomy is begun.

First, bone and ligament removal is extended laterally at the intended level. The superior facet, inferior facet, pars interarticularis, and transverse processes of the vertebrae to be resected are removed. After removal of the posterior elements, the ipsilateral pedicle is visible, as are the nerve roots. It should be noted that bleeding can be substantial at this point; bipolar electrocautery and hemostatic agents should be used generously to minimize bleeding. Using a high-speed burr, the pedicle is drilled down to the vertebral body such that a small rim of cortical bone remains. Using an up-angled curette, the remaining wall of the pedicle is broken away from the thecal sac and removed. Attention is paid to the exiting nerve root to minimize injury.

A systematic approach is critical to ensure a safely performed corpectomy. First, drilling is begun ventral to the

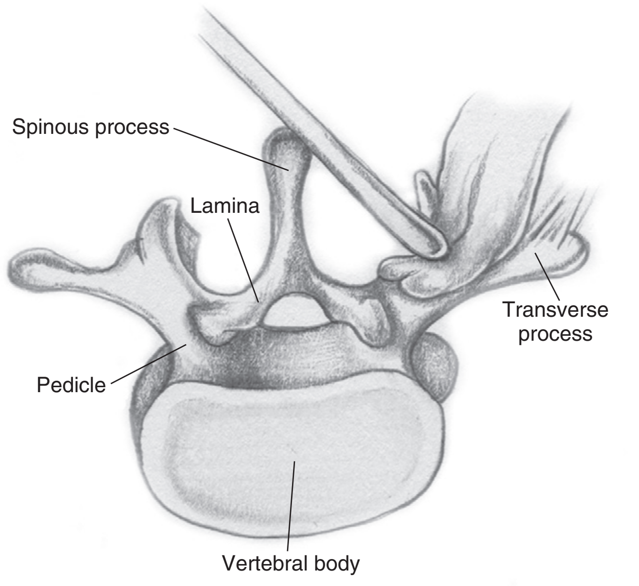

Figure 40-2 Exposure of the spinous process, lamina, and transverse process during the initial stage of a transpedicular approach.

thecal sac in a lateral to medial manner to create a small working space within which Kerrison rongeurs and curettes can be used to resect the posterior wall of the vertebral body and the posterior longitudinal ligament (PLL). Removal of the ipsilateral vertebral body occurs first. This allows direct access to the contralateral vertebral body and minimizes the degree of thecal sac retraction required to do so. Thrombin-soaked Gelfoam is packed into the vertebral body to control bleeding. Placement of a small, temporary rod before corpectomy can reduce the likelihood of spinal translation while the remainder of the anterior column is resected.

Following resection of the vertebral body, the intervertebral disks above and below the corpectomy site are resected. The upper disk is easily accessible, because it is situated immediately above the resected pedicle. The inferior disk is more difficult to resect, because the nerve root below the resected pedicle interferes with wide exposure at the inferior aspect of the vertebral body. The nerve root is carefully manipulated and is protected using a nerve root retractor. If the corpectomy is performed to resect tumor, it is imperative to use microinstrumentation, such as nerve microhooks and forceps with teeth; these are used to explore the dura-tumor interface and to resect tumor off the dura before resection of the posterior wall of the vertebral body and PLL.

Once the corpectomy has been performed, and neural elements are decompressed, the end plates are then decorticated and an interbody device is carefully placed. It is sometimes easier to place an expandable cage into the space, because the lumbar nerve roots can make placement of larger constructs difficult, and this can increase the potential for nerve root injury. Another option is insertion of a chest tube filled with poly-methylmethacrylate (PMMA; Fig. 40-3).

Rods are then placed and anchored to the screw heads. Extension of the instrumentation to the pelvis is recommended if the corpectomy is at L4 or L5, or if the patient

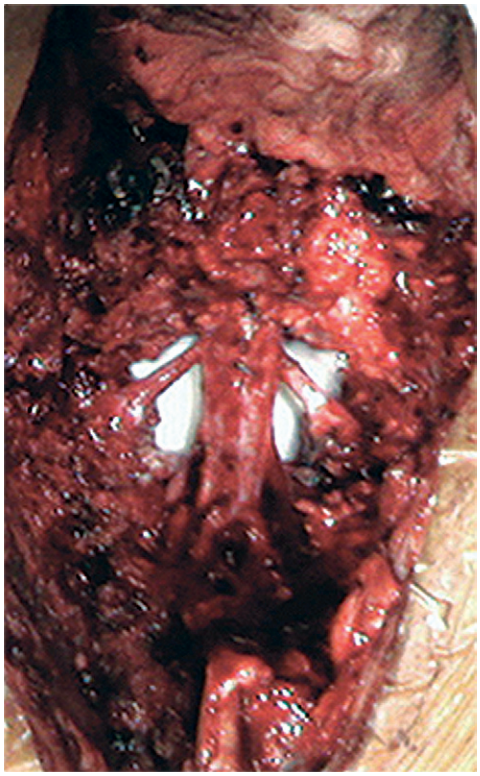

Figure 40-3 Exposure following an L5 transpedicular approach and corpectomy with a poly-methylmethacrylate chest tube placed at the L5 corpectomy site.

has poor bone quality for sacral fixation. The posterior elements are then decorticated, and osteobiologics are used for fusion of the posterolateral elements. A subfascial drain is placed, and muscles and fascia are closed anatomically with interrupted sutures, followed by skin closure with sutures or skin staples.

Anterior Approaches

LATERAL RETROPERITONEAL APPROACH

The lateral retroperitoneal approach is used to access anterior and lateral pathology from L1 to L4. It allows direct anterolateral dural decompression without compromising the posterior elements and it allows performance of anterior spine stabilization. If posterior supplementation is needed, it must be performed in a separate procedure, often in the form of percutaneous pedicle screw fixation.

The patient is positioned in the lateral decubitus position, with the pathologic side facing up. If the pathology dictates no side preference, the left-sided approach is preferred, because the spleen is easier to retract than the liver, and the aorta is easier to retract than the inferior vena cava. It is important to flex the ipsilateral leg to relax the psoas muscle, because this allows safer retraction of the ipsilateral lumbosacral plexus during the procedure.

A small flank incision is made directly over the intended level to minimize the length of incision (Fig. 40-4). Marking of the incision is done with the help of fluoroscopy. Dissection is carried out in a stepwise fashion, through the

Figure 40-4 The various skin incisions for a lateral retroperitoneal approach according to the level of the lesion.

subcutaneous tissue, external and internal obliques, and then the transversus abdominis muscles. Blunt dissection is carried out between the renal fascia ventrally and the quadratus lumborum and psoas muscles posteriorly to reach the spine (Fig. 40-5). The abdominal contents are then retracted medially using an abdominal retractor system (e.g., Omni tray).

The psoas muscle attaches medially to the spine, and care must be taken to identify the genitofemoral nerve that exits the body of the psoas muscle along its medial surface. The psoas muscle is then dissected off the lateral aspect of the vertebral body, posterior to anterior, beginning at the level of the transverse process. The lumbar segmental vessels are identified, ligated, and dissected from underlying bone. The disks above and below the vertebral body are identified, and the corpectomy and diskectomies are performed using a high-speed drill, curettes, and rongeurs. All diseased and infected bone is removed, the PLL is identified and excised, and the adjacent end plates are decorticated and prepared for the reconstruction of the corpectomy defect. Reconstruction is performed using a bony allograft, titanium cage, or an expandable cage (metallic or polyetheretherketone (PEEK); Fig. 40-6). A lateral plate can also be placed for further support, especially if posterior instrumentation is not planned to support the construct. Posterior instrumentation is highly recommended.

ANTERIOR RETROPERITONEAL APPROACH

The anterior retroperitoneal approach is generally used for pathology of the lower lumbar spine, from L4 through S1. This approach, like the lateral retroperitoneal approach,

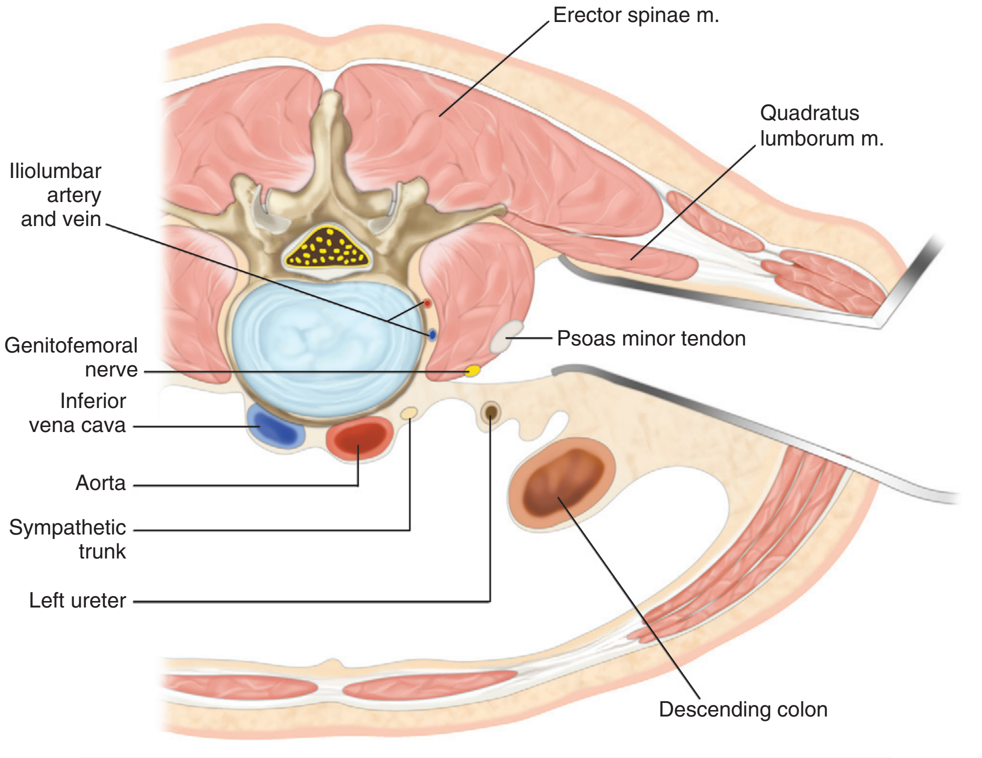

Figure 40-5 Exposure after blunt dissection during a lateral retroperitoneal approach.

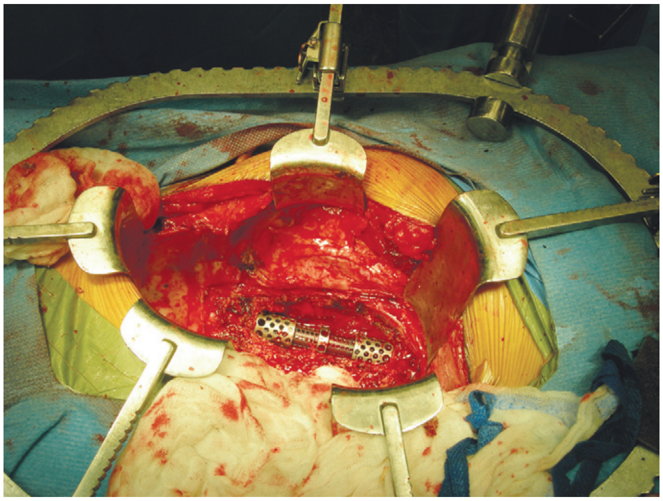

Figure 40-6 Placement of a titanium cage in an L2–L4 corpectomy site after a lateral retroperitoneal approach.

allows direct decompression and reconstruction of the anterior and middle spinal columns. However, it carries a higher risk of injury to adjacent abdominal viscera, as well as the hypogastric plexus, which if injured can result in sexual dysfunction that includes retrograde ejaculation.

The patient is placed supine on the operating table in slight Trendelenburg position to promote retraction of the intraabdominal contents; the table should be angled such that there is hyperlordosis at the lumbosacral junction to increase the angle of exposure. With the assistance of an access surgeon, a midline (preferred) or Pfannenstiel incision is made midway between the pubic symphysis and umbilicus. This can be extended if higher levels are to be exposed. Dissection is carried out in the midline through the subcutaneous tissue down to the rectus abdominis muscle. Muscle and subcutaneous tissues are retracted, and the linea alba is identified and incised. Peritoneum is then visualized and retracted medially.

A retroperitoneal route is taken to minimize injury to the intraabdominal structures. The peritoneal/abdominal contents are retracted using a self-retaining retractor system, and the great vessels and ureters are then visualized. The use of electrocautery at this point is avoided because of the risk of injury to adjacent vessels and nerves. The hypogastric plexus is located directly anterior to the L5 vertebral body, and it is bluntly dissected away from the L5 body and L5–S1 disk space. The median sacral vessels are ligated and divided. For the corpectomy, the disks above and below L5 must be removed using rongeurs and curettes; The L5 vertebral body is removed using a high-speed drill and rongeurs. Next, the PLL is removed, and the end plates are prepared for reconstruction. We prefer placement of an expandable titanium cage, but there are several options (see "Reconstruction" below). A lateral plate is then placed to support the cage, and posterior supplemental instrumentation is performed.

En Bloc Spondylectomy

En bloc spondylectomy is a useful approach in selected patients with solitary tumors of the lumbar spine. This

Figure 40-7 Exposure of the posterior lumbar thecal sac after removal of the posterior elements at L3 for the first stage of a spondylectomy (*top*). The removed posterior element complex is also shown (*bottom*).

procedure can decrease the rate of local recurrence in patients with solitary metastases of the lumbar spine,[5] and it can improve disease-free survival in certain primary spine tumors.[6] It is important to try to obtain a tissue diagnosis preoperatively to help decide on the surgical approach. The procedure itself is most often staged, with a posterior approach performed first, followed by an anterior approach at a later date.

The patient is placed in a prone position on a Jackson table, and a midline incision is made that extends two to three levels above and below the affected level. If a prior biopsy has been performed, the biopsy tract is usually demarcated, isolated, and resected. Posterior instrumentation is performed, and the hardware is placed, usually pedicle screws, above and below the targeted level. A generous posterior exposure is carried out to expose the spinous processes, laminae, transverse processes, and both the inferior and superior articular facets. A laminectomy of the levels cephalad and caudad to the lesion is performed, and a Gigli saw is introduced through the intervertebral foramina around each pedicle at the affected level. The pedicles are cut bilaterally, and the facet capsules opened, which allows en bloc removal of the entire posterior element complex (Fig. 40-7). Hemostasis is performed with bone wax, bipolar cautery, or other hemostatic agents.

Segmental vessels at the affected level are identified, ligated, and divided. In the lumbar spine, it is important to preserve the nerve roots during this stage, because injury can cause severe neurologic disability. A diamond thread-wire saw is inserted anteriorly along the intervertebral disk spaces, both at the level above and below the affected

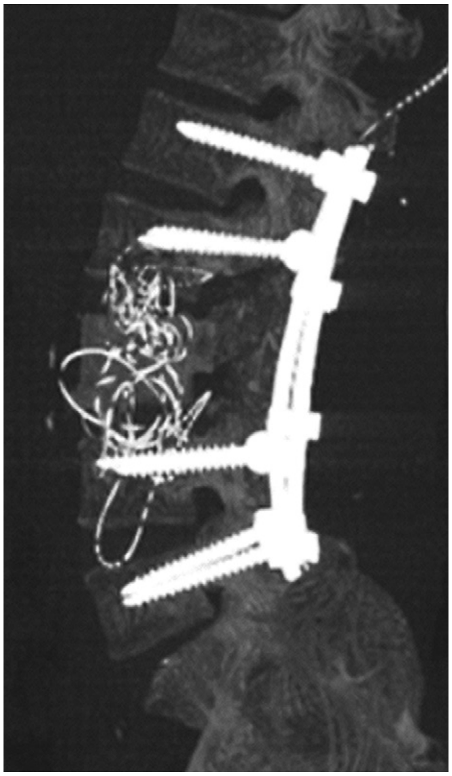

Figure 40-8 Postoperative sagittal computed tomography scan following stage 1 of an L3 total spondylectomy. Note the thread-wire saw left in place after the first stage in preparation for the second-stage anterior procedure. Posterior pedicle screws and rods were placed for posterior stabilization.

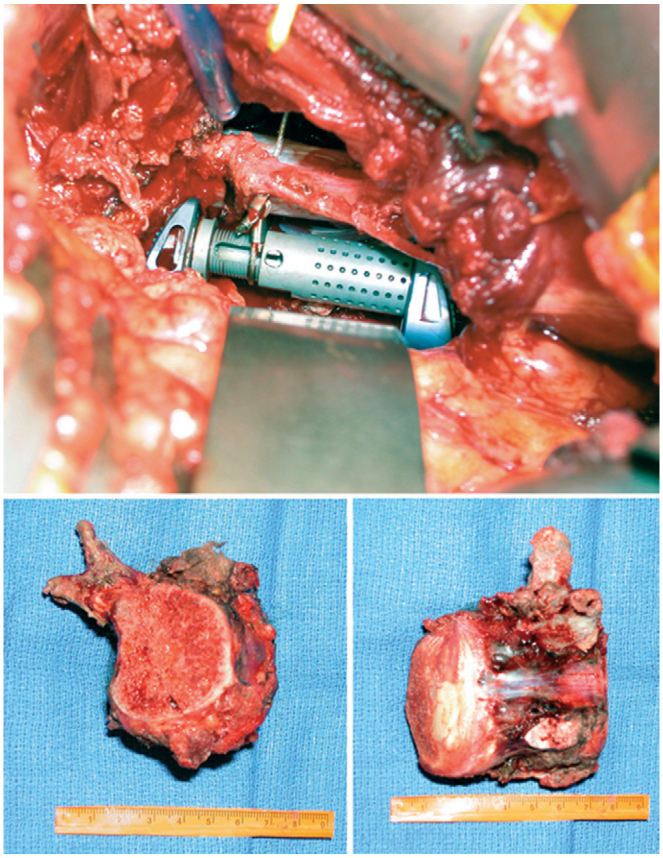

Figure 40-9 The second stage of an L3 spondylectomy after completion of an anterior L3 corpectomy. A titanium expandable cage was inserted at the corpectomy site (*top*); the corpectomy specimen with tumor removed en bloc is also shown (*below*).

vertebral body. The first stage is completed by finishing the posterior instrumentation construct with rod insertion and placement of any needed crosslinks (Fig. 40-8); the saw is left in place for the second stage, and the wound is closed in anatomic layers.

The second stage of this procedure occurs after the patient has had time to recover from the first stage. A lateral retroperitoneal approach is planned and performed according to the affected level. The thread-wire saw that was left in place from the previous surgery is located, and a vertebrectomy is performed. Usually an expandable cage packed with osteobiologics is placed followed by anterior instrumentation across the level (Fig. 40-9). The wound is then closed in anatomic layers.

Reconstruction

Several options are available for reconstruction of the corpectomy defect in the lumbar spine. In general either a titanium cage (expandable or mesh), bone graft, or PMMA construct is used. Each has its advantages and disadvantages in the setting of either neoplasm or infection.

Bone grafts are contraindicated in patients with metastatic tumors or infection of the spine. The infection or tumor can spread to the graft and destroy it, leading to spinal compromise and further degeneration. The disadvantages of a bone graft include donor site morbidity, the potential for necrosis of the bone, and the fact that external bracing is often required until bony fusion occurs, and this can impact the patient's quality of life.

PMMA, unlike bone graft, allows immediate stabilization of the involved spine segment. Patients do not need external immobilization; therefore PMMA is useful in patients with a short life expectancy (< 6 months). Additionally, the PMMA material is unaffected by infection or neoplasm, and it is also unaffected by postoperative radiation. Two options for PMMA reconstruction are either direct pouring of the PMMA into the corpectomy defect, with or without Steinmann pins, or injection of the PMMA into a chest tube construct situated between the adjacent vertebral bodies.

Titanium cages are often placed in corpectomy defects. Both fixed-length mesh cages and expandable (metallic/PEEK) cages are available. As with PMMA constructs, placing a cage provides immediate stabilization. The expandable cage allows adjustment of the cage height to fit the defect, and it can help correct spinal deformity, if such is present. Bony graft can be placed within the cage to create bony fusion; the disadvantage of the titanium cages is primarily cost.

Complications

- The primary complication with posterior approaches to the lumbar spine, especially those that involve corpectomy, is injury to the lumbar nerve roots. Unlike the thoracic spine, the lumbar nerve roots are not ligated because of their functional significance.

- When performing an anterior or lateral retroperitoneal approach, care must be taken to avoid injury to the ureter, which can be identified through its peristaltic motion. The ureter is retracted medially with the other abdominal contents.
- Dissection of the psoas muscle risks injury to the lumbosacral plexus and genitofemoral nerve. Injury to the genitofemoral nerve can result in hypoesthesia or neuralgia of the anterior thigh below the inguinal ligament.
- During an anterior approach to the lower lumbar spine, injury to the hypogastric plexus can occur; this can result in sexual dysfunction, including the potential for retrograde ejaculation.

Postoperative Care

- Postoperative antibiotics are given for at least a day; if the patient has a penicillin allergy, a third-generation cephalosporin or vancomycin are usually given.
- Pain is controlled postoperatively with narcotics in the form of patient-controlled analgesia and oral tablets as needed. Muscle relaxants are also administered and can be especially helpful in patients who have undergone posterior approaches because of the degree of muscle dissection and retraction.
- The patient is mobilized as soon as possible after surgery, beginning on postoperative day one. Thromboprophylactic devices, including sequential compression devices and leg hose, are used when the patient is in bed. Low-dose subcutaneous heparin is begun starting on postoperative day two.
- The diet is advanced when bowel function returns. A bowel regimen is useful, especially in patients who require a significant amount of narcotic medications.

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41

Lumbar Microdiskectomy: Midline Open and Far-Lateral Techniques

FRANK ATTENELLO and PATRICK HSIEH

Overview

HISTORY

Mixter and Barr[1,2] first provided the description of a herniated disk causing sciatica in 1934. The surgical technique outlined the treatment of lumbar disk herniation at that time, which involved an intradural approach and extensive laminar removal.[3] In the 1970s, however, focus on a less invasive surgical approach with decreased surgical manipulation and trauma to the paraspinal muscles, ligamentum flavum, and affected nerve root began to take shape.[4-6] Outcomes of decreased morbidity, shorter hospital stay, and faster recovery were widely recorded.[4,5,7-9]

Yasargil[10] and Caspar[11] were the first to document their separate experiences with microdiskectomy technique using an operating microscope. Williams[9] followed shortly thereafter with a description of a microlumbar diskectomy in a series of 532 patients that popularized the technique in the United States.[2]

The past decade has brought advances in fluoroscopy, image-guided techniques, and high-resolution endoscopy. These advances, along with widespread use of tubular retractors, have provided a minimally invasive form of lumbar diskectomy.[12] Early data from a randomized, controlled study from the Netherlands to compare minimally invasive tubular microdiskectomy with standard techniques suggests no differences in functional outcome and *less* favorable outcomes for minimally invasive treatment at 1 year in regard to leg pain, back pain, and recovery.[13]

PROSPECTIVE STUDIES

Over the past three decades, several prospective trials have compared surgical intervention for lumbar disk herniation with conservative management. In 1983, Weber and colleagues[8] first compared outcomes of patients receiving diskectomy with conservative management. It is important to note that the trial was not blinded, and 26% of patients initially assigned to conservative management subsequently crossed over to receive surgery. Diskectomy was found to be superior to conservative therapy by observer rating at 1 year, although statistically it had not improved significantly at 4 or 10 years.

The Maine Lumbar Spine Study is a large, nonrandomized, observational cohort study of 507 patients from community practice settings.[14-16] Almost all patients in the surgical cohort received open diskectomy for disk herniation. Followed at intervals of 1, 5, and 10 years, surgically treated patients reported a statistically significant improvement in primary symptoms at 1 and 5 years. At 10 years, no significant difference was reported between groups when polled for any improvement.[16] However, significance was noted: with surgical patients, more reported initial symptoms "much better" or "completely gone," and more reported satisfaction at 10 years. Limitations of the study included the nonrandomized design, because surgically treated patients had more notable baseline radiologic and clinical findings. Also, not all patients had imaging available to be reviewed by a neuroradiologist, and up to 25% of patients received additional lumbar surgery at 10 years in both groups.

In 2006, the Spine Patient Outcomes Research Trial (SPORT) provided the first multicenter, prospective, randomized, controlled trial that included 501 patients with lumbar disk herniation confirmed by magnetic resonance imaging (MRI) and signs and symptoms of at least 12 weeks' duration.[17,18] Open diskectomy was compared with nonoperative management, and study groups were assessed using a 36-item short-form bodily pain and physical function scale and the Modified Oswestry Disability Index. Results of this study were limited, because 50% of patients initially assigned to the surgery group and 30% of the nonoperative group crossed over. Although intention-to-treat analysis was not statistically significant, as-treated analysis did show statistically significant advantages for patients in primary outcomes in addition to self-reported improvement, satisfaction with symptoms, and reduction in the bothersomeness of back pain. Improvements were noted at time points that spanned from 6 weeks to 4 years in most recent study updates.[19] Cost evaluations of the same patient cohort have suggested surgery to be at least moderately cost-effective compared with nonoperative management.[20]

Indications

Duration of symptoms is significant in surgical candidate selection. At least 12 weeks of symptoms are suggested by results of SPORT.[18,21] However, clinical data suggest that prolonged radiculopathy symptoms of more than 6 months' duration may be associated with poorer outcomes.[7,22,23] SPORT suggests poorer outcomes after 12 months.[24]

Symptoms include radicular pain with either 1) evidence of nerve root irritation with positive nerve root tension sign on straight leg raise or 2) corresponding neurologic deficit. Exclusion factors include concomitant pathology such as tumor, infection, segmental instability, or vertebral fractures.[18]

Neuroimaging suggestive of lumbar disk herniation and corresponding to clinical symptoms is required.[2,18] MRI is the preferred method, but when it is contraindicated, myelography with axial imaging by computed tomography (CT) may be performed.

Anatomy

LUMBAR SPINE

- There are five lumbar vertebrae.
- L5 is sometimes "sacralized" (with L5 fused to the sacrum), or the S1 vertebral body may be "lumbarized" (with a well-developed disk seen between S1 and S2).
- When counting from L5, rather than from T12, ensure agreement on the level.

SPINAL CANAL

The anterior vertebral body, lateral pedicles and posterior bony elements comprise the spinal canal. (Fig. 41-1)

- Anterior vertebral body
- Lateral pedicles
- Posterior bony elements
- Cartilaginous base covers the end plates of adjacent vertebral bodies.
- The intervertebral disk is composed of the annulus fibrosis and nucleus pulposus. The nucleus pulposus is semigelatinous.
- The annulus fibrosis resists lateral forces of axial compression.
- The posterior longitudinal ligament (PLL) attaches to the disk space posteriorly and to the margins of the vertebral bodies above and below the disk space.
- The PLL is thin laterally and is thickest at the midline.

POSTERIOR ELEMENTS

- These include the pedicles, transverse and spinous processes, facet surfaces, laminae, and the pars interarticularis (Fig. 41-2).
- Each facet has two superior and two inferior surfaces.
- The superior facet surface lies dorsal to the disk space above the vertebral segment, and it articulates with the inferior facet surface of the next superiorly placed vertebral body.
- The inferior facet lies dorsal to the disk space below the vertebral segment, and it articulates with the superior facet of the next inferiorly placed vertebra (see Fig. 41-2).
- Pedicles extend from the dorsolateral surface of the vertebral body just below the superior end plate.
- Pedicles are oriented ventral and slightly inferior to the superior articular facet surface.
- The pars interarticularis or isthmus is a bony bridge that connects the superior and inferior facet surfaces and is continuous medially with the hemilamina of the vertebral segment (see Fig. 41-2).
- The spinous process is the convergence of two hemilaminae that converge in the midline.
- The transverse process projects from the dorsolateral surface of the pedicle.
- The mammillary process is a raised bony prominence on the proximal dorsal aspect of the transverse process.
- The mammillary process may serve as an external landmark for the long axis of the underlying pedicle.
- The intertransverse ligaments connect adjacent transverse processes.
- Ligamentum flavum (yellow ligament) attaches from the dorsal surface of the lamina at the inferior level to the ventral surface of the lamina at the superior level of the interspace. It overlies the spinal epidural space at the interspace.

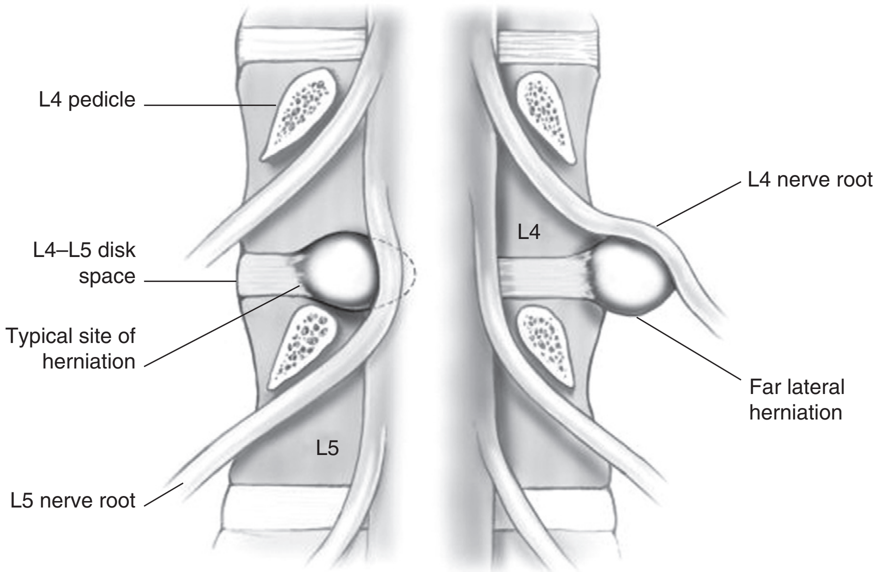

Figure 41-1 A coronal cross-section of the bony spinal canal.

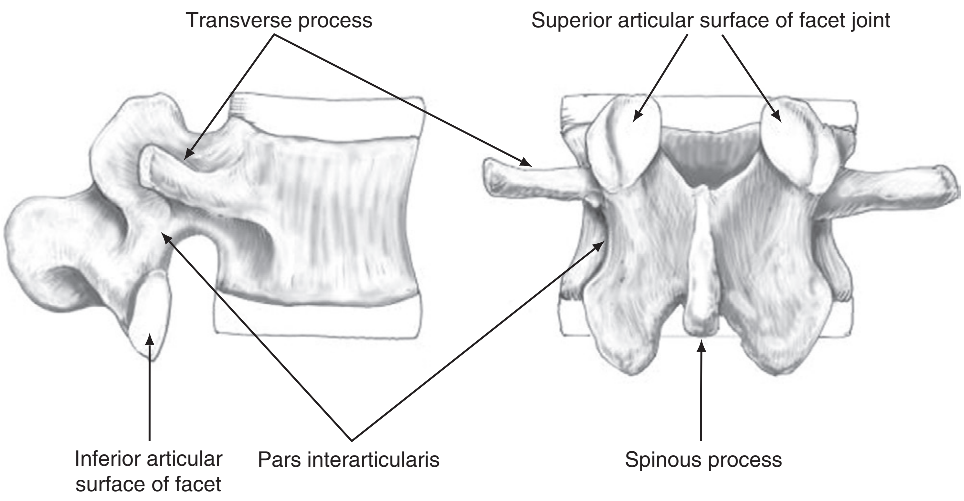

Figure 41-2 Posterior elements, lumbar spine.

- The ligamentum flavum ends laterally at the level of the facet joint.
- The ligamentum flavum is often hypertrophied in degenerative diseases of the lumbar spine.

NERVE ROOTS

- The nerve roots exit the spinal canal at the level of the corresponding pedicle.
- The L4 nerve root crosses the L3–L4 disk space and exits the spinal canal beneath the L4 pedicle before crossing the L4–L5 disk space.
- After exiting the foramen, the L4 nerve root crosses the L4–L5 disk space at its lateral margin (see Fig. 41-1).
- Paramedian disk herniations affect the lower spinal nerve root, so an L4–L5 disk herniation would result in compression of the L5 nerve root.
- A foraminal disk herniation or an extraforaminal or far-lateral disk herniation at L4–L5 would compress the L4 nerve root.
- In far-lateral disk herniation, extruded disk lies beyond the lateral intervertebral space, outside the facet.

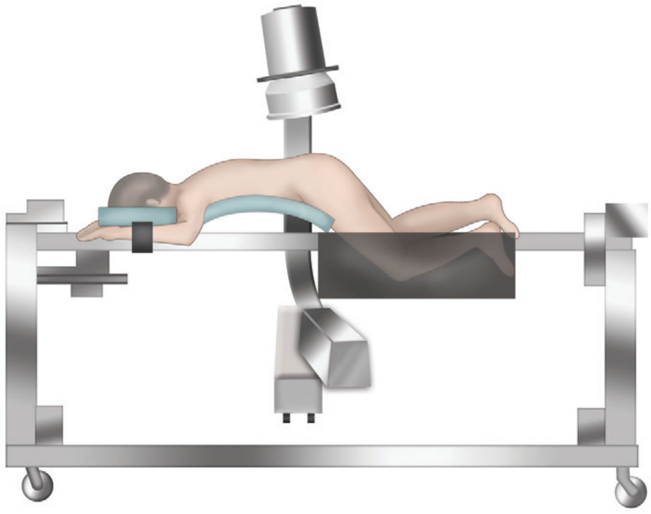

Figure 41-3 Positioning for far-lateral and open standard microdiskectomy. Patient is placed in a prone position, often with a Wilson frame. C-arm fluoroscopy may be used for localization.

Equipment

- Operating table, Wilson frame
- Fluoroscopy/C-arm
- Headlight
- Operating loupes
- Operative microscope
- High-speed drill
- Kerrison rongeurs
- Bipolar cautery

Positioning/Preparation

Before skin incision, administer prophylactic intravenous (IV) antibiotics. General or local anesthesia may be used, but general anesthesia is preferred, because it allows for control of both the airway and hemodynamics, especially in a prolonged case. Place the patient in a prone position. In some cases, it is acceptable to use a slightly flexed lateral decubitus position. A Wilson frame provides reduction of intraabdominal pressure and subsequent epidural venous congestion and bleeding, and it splays the lumbar spinous processes and interspaces (Fig. 41-3). Large gel rolls may be used for support in lieu of the Wilson frame. Fluoroscopic or radiographic imaging is used for localization to make the most accurate skin incision directed over the interspace.

Midline Open Lateral Diskectomy

Intraoperative radiography is used to make a 2- to 3-cm marking for a midline incision over the interspace of interest. The incision is carried through skin and subcutaneous tissue to the level of the spinal fascia (Fig. 41-4). Monopolar electrocautery or a scalpel is used to dissect through midline fascia paramedian to the spinous process on the side of

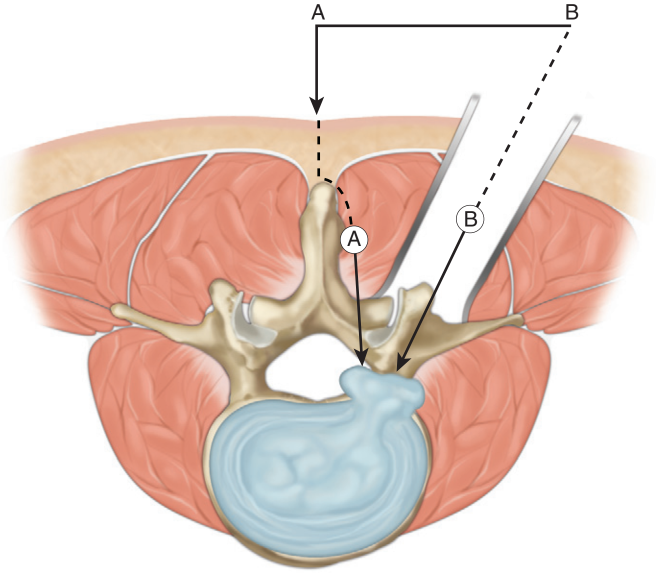

Figure 41-4 Surgical approach for diskectomy via transverse cut. **A,** Midline standard microdiskectomy, dissecting muscle free from midline and lateral retraction of muscle. **B,** An approach from a far-lateral position by a muscle-splitting route.

approach. Subperiosteal elevation of the paraspinal muscles off the spinous process and lamina is performed. Dissection is performed to the lateral edge of the lamina with care to avoid injury to the facet joint capsule. The surgeon must ensure that dissection occurs in the periosteal plane to minimize trauma to the paraspinous muscle and to prevent subsequent bleeding. The dissection should include half of the lamina both above and below the interspace. Lateral dissection proceeds over interlaminar and interspinous spaces to the border of the medial facet joint (Fig. 41-5, *A*). A self-retaining retractor is inserted for exposure.

BONY DECOMPRESSION

The surgeon should confirm the level of interest with a second radiograph before any bony removal at this point. After the level has been confirmed, use a high-speed drill to remove the inferior edge of the superior lamina overlying the disk space. Although it is possible to skip the hemilaminotomy when the interlaminar space is wide, adequate exposure should be obtained to provide adequate visualization and to minimize the need for any nerve root retraction.

Strip the ligamentum flavum from beneath the superior lamina of the inferior level using a curette and follow with removal of the ligament with Kerrison rongeurs (see Fig. 41-5, *B* through *D*). The nerve root lies inferolaterally. A coarse diamond drill may be used under microscope in place of, or in conjunction with, a curette or rongeur for removal of bone. The medial portion of the ligamentum flavum overlying the thecal sac is usually preserved.

DISK REMOVAL

The ligament is opened sharply with a scalpel and is either excised or removed piecemeal with a rongeur (see Fig. 41-5, *E*). The epidural space underlies this region and contains a variable amount of fat covering the dura of the thecal sac medially and the nerve root inferior and lateral to the thecal sac. Identify the traversing nerve root early to prevent nerve root injury. Bipolar cautery can be used to coagulate epidural veins and shrink epidural fat after clearly identifying the exiting nerve root. The disk space may be palpated by probing the dorsal vertebral body with a Penfield dissector or nerve hook. At this point, confirm an appropriate interspace with radiography if desired.

Inspect the nerve carefully before diskectomy, and clearly visualize the lateral edge of the nerve root to avoid durotomy and nerve injury. The epidural space around the nerve root is dissected free of any adhesions to the ventral epidural space or the herniated disk to allow for mobilization and retraction of the nerve root if necessary. Free fragments of disk may be located beneath the exiting nerve root, either caudally or rostrally, in relation to the interspace. If a disk fragment is found, it should be removed before retraction of the nerve root to prevent injury to the root by retracting a root that is already mechanically deformed and compressed by a herniated disk fragment. Some surgeons do not enter the disk space if a large free fragment is found; however, to minimize the likelihood of recurrent herniations, we typically enter the space and attempt to remove loose fragments that come out easily (see Fig. 41-5, *F*).

To do this, enter the disk space sharply using a scalpel. A small window is made in this manner through the annulus to allow access into the disk space. Up- and down-facing right-angled curettes and various sizes of pituitary rongeurs are used to perform the diskectomy (see Fig. 41-5, *G*). It is very important to avoid violating the anterior annulus to avoid vascular injury. Inspect the visible course of the nerve and also palpate it with blunt, right-angled instruments (e.g., Woodson dissector) into the lateral recess and neuroforamen to ensure adequate decompression.

CLOSURE

Irrigate the disk space with an angiocath before closure to flush out any free intradisk fragments. The foramen may be palpated to assess for foraminal narrowing as a result of bony overgrowth or disk protrusion. If needed, a foraminotomy can be performed at this point to further decompress the nerve. Copiously irrigate the wound and use bipolar cautery as necessary to achieve hemostasis.

The surgeon may consider placement of a topical epidural steroid and anesthetics over the surgical site. We often placed a mixture of Kenalog, Duramorph, and Avitene over the epidural space at the surgical site. To avoid postoperative expansion of the Gelfoam, which can lead to mass effect on the nerve root and thecal sac, avoid placement of Gelfoam in the epidural space. Finally, the fascia of the lumbar musculature, dermis, and skin are closed anatomically as separate layers.

Transmuscular Far-Lateral Diskectomy

Localization of a far-lateral disk, beyond the lateral intervertebral space, requires extensive muscle retraction from a midline approach (see Fig. 41-4).

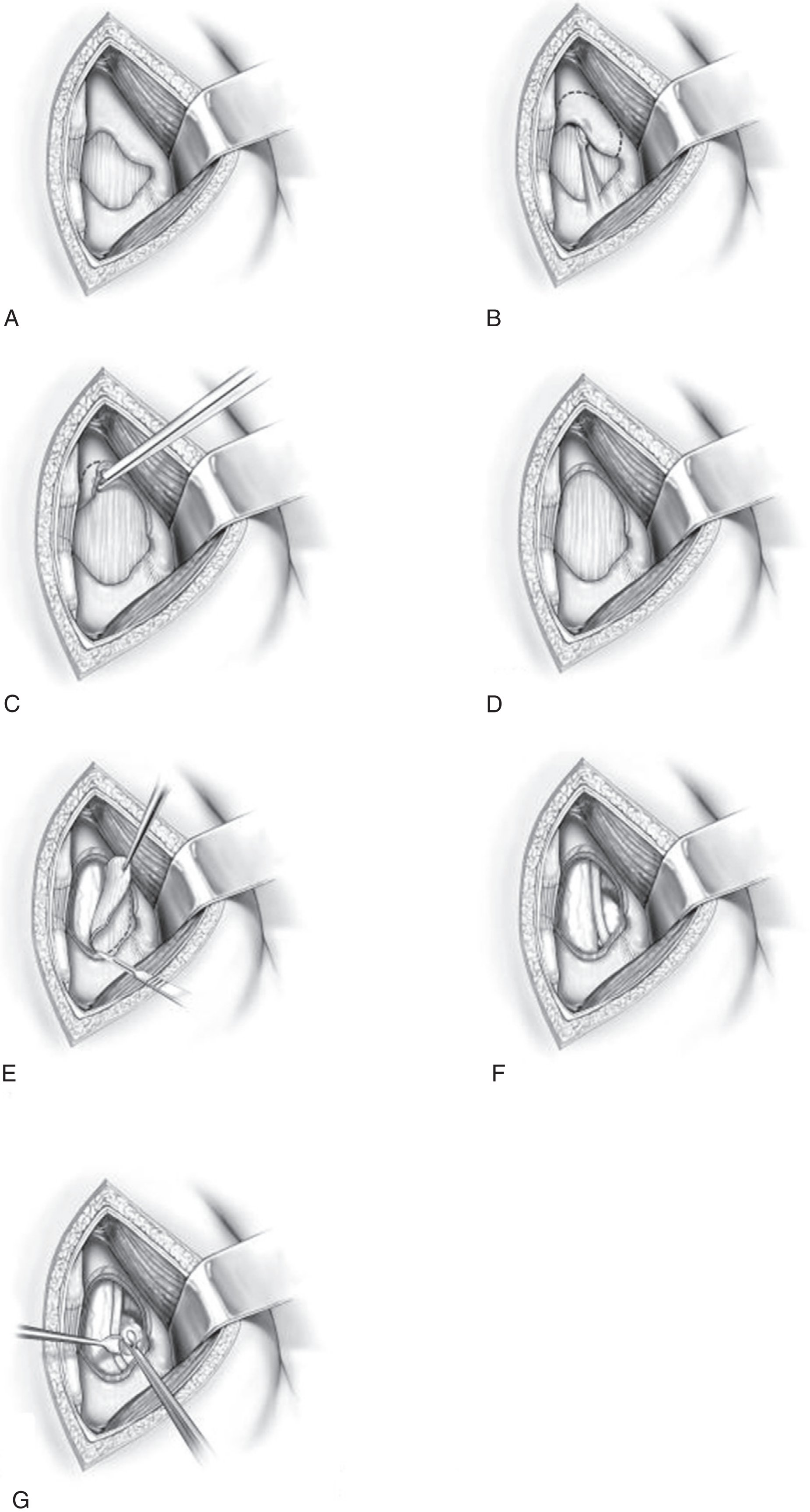

Figure 41-5 Midline open lateral diskectomy. **A,** Dissect laterally to expose half of each lamina above and below the interspace, as well as the entire intralaminar and intraspinous space, out to the medial facet joint. **B,** Strip the ligamentum flavum from beneath the superior lamina of the inferior level using a curette. The medial portion of the ligamentum flavum is usually preserved. **C** and **D,** Complete the hemilaminotomy, removing the lamina with a punch, such as a Kerrison rongeur. **E,** The ligament is opened sharply using a scalpel and is excised or removed piecemeal with a rongeur. **F,** To avoid potential recurrent herniations, enter the space and remove loose fragments and disk that come out easily. **G,** Use up- and down-facing right-angled curettes and pituitary punches to perform the diskectomy. It is critical that violation of the anterior annulus be avoided.

LOCALIZATION

The surgeon may localize with intraoperative radiography instead of plain radiography. Center the incision over the pars or isthmus of the affected level; it is useful at this point to mark the lateral and superior–inferior borders as seen on radiography. For example, for an L4–L5 lateral disk herniation with the L4 root affected, the upper and lower borders are the L4 transverse process and lower border of the L4–L5 disk space, respectively. Mark medial and lateral borders at midline and the lateral boundary of the pedicle (5 to 8 cm lateral), respectively. The incision is 3 to 4 cm in length and 3 to 6 cm paramedian over the L4 isthmus (Fig. 41-6, *A*).

EXPOSURE

Following skin incision, sharp dissection through the thoracolumbar fascia occurs first. Divide the superficial lumbar musculature longitudinally between the muscle fibers; specifically, incise the erector spinae aponeurosis longitudinally, and bluntly separate the multifidus and longissimus muscles. Following dissection, place a self-retaining retractor and define the surgical landmarks; include the isthmus, transverse process, facet joint, and intertransverse ligament (see Fig. 41-6, *B*).

Detach the intertransverse ligament from the rostral transverse process, and retract the ligament laterally. Using a high-speed drill, remove a crescent-shaped area of bone, including the angle between the superior aspect of the isthmus and the inferior portion of the rostral transverse process (see Fig. 41-6, *C*). Resection will allow for visualization of the ligamentum flavum and the inferior aspect of the pedicle underlying the transverse process. Resect the lateral ligamentum flavum using a Kerrison rongeur to expose the dorsal root ganglion of the affected nerve.

DISK RESECTION

At this point, the surgeon must visualize the nerve to avoid injuring it. The ganglion and the nerve are often displaced superiorly and laterally by the underlying disk herniation. Inspect medially, visualizing the nerve using a blunt microinstrument to gently retract the nerve in a lateral direction (see Fig. 41-6, *D*). Dissect lumbar arteries and veins free when possible from the lower foramen. Furthermore, trace the nerve distally to ensure no distal migration of the disk fragment has occurred.

Next, identify any free fragments or disk bulge medial and inferior to the exiting root. Incise the disk space sharply medial to the nerve to perform a limited diskectomy (see Fig. 41-6, *E*). Carefully examine the foramen, where the nerve exits below the pedicle, using a blunt nerve hook. Ensure no sequestered fragments are left in the foramen.

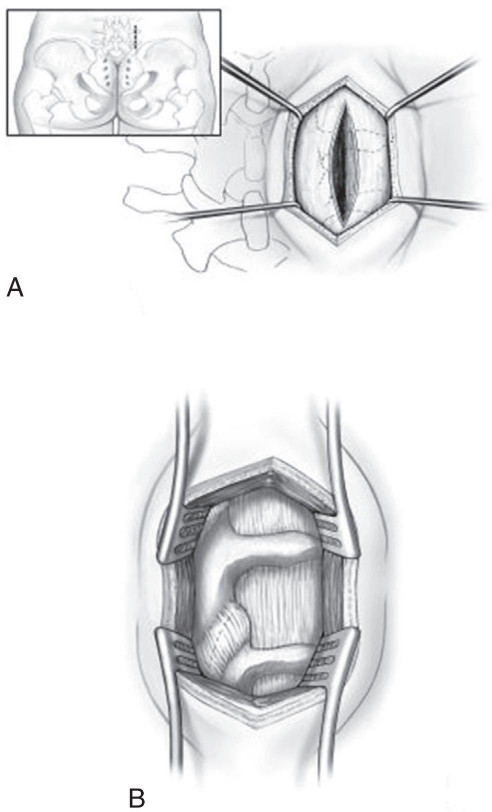

Figure 41-6 Far-lateral diskectomy. **A,** Begin with confirmation of the level with fluoroscopy and a 3- to 4-cm skin incision 3 to 6 cm off the midline centered over the pars interarticularis. **B,** Surgical landmarks—including the isthmus, transverse process, and intertransverse ligament—are clearly defined. **C,** Use a high-speed drill to remove a crescent-shaped area of bone that includes the angle between the superior aspect of the isthmus and the inferior portion of the rostral transverse process.

CLOSURE

Irrigate the wound copiously, and reapproximate the musculature; suturing is not required for musculature. Close the fascia, dermis, and skin anatomically as separate layers.

Minimally Invasive Tubular Microdiskectomy

LOCALIZATION

Localize placement of the dilators and retractor with fluoroscopy. Place incisions at 16 to 26 mm in length at 1 to 2 cm paramedian to the midline for paramedian or central disk herniations. For extraforaminal or far-lateral disk herniations, place incisions 16 to 26 mm in length 3 to 5 cm paramedian to midline.

EXPOSURE

Infiltrate the skin and paraspinal muscles with lidocaine and epinephrine for analgesia and to minimize blood loss. Incision is made through the skin and thoracolumbar fascia with sharp dissection using a knife or Bovie.

Exposure of the spine is achieved through blunt muscle-sparing dissection using serial placement of dilators (Fig. 41-7). Visualize the dilators under direct vision with fluoroscopy, and to prevent inadvertent entrance into the spinal canal, avoid using a Kirschner wire (K-wire) to guide the dilators. Place dilators to the intended depth to minimize muscle creeping and need for resection of muscles in the subsequent stages of the surgery. The surgeon must then maximize the visualization of the anatomy within the tubular retractor (Fig. 41-8). Once the bony exposure of the spine is visible within the tubular retractor, hemilaminotomy and diskectomy are performed in similar fashion as in open exposure.

COMPLICATIONS

Complications include durotomy, wound infection, diskitis, nerve root injury, and hematoma.[2,25-28] Among these complications, durotomy is the most frequent complication, with an incidence between 1% and 17%.[2,25-28] If primary repair of dura during surgery is unsuccessful, subsequent cerebrospinal fluid leakage may be associated with spinal headaches and pseudomeningocele formation. Reoperation for attempted closure of the dura versus a lumbar drain placement should be considered if the leak does not spontaneously resolve.

Reported rates of diskitis are uncommon and range from 1% to 5%.[26,28] Nerve root injury is rare, from 0.03% to 1.4%.[25,28] Of note, reoperation for a herniated lumbar disk has been associated with higher rates of durotomy, spinal hemorrhage, and nerve root injury.[28] Reoperation is required for recurrent extruded disk in 2% to 8% of patients.[25,27,29-31]

POSTOPERATIVE CARE

Provide physical therapy to encourage mobilization and allow physical activity and ambulation as tolerated. Although not mandatory, encourage avoidance of excessive strain or lifting for the first 6 to 8 weeks after surgery.

Acknowledgment

We acknowledge Arthur Ulm III, Erich Richter, David Peace, and Jeffrey Henn, authors of the previous edition of this chapter, for providing the foundation and multiple figures for the current chapter.

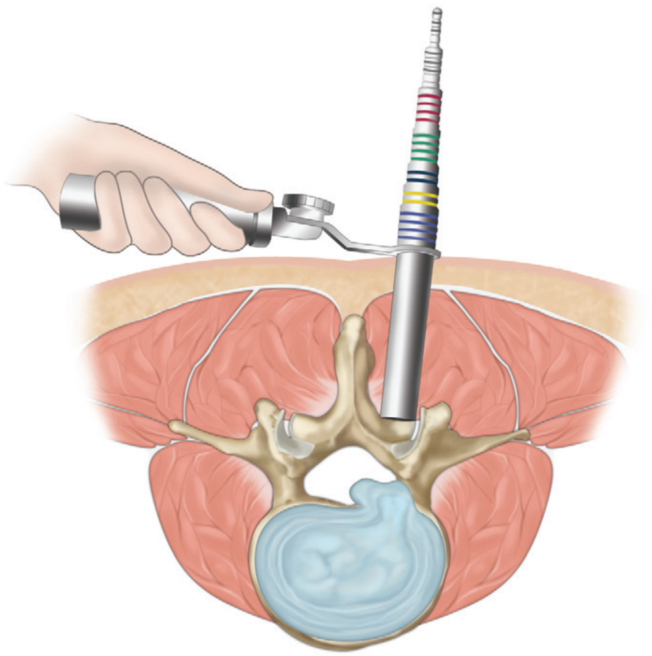

Figure 41-7 Serial dilation of tubular retractors to achieve muscle dissection and exposure of the spine.

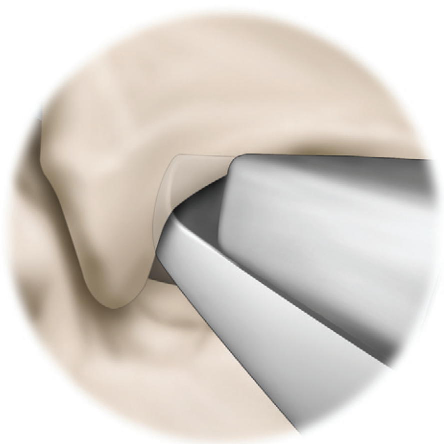

Figure 41-8 Following maximal exposure using tubular retractors, bony decompression is similar to that of an open procedure.

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42 Percutaneous and Endoscopic Diskectomy

GUN CHOI, SANG-HO LEE, and ABHISHEK KASHYAP

"Do not use a cannon to kill a mosquito."

CONFUCIUS

Overview

The understanding of preserving normal tissues to achieve surgical goals drives surgeons to adapt to minimally invasive spine surgery. The current posterior microscopic lumbar diskectomy is still considered a gold standard procedure all over the world because of its low morbidity and high success rate, but it is associated with muscle dissection and bone removal, which may create muscle weakness and instability and also may cause epidural scarring.

The surgeon should recognize that lumbar disk herniations can be managed by percutaneous endoscopic techniques to reach the disk pathology but limit tissue damage and further consequences of this tissue damage. Kambin and Sampson[1] and Hijikata[2] performed the initial nonvisualized posterolateral nucleotomy, and Kambin also described and illustrated the working zone of percutaneous endoscopic lumbar diskectomy (PELD). All the earlier percutaneous procedures concentrated on nonvisualized diskectomy to indirectly decompress the nerve root, and this was largely due to unavailability of working-channel endoscopes.[1-3]

In 1997, Tsou and Yeung[4] introduced the rigid rod-lens integrated working-channel endoscope. This allowed diskectomy with uniportal access under constant visualization. Because of recent advances in technology—refinement of optics, better mechanical instruments, bipolar flexible radio frequency (RF) electrodes, endoscopic lasers, and endoscopic burrs—the technique is being continuously refined to increase access to almost all types of disk herniations. The working cannula is now placed closer to the epidural space and the base of the herniation, allowing the surgeon to selectively target the extruded disk herniation.[5]

In recent times, surgeons have described different approaches to increase the success of PELD by targeted placement of the cannula to increase visualization and targeted decompression.[6,7] The transforaminal access is limited in certain situations at L5–S1. In such cases, an interlaminar PELD is done to address the herniated disk at this level.[8,9] The results of endoscopic diskectomy are comparable to microscopic diskectomy with the added benefit of reduced tissue damage, fewer complications, less epidural scarring, and an earlier return to work.[10-13] Recently, access to the difficult L5–S1 disk has been described through a transiliac route and migrated herniations.[14-16] In this chapter, we will describe the anatomy, surgical technique, and technical advances for percutaneous endoscopic diskectomy.

Surgical Anatomy

Percutaneous endoscopic diskectomy is usually performed through the intervertebral foramen (IVF). Rarely, for the L5–S1 disk, it might be difficult to achieve a trajectory through the IVF to the herniation because of anatomic constraints: high iliac crest, large facet joint, large ala, and narrow foramen.[17,18] The interlaminar access can be used for diskectomy. The anatomy pertinent to the IVF and interlaminar access is described for effective percutaneous endoscopic diskectomy.

TRANSFORAMINAL APPROACH

The IVF is the gateway for a transforaminal approach. It is formed by two mobile joints: the intervertebral disk and the zygapophyseal joint (Fig. 42-1, *A*). The dimensions of the foramen change dynamically from each level and from ongoing degenerative diseases of the disk.

The IVF from L1 to L4 is more the shape of an inverted pear, and at L5, it is more oval. The superior–inferior dimensions of the IVF are greatest at L2–L3. This length decreases as we move caudally, with the shortest lengths found at L5–S1. The anterior–posterior (AP) dimensions change from 7 mm at L1–L2 to 9 mm at L5–S1.[19,20]

The boundaries of the foramen are (see Fig. 42-1, *A*):

- Roof: Inferior vertebral notch of the pedicle of cephalic vertebra, outer free edge of ligamentum flavum
- Floor: Superior vertebral notch of the pedicle of caudal vertebra, posterior margin of the inferior vertebral body
- Anterior wall: Posterior aspect of adjacent vertebral bodies with their disk, lateral expansion of the posterior longitudinal ligament (PLL) and anterior longitudinal venous sinus
- Posterior wall: Superior and inferior articular process of corresponding facet joint and lateral prolongation of ligamentum flavum
- Medial wall: Dura
- Lateral wall: Fascia overlying the psoas muscle

The IVF contains (see Fig. 42-1, *B*):

- The exiting nerve root with the dural sleeve
- Lymphatic channels

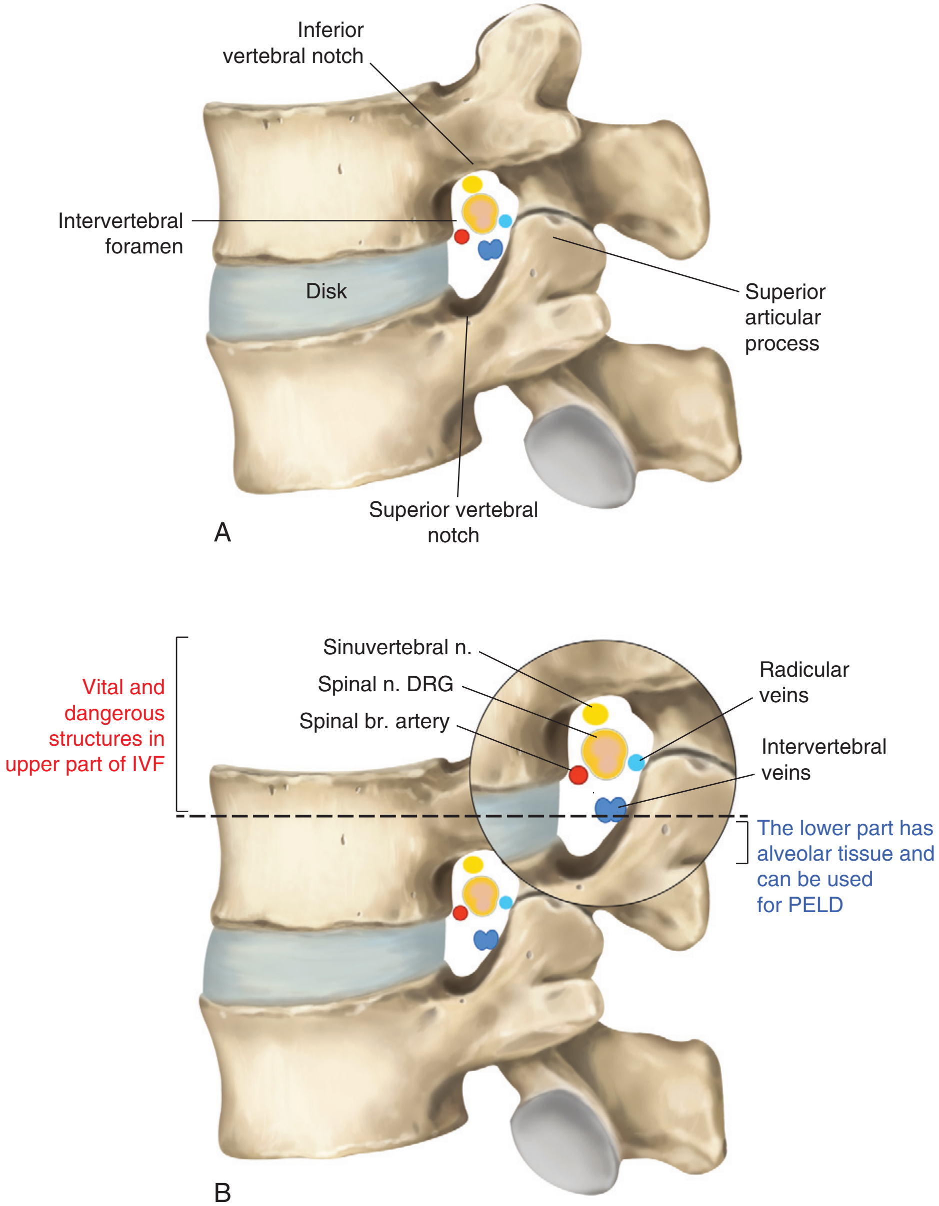

Figure 42-1 Anatomy of the intervertebral foramen (IVF). **A,** Osseous anatomy of IVF. **B,** The structures passing through the IVF. The neural tissue occupies almost 30% to 50% of the IVF in upper part, but the lower part is free of vital structures, and it allows safe placement of the working channel for percutaneous endoscopic lateral diskectomy (PELD). *DRG,* Dorsal root ganglia.

- Segmental artery
- Communicating veins between internal and external venous plexi
- Recurrent meningeal (sinuvertebral) nerves
- Adipose tissue
- Ligaments

The nerve root or the dorsal root ganglia occupy the upper part of the foramen. This neural tissue may occupy 30% to 50% of the IVF in the upper part.[21] The lower part is available for safe placement of the working cannula. The surgeon should always review foramen anatomy on both computed tomography (CT) and magnetic resonance imaging (MRI) scans before the procedure. It is important to review the foraminal sagittal MRI for abnormal large vessels in the lower part of the foramen, because if these are present, this vessel configuration will *not* provide a safe corridor to approach the disk; however, the success of the PELD does not depend on identification of these foraminal ligaments.

Triangular Safe Zone

A safe area for access to the herniated disk lies between the exiting and traversing nerve root. Kambin described this triangular safe zone in 1991 as being the annular zone bordered anteriorly by the exiting root, inferiorly by the end plate of the lower lumbar segment, posteriorly by the superior articular process of the inferior vertebra, and medially by the traversing root (Fig. 42-2). The maximal safe area for insertion of the endoscopic sleeve is the medial end of the triangle (see Fig. 42-2, *inset*). The point of insertion is to be referenced according to accepted and best-visualized

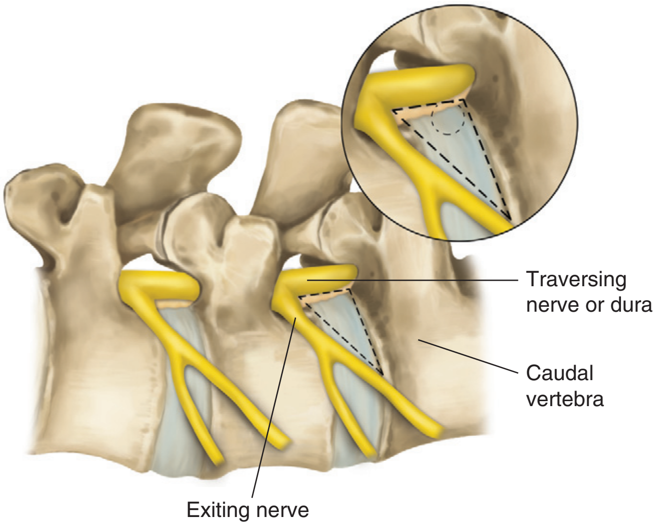

Figure 42-2 Kambin's safe triangular zone. The safe zone (*triangular outline*) is formed by the exiting nerve root (hypotenuse), the caudal vertebra (the base), and the traversing root/dura (height). *Inset:* The best placement of the cannula is on the medial aspect of the triangular zone.

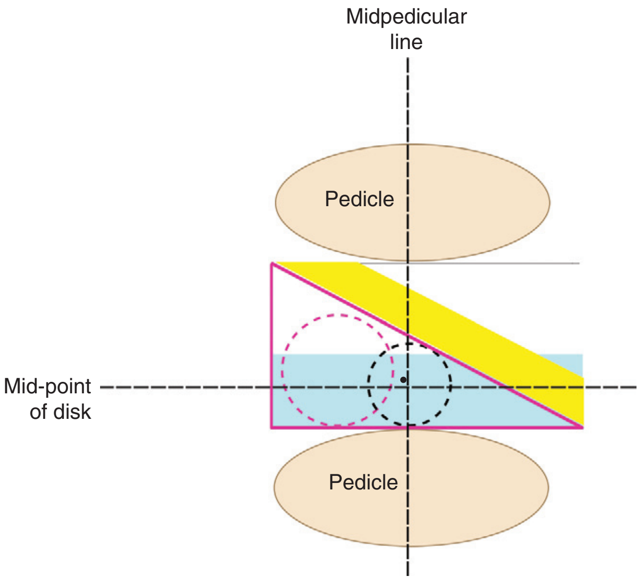

Figure 42-3 Mirkovic and colleagues studied the safe dimensions of the working cannula in cadaveric studies. A 6.3-mm cannula can be placed safely in the midpedicular line cephalad to the midline of the disk. A larger cannula can be placed eccentrically and medially.

radiographic landmarks for safe placement of a working cannula. Mirkovic and colleagues[17] investigated the IVF anatomy from L2 to S1 vertebrae to define the safe working zone and the largest working cannula that can be introduced. The average dimensions of the triangular safe zone were 18.9 mm wide and 12.3 mm in height with a 23 mm hypotenuse. A cannula with a diameter of 6.3 mm placed in line with the center of the pedicle and slightly cephalad to the disk midline or a 7.5-mm cannula placed in line with the medial one third of the pedicle and slightly cephalad to the disk midline provides safe and maximal intradisk access (Fig. 42-3).

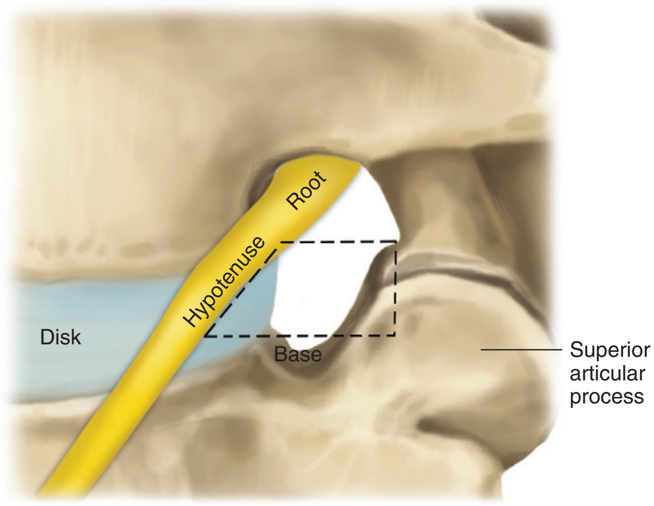

Figure 42-4 The working zone is a trapezoidal shape. Moving from upper to lower lumbar levels, the angle of the oblique side goes on decreasing, and the dimensions of the base go on increasing; therefore the cannula should be placed posteriorly in the intravertebral foramen, scraping the facet joint at lower lumbar levels.

In another cadaveric study, by Wimmer and Maurer,[22] the maximum safe cannula diameter is 8 mm on average from L1–L2 to L3–L4 levels. From L4–L5 to L5–S1 the diameter decreases to 7 mm, which is attributed to disk degeneration at these levels. In actuality, the working cannula diameter can be greater if the cannula is placed eccentrically in the safe zone, and distraction by the cannula occurs in the disk space. In a recent cadaveric study, the triangular safe zone dimensions were determined by Choi,[20] wherein the height of the triangular safe zone was formed by the lateral zone of the thecal sac, not the medial pedicular line; the base was formed by the superior end plate of the inferior vertebra; and the hypotenuse was formed by the spinal nerve. The average dimensions were 13.41 mm wide by 26.8 mm high with a 25.49-mm hypotenuse. The triangle formed was right angled at the upper lumbar vertebrae and obtuse angled at the lower segments; this allowed larger diameter cannulas at lower lumbar levels compared with upper lumbar levels.

Min and colleagues[23] described the exit zone of the IVF in cadaveric dissection and stated that the actual working zone was not a triangle but rather a trapezoidal space bound by the superior articular process, the exiting nerve root on the sides, and imaginary lines parallel to the disk space (Fig. 42-4). Descending from upper to lower lumbar levels, the angle of the oblique side goes on decreasing, and the dimensions of the base go on increasing. The authors also recommended directly viewing the annulus endoscopically before blind annulotomy. The exiting nerve root is closer to the entry portal than the dura.[24] This should lead the surgeon to place the cannula more eccentrically at lower lumbar levels. It is also recommended to place the cannula close enough to the facet joint to scrape it to avoid nerve injury.[19]

Compared with the lower levels, at the upper lumbar level, at L1–L2 and L2–L3, the thecal sac lies against the medial wall of the pedicle.[25,26] The upper lumbar disk is also more concave compared with the lower disk. The surgeon should target the more medial disk (6 to 9 cm) that is steeper at upper lumbar levels. The surgeon should remain lateral to the midpedicular line to prevent dural sac damage (Fig. 42-5).

The surgeon should preoperatively evaluate the foramen morphology, because the hypertrophied facet joint and the bulging disk may limit the actual dimensions of the safe working zone. These anatomic variations of the safe zone and also the potential for any congenital root anomalies, low-lying root, or abnormal large vessel may further lead to distortion of the safe zone. So it is important that the surgeon perform the procedure with the patient under local anesthesia so as to continuously assess the patient physically (toe and foot movements) and observe the patient's pain response while placing the working cannula.

Endoscopic Anatomy

Compared with joint arthroscopy or other endoscopies, there is no well-defined cavity for spinal endoscopy. Therefore the surgeon must create a potential space to dissect toward the pathology. Because the access is through a bony window with vital neural structures, the surgeon must preoperatively define the target lesion and the trajectory to the pathology. The surgeon should be able to recognize these vital neural structures and differentiate them from other structures endoscopically. Doing chromodiskography with indigo carmine can identify the disk pathology and differentiate it from other structures.

If the surgeon is outside the disk in a transforaminal approach, the periannular tissue is encountered first. The surgeon can differentiate between periannular and epidural structures by recognizing certain features. The periannular structures consist of loosely woven fibrous tissue with some fatty tissue overlying it. The periannular fat is stationary compared with the epidural fat (Fig. 42-6, *A* and *B*). Once this periannular fat is cleared off with an RF probe (see Fig. 42-6, *C*), the superficial layer of annular fibers and lateral expanse of the PLL are visible, but the PLL cannot be differentiated (see Fig. 42-6, *D*). Surgeons routinely perform the inside-out technique, first entering the posterior part of the disk completely and making space within the disk space; next, the herniated disk is pulled into this space and is drawn out through the cannula, a technique that might be helpful in contained herniations. The endoscope shows nuclear tissue that resembles blue fluffy cotton. Compared with the annular tissue, the nucleus is tough; it lies in layers and does not melt with the RF probe.

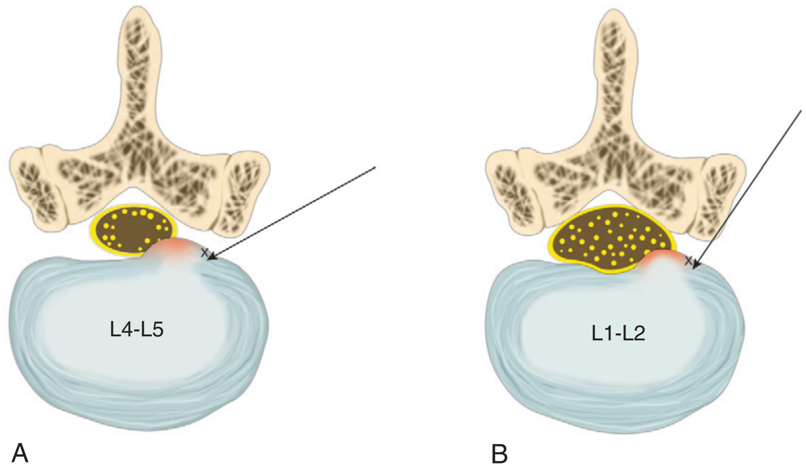

Figure 42-5 The entry point is different for upper and lower lumbar levels. **A,** The standard approach for lower lumbar herniations is at 20 to 30 degrees, with annular entry at the medial pedicular line. **B,** In upper lumbar levels, the approach angle is steeper, and the annular entry point is lateral to the midpedicular line to prevent dural injury.

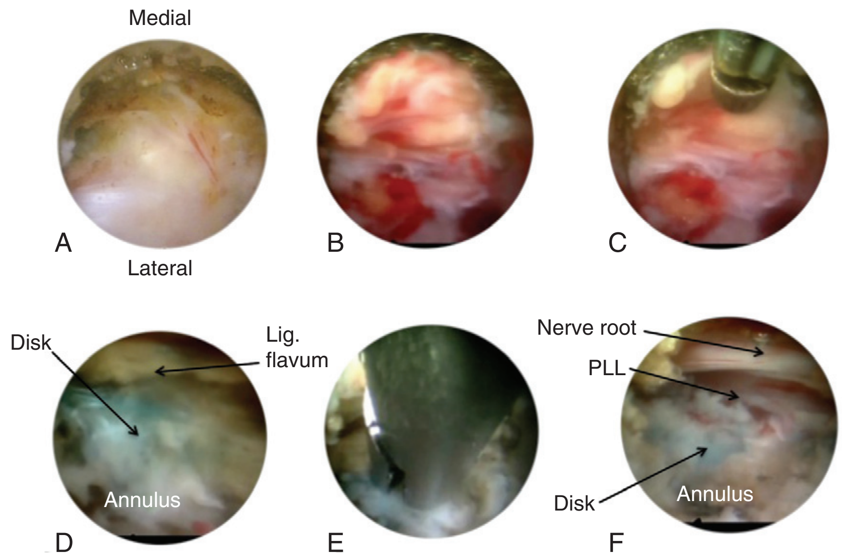

Figure 42-6 **A,** The periannular structures of loosely woven fibrous tissue with overlying stationary fat. **B,** The epidural fat keeps moving in and out of the cannula with respiration. **C,** Flexible bipolar radio frequency probe coagulating epidural vessels and fat. **D,** After releasing the fat and annular trap, the blue-stained disk fragment is observed and is ready to be removed. **E,** The blue-stained disk fragment is removed with disk forceps. **F,** The fully decompressed traversing nerve root and fluctuating dural sac are identified. PLL, posterior longitudinal ligament.

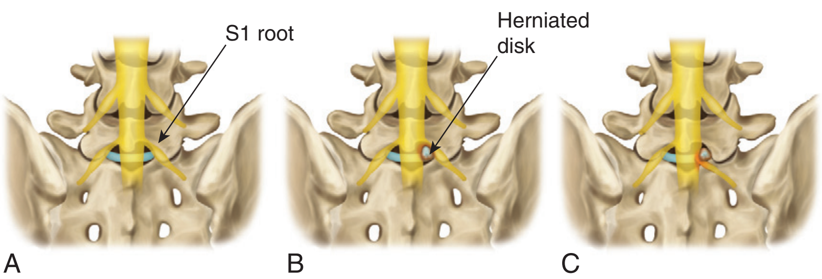

Figure 42-7 Pathoanatomy of intracanicular herniation at L5–S1. **A,** Axillary herniation is bordered by the thecal sac medially and the S1 nerve root laterally. **B** and **C,** Shoulder herniation is bordered by the S1 nerve root medially and the S1 pedicle laterally.

INTERLAMINAR APPROACH

The interlaminar PELD at L5–S1 is feasible because of the peculiar anatomy at this level. Ebraheim and colleagues[27] found that the interlaminar width and distance is greatest at L5–S1, and the free space in the spinal canal is also greatest there, because it contains only the thecal sac and sacral nerve roots. The ligamentum flavum is a 2- to 6-mm thick yellow structure that spans the interlaminar space. It is thinnest at this level and is the only barrier for the epidural space. The ligamentum flavum is an active ligament that has an essential biomechanical role, and it is an active barrier for the thecal sac.[28,29] Therefore the integrity of this ligament must be preserved. The wide interlaminar space and the thin ligamentum flavum allow easy passage and maneuverability of the working channel at this level. On withdrawal of the working channel, the opening in the ligamentum flavum spontaneously closes and restores its function as a protective barrier.

The other most important feature at this level is the peculiarity of the S1 nerve root anatomy. In cadaveric dissection, the relationship of origin of lumbar spinal roots to the intervertebral disk was studied.[30] It was found that the S1 nerve root originated above the level of the L5–S1 disk in 75% of cases and at that level in 25%, but it was never below that level. The angle of takeoff of the S1 nerve root from the thecal sac is relatively less than at the other lumbar levels.[31] All these features will contribute in the type of herniation at L5–S1. Thus the most common herniation here is axillary herniation, which displaces the nerve root far into the subarticular region and creates a potential space between the thecal sac and the nerve root (Fig. 42-7, *A*). Shoulder disk herniation at this level is relatively uncommon, but if present, it also provides access by pushing the nerve root medially (see Fig. 42-7, *B* and *C*).

Indications and Contraindications

INDICATIONS

Soft Lumbar Disk Herniation

- The ideal indication for transforaminal endoscopic diskectomy is an extraforaminal far-lateral disk herniation.
- Depending on the skill, this technique is useful for:
  - Recurrent herniation
  - Synovial cyst
  - Biopsy and débridement of diskitis
  - Foraminal stenosis

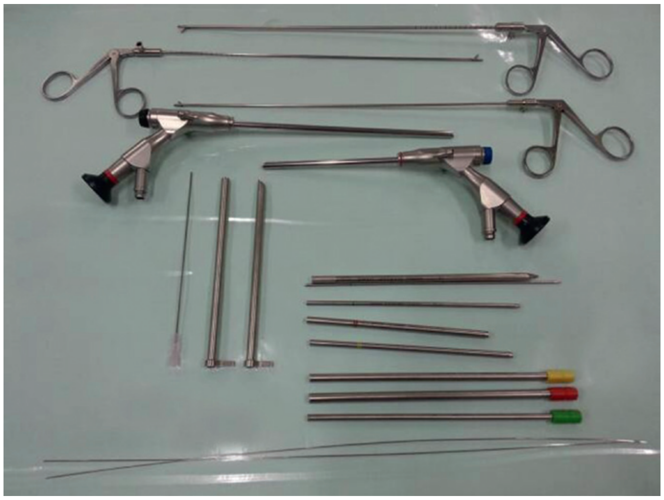

Figure 42-8 Equipment set for transforaminal endoscopic surgery includes forceps, endoscopes, spinal needle, working tubes, dilator, serial dilators, reamers, and guidewires.

RELATIVE CONTRAINDICATIONS

- Cauda equina syndrome
- Coagulopathy
- Instability

Operative Technique

EQUIPMENT (Fig. 42-8)

Spinal Endoscope

Anthony Yeung developed the first working-channel endoscope in 1997, and it was approved for use by the U.S. Food and Drug Administration (FDA) in March 1998. With a working-channel scope, the instruments are small and pass through the scope. These are off-axis scopes used to look around corners or edges at the depth of the operative field. An elliptical cross-section of the endoscope in a circular working cannula allows potential space for outflow of irrigation fluid. Recently, these endoscopes were modified to accommodate a large working channel, which allows passage of large-size forceps, chisels, and endoscopic burrs.

Instruments for Access

- Spinal needle/approach needle, 20 gauge 250 mm
- Guidewire, 1.8 mm in diameter
- Obturator/dilator with a blunt and tapered end to facilitate displacement of neural structures and prevent injury
- Working sleeve/cannula: hollow cylindrical sheath with an outer diameter of 7/8 mm and a working length of 165 mm (transforaminal endoscopy) or 145 mm (interlaminar endoscopy); cannula end may be beveled (intracanicular herniation) or round (extraforaminal herniation and migrated herniations)

Mechanical Instruments

- Diskectomy forceps, 2.5 mm or 3.5 mm
- Articulating forceps
- Probe
- Dissector
- Instruments for increasing access (foraminoplasty, bone cutting)
- Bone trephines, reamers
- Endoscopic drill and burr system

Electrosurgical Instruments

- Flexible RF trigger-flex bipolar probe (Elliquence, Oceanside, NY), a navigational cold electrocautery that causes minimal tissue destruction, used for hemostasis, tissue dissection, and annulopasty
- Lasers: Holmium yttrium-aluminum-garnet (Ho-YAG) laser preferably, a pulsed laser with minimal heat dissipation to surrounding structures; preferably a 90-degree side-firing kind to allow 360-degree reach under precision
- Endoscopy cart

PATIENT POSITIONING AND OPERATING ROOM SETUP

The PELD is performed on a radiolucent table (Jackson table); the patient is prone for a transforaminal PELD and is in the lateral decubitus position with the symptomatic side up for an interlaminar PELD. We prefer the lateral position for the interlaminar approach because it allows better holding of the scope, and dura is displaced to the opposite side by gravity. Epidural bleeding is also limited because of reduced abdominal pressure. The patient is draped with the lower leg and foot exposed to the surgeon's view for monitoring. The C-arm fluoroscopy is adjusted and is fixed such that the AP and lateral views are possible without moving the C-arm farther during the procedure, thus avoiding wasted time. The preferred AP view is the Ferguson view, in which both end plates are parallel. The assistant or technician preoperatively marks the skin lines for a predefined trajectory on the patient. The patient is draped, and the equipment is attached according to the operating room (OR) setup (Fig. 42-9). The surgeon should have unhindered access to both the C-arm image and the video from the endoscope (Fig. 42-10).

ANESTHESIA

To decrease the chances of iatrogenic nerve injury, we prefer to perform the procedure with the patient under combined local anesthesia and conscious sedation. The patient can provide real-time feedback to the surgeon by showing a pain response after nerve irritation by instrument pressure or retraction; the surgeon can either avoid the structure or adjust the placement. In doubtful situations, movement of the patient's toes and feet can help the surgeon confirm navigation and avoid nerve injury. This can be advantageous for elderly patients with comorbid conditions for general anesthesia.

The only significant pain generators during the procedure are the skin and the annulus. The skin, needle tract, and annulus are anesthetized by 1% lidocaine. The 1% strength is preferred for its quick onset and selective blocking of the sensory input but not motor responses. A transforaminal block is preferred for transforaminal access. We usually use a caudal block before the start of interlaminar PELD, because this provides sufficient time for the drug produce its effect (Fig. 42-11).

For conscious sedation, a combination of sedative and opioid analgesic is used; a short-acting sedation with continuous infusion is preferred. The conscious sedation begins by administering 3 mg (0.05 mg/kg) midazolam intramuscularly 1 hour before the procedure. If the patient is not feeling sleepy, half of the initial dose of midazolam is repeated in the OR. Remifentanil is preferred for its short duration of action (3 to 4 minutes); it is started as a continuous infusion at a dose of 0.1 μg/kg/min and is decreased

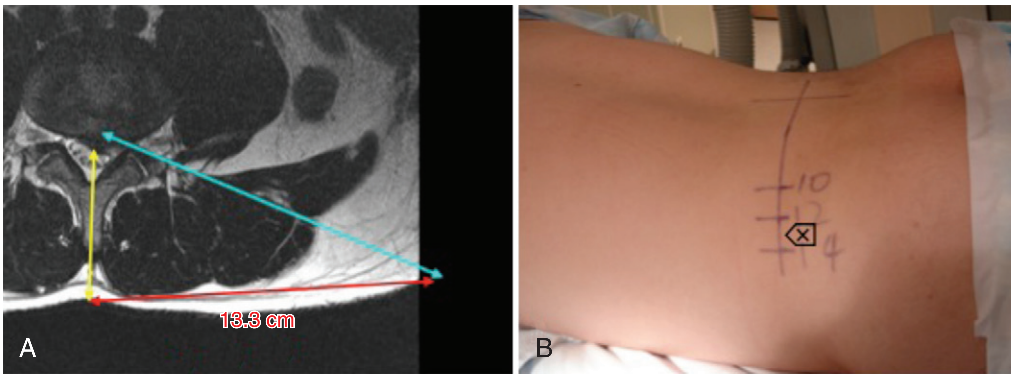

Figure 42-9 **A,** The approach trajectory is marked on the preoperative axial MRI image (*blue line*). The distance is measured on the skin surface (*red line*) from the midline (*yellow line*). **B,** The distance is marked on the patient; this represents the skin entry point for approach to the disk in PELD.

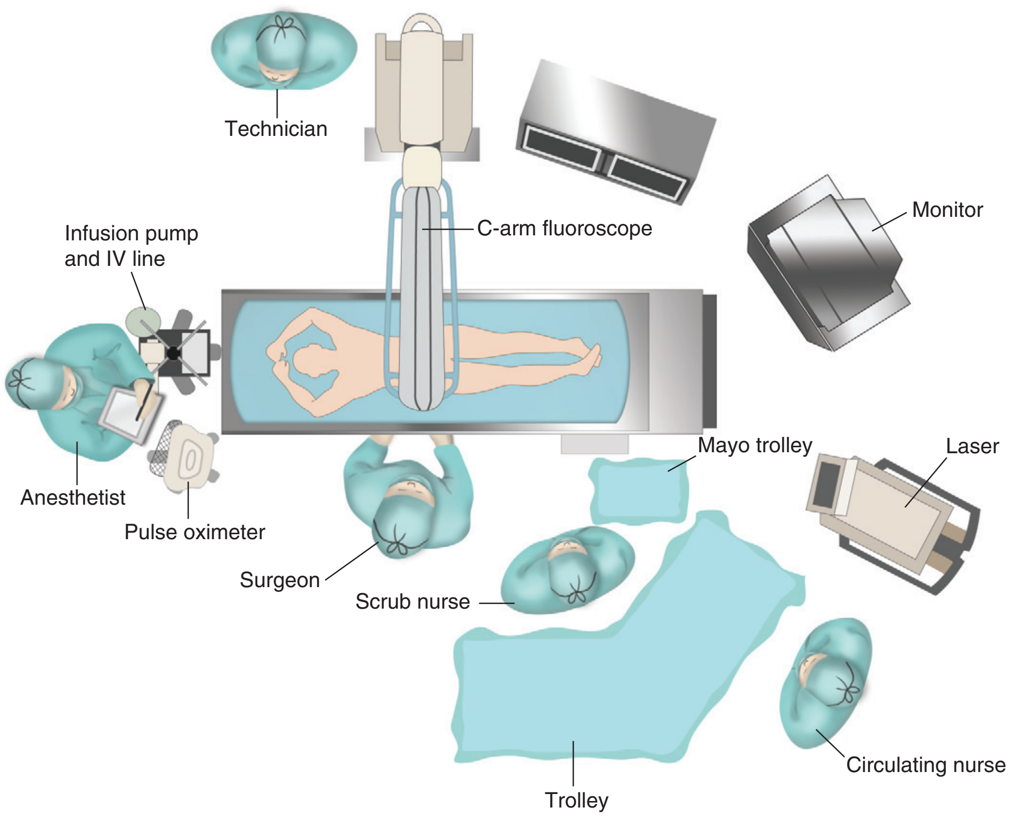

Figure 42-10 Operating room setup. The video and the image are placed opposite to the surgeon to ensure an unobstructed view to both images.

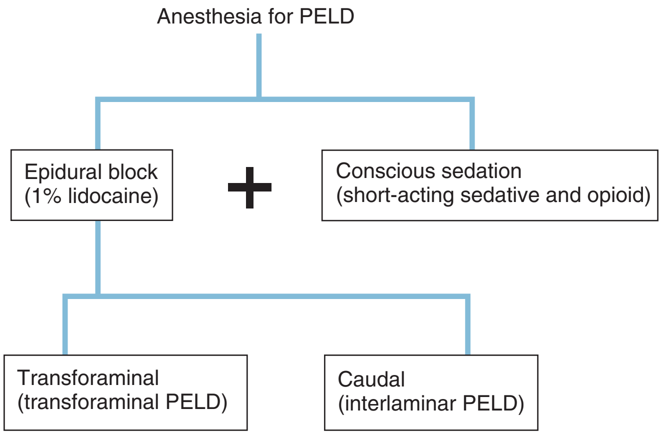

Figure 42-11 Anesthesia for percutaneous endoscopic lateral diskectomy (PELD).

to half after the annulus has been passed, the most painful part of the procedure.

SURGICAL TECHNIQUE

Transforaminal Endoscopy

PELD for Nonmigrated Herniations

STEP 1. NEEDLE INSERTION. After positioning and anesthesia, the most crucial step of the procedure is placement of the needle. The skin entry is determined on the axial MRI or CT images. The trajectory is marked on these images, avoiding the peritoneal contents to the target (herniation). This provides the distance from the midline to the skin entry point, and this is marked on the patient (see Fig. 42-9).

Once the starting point is determined, the skin window and subcutaneous tissue are infiltrated with 1% lidocaine. An 18-gauge needle is then inserted from the skin window along the desired trajectory, typically at a 25-degree angle to the floor (coronal plane), and it is passed anteromedially toward the target (Fig. 42-12, *A*). Infiltrating the needle tract with 1% lidocaine as the needle is advanced will anesthetize the tissue tract and prevent pain when the dilator is passed later in the procedure. The surgeon should continuously observe the AP and lateral views to reach the target, the posterior annulus (see Fig. 42-12, *B*); radiologically this coincides with the midpedicular line in an AP view and the posterior vertebral body in a lateral view (see Fig. 42-12, *C* and *D*). Before annular puncture, 2 to 3 mL of 1% lidocaine is infiltrated to aid in passing the obturator through the annulus without causing pain.

STEP 2. CHROMODISKOGRAPHY. The needle is advanced into the disk, and chromodiskography is performed by injecting a 2- to 3-mL mixture of radiopaque dye (Omnipaque), indigo carmine, and normal saline in a 2 : 1 : 2 ratio. Indigo carmine is a base that selectively stains the degenerated acidic nucleus and helps in identification of herniated fragments during endoscopic visualization.[32] The dye leaks through the annular tears into the epidural space with the direction concordant with the anatomic location of the ruptured fragment (see Fig. 42-12, *E*).

STEP 3. INSTRUMENT PLACEMENT. The needle is replaced with the guidewire, and the dilating obturator is railroaded

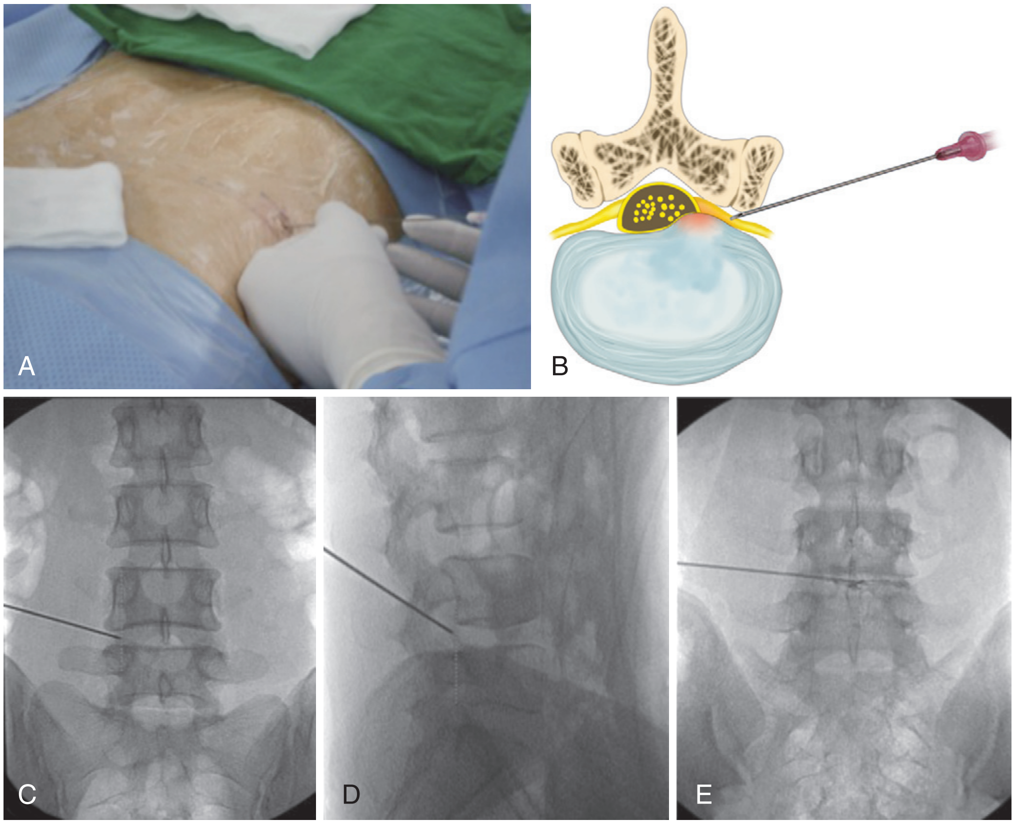

Figure 42-12 Needle insertion. **A,** The approach needle is inserted along the trajectory at an angle of 20 to 30 degrees under fluoroscopic control. **B,** Illustration shows the site of annulotomy at the medial pedicular line; the epidural block is given here. **C** and **D,** The anterior–posterior (AP) and lateral views show the target for annulotomy. The target is at the medial pedicular line for lower lumbar vertebrae and lateral to the medial pedicular line for upper lumbar vertebrae in an AP view. It is around the posterior vertebral body in a lateral view. **E,** Chromodiskography after annular puncture.

over to the annular window (Fig. 42-13, *A*). The fenestration is completed by manually advancing the blunt obturator, or a mallet, up to the center of the disk in AP view (see Fig. 42-13, *B*). The working cannula is passed over the obturator in a twisting manner, until it reaches deep in the annulus. The bevel faces dorsoinferiorly and also protects the exiting nerve root (see Fig. 42-13, *C*). If the patient complains of pain during passage, the cannula is passed with the open side facing the exiting nerve root, and it is rotated to face dorsoinferiorly once it passes the annulus. The obturator is replaced with the endoscope.

STEP 4. FRAGMENTECTOMY. Before the surgeon starts, the pathoanatomy of disk herniation should be understood. The lumbar disk herniates into the spinal canal either with a breach in the PLL or without a breach (subligamentous). The herniated mass is like an iceberg: the small herniated tip punches through the annulus and/or PLL ("tip of the iceberg") and a large part of the subannulus (below the "sea"). To achieve decompression, the annulotomy site is enlarged with a side-firing Ho-YAG laser and RF probe. The surgeon starts by creating a working cavity and identifying the annular tear. As described, the annular tear is enlarged, and the fragment is grasped and pulled into the working cavity and out (see Fig. 42-13, *D,* and Fig. 42-6, *D* and *E*). The surgeon usually starts working medially and withdraws the working channel until it reaches the medial pedicular line. The surgeon now can visualize the epidural space. If free fragments are suspected, they can be removed. A free-floating dural sac usually confirms adequate decompression (see Fig. 42-13, *E,* and Fig. 42-6, *F*).

PELD for Migrated Herniations. The surgeon should classify the herniation on T2-weighted sagittal MRI.[33] Regardless of whether it has extruded, herniations above or below the end plates are called *migrated herniations* (Fig. 42-14). The success of PELD depends considerably on appropriate placement of the working channel in an optimal trajectory to visualize and access the migrated fragment.[33,34] The surgeon has to visualize the epidural space for migrated herniation and uses a round cannula for migrated herniation, starting from initial placement of the cannula inside the disk and later moving to the epidural space, or initially placing the cannula in the epidural space. Sometimes the high, downmigrated disk cannot be retrieved by this optimal trajectory, in which case a foraminoplasty or open surgery might be required. This will be discussed later.

Technique of Interlaminar PELD

Step 1. Chromodiskography. The conventional posterolateral approach is used to perform the diskography initially with the patient positioned prone for axillary herniations. The patient is again positioned in lateral position before the start of the procedure; for reasons outlined earlier, we prefer the lateral position. Markings are made on the skin to

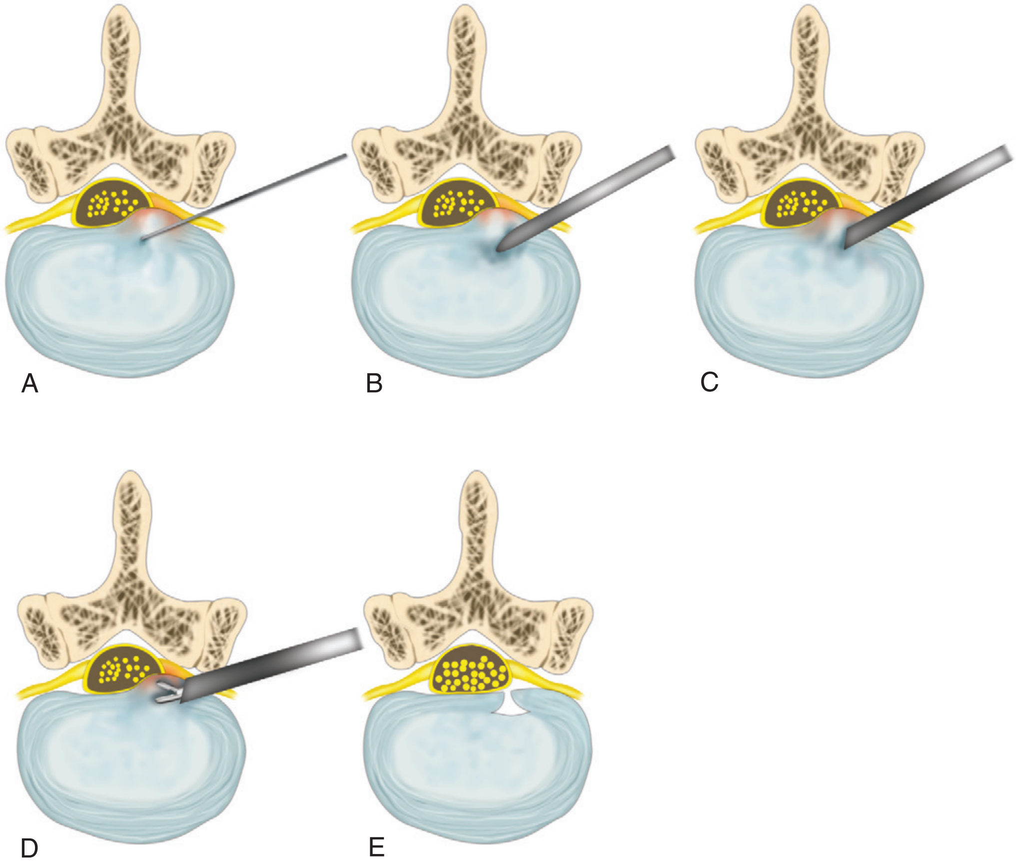

Figure 42-13 Steps of percutaneous endoscopic lateral diskectomy: the inside-out technique. **A,** The guidewire is passed through the needle after chromodiskography. **B,** The dilator is railroaded over the guidewire to the center of the disk in an anteroposterior view. **C,** The working cannula is placed with the bevel facing dorsomedially. **D,** The surgeon performs the diskectomy by working from medial to lateral, releasing the herniated mass from the annulus. After fragmentectomy, the surgeon levers the working channel to inspect the epidural space. **E,** The decompressed nerve after diskectomy.

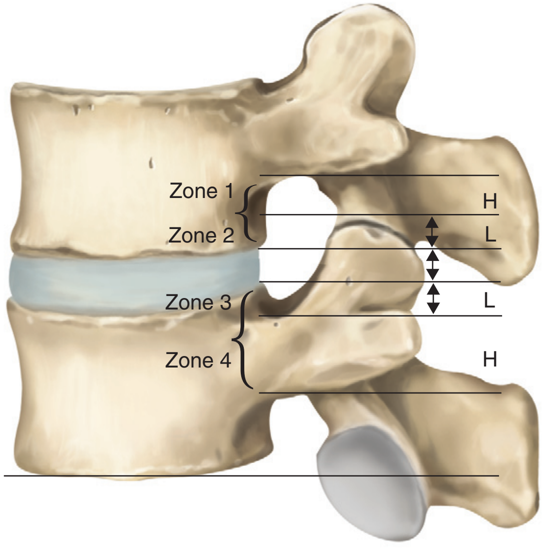

Figure 42-14 Classification of migrated disk herniation. The degree of herniation is classified into high (*H*) (zones 1 and 4) and low (*L*) (zones 2 and 3) relative to the posterior disk space.

outline the L5 and S1 landmarks. The superior edge of the S1 lamina and the inferior edge of the L5 lamina are visualized and marked, and the medial pedicular line of the S1 vertebra is marked on the symptomatic level (Fig. 42-15, *A* and *B*).

Step 2. Needle Insertion. As explained earlier, there are two types of intracanicular herniations at L5–S1, the *axillary* (most common) and *shoulder* types (see Fig. 42-7). The surgeon should recognize and differentiate between these two types of herniation on preoperative imaging. The other important point is to remember that the skin entry point is from the opposite side of the direction of the herniation (i.e., for an inferior migrated disk, a superior entry point, and vice versa; see Fig. 42-15, *C*).

AXILLARY HERNIATION. The skin entry is midway between the midline and the medial pedicular line and is closer to the superior edge of the S1 lamina. On the lateral view, the needle is targeted just below the superior end plate of S1 (see Fig. 42-15, *D*).

SHOULDER HERNIATION. The target is the shoulder of the S1 root, and the skin entry point is the most lateral area of the interlaminar space (see Fig. 42-15, *D*). The skin entry point and the tract are infiltrated with 1% lidocaine. Under continuous C-arm fluoroscopy imaging, the needle is passed into the epidural space (Fig. 42-16), with loss of resistance

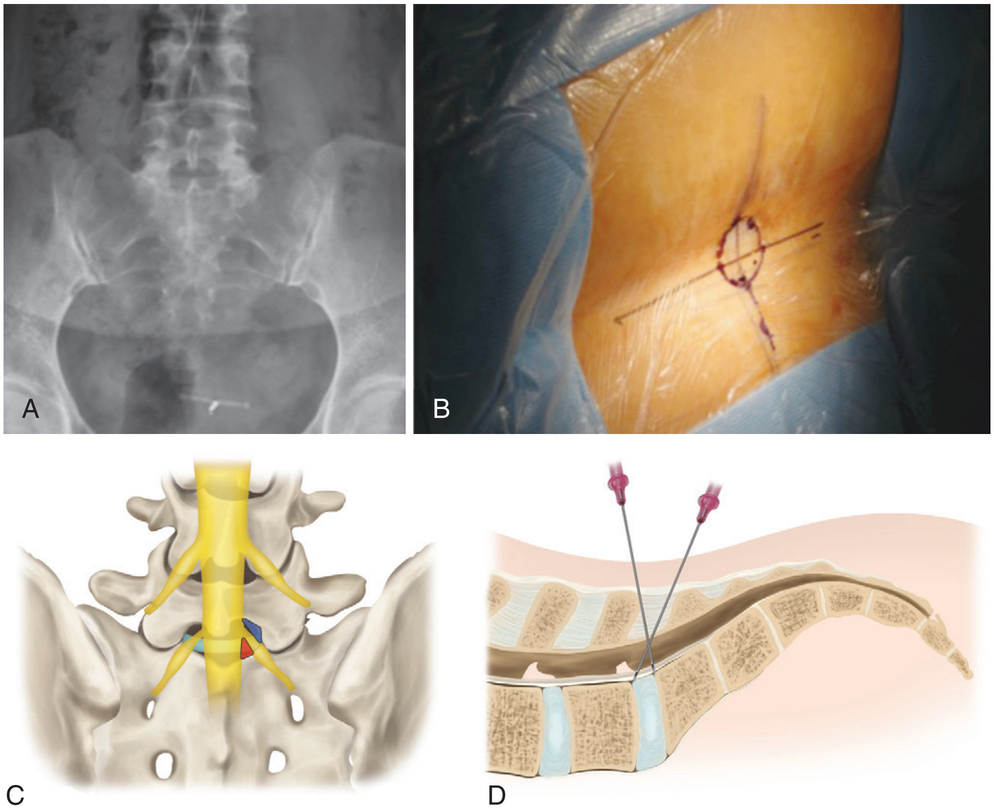

Figure 42-15 The interlaminar space is visualized under C-arm fluoroscopy (**A**) and is marked over the patient's skin (**B**). **C,** Needle insertion. The skin entry point is opposite the direction of the herniation. **D,** The needle is inserted near the midline in case of axillary herniation and near the S1 pedicle in case of shoulder herniation.

as the spinal needle enters the space. The position of the needle is confirmed by an epidurogram using radiopaque dye. After confirmation, an epidural block is given with 10 mL of plain 1% lidocaine. In case of shoulder herniation, the needle is passed into the disk space, and chromodiskography is performed.

Step 3. Instrument Placement. A guidewire is inserted through the spinal needle after removal of the stylet (see Fig. 42-16, *B*). A 0.7-cm incision is made on the skin over the guidewire and is followed by sequential dilation of the tract (see Fig. 42-16, *C*). It is important to confirm on lateral view that the dilators do not fall short of the ligamentum flavum (see Fig. 42-16, *D*). The working cannula is railroaded over the dilators, and the endoscope is introduced with continuous inflow of saline. The structures are identified to confirm whether the working channel is beyond the ligamentum flavum. The ligamentum flavum is identified as pale yellow fibrils running in a cephalocaudal direction (Fig. 42-17, *A*). The probe or the electrocautery is used to split the ligamentum flavum to gain entry into the epidural space. If the endoscope is already in the epidural space, the surgeon encounters the epidural fat as shiny yellow globules with small-diameter blood vessels (see Fig. 42-17, *B*).

Step 4. Fragmentectomy. The epidural fat is cleared with the RF probe. The surgeon can now recognize the neural tissue and the blue herniated disk tissue or the PLL (see Fig. 42-17, *C*). If the surgeon can localize the herniation and get a free space, the procedure can continue with removal of the fragment (see Fig. 42-17, *D*). Sometimes the herniation is anterior to the nerve root, and the space between the axilla is too small to place the working cannula without injuring the neural structure. In this situation, the surgeon again introduces the guidewire through the endoscope over the fragment up to the posterior surface of the S1 body. The endoscope is withdrawn, and again sequential dilators create working space over the guidewire; this creates a potential space between the neural structures. The working channel and the endoscope is again introduced. The surgeon can also use the beveled cannula as a nerve retractor by rotating the bevel opposite the nerve tissue (Fig. 42-18). The surgeon now encounters the blue-stained herniated tissue, which is removed. The S1 root is decompressed, and further adequacy can be confirmed by palpating the free course of S1 nerve root (see Fig. 42-17, *E* and *F*). The surgeon should always think and correlate with the amount of disk herniation at the end of the procedure. When the working cannula is withdrawn, the potential space in the ligamentum flavum closes automatically.

Techniques to Increase Access for Herniations

Extraforaminal Disk Herniation. The skin entry is relatively medial, and the approach angle is steeper. This allows the surgeon to avoid the exiting nerve root in foraminal herniation (Fig. 42-19).

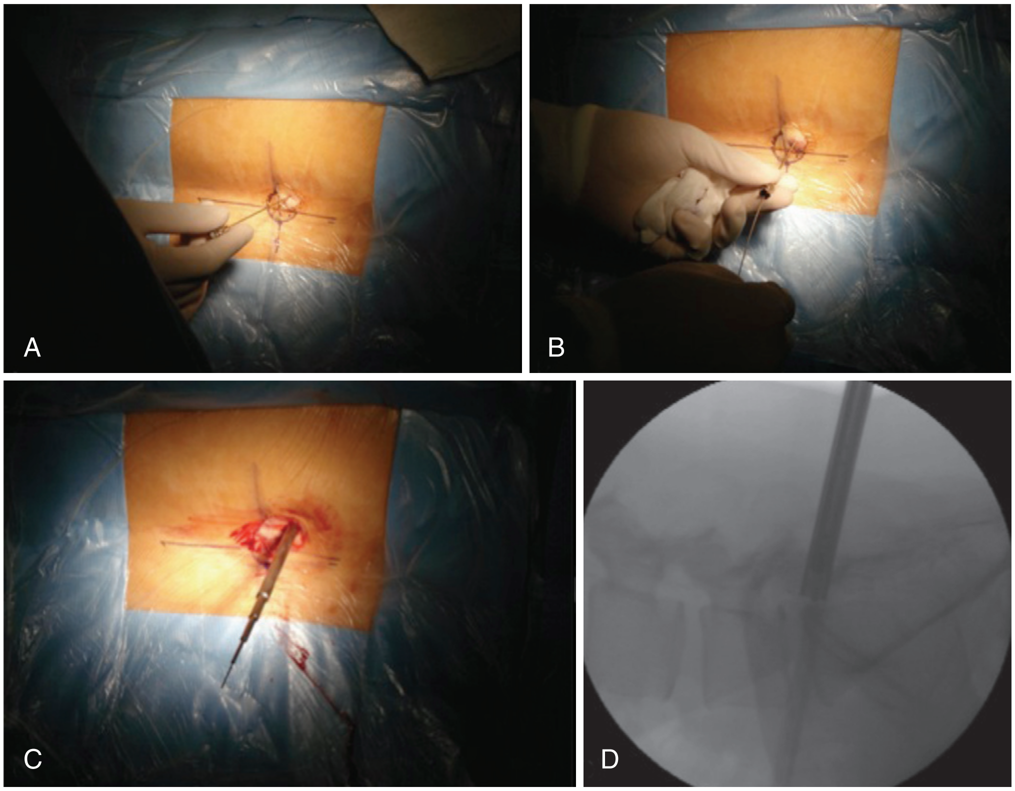

Figure 42-16 Instrument placement for interlaminar percutaneous endoscopic lateral diskectomy. **A,** The spinal needle is passed depending on the target. **B,** The guidewire is passed through the spinal needle. **C,** Serial dilators are railroaded over the guidewire. **D,** Lateral view to confirm that the cannula is on the ligamentum flavum.

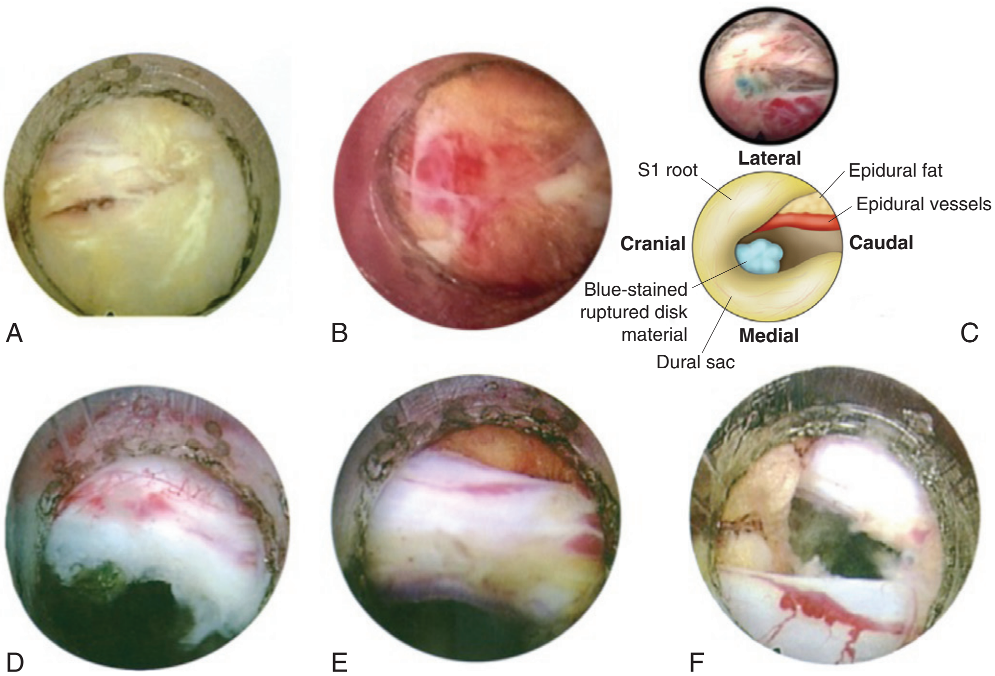

Figure 42-17 Endoscopic view of interlaminar percutaneous endoscopic lateral diskectomy. **A,** The first structure visualized may be the ligamentum flavum, which is split by a probe. **B,** On entering the epidural space, sometimes it is identified with the epidural fat—small, shiny globules of fat interspersed with tiny vessels. **C,** After coagulation and advancing the cannula, the blue-stained disk material or the posterior longitudinal ligament (PLL) is identified. The inset shows an illustration of the above figure. **D,** After fragmentectomy, the free edge of the PLL is seen. **E,** The nerve root is identified and can be seen decompressed. **F,** On further withdrawal, the decompressed S1 nerve root is visible; vacant space is present in the axilla and the dura.

Highly Downmigrated Herniations. The success of the PELD depends on achieving a safe target to visualize the herniated disk fragment. In zone 4 herniations, the natural bony obstacles, such as the superior articular process (Fig. 42-20), hide the herniated disk. Foraminoplasty can allow positioning and access to these difficult herniations with undercutting of the ventral (nonarticular) part of the superior facet. Foraminoplasty can be achieved by using bone trephines under fluoroscopic guidance or with an endoscopic drill.

Complications

Most of the complications that occur in PELD are due to a wrong trajectory toward the target (Table 42-1). The surgeon should study the preoperative imaging, both to define the effective trajectory and also to ensure the trajectory is followed by frequently observing the C-arm images. The most important structure that could be injured is the exiting nerve root; injury to this structure can occur while placing the needle and the working channel. Aiming at the facet and using the facet to graze into the foramen can avoid this injury. The other important point to be stressed is that performing the procedure under local anesthesia and conscious sedation can increase the safety of the procedure. Any undue pain during the procedure points out that the surgeon is near or on the neural structure.

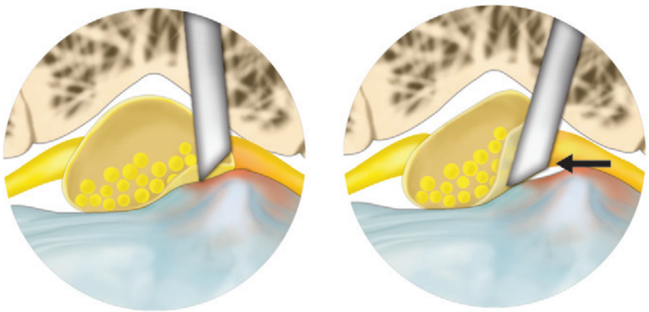

Figure 42-18 The working channel can be used as a nerve retractor to protect the nervous structures.

Major vascular trauma can result if the surgeon goes beyond the working area past the anterior disk margin, so care should be taken to remain posterior to the center of the disk on AP and lateral views. In addition, injury to the peritoneal and abdominal structures can occur; however, the surgeon can prevent this injury by preoperatively deciding the trajectory on axial MRI or CT.

Missed fragments (failure of PELD) usually occur in large, central, or migrated disk herniations.[35] The surgeon should decide preoperatively whether the trajectory will allow visualization of all the fragments.

Although the incidence of seizures during PELD is rare (0.02%),[36] the occurrence of neck pain is a prodromal sign that should alert the surgeon that the cervical epidural pressure is high enough to cause seizures. This usually occurs when the procedure is long, and the speed of infusion is high.

The neural foramen is a highly vascular area with venous communications between the ascending lumbar vein and basivertebral venous plexus. Persistent bleeding can lead to local foraminal hematoma, or it may migrate anteriorly to produce psoas hemotoma.[37] Foraminal hemotoma may require decompression if it is causing radiculopathy. The psoas hematoma is a self-limiting condition that resolves with conservative treatment.

The transforaminal endoscope passes adjacent to the exiting spinal nerve root and dorsal root ganglion in a narrow bony window, so the concern for nerve irritation (dysesthesia) or overt nerve damage is always present. Dysesthesia occurs in 5% to 15% of cases and is almost always transient. It can be avoided by limiting the use of cautery

Table 42-1 Complications of Percutaneous Endoscopic Lateral Diskectomy

IMMEDIATE COMPLICATIONS
Intraoperative injury to neural and vascular structures
Perforation of peritoneal and abdominal structures
Seizures
EARLY COMPLICATIONS
Hematoma
Dysesthesia
Infection

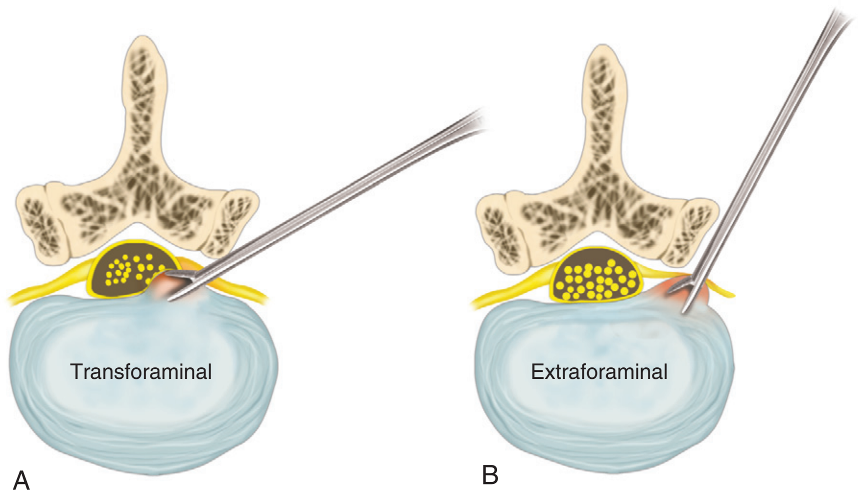

Figure 42-19 Extraforaminal herniation. The approach is steep and close to the midline.

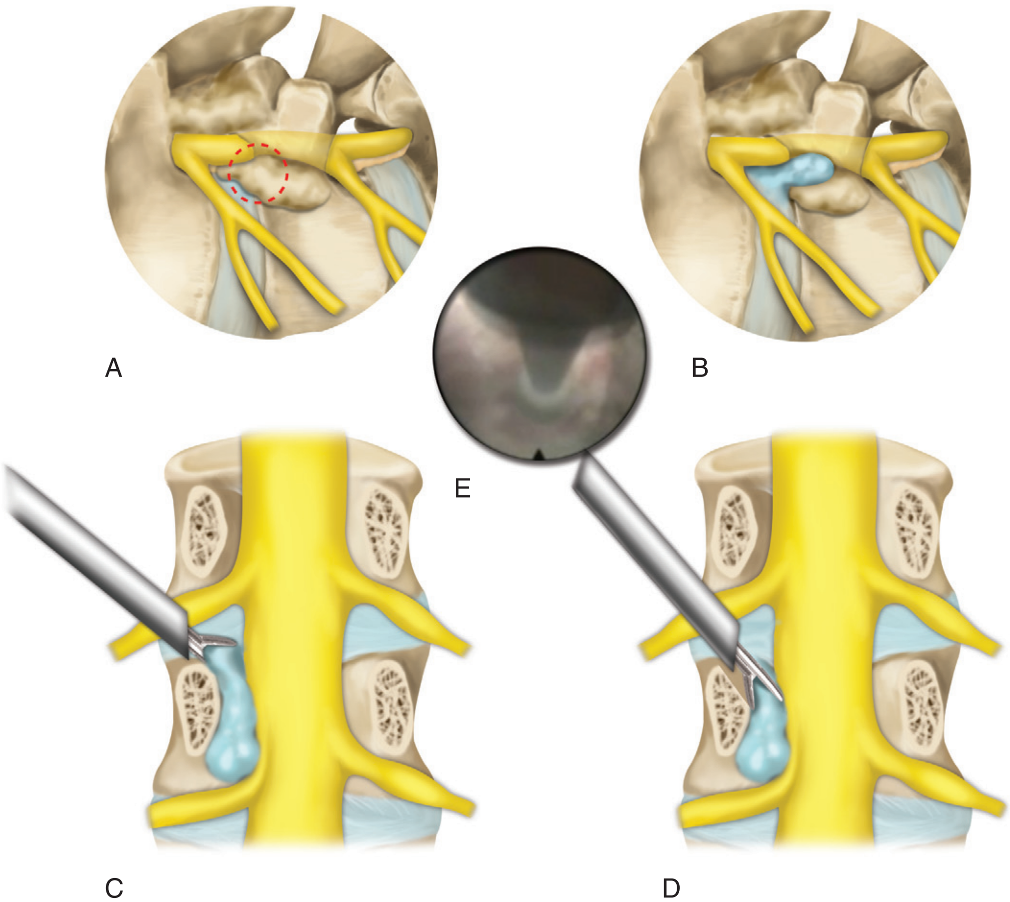

Figure 42-20 Foraminoplasty and oblique pediculotomy. **A,** The superior articular process may be a hindrance to proper positioning of the working cannula (*red dotted circle*) to visualize the herniation in zone 4. **B,** After foraminoplasty, the fragment can be visualized and removed. **C** and **D,** Sometimes an oblique pediculotomy, removal of the upper and medial walls of the pedicle, is needed to visualize the ruptured fragment. **E,** Endoscopic view of the burr.

and manipulation in the neural foramen, and Kambin reported on the intraoperative use of a mixture of fentanyl and saline before the procedure to decrease this incidence, with promising results.

Conclusion

The current perspective of PELD is that it should be considered a modern armament in the war against disk disease, with target-oriented fragmentectomy and minimal collateral damage (morbidity).

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43 Surgical Anatomy and Operative Techniques of Lumbar Stenosis

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General Considerations

Degenerative spine disease, or *spondylosis*, affects everyone—the infirm and the healthy, the sedentary and the athletic, the young and the old. Spondylosis occurs throughout the spine but is more prevalent within the main axial loading vertebrae of the body, the lumbar spine. Lumbar stenosis occurs in 5 of every 1000 Americans older than 50 years. Surgical decompression for lumbar stenosis is the most common surgery for individuals older than 65 years. Symptoms range all the way from low back pain (axial), radiating leg pain (radicular), paresthesia, weakness, and gait instability to loss of normal bladder and bowel function. These symptoms may occur acutely—such as with trauma, disk herniation, and cauda equina syndrome—but they more typically occur as a chronic, debilitating condition.

Lumbar stenosis is classified into two categories: *central canal stenosis* or *foraminal stenosis.* Canal compromise in lumbar stenosis is multifactorial and includes ligamentous hypertrophy, osteophyte overgrowth, spondylolisthesis, hypertrophic facets, and disk herniation. Less common causes include tumors, abscesses, and postoperative adhesions. The levels most commonly affected are L4–L5, followed by L3–L4, L2–L3, and then L5–S1.

In the average person, the normal anteroposterior (AP) diameter of the spinal canal as measured on an axial-cut computed tomography (CT) scan should be greater than 11 mm. Measurements less than 11 mm in the central canal are usually considered stenotic. In foraminal stenosis, or *lateral recess syndrome,* the “gutter” medial to the pedicle is stenotic from hypertrophy of the superior articulating facet from the caudal vertebral body. By CT measurement, foraminal stenosis/lateral recess syndrome occurs when the AP diameter from the posterior vertebral body to the superior articulating facet is less than 2 mm at the point where the nerve root exits. If the condition also involves potential spinal instability (i.e., spondylolisthesis or scoliosis), lumbar stenosis may also be subcategorized into a potentially unstable group. This chapter will focus on the more common etiologies of stable, chronic lumbar stenosis.

Regardless of the etiology, lumbar stenosis confirmed by radiographic imaging to be the cause of neurologic symptoms and failed medical management should receive prompt surgical intervention. Accurate diagnosis and timely management are of utmost importance in treatment of this ubiquitous disease. Although many patients will improve with medical management and a tincture of time, prompt recognition of situations that require surgical intervention is critical.

Symptoms

Patients with lumbar stenosis often come to their primary care physician with radiating leg pain and occasional low back pain. Central canal stenosis may classically present as *neurogenic claudication,* pain that radiates from the back down the legs and is typically exacerbated by low-back extension or exercise and is relieved by lumbar flexion and rest. Patients are generally older and will describe low-back pain or cramping stiffness that radiates down the thighs; in addition, they may also complain of paresthesia and weakness. These symptoms occur while walking, and this progressively limits the person’s ability to ambulate for any great distance.

Often, symptoms improve dramatically with sitting down and bending forward (lumbar flexion). Not uncommonly, patients describe an increased ability to ambulate or to tolerate pain when leaning forward while walking, and they typically relate a history of leaning forward on a walker or shopping cart. The pain is usually described as “achiness” that occurs in a bandlike distribution across the lower back and radiates as a burning or tingling pain down the thighs. Bladder and bowel dysfunction rarely occur, but if present, consider these a red flag warning of a more urgent condition.

The symptoms of lumbar stenosis are hypothesized to occur from ischemia to the lumbosacral nerve roots from a combination of exercise-induced metabolic demands and anatomic pressure-related vascular compromise. Cessation of exercise lowers the metabolic demand and reduces ischemia-induced symptoms. Lumbar flexion alleviates central canal stenosis by reducing the inbuckling from the ligamentum flavum, and it improves foraminal stenosis by widening the neural foramen of the compressed exiting nerve roots. On physical exam, patients usually do not demonstrate any focal weakness; however, patients may have decreased lower extremity reflexes. There should not be pain on palpation of the spine or lower extremity joints.

Differential diagnoses for neurogenic claudication or unilateral radiculopathy from central canal or foraminal stenosis include orthopedic pathology, such as knee or hip arthritis; trochanteric bursitis; and vascular claudication.

Orthopedic pathologies are usually elucidated with pain on palpation of the involved joints; presence of joint edema; a positive flexion, abduction, and external rotation (FABER) test; and radiographs. Vascular claudication can be deduced by a history of coronary or peripheral vascular disease or clinical findings. Symptoms include pain or paresthesia in a myotomal distribution; pain that improves with rest, even while standing upright (rare in neurogenic claudication); immediate improvement in symptoms with rest; and lower extremity symptoms with elevation of the foot above the level of the heart (increased foot pallor or decreased temperature and pulses).

Surgical Approach/Operative Techniques

SUBTOTAL/TOTAL LAMINECTOMY

The patient is positioned prone on a Wilson frame placed on a standard operating room (OR) table or a flat Jackson table (Fig. 43-1). After confirming the appropriate surgical level with intraoperative fluoroscopy, a midline incision is performed, followed by a bilateral subperiosteal dissection to expose the spinous processes and laminae. In general, exposure of the facets is avoided. However, in cases where there has been significant facet hypertrophy, it may be necessary to expose the medial aspect of the facets. Once the exposure has been completed, self-retaining retractors are placed, and intraoperative fluoroscopy is used to confirm the surgical level.

For single-level pathology, the lower half of the superior spinous process, supraspinous ligament, interspinous ligament, and the upper half of the inferior spinous process can be removed with a Leksell rongeur. A high-speed drill is used to remove the inferior half of the superior lamina, working from caudal to cranial and from medial to lateral directions. Care should be taken to preserve the pars interarticularis and to avoid resecting more than half of the facets; both of these actions can lead to iatrogenic instability.

After removal of the caudal half of the superior lamina, the surgeon should be able to visualize the superior extent of the ligamentum flavum and a small portion of the thecal sac. Using an up-angled curette or a Woodson probe, a plane is developed between the ligamentum flavum and the thecal sac. Kerrison rongeurs are used to resect the ligamentum flavum and epidural fat in a cranial to caudal direction. Caudally, the ligamentum flavum is attached to the posterior surface of the upper margin of the lamina below; it will be necessary to remove this portion of the inferior lamina with the Kerrison rongeurs to completely detach the ligamentum flavum.

After the thecal sac has been decompressed centrally, focus should be directed at decompressing the lateral recess, where a significant amount of stenosis may occur secondary to ligamentous and facet hypertrophy. To adequately visualize the lateral recess, it is often helpful to use a Woodson probe to gently depress the thecal sac to visualize the plane between the thecal sac and any residual ligamentum flavum or hypertrophic bone laterally. The use of cottonoids may be helpful in protecting the dura, thus reducing the incidence of unintentional durotomy. Any remaining ligamentum flavum or bony overgrowth in the lateral recess, subarticular region, or foramen can be resected with Kerrison rongeurs. A blunt probe should be easily passed through the foramen of the exiting and traversing nerve roots with minimal resistance. In cases of multilevel lumbar stenosis, this technique can be extended to encompass multiple levels by performing complete laminectomies at the intervening levels.

Figure 43-1 The patient is positioned prone on a Wilson frame with fluoroscopy available for localization.

UNILATERAL HEMILAMINOTOMY/ HEMILAMINECTOMY

Initial positioning and dissection steps for a unilateral hemilaminotomy/hemilaminectomy are similar to the total laminectomy as described above. The muscular dissection and bony removal are completed *ipsilateral* to the symptomatic side without exposure of the contralateral anatomy. The ipsilateral ligamentum flavum is left intact to protect the underlying dura during the contralateral decompression. After removal of the ligamentum flavum beneath the hemilaminotomy defect, Kerrison rongeurs are used to remove any remaining ligamentous or bony stenosis in the foramen of the ipsilateral and traversing nerve roots.

Once this has been completed, we turn our attention to performing a contralateral decompression. To better visualize the contralateral side, a high-speed drill is used to undercut the ipsilateral base of the spinous process and undersurface of the contralateral lamina. Next, a contralateral decompression is performed by resecting any remaining ligamentum flavum to the contralateral margin of the thecal sac. The surgeon may tilt the operating table away to obtain a better view of the contralateral thecal sac, exiting nerve root, and traversing nerve root. Kerrison rongeurs can be used to remove any ligamentous or bony stenosis in the foramen of the contralateral exiting and traversing nerve roots. Once the decompression has been completed, a blunt probe should pass easily into the foramen of the exiting and traversing nerve roots. In cases of multilevel lumbar stenosis, this technique can be extended to encompass multiple levels by performing hemilaminectomies at the intervening levels.

TUBULAR HEMILAMINOTOMY

The unilateral hemilaminotomy described above can also be performed with the assistance of a tubular retractor under loupe, microscope, or endoscope magnification. Tubular retractors use a paramedian muscle-splitting approach and result in smaller incisions and less soft-tissue trauma compared with a traditional midline subperiosteal approach. Patients are positioned prone on a Wilson frame placed on a standard OR table or on a flat Jackson table. A side rail extension is placed on the side of the table contralateral to the surgical side, from which a flexible arm originates, to allow attachment of a rigid rod.

Fluoroscopy is used to localize the correct surgical level, and a paramedian line demarcating the incision is drawn approximately 15 mm off the midline in a cranial to caudal direction. The tip of the initial dilator is pressed against the surface of the skin along the paramedian line at the anticipated level of entry, and fluoroscopy is used to identify the correct entry point and trajectory to the surgical level. A single, small stab incision is made in the skin through the lumbodorsal fascia, and a guidewire is inserted through the stab incision onto the lamina–facet junction. Fluoroscopy is used to confirm the correct position and trajectory of the guidewire, and the stab incision is lengthened on both sides to accommodate the diameter of the tubular retractor to be used (typically 18 mm). Sequential tubular dilators (Fig. 43-2) are then advanced over the guidewire and are docked on the lamina-facet junction (Fig. 43-3). A final tubular retractor is placed over the last dilator and is secured to the flexible arm connected to a rigid rod attached to the table (Fig. 43-4). Once fluoroscopy confirms correct placement of the tubular retractor, the sequential dilators are removed (Fig. 43-5).

Following placement of the tubular retractor, a thin layer of soft tissue overlying the lamina can sometimes remain (Fig. 43-6). This can be removed with monopolar electrocautery. Following removal of the remaining soft tissue, the inferior edge of the lamina and the base of the spinous process can be seen. A high-speed drill or Kerrison ronguer can be used to perform the hemilaminotomy, which is continued cephalad until the ligamentum flavum is detached from the lamina, and the dura is visualized. If there has been significant facet hypertrophy, a medial facetectomy may be necessary. After bony resection has been completed, an up-angled curette is used to create a plane between the dura and ligamentum flavum (Fig. 43-7), which is removed with a Kerrison rongeur. Once the ipsilateral dural edge of the thecal sac and the traversing nerve root are visualized (Fig. 43-8), attention is turned to the contralateral side.

Figure 43-2 Sequential muscle-splitting tubular dilators for minimally invasive spine surgery.

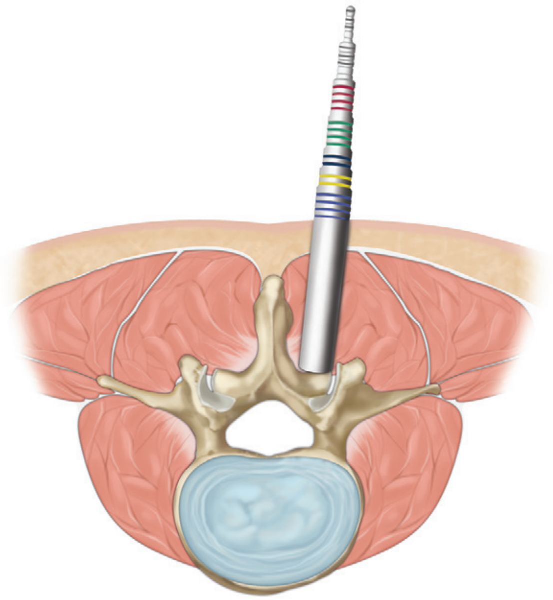

Figure 43-3 Docking site for the serial muscle-dilating tubes on the lamina–facet junction.

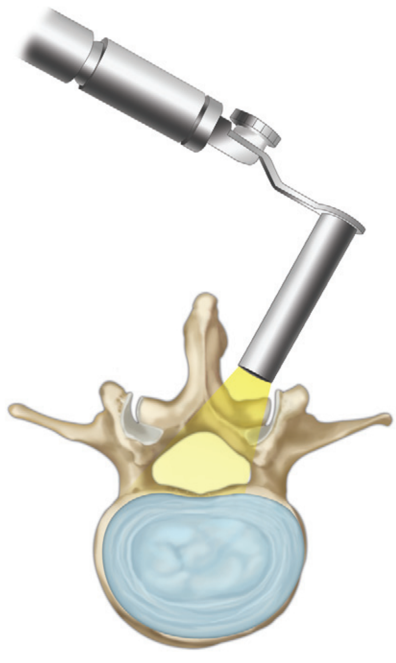

Figure 43-4 Final placement of tubular retractor attached to a flexible arm mounted to the table side rail.

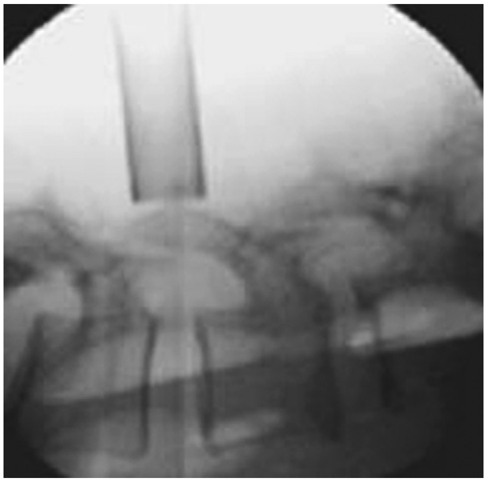

Figure 43-5 Intraoperative fluoroscopy demonstrates appropriate placement of final tubular working channel on the lamina-facet junction of the lumbar spine.

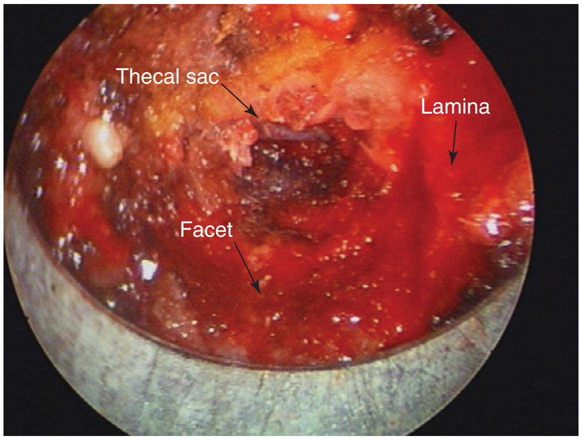

Figure 43-8 Endoscopic view demonstrates unilateral hemilaminotomy with medial facetectomy and decompression of the thecal sac.

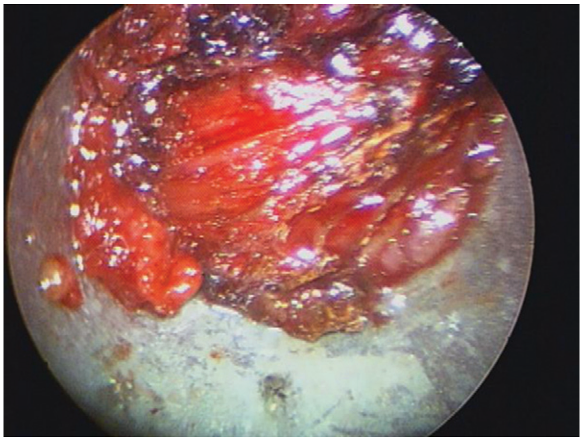

Figure 43-6 Endoscopic view from the tubular retractor with soft tissue overlying bony lamina.

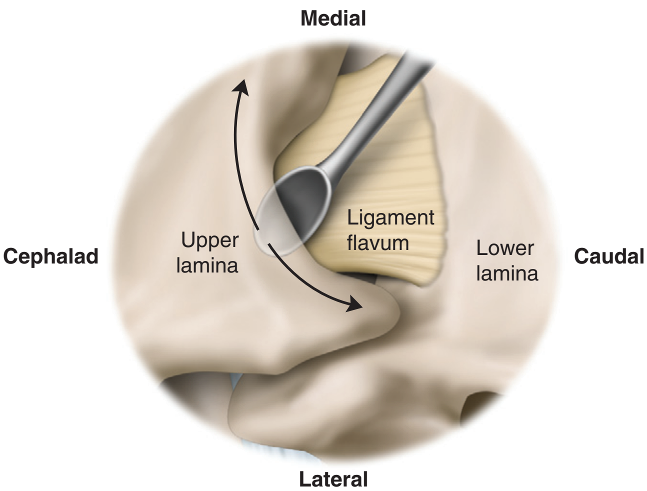

Figure 43-7 Illustration of an up-angled curette used to define the sublaminar plane from the underlying ligamentum flavum.

To obtain better visualization of the contralateral side, the tubular retractor often needs to be repositioned so that it is angled in a more medial direction. This will bring the base of the spinous process into view. The ipsilateral base of the spinous process and undersurface of the contralateral lamina are undercut using a high-speed drill. Once this additional bone has been removed, decompression is performed by resecting any remaining ligamentum flavum to the contralateral margin of the thecal sac. The surgeon may tilt the operating table away to obtain a better view of the contralateral thecal sac, exiting nerve root, and traversing nerve root.

Once the decompression has been completed, a blunt probe should pass into the foramen of the exiting and traversing nerve roots without difficulty. In cases of multilevel lumbar stenosis, it is possible to swing the tubular retractor in a cranial or caudal direction to address adjacent segments; however, we have found that it is often easier to repeat the guidewire placement and sequential tubular dilation procedure for each level.

Wound Closure

After obtaining hemostasis with bipolar electrocautery and thrombin-soaked Gelfoam, the wound is irrigated thoroughly with antibiotic saline solution. If a drain is necessary, we typically place a Jackson-Pratt drain through a separate stab incision of the skin and in the epidural space. The fascial layers are reapproximated with 1-0 Vicryl sutures, and the subcutaneous layer is reapproximated with 2-0 Vicryl sutures. Finally, the skin is closed with surgical staples, and a 3-0 nylon suture is used to secure the drain in place.

In cases where a tubular retractor is used, hemostasis at the surgical site is obtained, and the wound is thoroughly irrigated with antibiotic saline solution with the tubular retractor in place. As the tubular retractor is withdrawn, the muscle is inspected for any additional sources of bleeding. If necessary, hemostasis can be obtained with the use of bipolar electrocautery as the tubular retractor is slowly withdrawn. Because the incision required for the use of a tubular retractor is often much smaller than the one used for a traditional, self-retaining retractor, we use a different technique for closure. Once the tubular retractor is removed, the fascial layer is reapproximated with a 1-0 Vicryl suture, and the subcutaneous tissue is then reapproximated with 3-0 Vicryl sutures. Finally, the skin can be closed with a skin adhesive, such as Dermabond.

Postoperative Regimen

Our postoperative regimen typically consists of a short course of antibiotics, pain control, and early ambulation. In patients without a drain, we typically continue prophylactic antibiotic coverage for 24 hours; patients with a drain remain on a prophylactic antibiotic until the drain has been removed. Our standard antibiotic protocol is intravenous cefazolin for 24 hours. Alternatives to cefazolin in patients with a penicillin allergy include clindamycin and vancomycin.

In cases where we use a self-retaining retractor, we routinely order a patient-controlled analgesia (PCA) pump to provide opioids every 15 minutes as needed. This is often adequate, unless the patient has been on high doses of opioids before surgery, in which case the dosage will need to be titrated upward. On postoperative day (POD) 1, the patient is weaned off the PCA and is transitioned to oral pain medications that consist of an opioid (e.g., Norco) and a muscle relaxant (e.g., diazepam). Patients undergoing a muscle-splitting approach with the use of a tubular retractor usually do not require a PCA pump postoperatively, because soft tissue disruption is minimal. These patients often have sufficient pain control with oral medications alone after surgery.

Mechanical deep vein thrombosis (DVT) prophylaxis with a sequential compression device (SCD) is maintained after surgery until patients become ambulatory. Because patients are mobilized on POD 1 by physical and occupational therapists, chemoprophylaxis for DVT is often unnecessary. In patients who have difficulty with early mobilization postoperatively, DVT chemoprophylaxis with low-molecular-weight heparin can be started on POD 1 or 2. If a Jackson-Pratt drain was placed, it is removed once the output is less than 30 mL per 8-hour nursing shift for two consecutive shifts. The stab incision for the drain is reapproximated using a Steri-Strip.

Avoiding Complications

Structures most at risk during surgery for lumbar stenosis include the thecal sac and nerve roots; inadvertent injury can result in a cerebrospinal fluid (CSF) leak and/or sensory and motor deficits. This is especially true in the lateral recess, where visualization is often poor because of facet hypertrophy and thickened ligamentum flavum. To avoid injury to the thecal sac or nerve roots, it is imperative to ensure a good plane between the ligamentum flavum and the dura before resection of the ligamentum flavum with the Kerrison rongeur. In some cases, hypertrophied medial facets will need to be undercut with a high-speed drill to enable better visualization in the lateral recess. In areas where the ligamentum flavum is more adherent to the dura, it may be necessary to gently develop a plane using a Woodson probe, a Penfield dissector, or an up-angled curette. If an adequate plane cannot be developed, it is often preferable to leave a small, focal island of adherent ligamentum flavum, rather than risk an unintentional durotomy, if doing so does not result in any significant neural compression.

In cases where there has been an unintentional durotomy, the dural defect is primarily repaired with a 4-0 braided, silk-type suture. Once the adequacy of the repair has been verified by performing two or three Valsalva maneuvers, a dural substitute onlay (DuraGen) and a hydrogel dural sealant (DuraSeal) can be used to augment the repair if desired. If the durotomy is more extensive, the defect may require dural patching. CSF diversion with a lumbar drain is recommended in cases where there has been a substantial durotomy.

If a lumbar drain is placed, the drainage catheter should be introduced with a Touhy needle above the surgical site if possible. Approximately 15 mL of CSF should be drained every hour for a total of 3 to 5 days of CSF diversion. The patient must remain flat whenever the lumbar drain is opened, and the head of the bed may be elevated to 15 degrees for meals but should otherwise remain flat for this period. While the patient is on bed rest, stool softeners should be given along with DVT chemoprophylaxis (starting on POD 1 or 2), gastrointestinal (GI) prophylaxis, and an antibiotic for drain prophylaxis. Daily CSF specimens should be obtained to monitor for infection. The lumbar drain is typically clamped on POD 3, and the wound is monitored for the development of a pseudomeningocele or CSF leakage; if no evidence of either is apparent, the lumbar drain is removed, and the catheter entry site is sutured with a 4-0 nylon monofilament. If the wound is a concern, the lumbar drain may be opened for an additional 2 days of CSF diversion before clamping again. When CSF leakage is persistent, or in the presence of an expanding pseudomeningocele despite lumbar drainage, the patient should undergo repeat magnetic resonance imaging (MRI) and should return to the OR for exploration, repair of the durotomy, and continued CSF diversion postoperatively. Of note, DVT chemoprophylaxis is discontinued the day before removal of a lumbar drain and is resumed the day after removal.

In cases where a durotomy is encountered during a tubular hemilaminotomy, it may be extremely difficult or impossible to repair the dural defect primarily, even with the use of specialized knot pushers and needle drivers. It has been our experience that durotomies encountered during tubular procedures can be repaired with a dural onlay (DuraGen) and a hydrogel dural sealant (DuraSeal). By using a muscle-splitting approach, the potential space that facilitates pseudomeningocele formation and CSF leakage is obliterated with removal of the tubular retractor at the conclusion of the case. CSF diversion with a lumbar drain is typically not required.

Postoperative hematoma is another potential complication that should be considered in a patient with progressively worsening back and/or leg pain. Patients with postoperative hematomas can also present with worsening motor and/or sensory deficits. Patients suspected of having a postoperative hematoma should be further evaluated with an emergent MRI. In patients who cannot undergo

MRI because of a contraindication, an emergent CT myelogram should be considered. Risk factors for postoperative hematoma formation include the use of anticoagulants (warfarin, enoxaparin, heparin), antiplatelet medications (e.g., aspirin, nonsteroidal antiinflammatory drugs [NSAIDs], and clopidogrel), and some herbal supplements. Prior to proceeding with surgery, anticoagulants should be discontinued, and the patient's coagulation profile should be normalized. Antiplatelet medications should be discontinued at least 7 days before surgery. If the patient is taking antiplatelet medications or herbal supplements, it may be beneficial to check platelet function studies in addition to performing the standard coagulation studies prior to surgery.

44 Transpedicular Screw Fixation: Open and Percutaneous Techniques

IAIN H. KALFAS and TODD B. FRANCIS

Overview

Although earlier reports described the use of small facet screws to facilitate spinal fusion, it was Roy-Camille,[1] in 1970, who promoted the use of the pedicle as a point of fixation for thoracolumbar segmental instrumentation. Before pedicle screw fixation, instrumentation of the thoracic and lumbosacral regions consisted primarily of rods secured to the spinal column by hooks or sublaminar wires. Although they provided adequate segmental fixation, these systems were plagued with problems such as hook dislodgement, rod breakage, and neural injury from the sublaminar passage of wires or hooks. Such systems were also limited in their ability to attach to the sacrum.

Pedicle screw fixation has proven to be biomechanically superior to hook and sublaminar wire constructs.[2] Steffee referred to the pedicle as the "force nucleus of the vertebral body."[3] Unlike hooks or sublaminar wires, a pedicle screws engages all three anatomic columns of the vertebral body: anterior, middle, and posterior. Pedicle screw fixation does not require an intact lamina for placement, and when properly placed, it has a lower risk of neurologic injury than hooks or wires placed within the spinal canal.

Pedicle fixation has evolved from earlier versions, which typically used monoaxial screws coupled with fixation plates, to the current rod-based systems that use polyaxial screws and allow the surgeon to apply a variety of corrective forces to a spinal deformity. Because of their biomechanical advantages over hook and sublaminar wire systems, they also provide the opportunity for the use of shorter constructs and for earlier postoperative recovery. More recently, techniques for placing pedicle screws percutaneously have been developed, creating the challenge of screw placement with limited exposure of the spinal anatomy.

Several methods may be used for properly and accurately inserting pedicle screws. This chapter will review the advantages and disadvantages of each method. Regardless of the method used, a thorough understanding of the pertinent spinal anatomy and the indications and techniques for pedicle screw fixation is critical. Each surgeon should carefully and accurately interpret all relevant preoperative imaging studies and use the method of screw insertion that works best for them.

Pedicle Anatomy

The vertebral body pedicle is a strong, cylindric structure composed of an outer margin of cortical bone and a core of cancellous bone. It serves as an anatomic bridge between the dorsal spinal elements and the vertebral body. Depending on the spinal level, the dimensions of the pedicle will vary with regard to sagittal pedicle width (pedicle height), transverse pedicle width, and the pedicle angle in the sagittal, transverse, and coronal planes.

The transverse width of the pedicle is the anatomic parameter that most affects the feasibility of screw placement. In the lumbosacral region, the transverse width increases gradually from L1 to S1. Most pedicles below the L1 level are at least 8 mm in width, allowing for safe placement of screws in most cases. In the thoracic spine, the transverse width of the pedicles in the midthoracic region (T4–T9) is typically narrower than that of the pedicles in the upper thoracic (T1–T3) and lower thoracic (T10–T12) regions. The transverse width of a pedicle can be easily determined with computed tomography (CT) imaging.

The transverse angulation of a pedicle determines the medial angulation required for placement of a pedicle screw. This angle gradually decreases from T1 down to T12. At the T1 level the transverse angle is 10 to 15 degrees; at T12, the angle is 5 degrees. From L1 down to S1 the transverse angle gradually increases approximately 5 degrees per level. The angle at S1 is approximately 20 to 25 degrees.

The entry point for each pedicle also varies according to the spinal level. In the thoracic spine the pedicle entry point typically lies at a point even with the upper margin of the transverse process at its junction with the facet joint. There may be minor variations of this entry site, depending on the specific thoracic vertebral level.

In the lumbar region the entry point for pedicle screws is typically at the intersection of the center of the transverse process and the facet joint. The entry point for an upper sacral pedicle screw is the intersection of the sacral ala and the inferior margin of the adjacent facet joint (Fig. 44-1).

Techniques of Transpedicular Screw Insertion

Pedicle screw fixation can be used throughout the spinal column. Although screws can be placed into the pedicles of

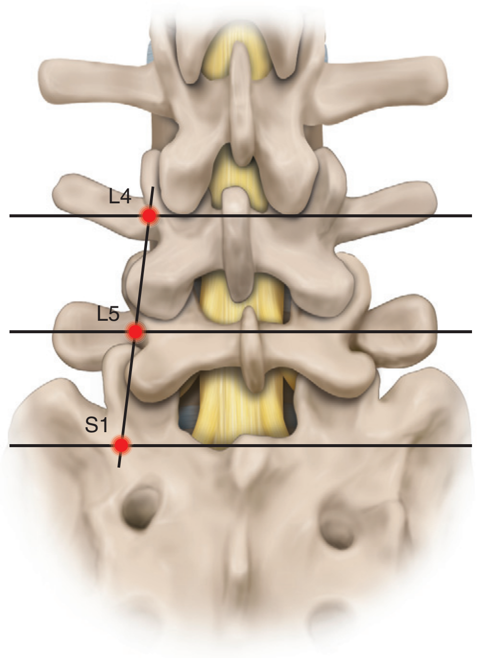

Figure 44-1 Pedicle entry sites localized at the L4, L5, and S1 levels on a representation of the dorsal surface of the lumbar spine.

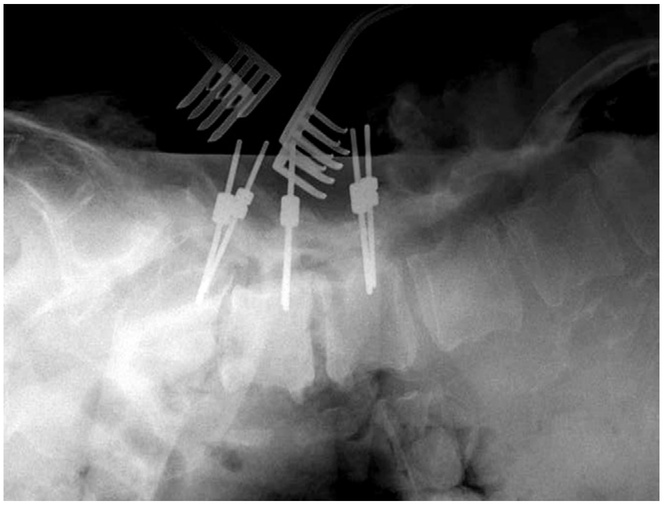

Figure 44-2 Intraoperative lateral radiograph demonstrates pedicle markers in satisfactory position at L3–L5.

the cervical spine, in particular at the C2 and C7 levels, they are more commonly used in the thoracic and lumbosacral regions. There are several techniques for assisting the surgeon with accurate placement of pedicle screws, either through an open or a percutaneous approach. The most common technique is the use of intraoperative fluoroscopy. Other techniques include a freehand method without any intraoperative imaging; the use of electromyography (EMG) monitoring; and the use of image-guided or computer-assisted spinal navigation. The specific technique used is based on the individual surgeon's preference, experience, and comfort level.

FREEHAND TECHNIQUE

The freehand technique relies solely on the surgeon's knowledge of the anatomy and spatial conception of the appropriate entry point and trajectory angle for screw insertion. Little or no intraoperative imaging is used; it can only be used with open, as opposed to percutaneous, spinal surgery. Performing this technique after decompression of the spinal canal can improve the accuracy of screw insertion by allowing the surgeon to directly visualize and palpate the medial wall of each pedicle. The accuracy of this approach will vary significantly depending on the individual surgeon's experience and skill level.

This freehand technique requires the surgeon to use anatomic surface landmarks in the surgical field to correctly identify the appropriate entry point for each pedicle. Once the entry point is identified, it is decorticated with a drill or rongeurs. A curved or straight pedicle probe, or "gearshift," is positioned over the site. The surgeon must then estimate the appropriate trajectory in both the transverse and sagittal planes as the probe is gently advanced into the pedicle. The probe is advanced slowly, using a constant twisting motion of the surgeon's dominant hand with gentle pressure. The blunt tip of the probe is designed to minimize the potential for the probe to break through the cortical walls of the pedicle. Care must be taken not to apply a significant downward force that may plunge the probe through the vertebrae or fracture the pedicle.

After the pilot tract has been created, the probe is removed, and a smaller sounding probe is inserted to assess for bony integrity of the pedicle and to determine the appropriate screw length needed. If no pedicle breach is detected, the hole can be tapped, and the appropriate screw can be inserted. If a breach of the pedicle is detected, the "gearshift" is reinserted, and an attempt is made to correct the trajectory. After each pedicle to be fixated has been cannulated, K-wires or pedicle markers can be placed into each tract, and intraoperative imaging can be obtained to confirm appropriate placement (Fig. 44-2).

The freehand technique is best used by experienced spine surgeons. In addition to requiring a precise conceptualization of the nonvisualized spinal anatomy and its relationship to the adjacent neural elements and soft-tissue structures, it also requires a feel for the correct amount of pressure to apply to the pedicle probe as it is advanced into each pedicle. If an incorrect entry point or trajectory is selected, it may irreversibly damage the pedicle, thereby preventing its use for screw fixation.

Karapinar[4] reviewed a series of 640 pedicle screws placed in the thoracolumbar spine using a freehand technique; postoperative CT imaging confirmed a pedicle breach by 37 inserted screws (5.8%). This breach rate was confirmed by Amato[5] in a review of 424 consecutive freehand lumbosacral pedicle screws in which the overall screw misplacement rate was 5%. The most common direction of screw misplacement was lateral; the most common level of misplacement was L3 (11%).

Parker and colleagues[6] recently published a review of 6816 consecutive pedicle screws placed into the thoracic and lumbosacral regions using a freehand insertion technique. This study found that the most common screw breach of a pedicle occurred laterally. The overall incidence of pedicle breach in the lumbar spine was 0.9% as opposed to a rate of 2.5% in the thoracic spine. The lowest rate of screw breach occurred at the L5 and S1 levels.[6] Although these rates of misplacement are relatively low, they demonstrate that even with routine use, consistently accurate placement may be difficult to achieve.

FLUOROSCOPICALLY ASSISTED SCREW PLACEMENT

The most common technique for placing pedicle screws is with the assistance of intraoperative fluoroscopy. As with the freehand technique, the surgeon must understand and recognize the surface landmarks and appropriate trajectories for screw placement. Unlike the freehand technique, intraoperative fluoroscopy adds an additional level of screw insertion accuracy by providing the surgeon with real-time imaging during creation of the pilot tracts and insertion of the screws.

Before screw insertion, a C-arm fluoroscopic unit is positioned so as to provide a lateral view of the surgical anatomy; this will assist the surgeon in determining the appropriate trajectory in the sagittal plane. It is also preferable to allow for rotation of the C-arm during instrumentation to provide an anteroposterior (AP) or oblique image. This will help guide the appropriate screw trajectory in the axial plane.

The entry site for a pedicle is identified using surface landmarks, and a pedicle probe is positioned over this point. A lateral fluoroscopic image is obtained to confirm the appropriate sagittal trajectory for the pilot hole. The probe is gently advanced into the upper part of the pedicle with additional spot imaging obtained. The C-arm is then rotated to provide an AP image to confirm that the probe is not being directed too far medially. With satisfactory fluoroscopic imaging, the probe is advanced to its final depth and is removed; bony integrity is confirmed with a sounding probe. When all pilot holes have been created, pedicle markers or K-wires can be placed within them, and final lateral and AP images are obtained before screw placement.

Although the use of fluoroscopy is optional during open surgery for pedicle fixation, it is necessary when using percutaneous techniques for screw placement.[7,8] The lack of any visualization of the spinal surface anatomy during percutaneous procedures creates this dependence on fluoroscopic assistance. Percutaneous pedicle fixation is best performed with two C-arm units: one is positioned to provide a lateral image, the other is positioned to provide an AP image. The unit providing the AP image is tilted toward the head of the patient to allow for better surgeon access to the surgical field. Images are obtained from both units before beginning the procedure to ensure adequate positioning. A metallic instrument is placed on the skin overlying the levels to be instrumented, and images are obtained to select the appropriate sites for the stab incisions to be used.

Several different percutaneous pedicle screw systems are currently available, and each system has design features that distinguish it from the others. In general, the percutaneous method typically involves placing a Jamshidi needle through a stab incision and advancing it to the level of the pedicle entry point. AP and lateral fluoroscopy are obtained to confirm the appropriate entry point and the axial and sagittal trajectories. The pedicle is cannulated by advancing the Jamshidi needle through it and into the vertebral body. Serial imaging is obtained as the needle is advanced to confirm a satisfactory trajectory.

When satisfactory positioning has been obtained, the core of the needle is removed, and a K-wire is placed into the pedicle. If desired, a tap with a soft tissue protector sleeve can be advanced over the guidewire to tap the pedicle. The tap is removed, and the appropriate pedicle screw is inserted over the K-wire. The screw is advanced into the pedicle with fluoroscopic imaging to monitor its depth and trajectory. During tapping of the pedicle and insertion of the screw, care must be taken to ensure that the K-wire remains in the vertebral body until the pedicle screw has passed the limit of the pedicle. Any manipulation of the K-wire should be performed under fluoroscopic guidance; the K-wire can be removed once the pedicle screw has entered the vertebral body. Following satisfactory placement of all screws, the appropriate-length rods are placed according to the manufacturer's guidelines.

Regardless of the surgical approach, several earlier studies have demonstrated the inaccuracies of fluoroscopy in guiding pedicle screw placement in the lumbosacral spine. The rate of disruption of the pedicle cortex by an inserted screw ranges from 15% to 31% in these studies.[9-11] The disadvantage of fluoroscopy in orienting the spinal surgeon to the unexposed spinal anatomy is that it displays at most only two planar images. Although the lateral view can be relatively easy to assess, the AP or oblique view can be difficult to interpret. For most screw fixation procedures, the position of the screw in the axial plane is most important; this plane best demonstrates the position of the screw relative to the neural canal. Conventional fluoroscopic imaging cannot provide this view.

In some cases it may be difficult to acquire satisfactory imaging with fluoroscopy. Because of the need to penetrate the shoulders with the imaging beam, pedicle fixation in the upper thoracic region can be difficult to monitor with fluoroscopy. Optimal imaging may also be difficult to obtain in the lumbosacral region in obese patients.

A significant concern with the use of intraoperative fluoroscopy is the radiation exposure experienced by the surgical team and the patient, particularly with percutaneous pedicle screw fixation techniques. Rampersaud[12] demonstrated that, compared with other orthopedic procedures that use intraoperative fluoroscopy, spinal procedures potentially result in a tenfold to twelvefold increase in radiation exposure as a result of factors such as backscatter radiation and the increased energy levels needed to image the lumbar spine. This creates a potentially significant hazard to those individuals who perform a high volume of complex spinal surgeries. If fluoroscopic imaging is used, it is important that exposure times be kept to a minimum and that all appropriate safety precautions for intraoperative imaging be implemented.

IMAGE-GUIDED NAVIGATION-ASSISTED SCREW PLACEMENT

Image-guided, or computer-assisted, spinal navigation is a computer-based surgical technology designed to improve intraoperative orientation to the nonvisualized anatomy during fixation screw placement.[13,14] It gives the spinal surgeon the ability to manipulate multiplanar CT and fluoroscopic images during the procedure in order to gain a greater degree of orientation to the surgical anatomy, thus optimizing the precision and accuracy of the surgery. An additional advantage is that, compared with conventional intraoperative imaging, it eliminates or significantly reduces radiation exposure to the surgical team.

Spinal navigation systems consist of an image-processing computer workstation interfaced with a two-camera optical localizer device (Fig. 44-3). A handheld navigational probe mounted with a fixed array of passive reflective spheres serves as the link between the surgeon and the computer workstation (Fig 44-4). Passive reflectors can also be attached to standard surgical instruments. The spacing and positioning of the passive reflectors on each navigational probe or customized, trackable surgical instrument are monitored by the computer workstation. During navigation the optical localizer emits infrared light toward the operative field. The infrared light is then reflected back to the optical localizer by the passive reflectors. This information is relayed to the computer workstation, which can then calculate the precise location of the instrument tip in the surgical field and can also calculate the location of the anatomic point on which the instrument tip is resting.

Navigational technology effectively links preoperatively or intraoperatively acquired spinal image data to the corresponding intraoperative anatomy. It is based on the principle that both the image data and the surgical anatomy each represent a three-dimensional coordinate system. Each point in the image data set and in the surgical field has a location in space defined by a specific Cartesian (x, y, and z) coordinate. Using defined mathematic algorithms, a specific point in the image data set can be "matched" to its corresponding point in the surgical field. After matching a limited number of these points together, any point in the surgical field can then be selected, and its corresponding point in the images is displayed in several planes to give the surgeon a better orientation to the pertinent surgical anatomy.

The establishment of a spatial relationship between the image data and the surgical anatomy is achieved through a process termed "registration." Three different registration techniques can be used for spinal navigation: 1) paired point registration, 2) surface matching, and 3) automated registration.

Paired-point registration involves selecting a series of discrete corresponding anatomic points in a CT dataset and in the exposed spinal anatomy. These points typically are the tip of a spinous or transverse process or the apex of a facet joint. Following the selection of one of these points in the CT image data, the tip of the navigation probe is placed on the corresponding point in the surgical field. Infrared light from the camera is reflected off the probe toward the camera and into the computer, which does the calculations to determine the spatial position of the probe's tip and the anatomic structure on which it rests. This effectively "links" the point selected in the image data with the point selected in the surgical field. When a minimum of three such points are registered, the probe can be placed on any other point in the surgical field, and the corresponding point in the image dataset will be identified on the computer workstation.[15]

Surface-matching registration involves selecting multiple, random (nondiscrete) points on the exposed surface of the spine in the surgical field. This technique does not require prior selection of points in the image set, although several discrete points in both the image dataset and in the surgical field are frequently required to improve the accuracy of surface mapping. The positional information of these points is transferred to the workstation, and a topographic map of the selected anatomy is created and "matched" to the patient's image set.[16]

Automated registration is performed when fluoroscopic navigation or intraoperative CT imaging systems are used. This technique involves attachment of a reference frame on the exposed spinal anatomy or, with lumbar surgery, the iliac crest. A second reference frame is attached to the CT imaging scanner or fluoroscope. As the intraoperative

Figure 44-3 Image-guided navigational workstation with infrared camera localizer system.

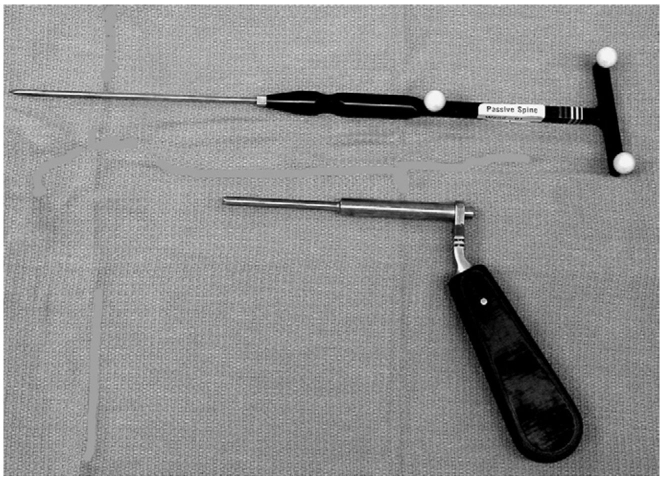

Figure 44-4 Navigation probe and drill guide for spinal surgery.

images are acquired, the two reference frames allow for registration to occur without the need for surgeon input. The CT scanner or fluoroscope can then be removed, and real-time navigation of up to five separate spinal levels can be performed.[17]

Four general types of computer-assisted spinal surgery are currently available. *CT-based navigation* uses CT images of the patient acquired before the surgery. Conventional intraoperative imaging is not necessary when using this method of navigation. During navigation the surgeon is presented with reformatted CT images in multiple planes, with the selected screw entry point and trajectory superimposed on the images (Fig. 44-5). This information updates in real time as adjustments are made to the selected trajectory in the surgical field.

Fluoroscopic navigation uses a standard AP and lateral image of the spinal anatomy acquired immediately before the start of the procedure. No additional intraoperative imaging is needed, and registration is automated. The selected trajectory information is superimposed on the AP and lateral images on the workstation screen (Fig. 44-6). Unlike CT-based navigation, an axial image is not provided. The advantage of fluoroscopic navigation is that it uses less radiation than conventional fluoroscopy and does not require a preoperative CT scan, as does CT-based navigation.

Intraoperative isocentric fluoroscopic navigation is a variation of standard fluoroscopic navigation. It acquires images just before surgery by rotating the specialized C-arm in a 180-degree arc around the patient; registration is automated. The acquired images can then be reformatted to provide images in the axial and sagittal planes similar to CT-based navigation but without the need to acquire a preoperative CT scan. Although the images are not of the same quality as a standard CT image set, they are adequate for navigation in most cases.

Intraoperative CT navigation is the most recent advancement in spinal navigation. It consists of a portable CT scanner that uses flat-panel detector technology to improve intraoperative image acquisition and quality. The scanner has a configuration similar to a standard C-arm fluoroscope. In addition to being able to acquire standard AP and lateral images, its C-arm configuration can be "closed" to completely encircle the patient. This allows the flat-panel detector to be swept in a 360-degree arc around the patient, significantly improving the acquired image quality. The reformatted images are similar in quality to conventional CT imaging and are superior to isocentric C-arm imaging (Fig. 44-7). Registration is automated, allowing for spinal navigation immediately after image acquisition.

Following accurate registration, the navigation probe can be positioned on any surface point in the surgical field. As the probe is tracked by the camera, the computer workstation will relate the corresponding image data through the selected anatomic point. If CT-based navigation is used, three separate, reformatted CT images centered on the corresponding point in the image dataset are displayed. These images will allow the surgeon to select the appropriate screw trajectory and entry point in the sagittal, coronal, and axial planes. The appropriate screw length and

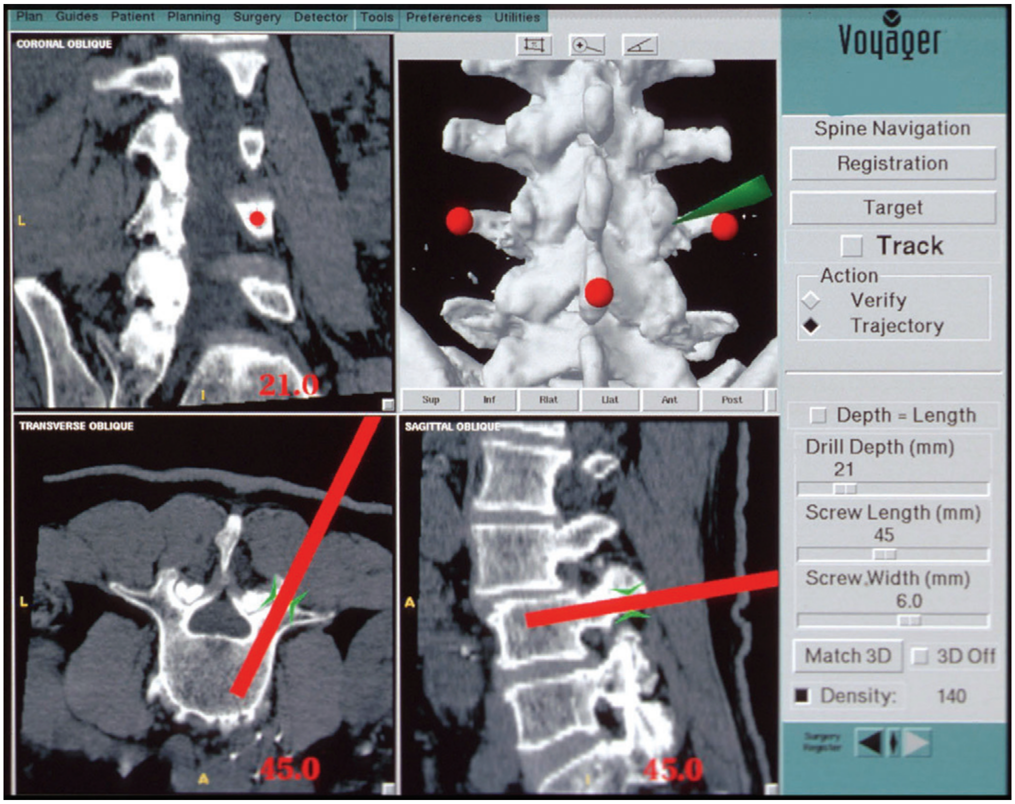

Figure 44-5 Workstation screen demonstrates navigation for an L3 pedicle screw.

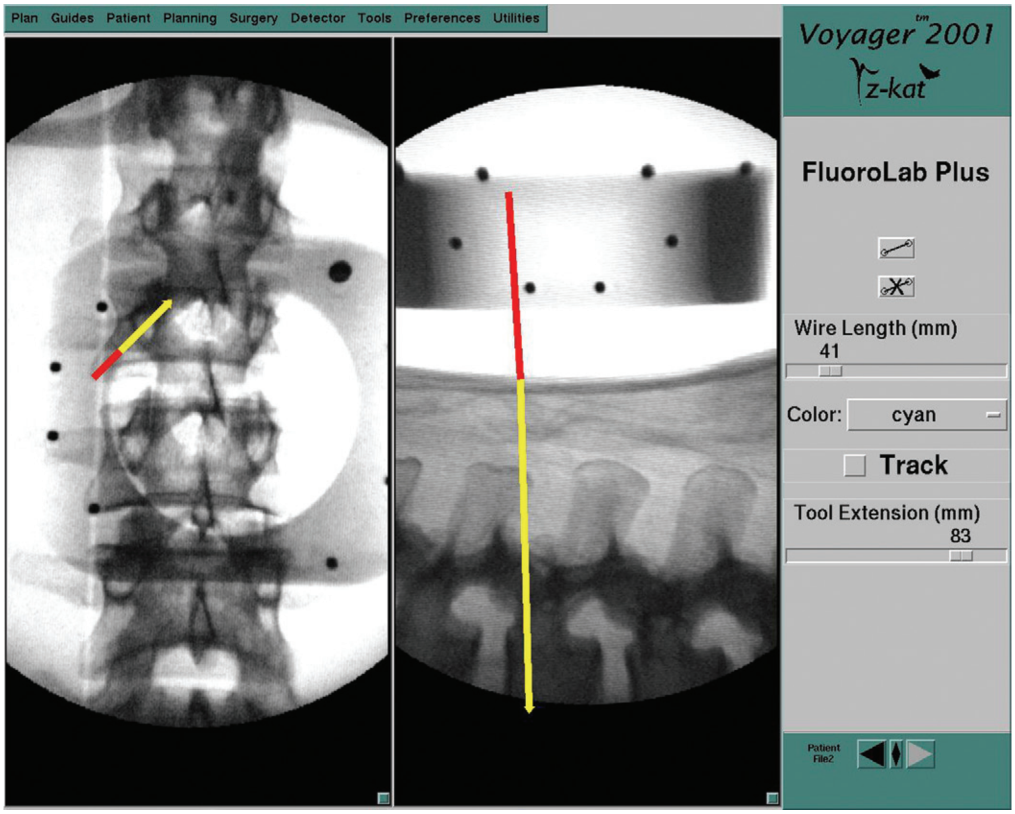

Figure 44-6 Workstation screen of a fluoroscopic navigation system. Standard anteroposterior and lateral views are provided with superimposed trajectory lines (*arrows*).

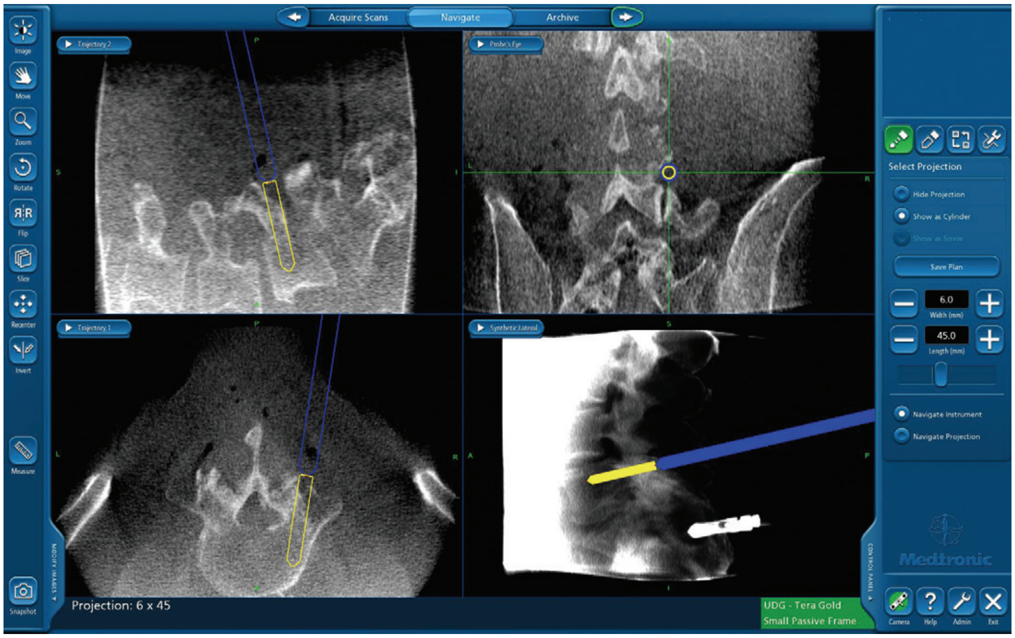

Figure 44-7 Workstation screen of an intraoperative computed tomography navigation system. Trajectory lines indicate selected trajectory for an L5 pedicle screw.

diameter can also be selected. As the surgeon moves the probe into different positions and angles, the image data will update in real time to demonstrate the new selected entry point and trajectory. If fluoroscopic navigation is used, the trajectory line will be superimposed on the preoperatively acquired AP and lateral fluoroscopic images on the workstation monitor.

For each pedicle to be navigated, the surgeon must identify the appropriate pedicle entry point based on the standard anatomic surface landmarks. The navigation probe is placed through a handheld drill guide and is docked onto the entry point. The pedicle is then navigated, and the appropriate trajectory in both the sagittal and axial planes is identified. The placement and angle of the drill guide and probe assembly are adjusted to find the optimal screw trajectory. When this occurs, the probe is removed from the drill guide, and a drill 3 mm in diameter is inserted through the guide. A pilot hole is drilled along the selected trajectory to the appropriate depth, and a pedicle sound is used to confirm adequate positioning.

Although its clinical use has expanded to other spinal procedures, image-guided spinal navigation was initially evaluated by assessing its accuracy when used to place pedicle screws into the thoracic and lumbosacral spines of cadaver specimens.[14] The first study to evaluate navigational accuracy in the clinical setting was performed in a series of 30 patients undergoing lumbar pedicle screw fixation. Accuracy of screw insertion was documented by plain film radiography and thin-section CT imaging of the instrumented levels. Satisfactory screw placement was noted for 149 out of 150 inserted screws.[13]

Several additional studies have also demonstrated the improved accuracy of pedicle screw insertion with the assistance of image-guided navigation compared with fluoroscopy.[18-21] These studies all demonstrate a statistically significant improvement in the accuracy of pedicle screw placement in the navigation-assisted cohort.

ELECTROMYELOGRAPHIC MONITORING

A less frequently used technique for facilitating pedicle screw placement is with intraoperative EMG monitoring. Calcancie and colleagues[22] introduced the triggered-EMG recording technique to objectively evaluate the integrity of pedicle screw placement. Multiple EMG electrodes are placed into the appropriate muscle groups of the lower extremities, and a monopolar electrode is used to stimulate the top of the pedicle screw at increasing current intensities. Needle electrodes in the appropriate muscle groups will measure the muscle action potential during the stimulation. A breach in the pedicle wall significantly reduces the stimulation threshold, and a threshold response between 10 and 20 mA gives a reasonable probability that no breach of the medial wall has occurred. Thresholds greater than 15 mA have a 98% likelihood of accurate screw positioning on postoperative CT scan.[23]

EMG monitoring can be used with any of the previously described techniques for pedicle screw insertion. A retrospective analysis of 4857 pedicle screws placed with triggered EMG monitoring in conjunction with direct palpation and intraoperative imaging demonstrated improved accuracy in screw placement with few complications.[24] The primary drawback of this technique is that it alerts the surgeon of a pedicle breach only after a screw has already been inserted and has potentially produced a neural injury.

Conclusion

Pedicle screw fixation is a proven and accepted technique for providing spinal stabilization. Successful screw insertion requires the spinal surgeon to have a sound grasp of the spinal anatomy and the variation of this anatomy from one spinal level to the next. Several methods are available to facilitate the safe and accurate placement of these screws. The accuracy of each method is highly dependent on the experience and ability of each individual spinal surgeon. Although the freehand technique is an accepted method for inserting pedicle screws, it should only be used by experienced surgeons who feel comfortable with the relevant anatomy. Most spinal surgeons can achieve sufficient screw insertion accuracy with the fluoroscopically assisted technique, the image-guided navigation technique, or the EMG monitoring technique. Each spinal surgeon should use the technique that works best in their hands and ensures them the greatest degree of screw insertion accuracy.

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45 Posterior and Transforaminal Lumbar Interbody Fusion

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Overview

Posterior lumbar interbody fusion (PLIF) after lumbar disk removal was first reported by Jaslow[1] in 1946, and Cloward[2] presented his first 100 cases at the Harvey Cushing Society meeting in 1947. More recently, Steffe,[3] Brantigan,[4] and Ray[5] have reported on the use of posterior segmental instrumentation or cage implants for PLIF, a surgical technique that allows fusion across two adjacent vertebrae by inserting grafts, titanium-threaded cages, bone dowels, or carbon-fiber spacers filled with bone graft into the disk space. All PLIF techniques require removal of the disk material from within the disk space; bone grafts and spacing devices are then used to create a bony “bridge” that will fuse the two adjacent vertebral bodies.

PLIF is a valuable way of achieving a spinal fusion. If spinal instability is present (i.e., spondylolisthesis or slippage of the vertebrae), PLIF should be performed with spinal stabilizing instruments, such as pedicle screws or hooks and rods to immobilize the loose vertebrae. The many advantages in instrumented PLIFs, or 360-degree fusions, include a decrease in pain and an increase in functional activities.[6] Compared with anterior-posterior (AP) fusions,[7] instrumented PLIFs also have equal patient satisfaction, much lower costs, and faster return to work and other activities. Furthermore, a recent biomechanical study by Bennett and associates[7] found that PLIFs double the spinal stiffness produced by transpedicular fixation following laminectomy and facetectomy. Other theoretical advantages of PLIF are technical and include the fact that a much larger area of bone surface exists for the fusion, with the fusion at the center of motion and at the site of maximum compression loading. The disk space is maintained in a distracted position without the collapse that is often seen in transverse-process fusion using transpedicular fixation. In addition, the blood supply is better at the decorticated end plate than at the transverse process.

Perhaps the greatest concern with a standard PLIF is the amount of neural retraction needed. An inappropriate amount could potentially lead to nerve root injury, cauda equina injury, dural laceration, and epidural fibrosis.[5,8] Consequently, the unilateral posterior transforaminal lumbar interbody fusion (TLIF) was developed to address some of these problems. The concept of a unilateral approach to the anterior column was refined and popularized by Harms.[9] The purpose of this approach was to obtain the same goals as a PLIF without the potential risks and complications.

The TLIF technique allows clearance of the entire intervertebral disk compartment by opening the neural foramen on one side. After appropriate clearance, it is possible to achieve further enlargement of the cleared intervertebral compartment by posterior transpedicular distraction. This enables definitive anterior column support and certain fusion by transforaminally introduced bone material and support structures. After the introduction of these anterior fusional elements, segment stability is restored by converting the distraction force into compression force.[10] The TLIF approach helps to avoid damage to important anatomic structures, such as the nerve roots, dura, ligamentum flavum, and interspinous ligament.

Preservation of the ligamentous structures is of great importance to restoring biomechanical stability of the segment and its adjacent counterparts. The advantages of unilateral TLIF over the standard PLIF include the ability to provide bilateral anterior column support through a single posterolateral approach of the disk space. The transforaminal approach preserves the anterior and most of the posterior longitudinal ligamentous (PLL) complex, which provides a tension band for compression of the graft and prevents retropulsion of the graft. It avoids excessive soft-tissue dissection, which may help prevent scarring, instability of adjacent segments, and injury to the exiting nerve root. Epidural bleeding is less of a problem than with the standard bilateral PLIF because of the unilateral transforaminal approach, and with experience, proper cage placement within the disk space is consistently achieved.[8,11]

Indications and Contraindications

INDICATIONS

- Broad-based herniations
- Totally degenerated disks with marked instability (spondylolisthesis, some cases of scoliosis)
- Recurrent disk herniation
- Pseudarthrosis of transverse process fusion (as an alternative to anterior lumbar fusion) in the absence of epidural scarring
- Back pain as a result of symptomatic spondylosis and/or symptomatic degenerative disk disease

CONTRAINDICATIONS

- Conjoined nerve root precluding access to the disk space
- Osteoporotic patients
- Active infection
- Previous anterior lumbar interbody fusion

Operative Technique

EQUIPMENT

- Radiograph-compatible operating table
- Jackson table, Wilson frame, or chest rolls
- Fluoroscopy
- Headlight system
- Pneumatic compression stockings or antiembolic stockings for both legs
- Lumbar laminectomy set
- Steinmann pins
- Bone graft source
- Lumbar pedicle screw system

POSTERIOR LUMBAR INTERBODY FUSION PROCEDURE

Laminectomy

- Patient is placed in prone position with chest rolls, on a Wilson frame, or using the Jackson table.
- A midline longitudinal skin incision is made.
- Subperiosteal dissection extends laterally beyond the border of the articular facet joints.
- Laminectomy and complete decompression of nerve roots are performed in the desired level. Total or subtotal laminectomy is easier than the partial laminectomy to handle the thecal sac and nerve roots (Fig. 45-1).
- Medial facetectomy is recommended for preservation of posterior column function.

Traditional Diskectomy

- After gently retracting the nerve roots and thecal sac, the epidural space is identified, and epidural vessels are coagulated (Fig. 45-2).
- Carefully retracting the nerve root at risk, a No. 15 scalpel is used to incise the annulus widely. A large rectangle of annulus and available disk is removed (Fig. 45-3).
- Traditional bilateral diskectomy requires removal of as much disk as possible to ensure that none bunches up to the midline, compressing the dural sac, when bone grafts or cages are placed laterally (Fig. 45-4).
- An up-biting pituitary forceps is used to remove disk beneath the thecal sac without manipulating it.
- Ring curettes are often used to further empty the disk space.
- Backward-angled curettes are carefully placed between the dural sac and the annulus to push down any bulging disk or osteophyte near the midline.

End Plate Preparation

- A vertebral spreader is used to widen the disk space.
- The size of the reamer-distractor varies from 8 to 12 mm practically. Once the reamer-distractor is attempted within the disk space, it is turned 90 degrees to distract the space (Fig. 45-5). The next larger sized reamer-distractor is then tried, and this is repeated using progressively larger reamer-distractors until the ideal disk height is achieved. The final dilator is left within the disk space in the distracted position.
- A Penfield dissector or ruler is placed into the disk space, and images are obtained.
- The osteotome should not be placed more than 50% to 60% through the AP diameter of the vertebral body.

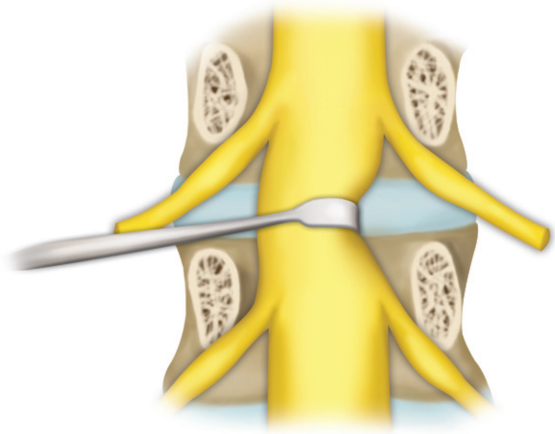

Figure 45-2 Careful retraction of the nerve roots and thecal sac.

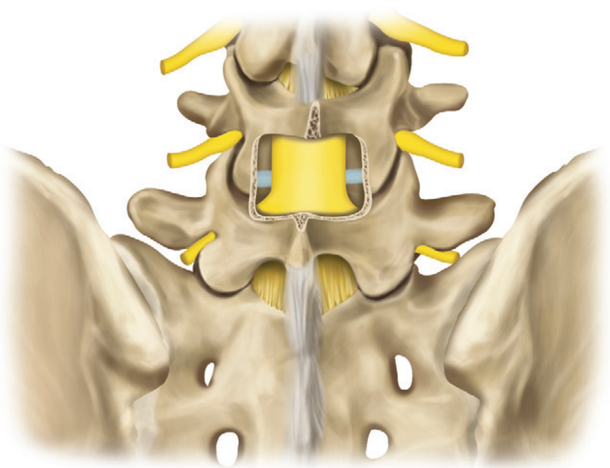

Figure 45-1 L4 subtotal laminectomy.

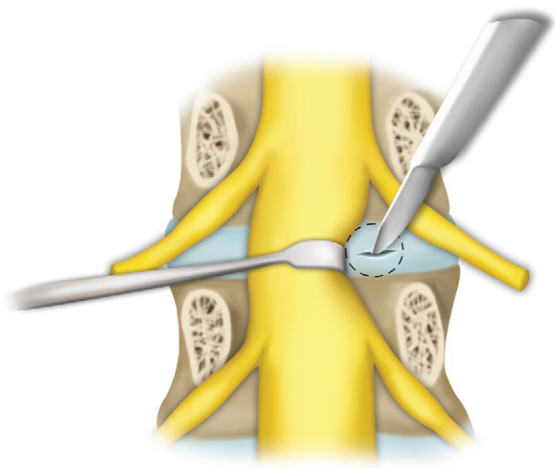

Figure 45-3 Removal of the annulus with a No. 15 scalpel.

- Osteotomes are placed parallel to the end plates at both the superior and inferior aspects of the disk space and then are placed medial and lateral.

Bone Graft Preparation

- Separate the skin incision on the posterior superior iliac crest.
- Remove the long tricortical iliac bone.
- Shape the bone as three pieces of bone graft material, with the height measuring the distracted disk space near the vertebral spreader (Fig. 45-6).
- Donor site bleeding control is achieved with bone wax and closure.

Bone Graft Placement

- The nerve root and dural sac should be very carefully protected with handheld retractors that are regularly released.
- The prepared tricortical grafts or cage filled with autograft are then tapped into the widened disk space.
- A bleeding cancellous bone surface should then be available on the cephalad and caudal edges of the space and possibly laterally as well.

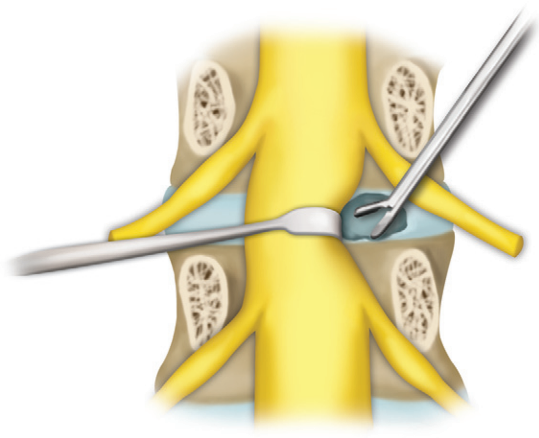

Figure 45-4 Traditional diskectomy before end plate removal.

- We generally prefer to place the more medial bone grafts first, to minimize total mobilization of the dural sac (Fig. 45-7).
- Others place the grafts laterally and then push them toward the midline.
- The superior edge of the graft should be at least 5 mm ventral to the floor of the spinal canal.
- Two to three pieces of tricortical graft material (Fig. 45-8) or cage filled with autograft (Fig. 45-9) can safely be placed on each side of the thecal sac.
- After placing the grafts, be certain that the dural sac and nerve roots are not being compressed.

Closure and Postoperative Care

- Control bleeding of the disk space, epidural space, and paraspinal muscles.
- Place a drain for 24 hours, and close the wound in layers.
- Patients are mobilized on the day of surgery and usually go home in an orthosis 1 or 2 days later.

TRANSFORAMINAL LUMBAR INTERBODY FUSION PROCEDURE

Patient Positioning and Pedicle Screw Placement

- After endotracheal anesthesia, the patient is placed in a prone position with avoidance of epidural venous distension from abdominal compression.
- Posterior spinal elements are exposed through a midline longitudinal incision.
- A subperiosteal dissection of the paraspinous muscles is completed to the transverse processes.
- To minimize blood loss, pedicle screws are sized and inserted under C-arm fluoroscopy guidance before decompression and distraction (Fig. 45-10).

Unilateral Facetectomy and Contralateral Distraction

- If radiculopathy is present, the spinal canal is entered through a unilateral laminectomy and inferior facetectomy on the side of the radicular pain. If no radiculopathy is present, the side is chosen arbitrarily.

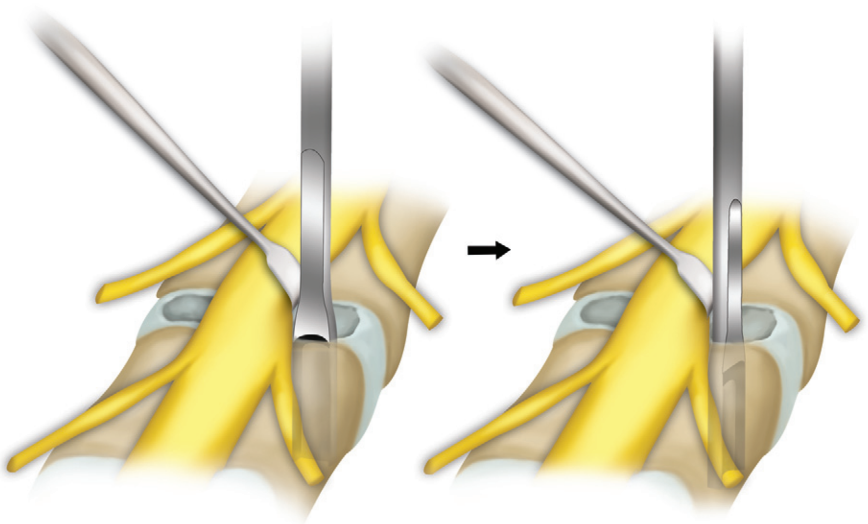

Figure 45-5 Reamer-distractors of progressively increasing size are inserted to widen the disk space, until optimal distraction is achieved.

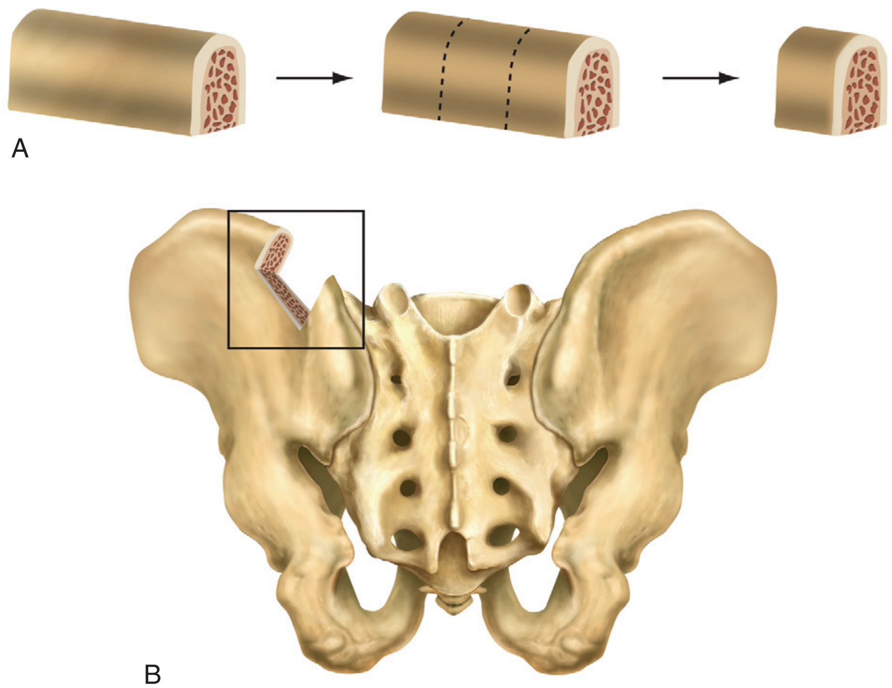

Figure 45-6 Iliac bone harvesting. **A,** Graft harvest. **B,** Location of graft harvesting from the iliac crest.

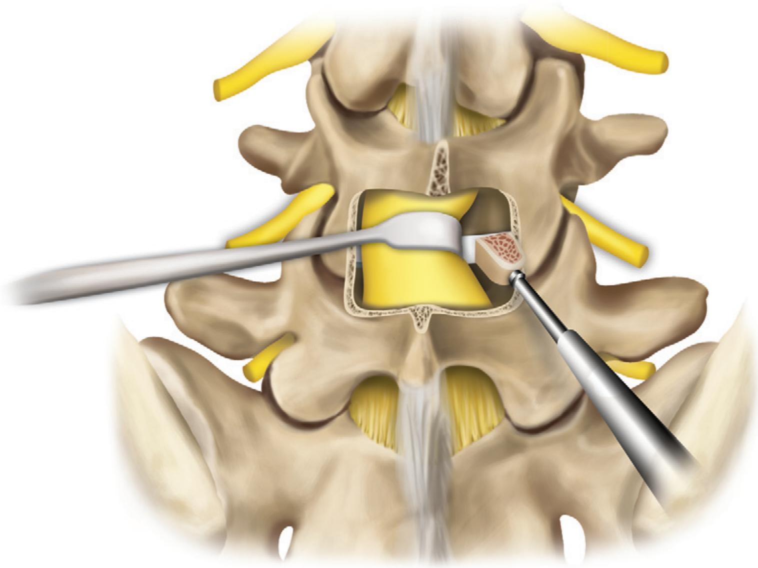

Figure 45-7 Bone graft placement.

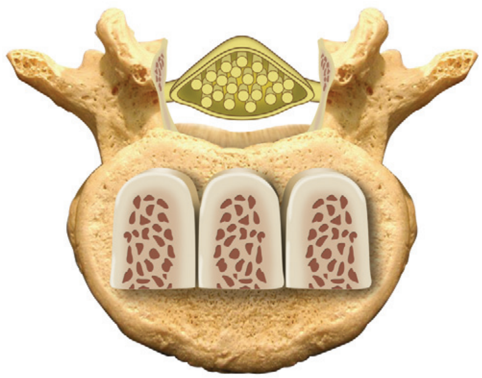

Figure 45-8 Three bone grafts are placed.

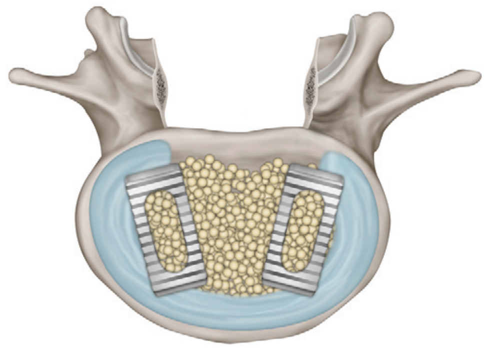

Figure 45-9 Cage filled with autografts is placed.

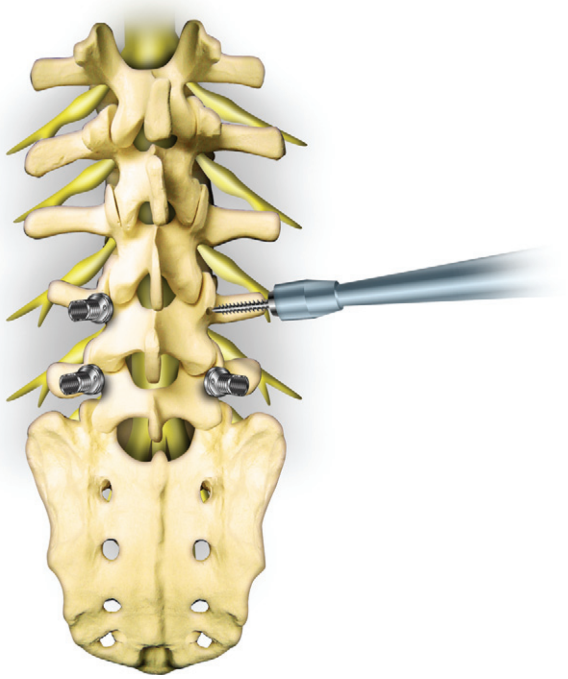

Figure 45-10 After the subperiosteal dissection, pedicle screws are sized and inserted before decompression.

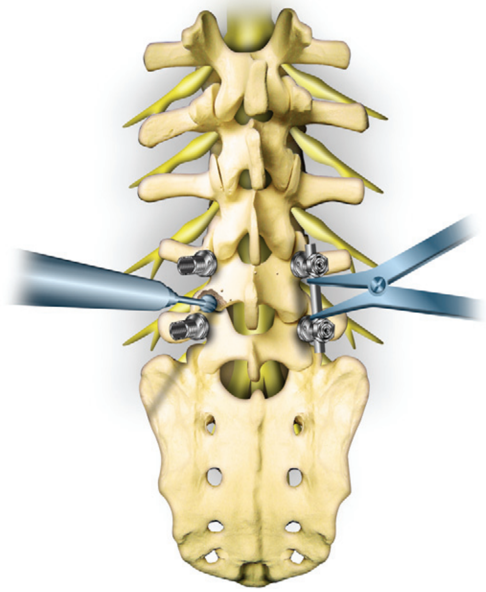

Figure 45-12 The inferior articular process of the cranial vertebra is thinned out with the use of a burr, while distraction forces are applied to the contralateral side.

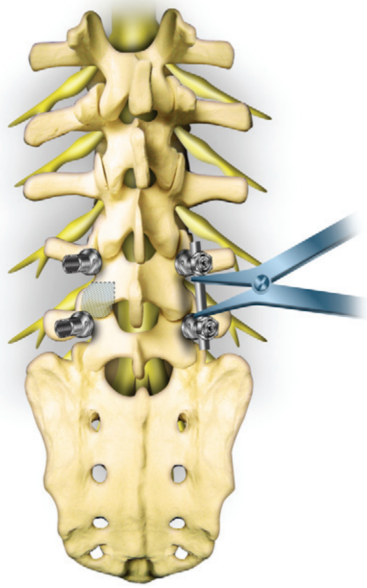

Figure 45-11 Apply the rod system at the nonradiculopathic side, and distract the disk space. A facetectomy will be done at the radiculopathic side.

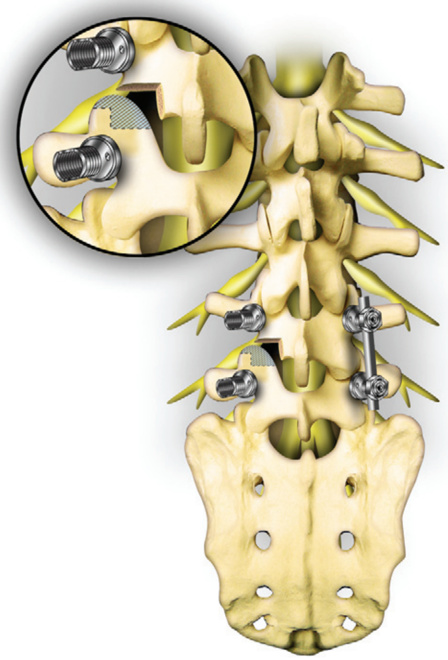

Figure 45-13 After thinning by using a drill, resect the inferior articular process of the cranial vertebral body with a chisel or bone cutter, thereby uncovering the neural foramen. The degree of bone to be resected from the superior facet of the inferior vertebra is indicated.

- Apply the rod system at the contralateral side, and distract the disk space (Fig. 45-11). The interspinous ligament, as well as the ligamentum flavum on the opposite side, is left intact. The degree of bone resection necessary for this unilateral TLIF technique is indicated in Figure 45-11.
- The next step is to gain access to the disk at L4–L5 via the transforaminal approach. The inferior articular process of the cranial vertebra is now thinned out with the use of a burr, while distraction forces are applied to the contralateral side (Fig. 45-12).
- Once thinned, resect the inferior articular process of the cranial vertebral body with a chisel or bone cutter to uncover the next stage in the approach to the neural foramen. The degree of bone to be resected from the superior facet of the inferior vertebra is indicated in Figure 45-13.

- The capsular part of the ligamentum flavum is now visible and can be resected. To avoid damage to the nervous structures, it is necessary to cut around the superior articular facet of the caudal vertebral body. Care must be taken to ensure that the lateral delimitation of the ligamentum flavum is largely preserved.
- Only in exceptional cases is resection of the lateral part of the ligamentum flavum necessary (Fig. 45-14). Tactile exploration of the neural foramen is recommended with palpatory identification of the cranial nerve root and the position and breadth of the pedicle of the caudal vertebral body.
- Resect the superior facet of the inferior vertebra as the final step in gaining access to the disk at L4–L5, the posterolateral parts of the annulus fibrosus, and the longitudinal ligament (Fig. 45-15).
- The entire neural foramen is identified after resection of the upper medial parts of the superior articular facet of the lower vertebral body. The upper nerve root that passes around the pedicle of the upper vertebral body and the lateral part of the intervertebral disk can be identified. The nerve root can be identified merely by palpation in its course within the foramen, especially where it crosses over the lateral parts of the intervertebral space (Fig. 45-16). The origin of the next nerve root in the caudal direction and the dural sac in the medial border can also be identified. After identification of these nervous structures, meticulous coagulation of the epidural veins in the neural foramen is carried out.

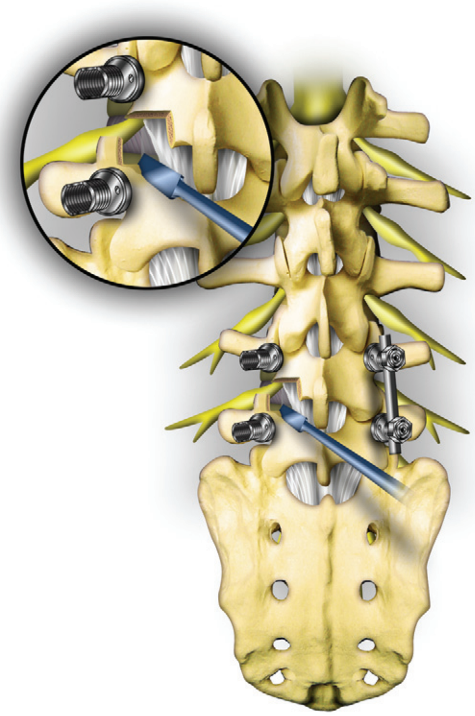

Figure 45-15 Resect the superior facet of the inferior vertebra. This is the final step in gaining access to the disk at L4–L5, the posterolateral parts of the annulus fibrosus, and the longitudinal ligament.

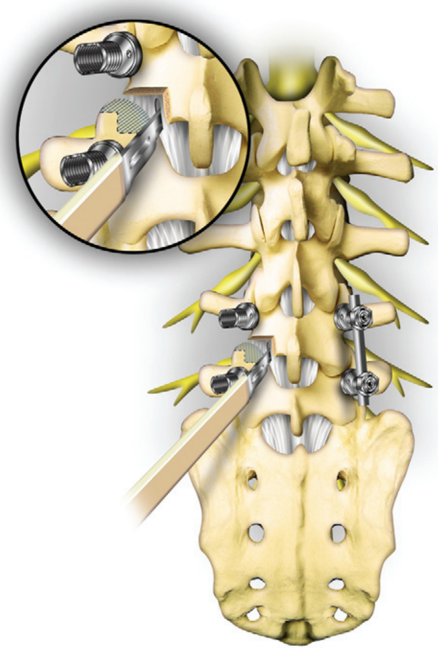

Figure 45-14 Ligamentum flavum removal. Care must be taken to ensure that the lateral delimitation of the ligamentum flavum is largely preserved. The exiting nerve root is identified and is protected from surgical trauma. Tactile exploration of the neural foramen is recommended with palpatory identification of the upper nerve root and the position and breadth of the pedicle of the caudal vertebral body.

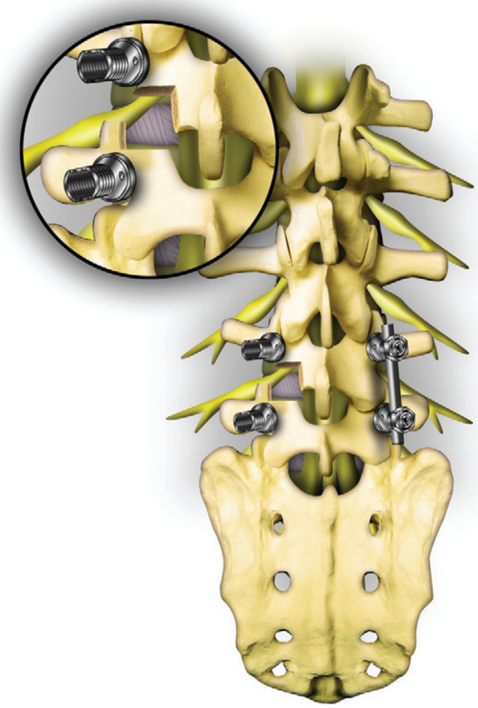

Figure 45-16 After resection of the upper medial parts of the superior articular facet, the neural foramen is opened. The upper nerve root and the lateral part of the intervertebral disk can now be identified.

Total Diskectomy through a Unilateral Approach

- The thecal sac is gently retracted medially if necessary.
- A diskectomy is performed through this unilateral approach (Fig. 45-17).
- The intervertebral disk compartment partially cleared using various rongeurs. Curettes can be used to remove the intervertebral disk remnants adhering to the upper plates. With the curettes, the cartilaginous coats of the end plates can be removed at the same time without destroying the osseous structure of the end plates.

End Plate Preparation

- After the initial diskectomy, gradual distraction is applied to the pedicle screws on the opposite side.
- An osteotome is used to remove the posterior lateral lip of concave bone to achieve a flat end plate surface. This is important because the upper plates of the lumbar vertebral bodies always have a pronounced concave shape.
- By a marginal resection of the dorsal edges of the end plates, a parallel plane between the adjacent vertebral bodies can be established. This is for the introduction of the structural graft. The dorsal lips of the vertebral body should be resected to form a uniform aperture (Fig. 45-18).
- Carefully curette the remaining cartilaginous parts of the end plates. A chisel is not indicated, because it will destroy the cortical structure of the end plates.
- It is necessary to remove the anterior one third or one quarter of the opposing end plates to enable definitive osseous fusion.[12] By this resection with angular chisels, the cancellous bone structure of the vertebral body is exposed, guaranteeing rapid osteointegration. Only the anterior one third or one quarter is resected. The remaining part of the osseous end plate must be carefully preserved to accommodate the supporting structural graft, which will be inserted later. In the process of chiseling, the anterior longitudinal ligament (ALL) must not be damaged because this can result in vascular injury (Fig. 45-19). A surgeon who is inexperienced in this procedure should initially use an image intensifier or fluoroscopy when completing this step.

Cancellous Bone and Strut Bone or Cage Graft

- The previously harvested cancellous bone is introduced into the retracted intervertebral disk compartment and is brought to the ALL. The cancellous bone is then impacted with straight and angled impactors. This procedure can attain a definite bone layer in the anterior one third of the intervertebral space. Also, this impacted cancellous bone prevents the structural graft from being positioned too far anteriorly (Fig. 45-20).
- Cut the structural graft to the appropriate height and insert it. A cage of the proper height packed with cancellous bone is inserted into the disk space. For biomechanical reasons, the graft should be situated in the middle or posterior half of the intervertebral space. Insert the first graft transforaminally into the disk space; place it primarily close to the posterior wall, and slide it anteriorly to the contralateral side (Fig. 45-21).
- Bring the first graft over the midline to the opposite side in a rolling movement. The graft is supported on the

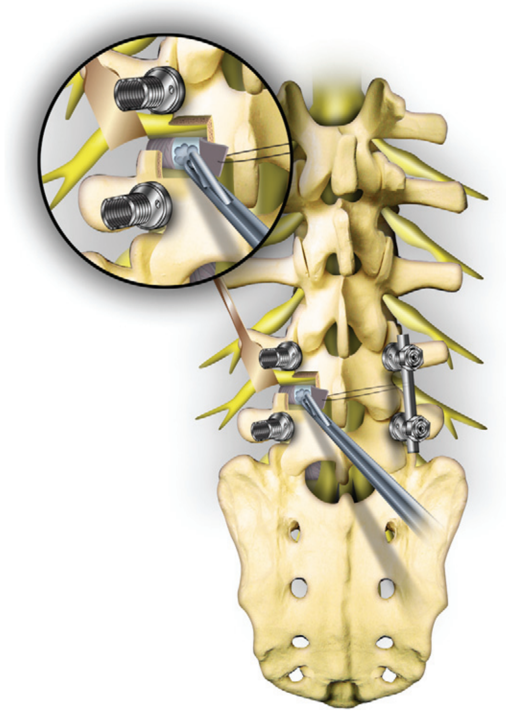

Figure 45-17 The thecal sac is gently retracted medially, if necessary. The diskectomy is performed through this unilateral approach.

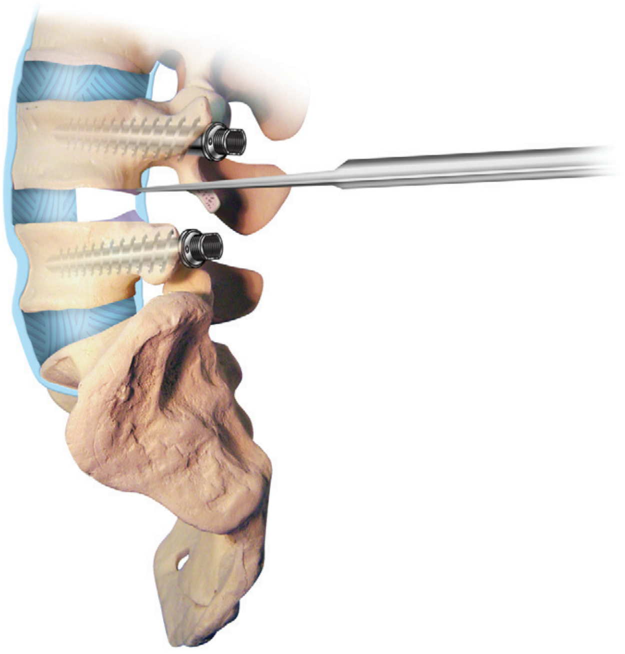

Figure 45-18 Clear the intervertebral disk compartment by using various rongeurs and curettes. An osteotome is used to remove the posterior lateral lip of concave bone to achieve a flat end plate surface. The dorsal lips of the vertebral body should be resected to form a uniform aperture.

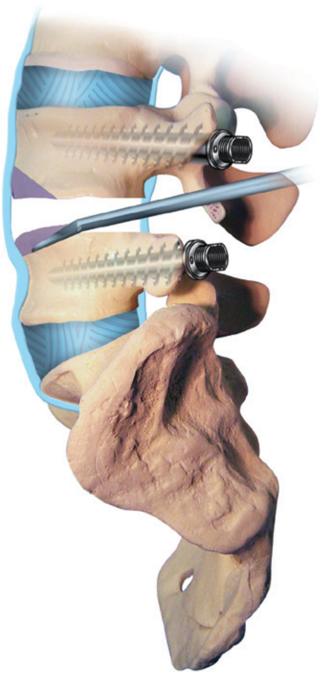

Figure 45-19 Remove the anterior one third or one quarter of the end plates to enable osseous fusion. The remaining part of the osseous end plate must be carefully preserved to accommodate the supporting structural graft. The anterior longitudinal ligament must be preserved to prevent vascular injury.

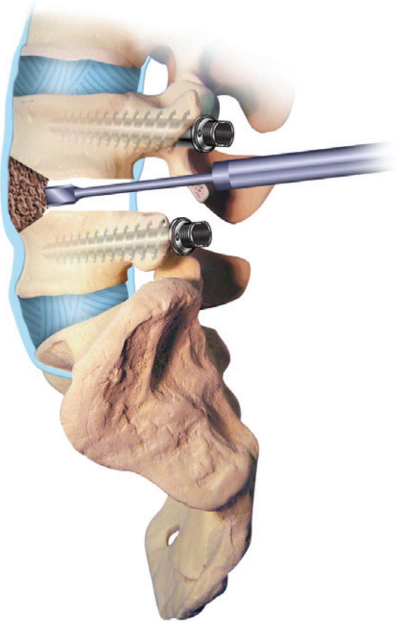

Figure 45-20 Cancellous bone is introduced into the intervertebral disk space and is brought to the anterior longitudinal ligament. This is necessary to attain a definite bone layer in the anterior one third of the intervertebral space. At the same time, this impacted cancellous bone prevents the structural graft from being positioned too far anteriorly.

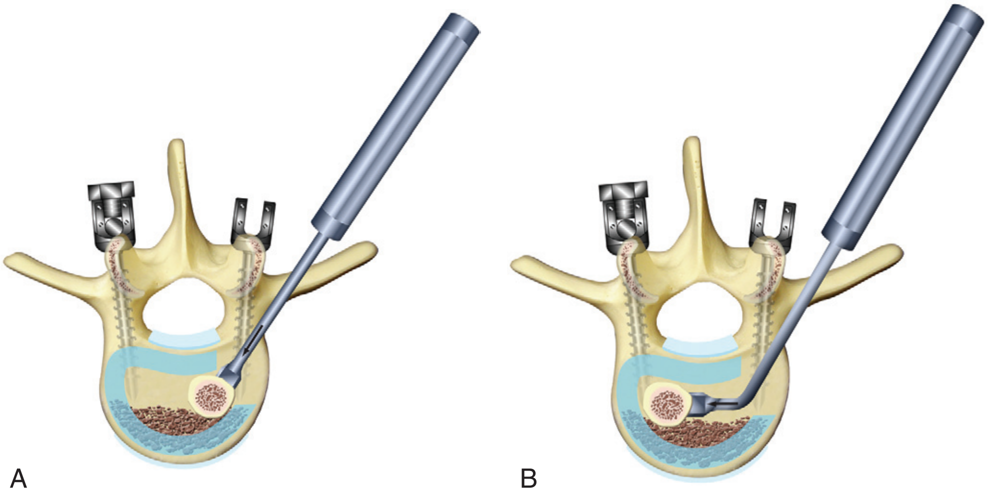

Figure 45-21 Insert the first graft transforaminally into the disk space. Place it primarily close to the posterior wall, then slide it anteriorly to the contralateral side.

ventrally introduced autologous bone chips, which prevents it from becoming positioned too far ventrally.

- A second graft is seated next to the first one to line them up to the left and to the right of the midline, respectively. In this way, a good broad area of support from the adjacent vertebral bodies is attained (Fig. 45-22).
- After insertion of the bilateral strut graft or cages from a unilateral approach, the final position is checked visually and radiologically. Then the disk space distraction is released.

Final Assembly of a Rod-and-Screw System and Closure

- The construct is compressed to establish an optimal graft-bone interface and to reestablish lumbar lordosis at the operated segments (Fig. 45-23).
- The rod-and-screw system is tightened and cross-linked.
- Perform a posterolateral fusion with cancellous iliac bone graft over the transverse processes after adequate decortication on both sides (Fig. 45-24).

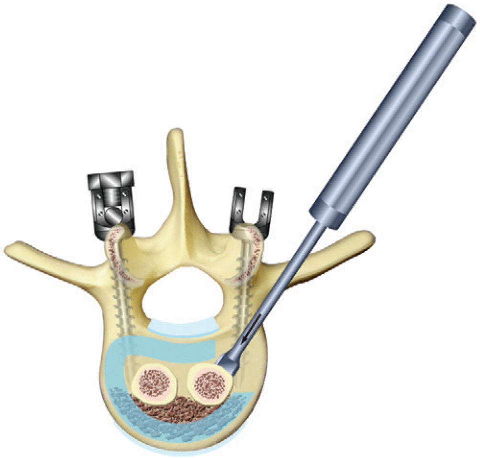

Figure 45-22 A second graft is seated next to the first one to line these up to the left and to the right of the midline, respectively. In this way, a good broad area of support from the adjacent vertebral bodies is attained.

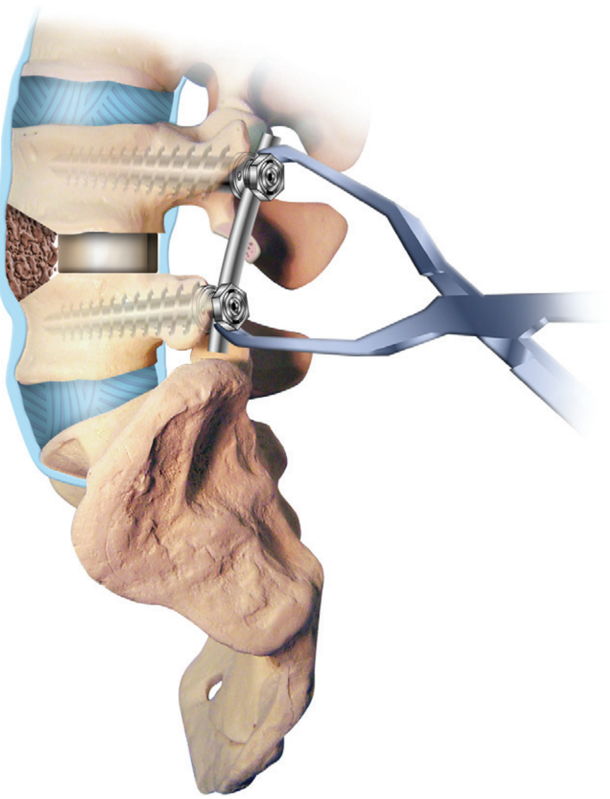

Figure 45-23 After insertion of the bilateral cages from a unilateral approach, the final position of the structural graft is checked visually and radiologically. Then the disk space distraction is released. The construct is compressed to establish an optimum graft-bone interface and to reestablish lumbar lordosis at the operated segments.

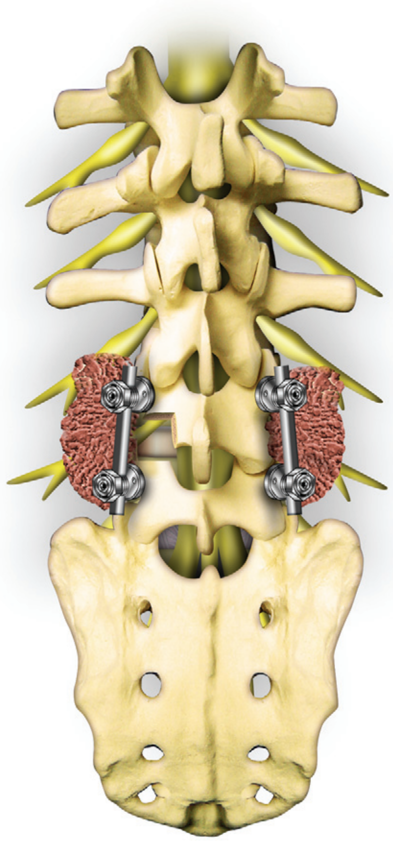

Figure 45-24 After tightening and crosslinking of the rod-and-screw system, perform a posterolateral fusion with bone graft over the transverse processes.

- Insert drains and carry out the muscle closure, followed by fascia suture, subcutaneous suture, and finally by skin closure.

Postoperative Care

- All wound drains are removed 24 to 48 hours after surgery.
- Patients with a single-level lumbar fusion do not need external orthosis.
- Weight-bearing standing radiographs are obtained before hospital discharge to ensure the implants have not shifted (Fig. 45-25).
- Patients are mobilized on postoperative day 1.
- Physical therapy for rehabilitation is then provided.
- Patients are usually discharged from the hospital 2 to 3 days after operation if there are no complications.

Complications

- Pseudarthrosis
- Excessive hemorrhage
- Dural tear
- Infection

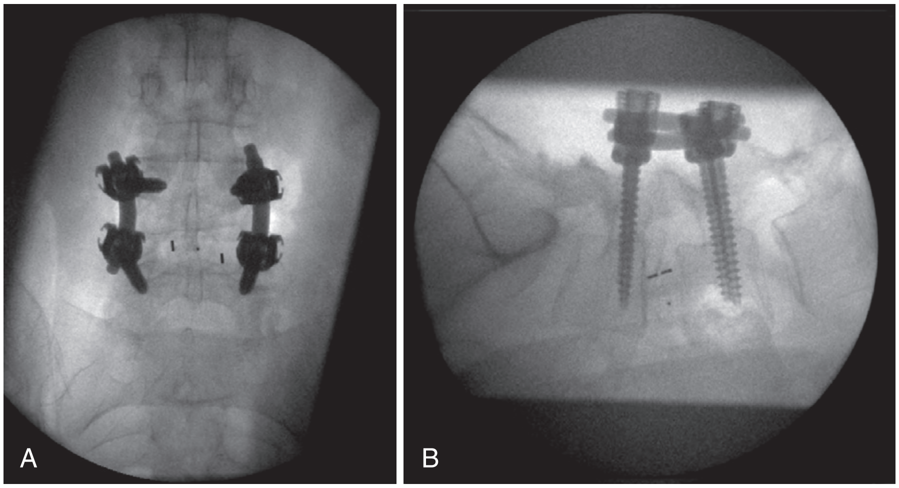

Figure 45-25 Postoperative radiographs of a transforminal lumbar interbody fusion.

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46 Anterior Lumbar Interbody Fusion

MICHAEL Y. WANG, KEVIN S. CAHILL, and CARL LAURYSSEN

Overview

Anterior lumbar interbody fusion (ALIF) has evolved as one of the predominant surgical techniques for the treatment of diskogenic back pain. Through an anterior retroperitoneal approach, the entire ventral surface of the disk is exposed, making complete diskectomy and subsequent placement of a large intradisk implant straightforward.

Although various surgical techniques have been developed to access the anterior lumbar spine—open retroperitoneal, transperitoneal, endoscopic, and balloon-assisted endoscopic—the mini-open retroperitoneal approach has become the most widely accepted. Mini-open access allows wide exposure of up to three disk spaces from L3–L4 to L5–S1. Furthermore, standard open techniques and instrumentation can be used, allowing for direct manipulation of vascular structures. Surgeon disorientation is also kept to a minimum.

Advantages of an Anterior Approach

Lumbar interbody fusion can be approached from a number of different access corridors: anterior, anterolateral, extreme lateral, transforaminal, and posterior. The anterior retroperitoneal corridor provides the most direct and complete exposure of the disk space. Through this approach, the view is centered in the midline with lateral exposure to either side of the vertebral bodies. This extensive lateral exposure allows for the most extensive disk removal and permits placement of a single-unit implant that nearly matches the vertebral end plate in surface area. The implant enables coverage of a large vertebral body surface area and allows for low nonunion rates, and it minimizes the risk of interbody subsidence. Likewise, restoration of disk height allows for indirect neurologic decompression through expansion of the neural foramen and results in reduction of ligamentous buckling. Although direct neurologic compression is not routinely performed with ALIF techniques, posterior disk herniations and posterior longitudinal ligament (PLL) removal are also possible.

Another major advantage of ALIF is that the technique spares both the posterior spinal musculature and the anterolateral psoas musculature. This results in a reduction of the postoperative pain and disability that frequently accompanies posterior spinal fusions and has also been reported following transpsoas extreme lateral interbody fusions. In addition, because ALIF avoids the extensive stripping of the dorsal soft tissues, the muscle denervation and atrophy implicated in abnormal biomechanics and failed back surgery syndrome are avoided. Likewise, because the psoas muscle is not traversed by the surgical approach, the lumbar plexus is not at risk of injury during the approach or by the retractors. As a result, the ALIF technique can be safely used at levels that may pose increased neurologic risk during an extreme lateral approach (L4–L5) and those that may not be accessible by a lateral approach (L5–S1).

Patient Selection

The surgical treatment of diskogenic back pain remains controversial. Although the intervertebral disk undoubtedly contains nociceptive receptors, the relationship between symptoms of back pain, diagnostic studies, and surgical outcomes remains unclear. Because of the ubiquity of back discomfort and the high incidence of disk abnormalities on magnetic resonance imaging (MRI), strict criteria in selecting patients for surgery remains critical.

Several factors do appear to be predictive of pain relief following lumbar interbody fusion: 1) the history should be consistent with mechanical symptoms of axial pain aggravated by spinal loading and motion; 2) radiographic studies should demonstrate severe disk degeneration localized to discrete levels; 3) provocative diskography should produce concordant pain only at the affected levels and should demonstrate an abnormal nuclear distribution; and 4) abnormal excessive motion on dynamic studies or sagittal deformity are highly predictive of postoperative improvement.

Indications and Contraindications

INDICATIONS

- Diskogenic disease at the level of L3–L4, L4–L5, and/or L5–S1
- Revision of a failed posterior fusion at the level of L3–L4, L4–L5, and/or L5–S1

RELATIVE CONTRAINDICATIONS

- Severe medical comorbidities
- Morbid obesity
- Retroperitoneal scarring from previous surgery
- Aortic aneurysm

- Severe peripheral vascular disease
- Solitary kidney on the side of the exposure because of the risk of ureteral injury (without stenting)
- Severe osteoporosis with a high risk of interbody graft settling
- Spinal infection
- High-grade spondylolisthesis in the absence of a posterior fusion

Operative Technique (Mini-Open Approach)

EQUIPMENT

- Table-mounted abdominal retractor system
- Lateral fluoroscopy or flat-film radiographs
- Vascular clips and ligature suture
- Long curettes
- Long Kerrison punches
- Laminar spreader or interbody distractor
- Tamp
- Long-handled osteotomes (for vertebrectomy)
- High-speed drill (for vertebrectomy)
- Interbody spacers
- Bicortical iliac crest autograft
- Femoral ring allograft
- Cylindrical threaded allograft bone dowels
- Cylindrical threaded titanium cages
- Titanium mesh cage
- Alternate material cages (carbon fiber, resorbable polylactic acid, polyetheretherketone [PEEK] polymer)
- Osteoconductive/osteoinductive substances to fill interbody spacers
- Vertebral autograft
- Cancellous iliac crest autograft
- Cortical or cancellous allograft chips
- Demineralized bone matrix
- Bone morphogenetic protein
- Anterior thoracolumbar plating system (optional)

PATIENT POSITIONING

- The patient is positioned supine on a standard operating table with the arms abducted at 90 degrees.
- Careful attention should be paid to the degree of lumbar lordosis following positioning, and an inflatable bladder should be placed under the patient's back to elevate the midlumbar spine. This not only opens the anterior disk space to assist in the diskectomy, it also allows for easier placement of lordotic implants.
- Abduction of the arms permits placement of the table-mounted abdominal retractor closer to the patient's torso without the risk of an upper extremity compressive neuropathy.
- If autograft is to be harvested, the anterior abdomen and iliac crest are prepped.

EXPOSURE

- A 12-cm skin incision is made to the left of the midline over the appropriate disk space (Fig. 46-1).

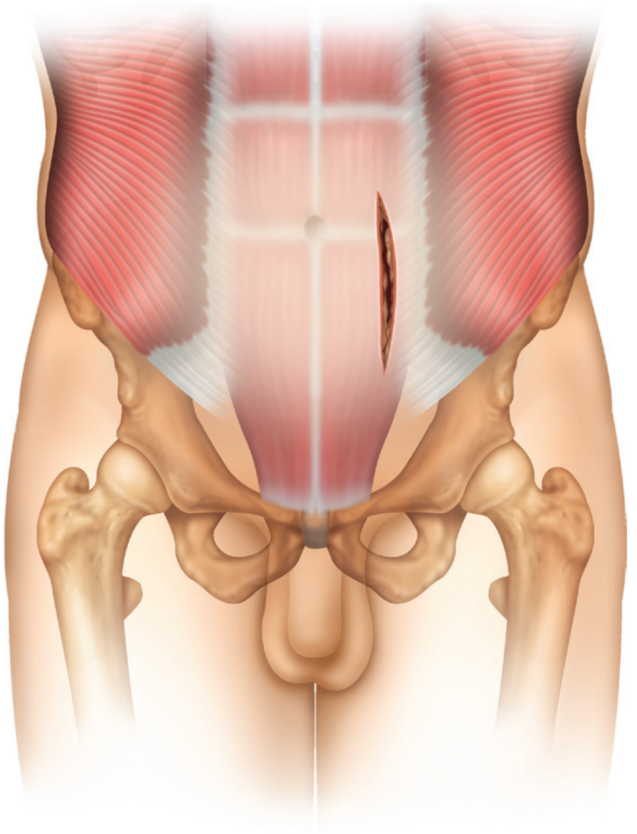

Figure 46-1 Incision along the left lateral aspect of the rectus abdominis.

- Blunt finger dissection is used to mobilize the skin and soft tissues off of the left anterior rectus sheath (Fig. 46-2).
- The anterior rectus sheath is divided longitudinally near the midline.
- The medial border of the intrafascial muscle belly is mobilized over a cranial-to-caudal distance of 12 cm.
- The muscle is then mobilized laterally to expose the underlying arcuate line. Alternatively, a lateral incision can be made in the anterior sheath, with the muscle mobilized medially (Fig. 46-3).
- Blunt dissection under the arcuate ligament—which marks the most caudal aspect of the incomplete posterior rectus sheath, superficial to the exposed peritoneum—allows access to the retroperitoneal space (Fig. 46-4).
- Inserting the fingers and then the entire hand into the retroperitoneal space allows the surgeon to sweep the intraperitoneal contents superiorly, inferiorly, and medially to reveal the spinal column in the midline (Fig. 46-5). Because this technique relies on palpation and not visualization, the surgeon must be familiar with the relevant anatomy. Palpation of the great vessels helps to avoid vascular injury, and care should be exercised to avoid tears in the peritoneal lining. These can be either repaired primarily or opened to prevent bowel strangulation.
- The ureter must be identified to prevent inadvertent injury, and it is typically found on the peritoneal side of the exposure.

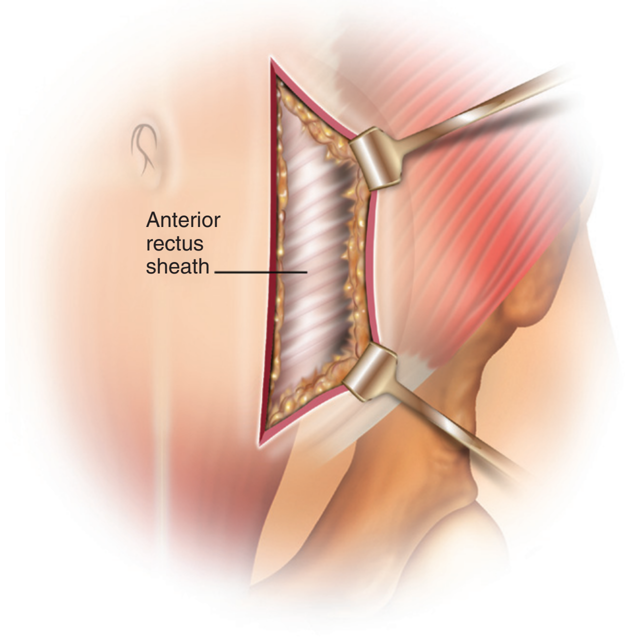

Figure 46-2 Blunt dissection and retraction of the superficial soft tissues expose the anterior rectus sheath.

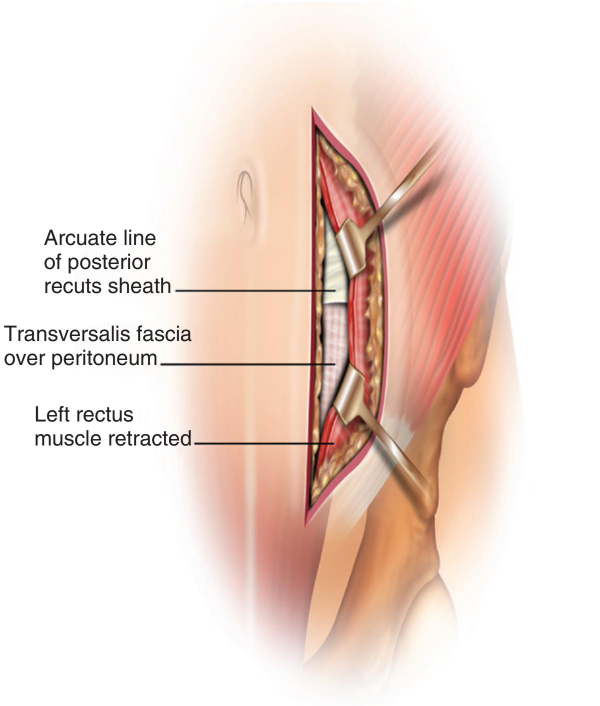

Figure 46-3 Blunt dissection along the fibers of the rectus abdominis muscle medially expose the posterior sheath. The arcuate line marks the transition at the lower end of the incomplete posterior rectus sheath to peritoneum.

- Deep, self-retaining abdominal retractors can then be placed and attached to the table-mounted frame to maintain a midline corridor to the spine (Fig. 46-6).
- Proper localization is confirmed with lateral radiography.

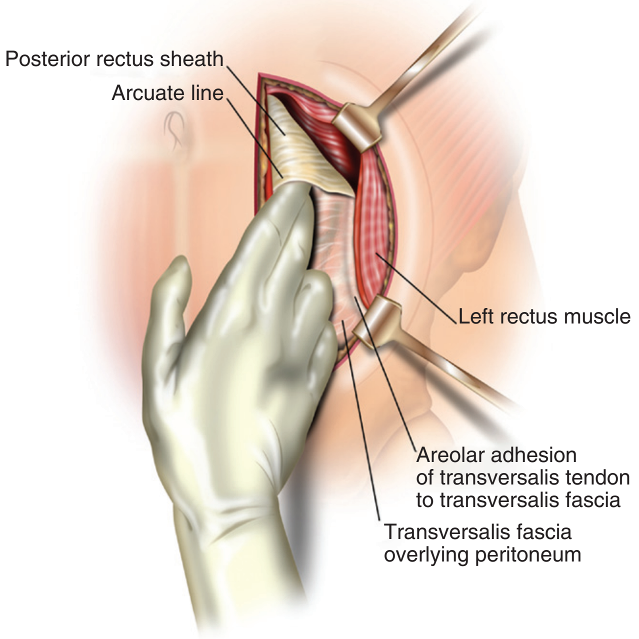

Figure 46-4 Identification of the retroperitoneal layer is accomplished with blunt finger dissection under the arcuate line between the posterior rectus sheath and the peritoneum.

VASCULAR DISSECTION

- The aorta and vena cava are then identified. For exposure of the L5–S1 interspace, the disk can typically be accessed below the bifurcation of the great vessels (the interiliac corridor). At the L3–L4 and L4–L5 levels, the aorta and vena cava will have to be retracted to the left, from their midline position (the left lateroaortic route). Alternatively, an anterolateral approach may be used at these levels that involves performing the diskectomy lateral to the aorta and vena cava.
- In the absence of scarring, blunt dissection with a sponge stick is very effective for mobilizing the vessels. Segmental arteries traversing the disk space or tethering the aorta need to be ligated securely. Iliolumbar veins can also be a troublesome source of bleeding. Any nearby iliolumbar veins should be prophylactically ligated, because inadvertent tearing of these vessels can be difficult to control and can lead to substantial blood loss (Fig. 46-7).
- The middle sacral artery and vein may need to be ligated for access below the bifurcations.
- The vascular anatomy of this region can be quite variable (Fig. 46-8).
- If the iliac vessels are medially located, an assistant should retract them laterally with handheld retractors to expose the disk space widely.

DISKECTOMY

- Excessive electrocautery along the anterior longitudinal ligament (ALL) should be avoided to prevent injury to the hypogastric plexus, which may result in retrograde

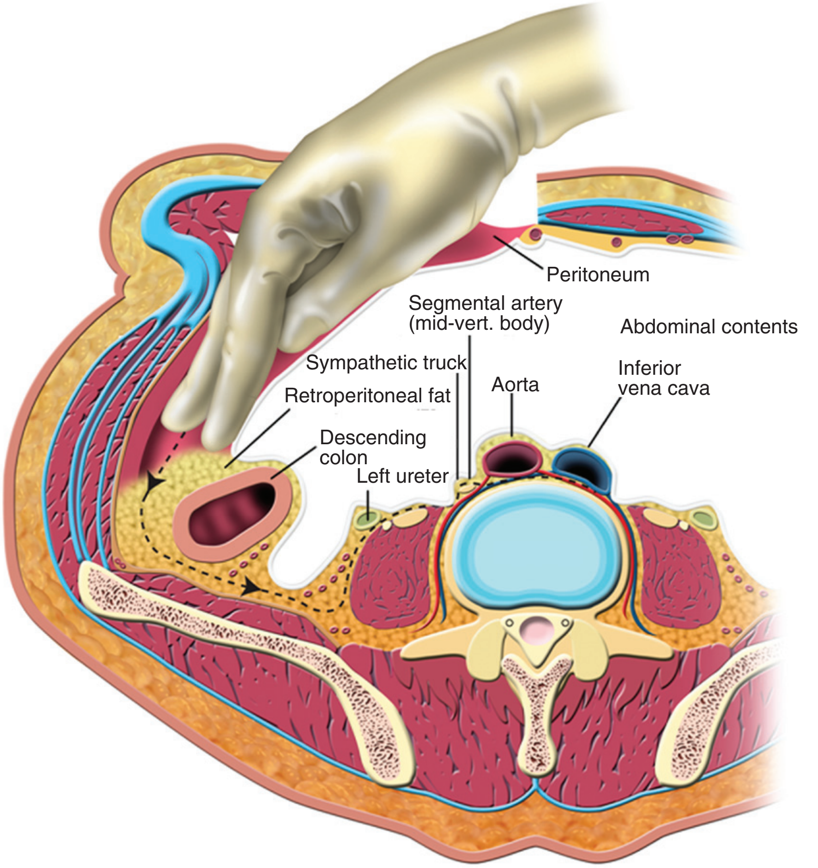

Figure 46-5 Axial section showing the approach of the blunt finger dissection used to reach the anterior aspect of the lumbar spine.

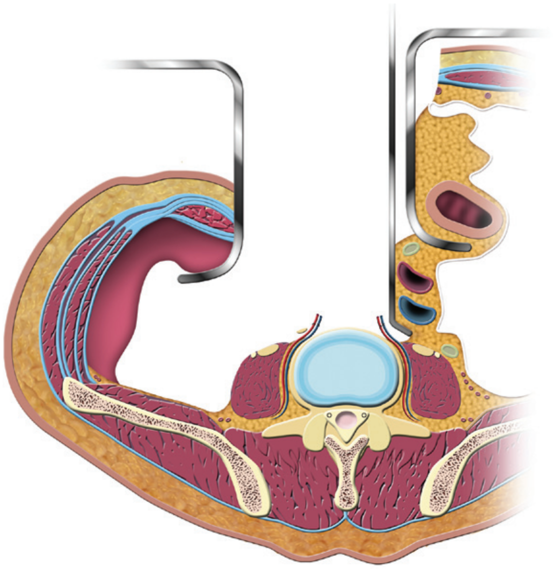

Figure 46-6 Deep retractor placement allows for a centered midline anterior approach to the spinal column.

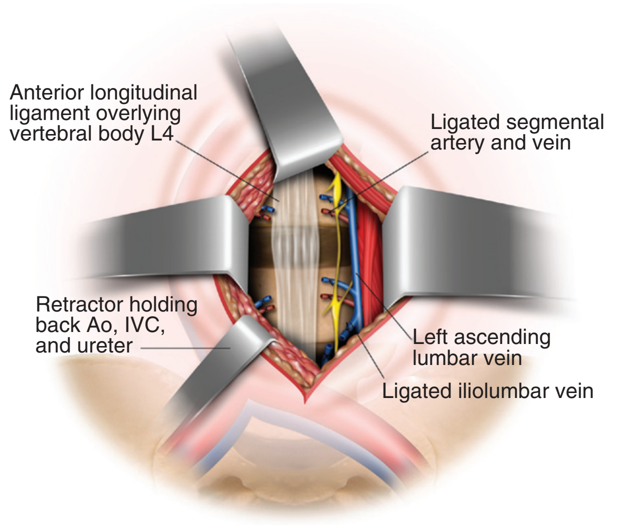

Figure 46-7 Intraoperative view of the anterior longitudinal ligament with neighboring segmental arteries and the iliolumbar vein. Ao, aorta; IVC, inferior vena cava.

ejaculation (Fig. 46-9). Instead, blunt dissection should be used to sweep the plexus from left to right.

- After determining the midline, the ALL is incised with a No. 10 scalpel blade on a long handle.
- Complete disk removal is then accomplished with curettes and rongeurs.
- The cartilaginous end plates should be completely removed, and vertebral body surfaces should be decorticated to prepare the graft recipient site.
- In select cases, the intervertebral space will then need to be increased through serial dilation of the disk space before implant insertion.

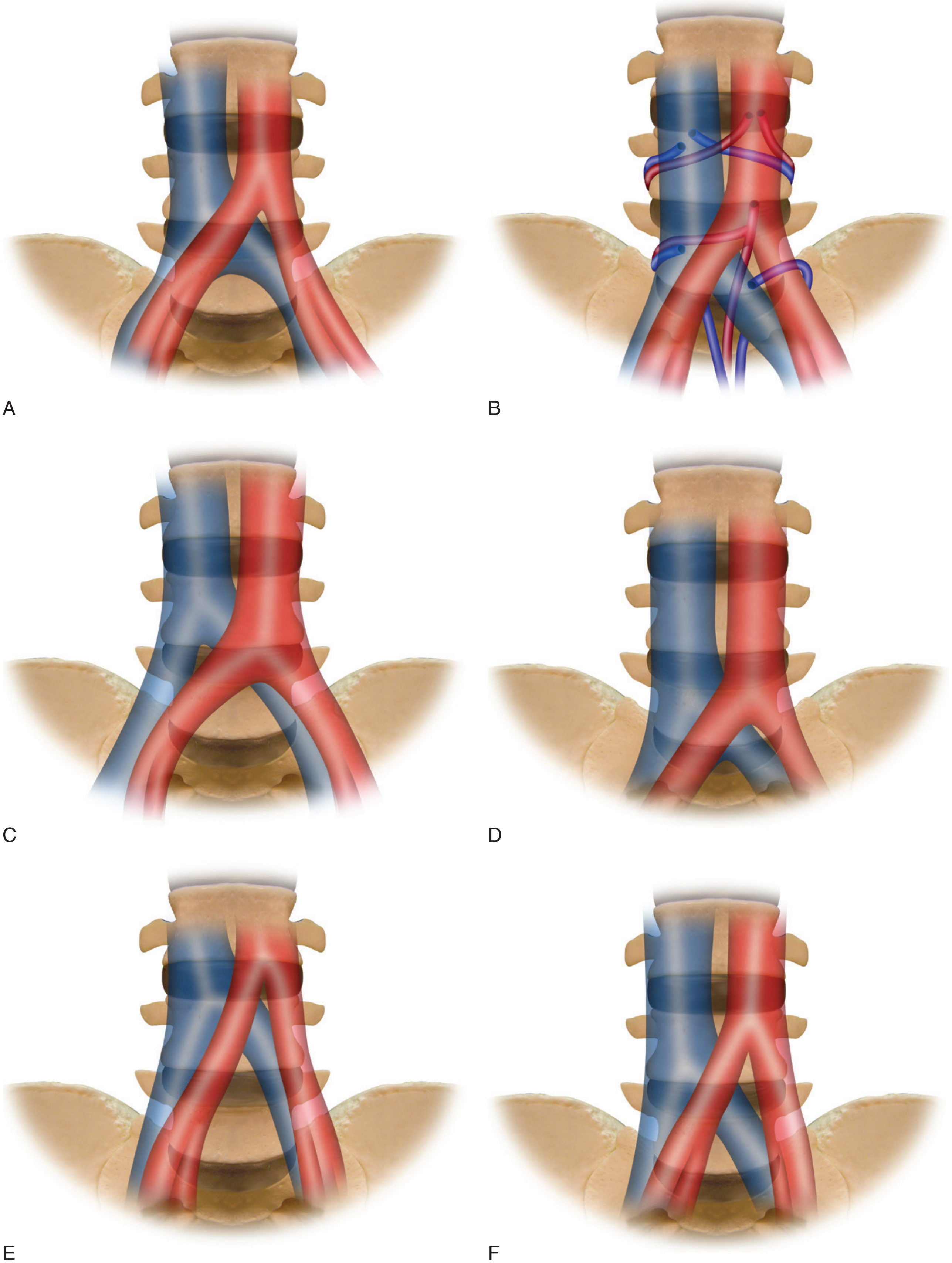

Figure 46-8 Various relationships between the aortic and vena cava bifurcations to the L5–S1 disk space.

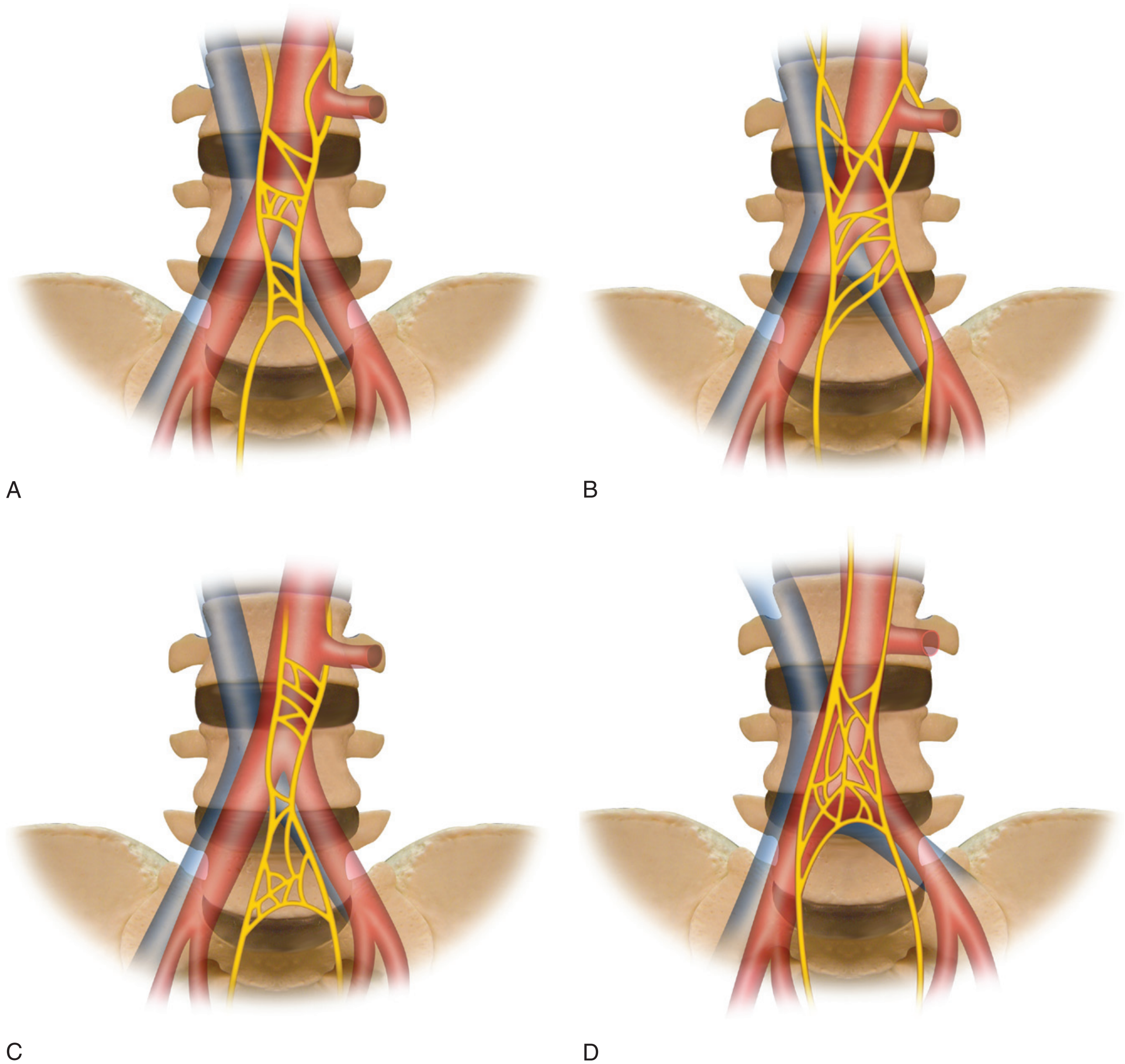

Figure 46-9 Variations in the arrangement of the superior hypogastric plexus.

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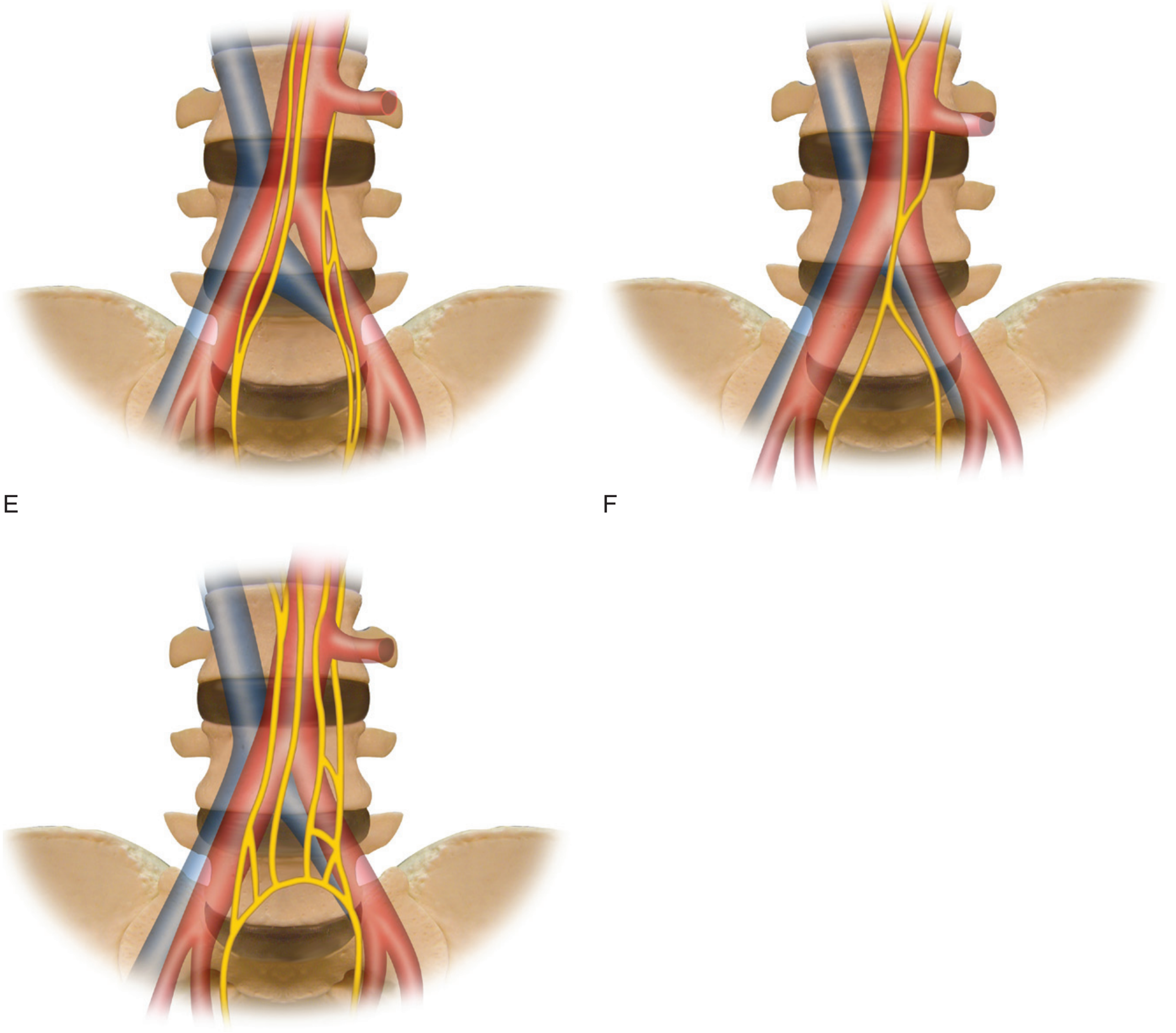

E F G

Figure 46-9, cont'd

- Distraction between vertebral bodies can increase the foraminal height and effect an indirect neural decompression.

INTERBODY IMPLANTS

- A variety of interbody spacers can then be placed to maintain disk height and promote interbody fusion.
- Bicortical iliac crest autograft can be inserted with the ridge of the crest placed anteriorly. In this position, cortical bone supports the interspace, maximizing contact between cancellous autograft and vertebral end plates.
- Rings of femur or humerus allograft bone can be cut to size to fit into the disk space. The cylindrical geometry of these long bones matches the vertebral end plates nicely, because the strongest vertebral end plate is at the periphery. The allograft should be cut for an appropriate lordosis. The central canal should be packed with osteoconductive/osteoinductive materials, as is the case with all implants except autograft bone. Commercially, precision-machined allograft rings are also readily available.
- Precision-machined, cylindrical, threaded allograft bone dowels have the advantages of an allograft but a reduced risk of backout because of their threaded contact with host bone.
- Titanium-threaded fusion cages have been purported to provide superior stabilization when compared with impacted spacers (Fig. 46-10). This presumably decreases the need for supplemental posterior fixation.
- Titanium mesh cages have a long track record of safety and efficacy and remain a versatile option.
- Impacted cages composed of alternate materials—such as carbon fiber, resorbable polylactic acid, and PEEK polymer—are widely available.

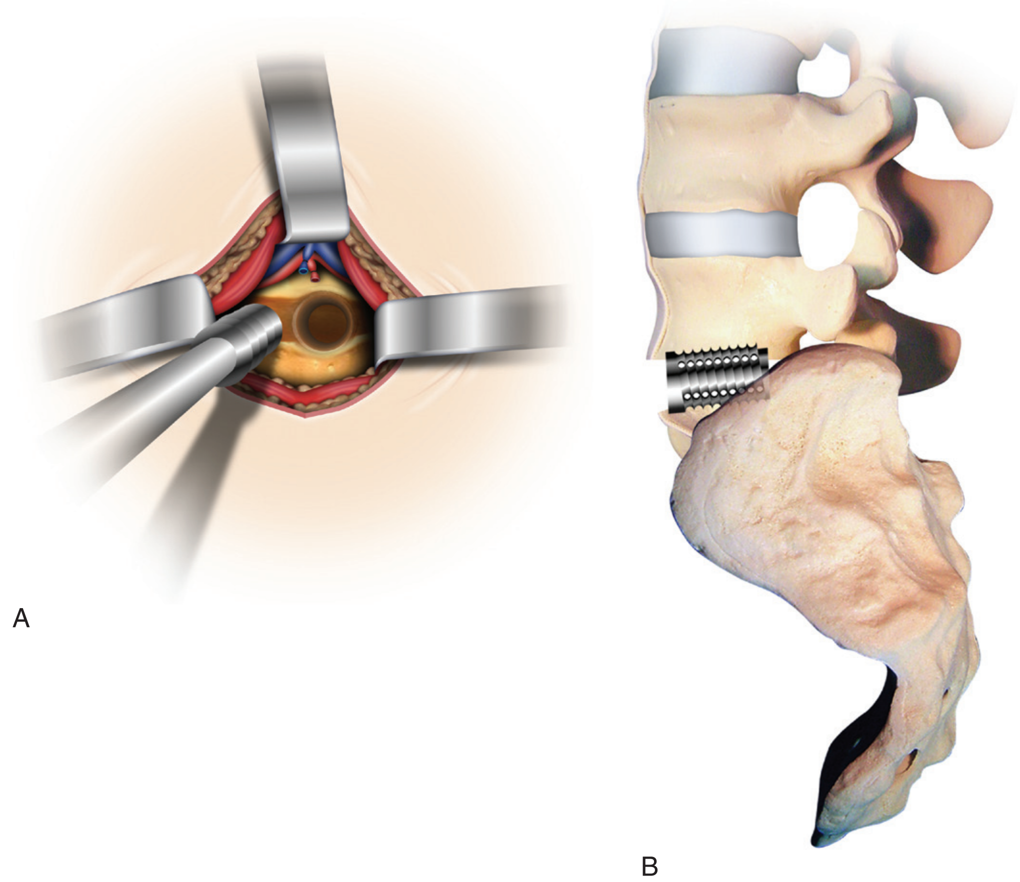

Figure 46-10 Placement of titanium-threaded fusion cages into the disk space. **A,** Intraoperative view. **B,** Sagittal view.

PLATING (OPTIONAL)

- Plating of the anterior lumbar spine enhances the rigidity of the construct and decreases the risk of interbody spacer migration (Fig. 46-11).
- Additional options include the use of buttress plates attached to only the superior or inferior vertebral body.
- Newly developed cages are available that contain an integrated, zero-profile anterior plate (SynFix-LR; Synthes, Solothurn, Switzerland) or allow for implantation of screwless plating devices (ROI-A; LDR Medical, Austin, TX). These novel cage designs allow for improved cage stability that may approach levels previously only achieved by supplementation with posterior pedicle screw instrumentation (Fig. 46-12).

BIOLOGICS (OPTIONAL)

- Recombinant human bone morphogenetic protein (BMP) 2 (Infuse; Medtronic, Memphis, TN) has been approved by the Food and Drug Administration (FDA) for use in ALIF to promote bony fusion.
- Fusion rates using BMP for ALIF have been reported to approach 100%. However, complications have been associated with use that include increased rates of retrograde ejaculation and increased graft resorption.

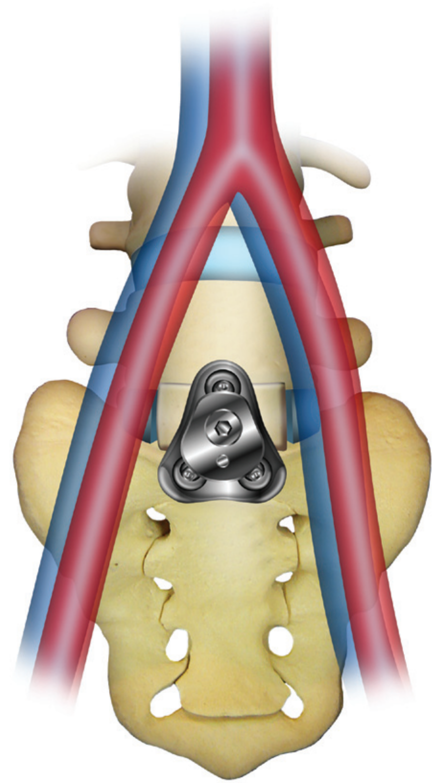

Figure 46-11 Anterior plating at the L5–S1 level.

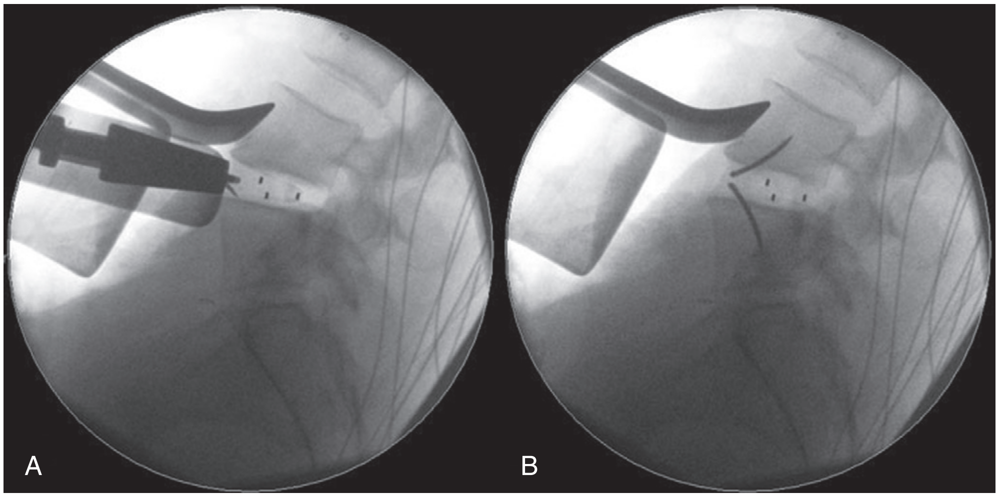

Figure 46-12 Intraoperative radiographs of the ROI-A cage with incorporated plating devices. **A,** Insertion of the device at L4–L5. **B,** After deployment of the screwless plating devices.

CLOSURE

- The wound is irrigated, and all cottonoids and retractors are removed.
- A final radiograph is taken to confirm implant location and to check for retained sponges.
- The wound is inspected for any bleeding, and all vasculature ligatures are checked.
- The peritoneal lining and ureter are inspected. Small tears in the peritoneum should be either repaired primarily or opened widely to prevent bowel strangulation.
- The rectus sheath is reapproximated with resorbable suture.
- The skin is closed with a running subcuticular stitch.

Postoperative Care

- Patient-controlled analgesia is appropriate for pain control.
- The patient is mobilized the day after surgery.
- A liquid diet is begun as soon as the patient has bowel sounds.
- Depending on the number of levels treated, a 1- to 3-day hospital stay is typical.
- Weight-bearing standing radiographs are obtained before hospital discharge to ensure that the implants have not shifted.
- For multilevel fusions, the patient should wear a rigid orthosis, such as a thoracolumbral sacral orthosis with thigh extension for L5–S1, for 3 months postoperatively.
- For multilevel fusions, posterior supplemental instrumentation may be necessary. This can be performed under the same anesthetic or in a delayed fashion.

Complications

- Injury to the alimentary tract can be avoided by packing the peritoneum away from the operative corridor. Postoperative ileus is uncommon and should be treated with intravenous hydration, minimization of narcotic doses, and restricted oral intake.
- Damage to the ureter is uncommon and can be avoided by its proper identification.
- Careful manipulation of the numerous vessels encountered during ALIF will minimize the risk of vascular complications, and nearby arteries and veins should be prophylactically ligated.
- Retraction or electrocautery of the hypogastric plexus should be avoided to minimize the possibility of retrograde ejaculation. Male patients are offered the opportunity to bank their sperm before surgery.
- Proper graft sizing and shaping is critical. Undersized grafts can lead to fusion in a kyphotic attitude. Grafts with a small surface area are prone to settling. Ideally, the interbody spacer should maintain vertebral height and physiologic lordosis with distraction across the neuroforamina.
- Telescoping of the graft into adjacent end plates can be minimized by preserving the vertebral end plates and using a graft with the maximal cross-sectional contact area.
- Pseudarthrosis rates can be minimized by proper recipient site preparation, incorporation of osteoinductive substances, supplemental posterior stabilization, proper nutrition, and postoperative immobilization. Patients addicted to tobacco are strongly encouraged to refrain from or to minimize use in the perioperative period.
- Abdominal wall weakness from partial denervation of the rectus abdominis muscle may result in injury to the superficial segmental nerves during exposure.

Conclusion

ALIF is a highly effective method for fusing the lower lumbar spine in carefully selected patients with back pain from degenerative disk disease.

47 Lateral Lumbar Interbody Fusion

PATRICK A. SUGRUE and JOHN C. LIU

Overview

Conditions such as spinal deformity, degenerative disk disease, adjacent segment disease, low-grade spondylolisthesis, spinal oncology, and traumatic deformity or instability are examples of conditions that may require instrumented spinal fusion. There are a variety of approaches to the spine, and these include anterior, posterior, and combined approaches. The choice of approach is largely dependent on the nature and location of the spinal pathology, surgeon preference and experience, and patient medical comorbidities. The lateral approach to the spine uses a retroperitoneal dissection to access the lateral aspect of the vertebral body or intervertebral disk. The minimally invasive lateral transpsoas approach for spinal fusion, also known as *direct lateral interbody fusion* (DLIF) or *extreme lateral interbody fusion* (XLIF), is designed to provide lateral access to the intervertebral disk and lateral vertebral body. This technique involves a retroperitoneal transpsoas dissection by splitting the fibers of the psoas muscle body to minimize the approach-related morbidity of an open lateral approach.

Pimenta[1] first introduced the idea of a lateral approach to the anterior spine in 2001, and Ozgur[2] later popularized the lateral transpsoas approach in what he called the "extreme lateral interbody fusion." Although this technique has been expanded to include performing a corpectomy through a minimally invasive transpsoas approach,[3] the focus of this chapter will be on lateral interbody fusion. The biomechanical advantages of using an interbody fusion to augment the anterior and middle column have been demonstrated and take advantage of the increased load sharing of the vertebral body compared with the posterior column.[4-6] Furthermore, the use of the DLIF approach allows for indirect neural decompression without exposing the thecal sac or the nerve roots. Likewise, the transpsoas approach does not require mobilization of the great vessels, nor does it carry the risk of retrograde ejaculation associated with a transabdominal retroperitoneal approach for anterior lumbar interbody fusion (ALIF).

The goal of the lateral transpsoas approach is to deliver a large interbody graft, while minimizing blood loss, and to reduce approach-related morbidity associated with larger lateral approaches. One of the greatest risks of the lateral transpsoas approach is injury to the lumbar plexus and genitofemoral nerve during the approach and dissection through the psoas muscle.[7-10] The risk of neural injury can be minimized with the use of multimodal neuromonitoring and appropriate radiographic guidance.

Indications

The lateral transpsoas approach can be used for any condition that requires access to the interbody space from T12–L1 through L4–L5 (Fig. 47-1). This approach cannot be used at L5–S1 because of the location of the iliac crest, which obstructs direct lateral access. Likewise, the lumbar plexus courses more anteriorly at the more caudal levels of the lumbar spine, and the iliac vasculature courses more laterally at the more caudal levels; thus both are at great risk. Oftentimes, and particularly in men, the L4–L5 disk space is also not accessible because of the size of the iliac crest. In the setting of a lumbar scoliosis, the more caudal levels may be accessible only on the convexity of the curvature, because the approach angle is more rostral (Fig. 47-2). Acosta and colleagues[11] showed that a large interbody graft delivered through a lateral transpsoas approach can provide some degree of coronal correction and focal restoration of sagittal alignment. Although the lateral transpsoas approach can have many applications, the ideal candidate is typically a patient with focal coronal imbalance or disk degeneration who does not require direct neural decompression. For example, a patient with adjacent segment degeneration above a prior posterolateral fusion may benefit from a lateral transpsoas interbody fusion (LTIF), because the interbody can restore some disk height and can supplement extension of the posterior instrumented fusion (Figs. 47-3 and 47-4). The posterior elements do not need to be disrupted, and the challenges of posterior revision surgery can be avoided; however, the patient must have favorable anatomy in terms of access to the intervertebral space and the working channel between the twelfth rib, and the iliac crest must be such that the procedure can be done safely and effectively.

Contraindications

There are a few technical/anatomic aspects that preclude the use of a lateral transpsoas approach in certain circumstances. For example, the lumbar plexus courses progressively more anteriorly at the more caudal levels. Thus despite the use of neuromonitoring, the risk of nerve damage at the level of L5–S1 is significant, and the lateral transpsoas approach should be avoided. Likewise, the iliac crest can often block direct lateral access to L5–S1.

Contraindications to the use of LTIF without posterior column support center on the biomechanical factors at a given level. Stand-alone LTIF should not be used at a level

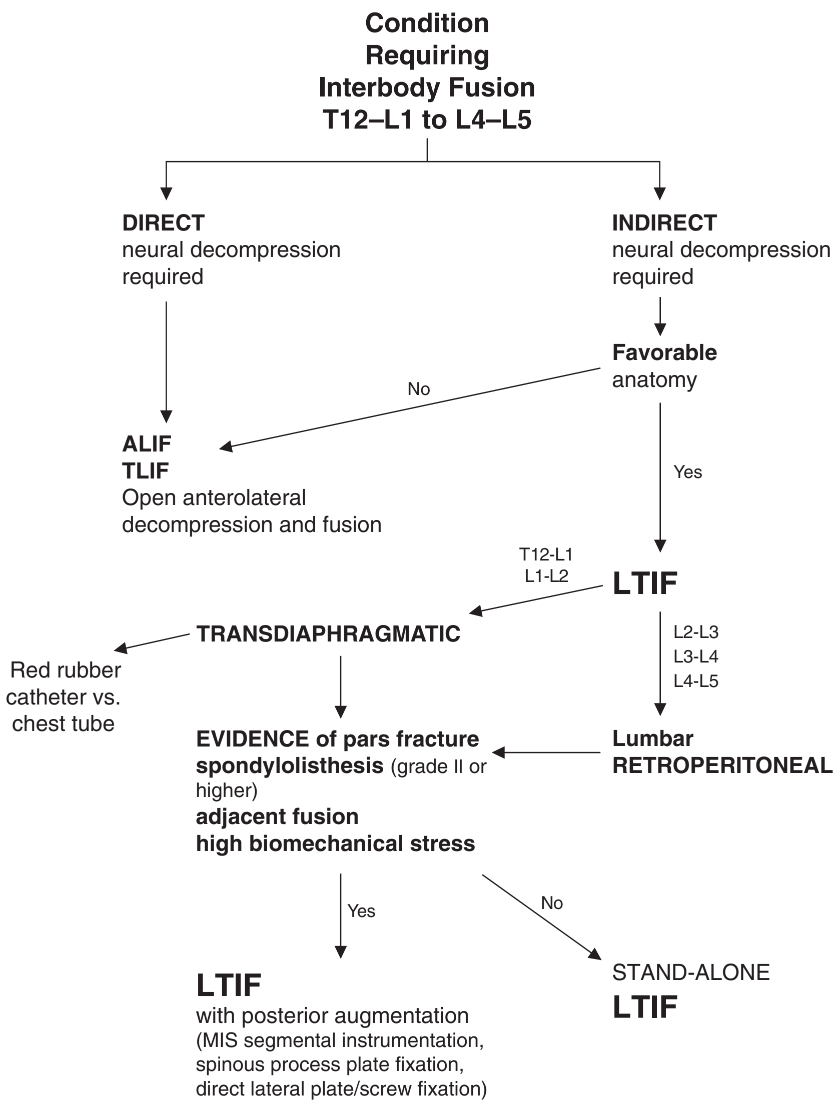

Figure 47-1 Algorithm for the use of lateral transpsoas interbody fusion. *ALIF,* anterior lumbar interbody fusion; *LTIF,* lateral transpsoas interbody fusion; *MIS,* minimally invasive surgery; *TLIF,* transforaminal lumbar interbody fusion.

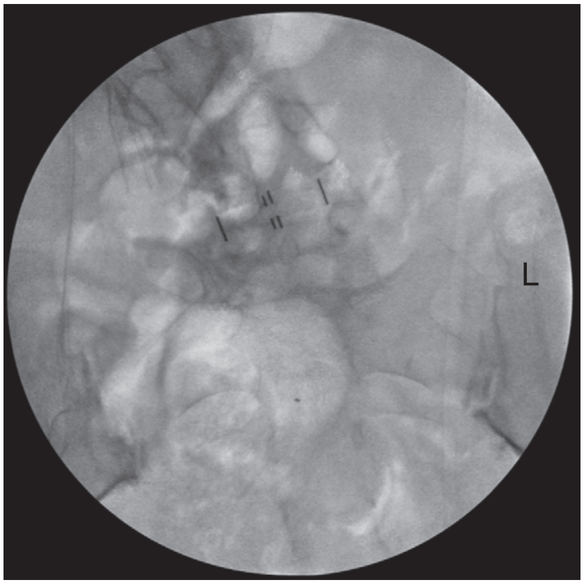

Figure 47-2 Intraoperative anteroposterior fluoroscopy image demonstrates placement of direct lateral interbody fusion graft from the convexity of the lumbar scoliosis. *L,* the patient's left side.

of high biomechanical stress, such as adjacent to a previous fusion or with a high-grade spondylolisthesis. In the setting of increased segmental stress, such as a pars fracture or at the apex of a kyphosis or scoliosis, posterior column support should be strongly considered. Posterior stabilization is often necessary to increase the stability of the construct, because lateral fixation has been not been shown to add construct stiffness compared with lateral interbody fusion alone.[12] The lateral transpsoas interbody approach is also contraindicated in patients who have undergone prior retroperitoneal surgery or those with a retroperitoneal abscess. Preoperative imaging may reveal abnormal vascular anatomy or an abnormally large psoas muscle that prevents safe access to the lateral spine. Any patient who requires direct neural decompression is also a poor candidate for a lateral transpsoas approach, because the lateral interbody fusion provides only indirect decompression with restoration of disk height and ligamentotaxis. Although LTIF has been shown to improve focal coronal alignment, it has not been shown to provide meaningful global sagittal correction.

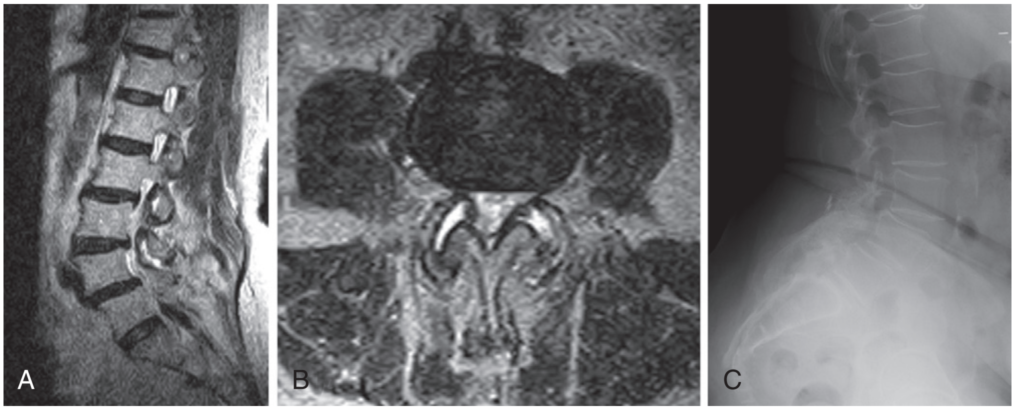

Figure 47-3 65-year-old woman with prior L4–L5 laminectomy and posterolateral fusion who developed adjacent segment degeneration. **A,** T2-weighted sagittal magnetic resonance imaging (MRI) demonstrates grade 1 spondylolisthesis and degenerative disk disease. **B,** T2-weighted axial MRI demonstrates significant facet degeneration and hypertrophy. **C,** Lateral standing radiograph demonstrates grade 1 L3–L4 spondylolisthesis and end plate changes.

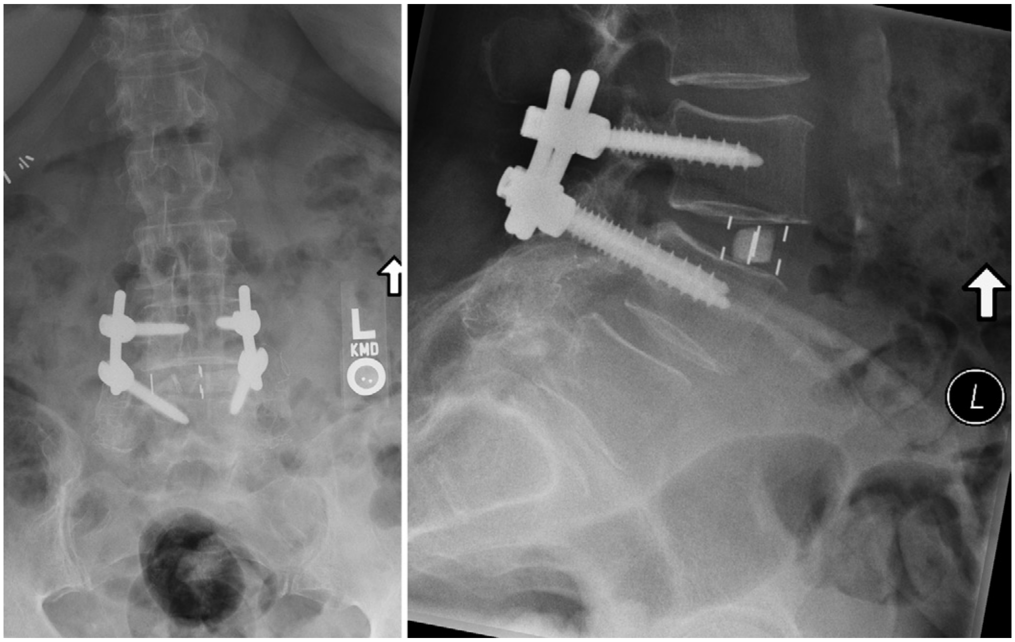

Figure 47-4 Postoperative anteroposterior (*left*) and lateral (*right*) radiographs following L3–L4 direct lateral interbody fusion and placement of segmental instrumentation through a minimally invasive approach.

Preoperative Planning

Careful study of preoperative imaging is essential when planning LTIF. The patient's anatomy must be closely evaluated to ensure that the disk space can be accessed safely and effectively. For example, a large psoas muscle, seen best on magnetic resonance imaging (MRI; Fig. 47-5) may prevent a transpsoas dissection. Likewise, the anatomic location of the aorta, inferior vena cava, and iliac vessels must be completely visualized to minimize the risk of vascular injury. When planning an approach to the upper lumbar spine, the eleventh or twelfth ribs may block direct access, thus necessitating an intercostal approach or a rib resection. The height of the iliac crest must also be taken into consideration, because it can block not only L5–S1 but sometimes L4–L5 also.

When performing an LTIF in the setting of lumbar scoliosis, the disk space can be accessed from either the concavity or the convexity of the curve. The advantages of approaching from the convexity include the fact that the lateral access of the spine is closer to the abdominal surface, thus minimizing the working depth through the tube. Likewise, the disk space is often widened on the convex side, making entering the disk space easier. Conversely, although the concavity is deeper, it allows the surgeon to reach multiple levels through a single incision. However, the lateral aspect of the disk space is often more collapsed on the concavity, making access to the disk space more difficult. The lumbar plexus also runs more anteriorly on the concavity, increasing the risk of nerve injury during the approach.

The approach to the T12–L1 and L1–L2 disk spaces is transdiaphragmatic. Thus it is important to plan for an intrathoracic exposure. Most often taking down the diaphragm does not necessitate the placement of a chest tube postoperatively, unless the pleura or lung parenchyma has been violated. It is important to close the diaphragm in layers completely, which can be done over a red rubber catheter, draining the intrathoracic space. After the final suture is placed, a Valsalva maneuver is performed, the red rubber catheter is removed, and the suture is tied down securely. Having support from colleagues in thoracic surgery is essential in the event of a complication.

Intraoperative use of fluoroscopy is essential when performing LTIF, and it is important to ensure that the appropriate radiology staff are available during the case. Intraoperative stereotactic navigation is an alternative to fluoroscopic guidance. The use of fluoroscopy provides significant radiation exposure; to minimize that exposure, stereotactic navigation can be used. However, the advantage of fluoroscopy is that it provides real-time anatomic assessment. Stereotactic navigation only provides a static image of the anatomy. As the diskectomy is performed, or in the setting of placing multiple interbodies, the navigation registration can become inaccurate. Likewise, the reference frame for stereotactic navigation must remain undisturbed throughout the case, or the navigation will become inaccurate.

Figure 47-5 T2-weighted MRI in the axial plane demonstrates a large psoas muscle that prevents safe access to the lateral spine.

Addressing the risks and benefits of LTIF with the patient before surgery is essential. The greatest risk is injury to the lumbar plexus. As many as 36% of patients will have ipsilateral iliopsoas weakness postoperatively, and the most commonly affected levels are L3–L4 and L4–L5.[13] Moller and colleagues[13] have also reported that 84% of those with subjective ipsilateral iliopsoas weakness improved completely by 6 months postoperatively. The etiology of such weakness is multifactorial in nature and includes dissection through the psoas muscle, edema, nerve stretch, and placement of the tubular retractors through the muscle down to the level of the lateral annulus. This risk can be minimized by docking the tubular retractor superficial to the psoas muscle and performing careful intramuscular dissection guided by neuromonitoring and direct visualization of the genitofemoral nerve.

Operative Technique

Positioning is a key component to performing a safe and successful LTIF. The patient is placed in the lateral decubitus position with the hip, not the waist, over the break in the operating table (Fig. 47-6). A beanbag can be used to help maintain position. The lateral aspect of the bottom knee must be thoroughly padded to reduce the risk of peroneal nerve compression. Likewise, the top leg should be bent as much as possible to relax the psoas muscle to aid in dissection. A pillow should be placed between the patient's legs, an axillary roll should be placed along the downside lateral chest wall, and all bony prominences should be fully padded to reduce the risk of additional injury. The bed should then be flexed to help open the lateral disk space on the side of approach. This also increases the working space between the twelfth rib and the iliac crest. Finally, the patient must be well secured to the bed. During the case, the fluoroscopy C-arm will remain in the neutral position in both the anterior-posterior (AP) and lateral planes, and thus the patient and bed can be manipulated to obtain true AP and lateral images. The patient must also be placed in a position on the bed such that the C-arm can freely pass beneath the table.

Before draping the patient, the C-arm gantry is placed at zero degrees (Fig. 47-7) and will remain there for the duration of the case. The patient will be moved with the bed to

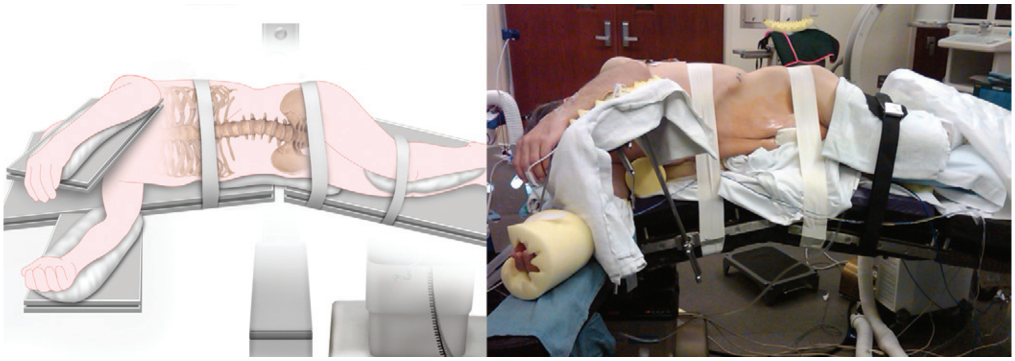

Figure 47-6 The patient is placed in the lateral decubitus position with the top leg flexed in order to relax the ipsilateral psoas muscle. The patient must be secured in place thoroughly using tape, padding, beanbags, or other methods.

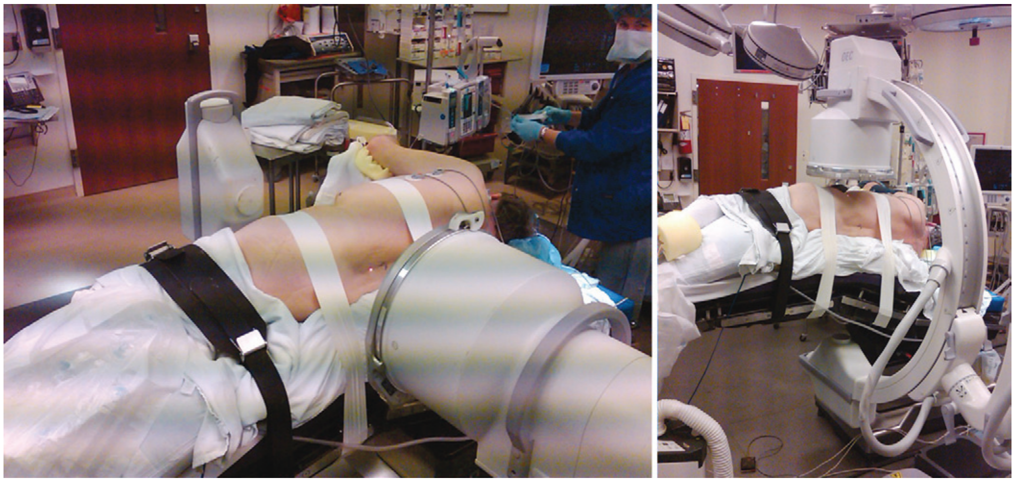

Figure 47-7 The zero-degree gantry of the C-arm.

Figure 47-8 Radiographs demonstrate true lateral (*left*) and anteroposterior (AP) (*right*) images. Note that in the lateral view the end plates can be visualized easily, and the pedicles are superimposed. The AP view demonstrates the spinous processes at each level seen in the midline and the transverse section of each pedicle.

obtain true AP and lateral images. By maintaining a zero-degree gantry, the surgeon can confidently work perpendicular to the floor at all times at a comfortable angle and can access the disk space safely. Such orientation minimizes the risk of taking a trajectory that is too anterior, risking the aorta, inferior vena cava, or iliac vessels or placing the interbody graft off target into the foramen.

True AP and lateral images must be visualized at each operated level (Fig. 47-8). If multiple levels are being accessed, the patient and bed must be moved after each level to ensure true AP and lateral views for that level. In the lateral view, the end plates must be visualized cleanly, and the pedicles should be superimposed, so that only one pedicle is visualized. Likewise, in the AP view, the spinous processes at each level should be visualized in the midline, and the transverse section of the pedicles should be visualized equally bilaterally.

Once the true AP and lateral views have been obtained, the incision can be marked. Typically, the incision is 2.5 to 3.0 cm in length and can be localized marking an "X" over the targeted disk space using fluoroscopy (Fig. 47-9). A single incision can be used to access multiple levels, thus such an incision would be placed at the midpoint between the targeted levels. The ideal target is the anterior half of the disk space. The trajectory to the target must be perpendicular to the floor to ensure safe dissection. Once the incision and trajectory have been planned, and the patient is in the appropriate position with true AP and lateral images, the surgical site can be prepped and draped.

Dissection through the posterior abdominal wall is performed through the following layers, in order, from superficial to deep: skin, subcutaneous fat, external oblique muscle, internal oblique muscle, and transversus abdominis muscle. These layers can be dissected using a blunt instrument and with the assistance of handheld retractors. The muscle should be split in the direction of the muscle fibers, not by using a muscle-cutting technique. This dissection should be with performed with little resistance. If resistance is encountered, the surgeon is likely in the incorrect plane. Once the retroperitoneal fat is visualized, a finger sweep is performed

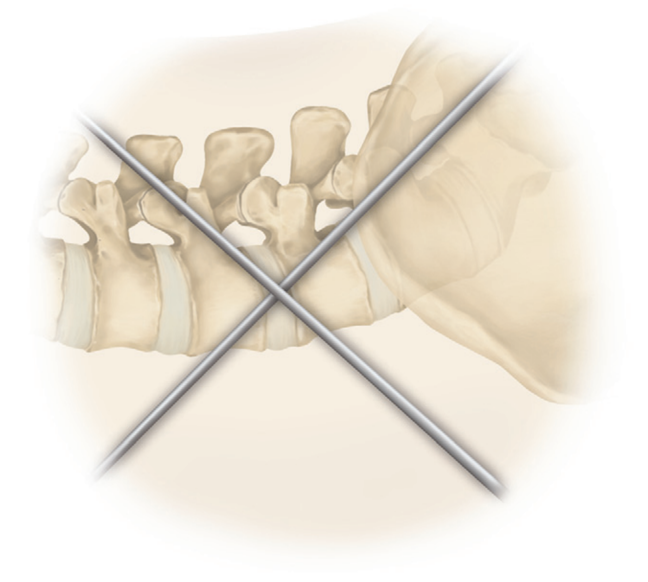

Figure 47-9 Schematic drawing of an "X" marks the incision over the targeted disk space.

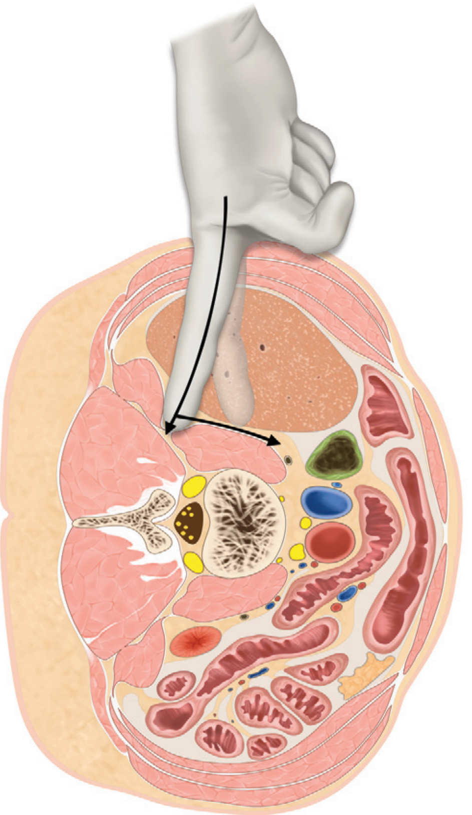

Figure 47-10 A posterior-to-anterior finger sweep is done, feeling along the transverse process and mobilizing the peritoneal contents anteriorly.

in the posterior to anterior direction (Fig. 47-10). The transverse process of the spine can be palpated, and it can be used to guide the surgeon's finger down to the psoas muscle. The finger sweep then mobilizes the peritoneal contents anteriorly. At the level of T12–L1 and L1–L2, the diaphragm

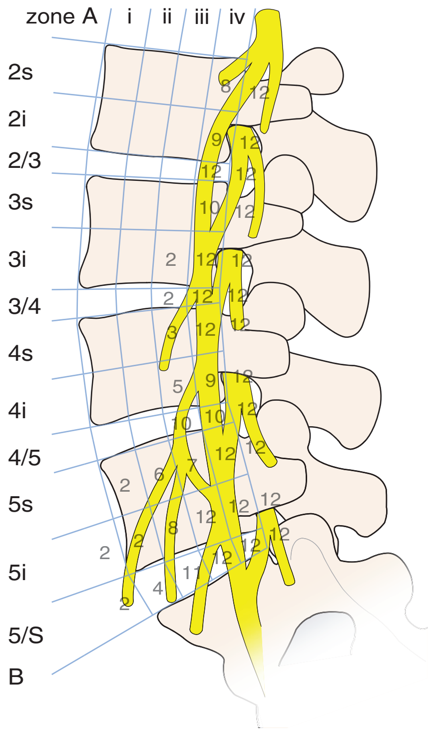

Figure 47-11 Schematic rendering of the lumbar plexus as it passes through the psoas muscle. (From Moro T, Kikuchi S, Konno S, Yaginuma H: An anatomic study of the lumbar plexus with respect to retroperitoneal endoscopic surgery. *Spine (Phila Pa 1976)* 2003;28(5):423-428.)

must be transected. It is sometimes helpful to tag the edges of the diaphragm with suture to aid in closing the appropriate layer at the conclusion of the case.

During the transpsoas dissection, the lumbar plexus and genitofemoral nerves are at risk of injury. Multiple studies have eloquently described the anatomic relationships and courses of the lumbar plexus nerves (Fig. 47-11).[9,10,14,15] The anterior one half to one third of the disk space is the safest target, because the lumbar plexus courses progressively more anteriorly and splays out at the more caudal levels. Furthermore, Davis and colleagues[16] have shown in cadaveric studies that the femoral nerve in particular courses through the midpoint of the disk space at L4–L5. Placement of the tubular retractor system through the psoas muscle thus puts these nerves at particular risk, not only for direct injury but also for traction injury. The genitofemoral nerve originates at the level of L1 and L2; it traverses the psoas muscle, from posterior to anterior, between the superior aspect of the L3 vertebral body and the inferior aspect of the L4 vertebral body. It travels along the anterior aspect of the lower psoas to provide genital, perineal, and medial thigh sensation. Other nerves at risk include the subcostal, iliohypogastric, ilioinguinal, and lateral femoral cutaneous nerves.[7,13]

The importance of neuromonitoring in the lateral transpsoas approach cannot be overemphasized. Although direct visualization of the genitofemoral nerve is the best way to prevent injury, neuromonitoring with both free-run and triggered electromyelograph (EMG) is required with the transpsoas approach to prevent injury to the branches of the lumbar plexus. The free-run EMG is used throughout the entire procedure. During the transpsoas dissection, the triggered EMG probe is passed through the muscle into the anterior one half to one third of the disk space. If EMG activity is detected, the probe is moved more anteriorly in a new trajectory. Fluoroscopy is used to ensure that the probe is passing into the disk space at the appropriate trajectory. A normal healthy nerve will typically stimulate at 2 mA, but a chronically compressed or injured nerve will typically require a higher level of stimulation to conduct a response, therefore the triggered EMG probe is typically set at 6 mA during dissection. Once the triggered EMG probe has safely passed through the psoas muscle and has been verified in the appropriate disk space using fluoroscopy, a guidewire is passed through the center of the probe into the disk space (Fig. 47-12).

Once the guidewire is in place, the triggered EMG probe can be removed. The tubular retractor system is then sequentially placed to dilate the working space through the psoas muscle to the lateral aspect of the annulus. Free-running EMG can help detect any nerve irritation while the sequential dilators are inserted. Typically, a 22-mm tube is used. The tubular retractor is then fixed in place to the multiaxial arm attached to the side of the operating table (Fig. 47-13). Additional stabilization of the retractor can be achieved using a stabilization screw placed through the retractor blade into the adjacent vertebral body. Before placing the screw, the triggered EMG probe can be used to ensure that the trajectory of the screw does not put any

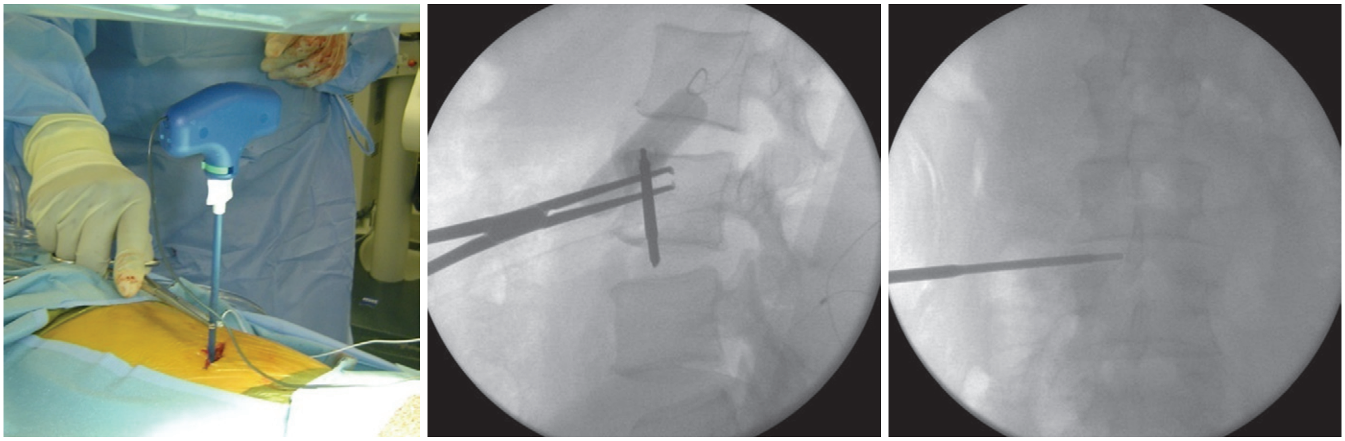

Figure 47-12 Placement of neuromonitoring probe through planned path of dissection through the psoas muscle all the way down to the lateral disk space.

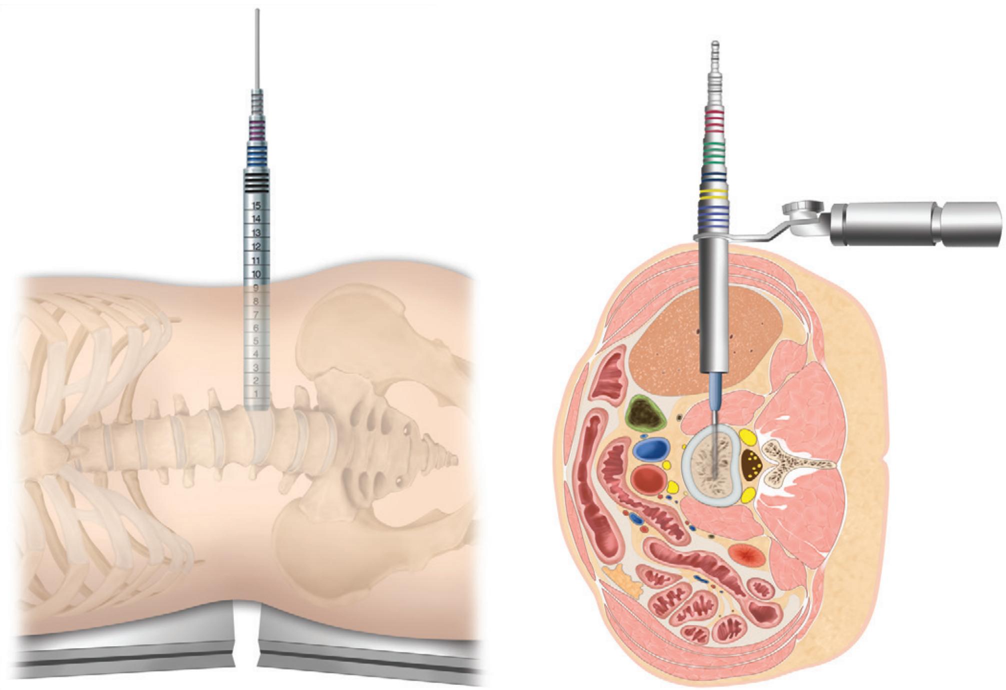

Figure 47-13 Sequential dilation of the tubular retractor system, docking on the lateral disk space.

neural structures at risk (Fig. 47-14). Typically, only one stabilization screw or shim, depending on the system used, is required. The stabilization screw should be placed close to the end plate to minimize risk to the segmental artery on the lateral vertebral body wall.

Because of the risk of either direct or traction injury to the nerves coursing through the psoas muscle, an alternative technique for docking the tubular retractor has been devised. By docking the tubular retractor superficial or lateral to the psoas muscle, the amount of tissue trauma to the muscle itself, as well as trauma to the nerves, can be greatly reduced. The advantages of shallow docking include the reduced risk for nerve and muscle tissue damage in an effort to help reduce injury to the lumbar plexus, iatrogenic ipsilateral psoas weakness, and postoperative iliopsoas pain. However, by docking shallow, the muscle around the tubular retractor can creep into the working channel and make visualization difficult. Likewise, it is essential to maintain the same dissection trajectory through the muscle with each pass of a new instrument.

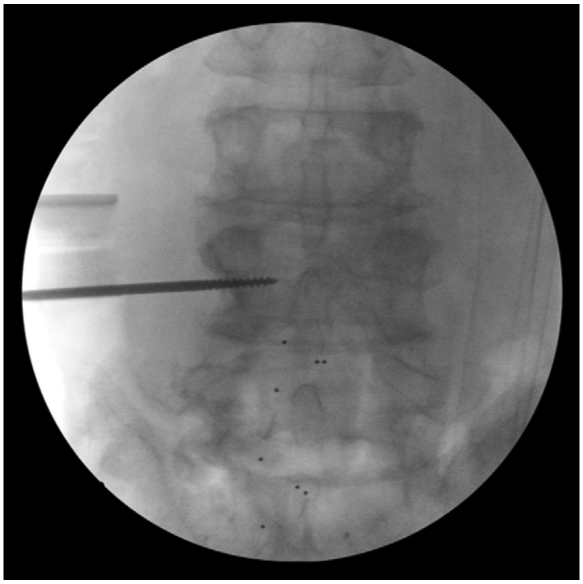

Figure 47-14 Radiographs demonstrate placement of the stabilization screw in the vertebral body.

Before starting the diskectomy, it is important to radiographically verify the appropriate level. Any remaining muscle tissue on the lateral vertebral body wall should first be probed with the triggered EMG probe in all four quadrants (Fig. 47-15), and it should be retracted out of the field using a blunt instrument and bipolar electrocautery if needed. Visualization can be enhanced by a variety of methods that include the use of loupe magnification, an operative microscope, or a light source that attaches to the tubular retractor.

The diskectomy is initiated with the annulotomy knife with the goal of fully detaching the intervertebral disk from the end plate and completely releasing the ipsilateral side. Eventually, the contralateral annulus must be completely released; this will enable the interbody graft to span the width of the vertebral body along the cortical rim and expand the disk height fully and symmetrically to provide maximal neural indirect decompression and to potentially provide some coronal correction. A Cobb periosteal elevator or disk shaver can be used to release the contralateral annulus (Fig. 47-16). The diskectomy can be completed using a combination of pituitary rongeurs, shavers, and curettes. It is imperative to maintain orientation and trajectory perpendicular to the floor to avoid grabbing any disk or soft tissue adherent to the annulus or vascular or neural structures.

Once the diskectomy is complete, various sequential trials of interbody graft sizes can begin. Ideally, the graft should span the width of the vertebral body and rest on the cortical rim to maximize its biomechanical strength and stability.[17] In the AP plane, the interbody should extend from pedicle to pedicle (Fig. 47-17). Once the appropriately sized trial is selected, the end plates should be prepared in order to optimize conditions for fusion. There are many different types of interbody grafts that can be used, depending on surgeon preference and clinical judgment. The tapered front of some interbody grafts helps to reduce the risk of violating the end plate when delivering the graft to the disk space. Likewise, when placing an interbody graft in the lumbar spine, a lordotic shape can be helpful to maintain appropriate lordotic

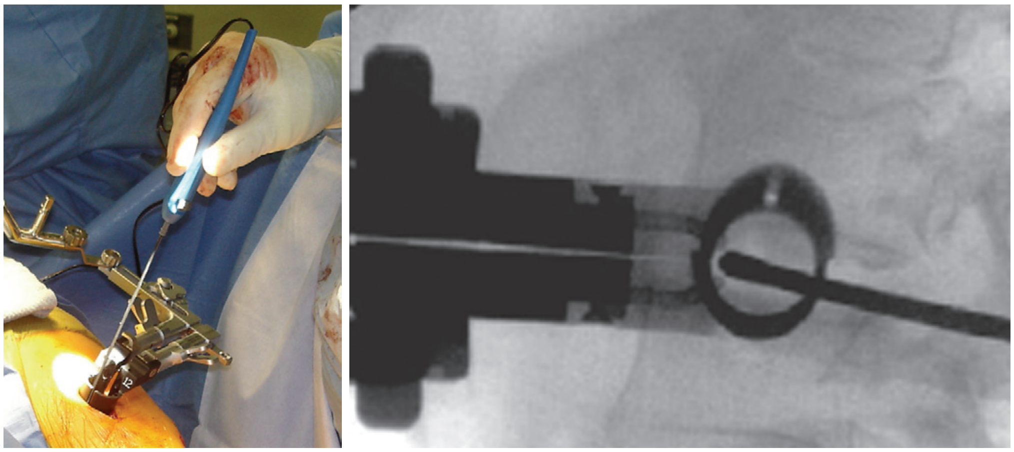

Figure 47-15 Final use of triggered electromyelograph probe before beginning diskectomy.

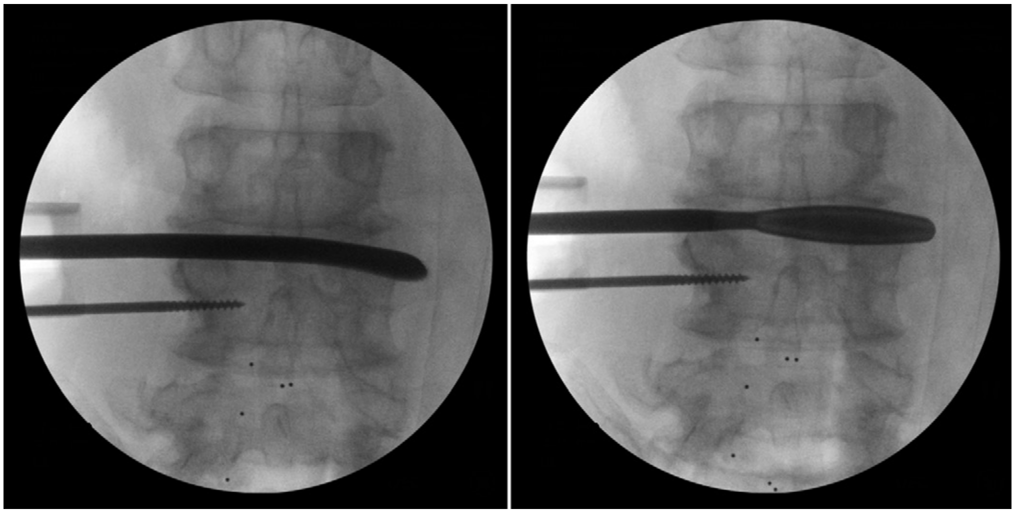

Figure 47-16 Radiograph demonstrates contralateral annulotomy.

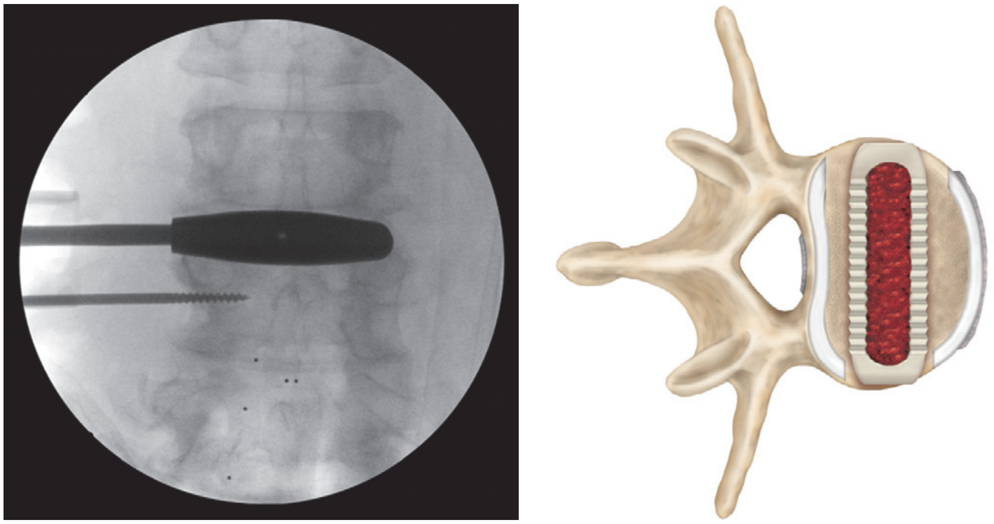

Figure 47-17 Radiograph (*left*) demonstrates proper placement of interbody graft. Schematic drawing (*right*) demonstrates placement of graft on the cortical rim of the vertebral body on its anterior half.

alignment. The use of osteobiologics is beyond the scope of this chapter and is largely based on the surgeon's clinical judgment. Final AP and lateral radiographs will verify appropriate interbody graft placement (Fig. 47-18).

Closure is performed in multiple layers: transversalis fascia, external oblique fascia, subcutaneous tissue, and skin. Special attention should be paid to closure of the transversalis fascia and external oblique to help prevent postoperative development of an incisional hernia. A GU-6 needle is helpful when closing the deep fascial layers, and the skin is ultimately closed with adhesive (Fig. 47-19).

Postoperative Care

A complete blood count should be obtained immediately postoperatively and the following morning to determine whether an occult retroperitoneal hemorrhage is present. Typically, patients undergoing LTIF do not require an orthosis postoperatively and typically spend only a few days in the hospital.

Complications and Bailout Strategies

One of the most common complications in the LTIF is injury to the lumbar plexus and associated nerves as they course through the psoas muscle. Moller and colleagues[13] reported that 36% of patients experience subjective ipsilateral iliopsoas weakness, 25% experience anterior thigh numbness, and 23% experience anterior thigh pain postoperatively. Eighty-four percent of patients with iliopsoas weakness improve completely by 6 months postoperatively, and most report being back to baseline strength by 8 weeks. By 6 months, 69% of patients with anterior thigh numbness improved, and 75% of patients with anterior thigh pain also completely improved. Docking the tubular retractor

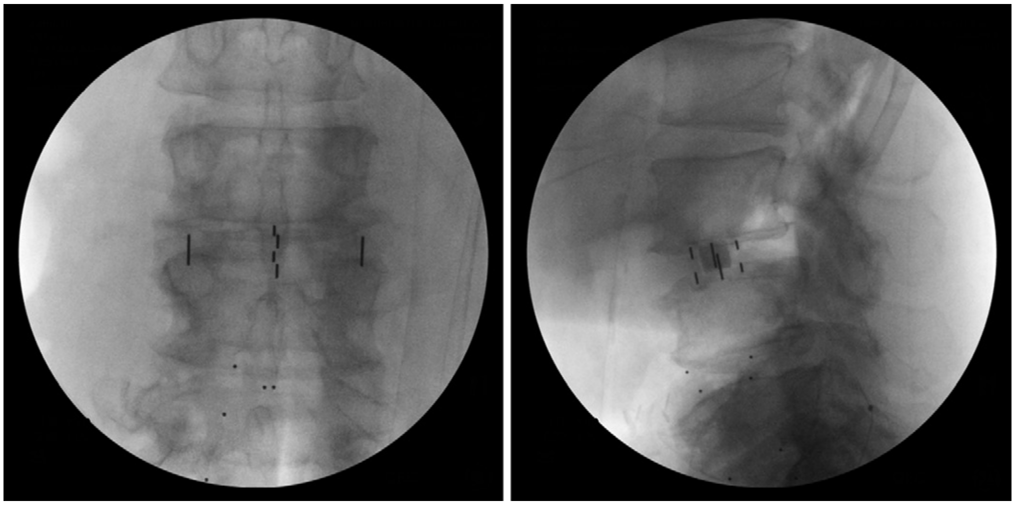

Figure 47-18 Fluoroscopy images demonstrate appropriate placement of graft.

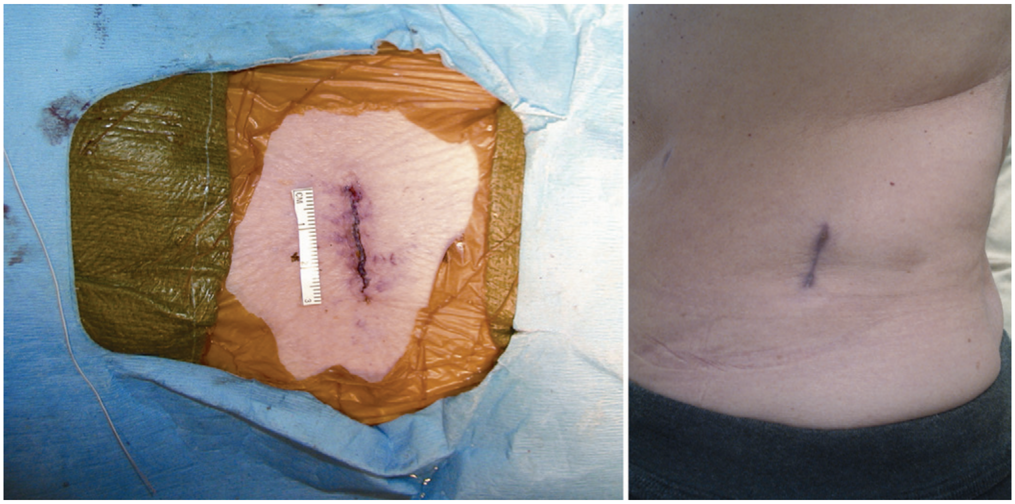

Figure 47-19 Photographs of incision following multilayer closure.

superficial to the psoas muscle aims to reduce the risk of direct or traction nerve injury.

In the event that the lumbar plexus cannot be identified upon transpsoas dissection, the validity of the neuromonitoring system must be verified. First, a technical problem with the monitoring itself must be ruled out. If the equipment is functioning properly, and the lumbar plexus cannot be identified, the potential risk to the lumbar plexus without neuromonitoring guidance is significant, such that aborting the case should be considered. Conversely, if multiple areas of the psoas muscle show response to stimulus, a more anterior position should be used. If a safe trajectory cannot be determined, the case may also need to be aborted. Patients should be made aware of this possibility preoperatively.

Segmental artery injury during LTIF is rare but must be dealt with quickly to avoid rapid blood loss. With the expeditious use of hemostatic agents and bipolar electrocautery, the bleeding can be definitively controlled through a tubular retractor. The rapid bleeding associated with a segmental artery injury can quickly compromise visualization through the tubular retractor. Likewise, given the potential for rapid loss of blood, the anesthesia team should be alerted as soon as possible in the event that hemodynamic issues arise.

Conclusion

The lateral transpsoas approach can be used for a variety of etiologies that require interbody fusion in the lumbar spine. Successful use of this technique begins with careful patient selection and thorough preoperative evaluation of the patient's anatomy. It is essential to use both radiographic and neurophysiologic guidance to safely and effectively perform the lateral interbody fusion.

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48 Spondylolisthesis Reduction

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Overview

Spondylolisthesis, a slippage or displacement of one vertebra on another, is a common spinal condition that affects children and adults. Spinal pathology may vary for the slip severity, but the clinical presentation can be quite similar. Often, patients come to medical attention with severe back and leg pain, and a cosmetic or postural component may be apparent. Cauda equina symptoms are an uncommon feature in the vast majority of patients with low-grade spondylolisthesis, and they may occur in only a small percentage of high-grade spondylolisthesis.[1]

Classification

A widely used classification, as described by Meyerding,[2] is useful in understanding the amount of listhesis. The Meyerding grade is shown in Table 48-1.

The percentage of slippage is calculated by measuring the distance between the posterior borders for the cephalad vertebral body and the caudad vertebral body, and then dividing that distance by the length on the inferior end plate (Fig. 48-1). Most authors agree that grade three and four slips are considered high-grade and are generally associated with higher incidence of progression and disabling symptomatology.

In addition to the translational deformity, high-grade slips can have angular deformity as well. The degree of angulation can be expressed as a *slip angle* (Fig. 48-2). This slip angle or lumbosacral kyphosis can have a profound impact on the entire lumbar spine, because the patient often compensates with hyperlordosis, which leads to facet joint changes, stenosis, and potential retrolisthesis proximal to the more obvious deformity at L5–S1.[3]

Evidence-based Decision Making

Unfortunately, no prospective randomized studies compare the radiographic and clinical outcomes of reduction and fusion versus in situ fusion. Current studies of high-grade spondylolisthesis are of limited number, and only level III studies exist. Using this available literature, short- and long-term outcomes of patients undergoing these procedures suggest that both reduction and in situ fusion can be performed safely and can provide reliable radiographic and clinical outcomes in terms of patient success and pain improvement. Comparable adverse outcomes and risks occur with both procedures. The literature also suggests that patients with high-grade developmental spondylolisthesis may benefit from having a reduction of the deformity to improve global spinal alignment and perhaps enhance the biomechanical environment for fusion. Strong consideration for reduction should be given to pediatric patients with a significant lumbosacral kyphosis. Ultimately, it is up to the surgeon to treat each patient in an individualized plan that best suits the clinical scenario.[3-23]

Treatment Options

Surgical procedures for spondylolisthesis in this chapter will focus on three primary techniques. In the setting of low-grade slips, we recommend in situ fusion with posterior instrumentation.[24] In the setting of high-grade slips, in situ fusion or a reduction and fusion may be done.[3-23] The indications for reduction of a high-grade slip include 1) progression of a high-grade slip; 2) inability to stand upright, with significant lumbrosacral kyphosis; 3) unacceptable clinical appearance; or 4) a high slip angle that is not reduced, which is more likely to develop a progression after fusion.[11,13]

LOW- AND HIGH-GRADE SLIP TREATED WITH FUSION

A midline incision is made over the lumbar spine. The incision is taken down through the lumbodorsal fascia, and the spinous processes of the involved lumbar spine and sacrum are subperiosteally dissected (Fig. 48-3). Intraoperative radiographs can be used to confirm the levels. Exposure of the transverse processes of L5 and S1 follow. Typically, the goal is just to fuse L5–S1, but sometimes the L4–L5 facet is so deteriorated and adherent to the old pars fracture, it may require fusion up to L4. Low-grade slips can be managed with fusion of only the L5–S1 segment; however, higher grade slips will often need fusions extending to the L4 level.

A Gill laminectomy is performed, and typically the lamina is quite unstable as a result of the chronic pars fractures. A central laminectomy is performed by resection of the medial articular facets, because these are grossly unstable (Fig. 48-4). The next step is to inspect the spinal canal, looking at each nerve root and decompressing each root in the subarticular region, as well as within the foramen, with angled Kerrison rongeurs and curettes. In particular, the L5 roots typically get severely pinched in the caudal-cranial direction because of the pedicle abutting the sacrum. Often a posterior lumbar interbody fusion (PLIF) can be used to regain the foraminal height, thereby indirectly decompressing the L5 nerve root.

The S1 nerve root is retracted medially (Fig. 48-5, *A*), then bipolar cautery is used to cauterize all the epidural veins. A window into the annulus is made by resecting a small portion of the posterior superior lip of the remodeled

Table 48-1 Meyerding Classification

Meyerding Grade	Slip (%)
I	0-25
II	25-50
III	50-75
IV	75-100

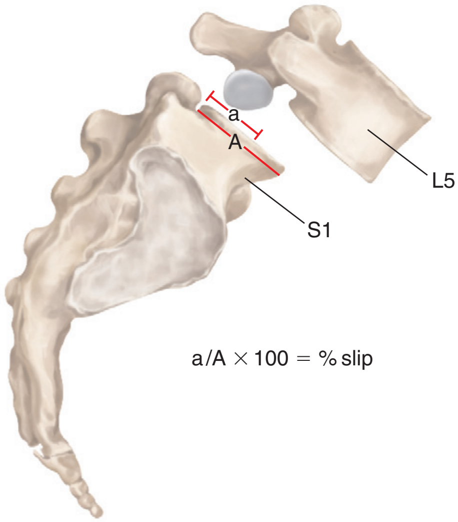

Figure 48-1 The percentage of slippage is calculated by measuring the distance between the posterior borders for the cephalad vertebral body and the caudad vertebral body and dividing that distance by the length on the inferior end plate. This calculation gives the Meyerding grade.

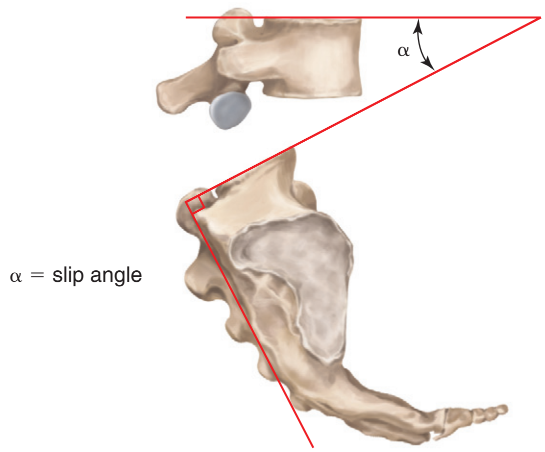

Figure 48-2 The degree of angulation can be expressed as the *slip angle,* or lumbosacral kyphosis; this can be measured by drawing a line from the superior end plates of L5 and S1 and determining the angle made by these lines.

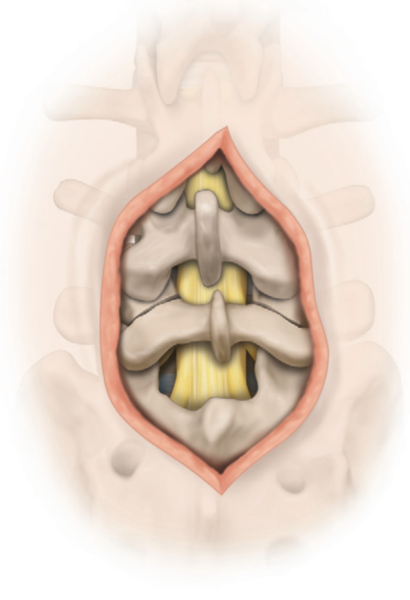

Figure 48-3 Intraoperative illustration of the exposed spine noting the pars defects.

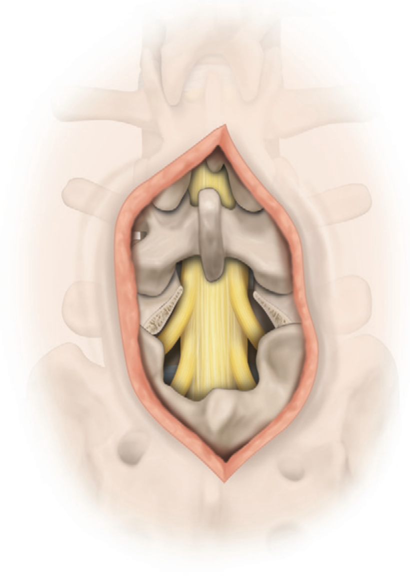

Figure 48-4 A central laminectomy is performed by resection of the medial articular facets because these are grossly unstable.

sacrum with an osteotome and pituitary rongeurs (see Fig. 48-5, *B*). This allows for good access to the intervertebral disk space. Serial dilators are then inserted from 6 to 10 mm bilaterally. The disk space is then reamed out, including the disk and cartilage end plate. Often a 22- to 32-mm by 10- to 12-mm intervertebral cage device is used. This is placed into the L5–S1 interval bilaterally to get good anterior column support, and after doing this, the L5 nerve root will be completely mobile and free as a result of the caudal and cranial decompression (Fig. 48-6).

The transverse process of L4, L5, and the sacrum are carefully decorticated. The autologous bone graft is then packed into posterolateral gutters, fusing the L4 through sacral segments. Two pedicle screws are inserted into L4, L5, and the sacrum. The sacral screws are placed bicortically to maximize stability of the construct, and two 5.5-mm rods are cut to the appropriate length and contoured; the

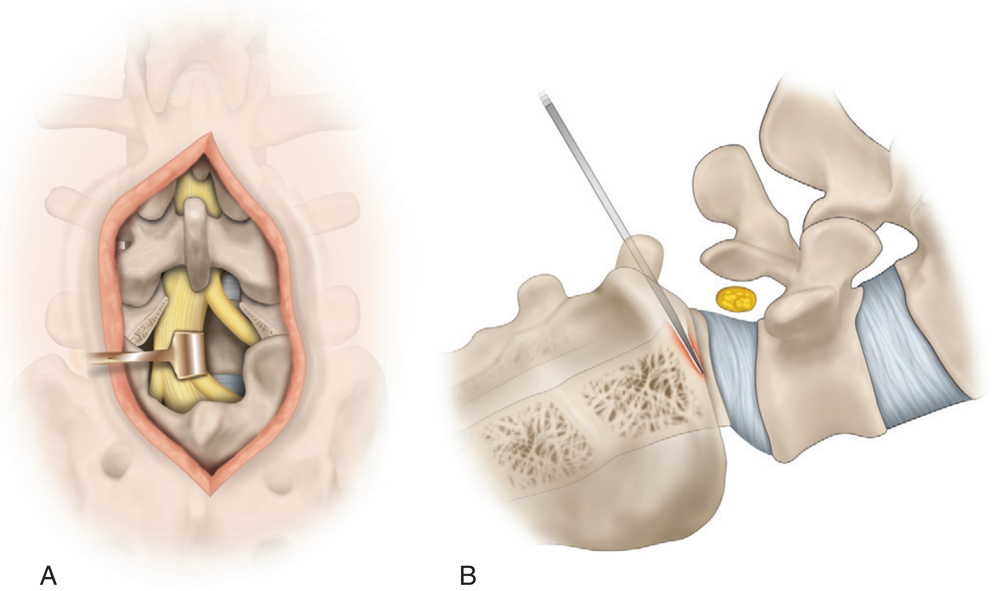

Figure 48-5 **A,** The S1 nerve root is retracted medially, allowing for good access to the intervertebral disk space. **B,** A window into the annulus is made by resecting a small portion of the posterior superior lip of the remodeled sacrum with an osteotome and pituitary rongeurs.

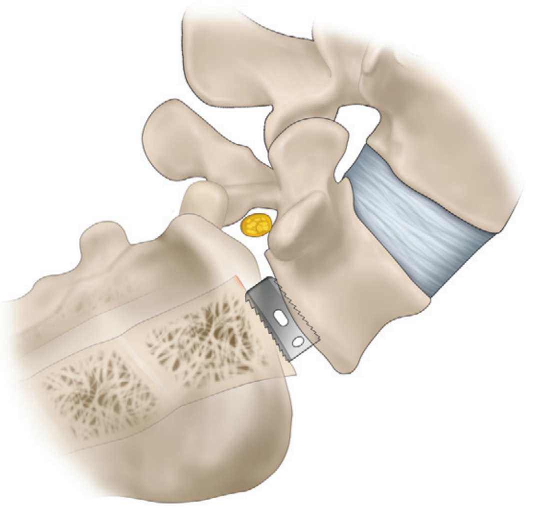

Figure 48-6 An intervertebral cage device is used. This is placed into the L5–S1 interval bilaterally to get good anterior column support and indirect decompression; after doing this, the L5 nerve root is now completely mobile and free because of the caudal cranial decompression.

rods are placed into the screw heads, and the nuts are tightened according to the manufacturer's specifications. Intraoperative anteroposterior (AP) and lateral radiographs can be used to confirm good positioning of the hardware and proper alignment of the spine. Compression between the L5–S1 screws can be performed to get further lordosis and compression of the anterior cages to prevent these cages from backing out inadvertently before final tightening of the nuts. The wound is then irrigated and closed over a drain.

FORMAL REDUCTION MANEUVER

For higher grade slips, the first step is to place the pedicle screws in the sacrum. The sacral fixation must be solid, because it serves as the base for the reduction maneuver. To this end, we recommend bicortical fixation into the sacrum. Some authors recommend an S2, iliac, or sacral plate bolster. The plate allows for fixation into the promontory and the ala. Once the stable sacral base is established, a reduction can be performed. Screws should then be placed into the L4 vertebra and into the L5 vertebra, if it is accessible. The distractor is applied to L4 and the sacrum to help disengage the L5 vertebra (Fig. 48-7).

At this point, the L5 screw can be placed more easily (Fig. 48-8), and a reduction screw with elongated "tulips" in the L5 vertebra can allow for better reduction of the spondylolisthesis. With the sacral fixation firmly fixed to the contoured rod, the L5 body can be slowly displaced dorsally, reducing the slip, by tightening a nut into the elongated tulip. As the nut is being tightened, the screw slowly brings the L5 body to the rod, which reduces the spine. The rod should be allowed to slide cranially in the L4 screw tulip, because the reduction is performed before final tightening. Great care must be taken to visualize the L5 nerve root to ensure that it is not being compressed during the reduction maneuver.

Further angular correction can be performed by manipulating the L4 and L5 screws by pulling them down to the sacrum, thereby restoring lordosis (Fig. 48-9). Lastly, interbody spacers can be placed at this time. However, the cages can be placed even before the reduction maneuver, if this is technically possible. The advantage of placing the cages before the reduction is that the disk space is distracted and maintained in this state while the reduction is being performed; this makes the reduction safer for the L5 root and

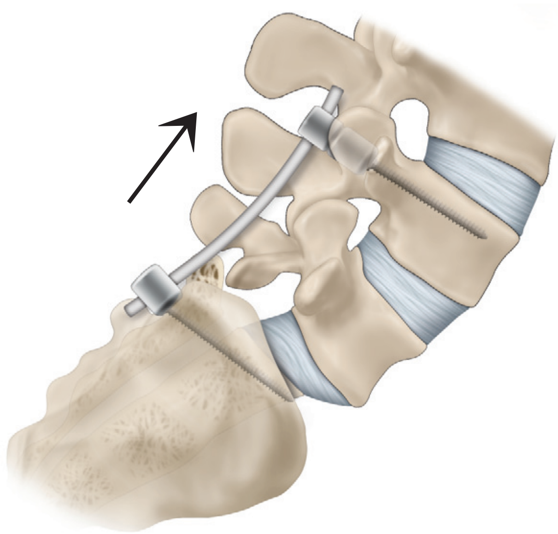

Figure 48-7 The distractor is applied to the L4 and sacrum to help disengage the L5 vertebra.

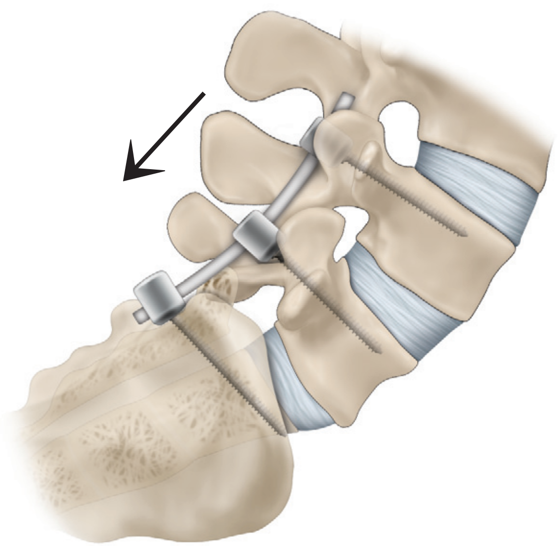

Figure 48-9 Further angular correction can be performed by manipulating the L4–L5 screws by pulling them down to the sacrum, thereby restoring lordosis.

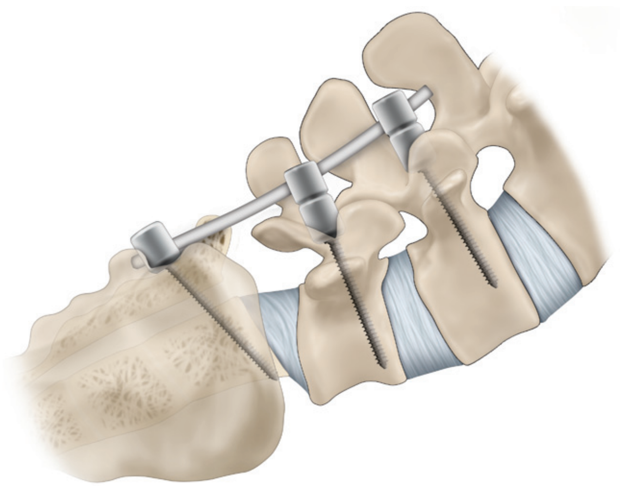

Figure 48-8 The L5 screw can be placed more easily, now that the vertebra is disengaged.

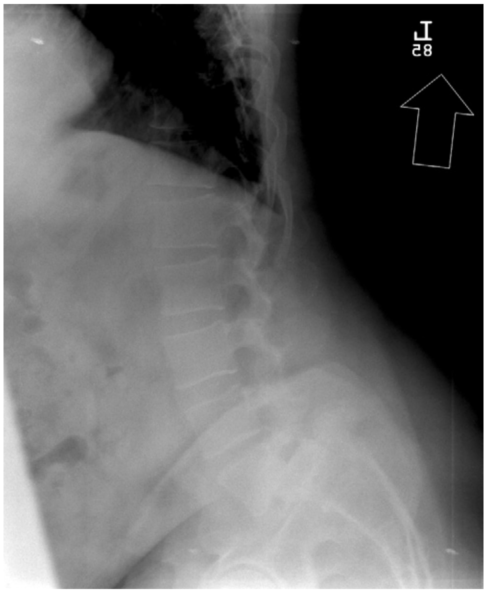

Figure 48-10 Prereduction lateral plain radiograph.

helps prevent an iatrogenic injury during the reduction. After final correction is achieved, the construct can be tightened for the last time. See Figures 48-10 and 48-11 for plain radiographs before and after reduction.

HIGH-GRADE SLIP TREATED WITH ANTERIOR AND POSTERIOR TECHNIQUES

Anterior Surgical Technique

Patients are placed supine on a Jackson table. A standard left-sided paramedian approach is accomplished with exposure of the L4–L5 disk, as well as additional superior vertebrae, as each case dictates. L4–L5 is identified, and a standard anterior diskectomy is performed. The disk material and cartilaginous end plates are removed to the posterior longitudinal ligament (PLL), and the disk space is sized; this process is repeated for any additional levels to be treated.

The L4–L5 segment is then identified. Using biplanar fluoroscopy, a K-wire is placed at the anterior third of the L5 end plate and is then drilled into the L5 body, across the L5–S1 disk, and into the body of S1 (Fig. 48-12). An effort is made to have the K-wire traverse the S1 end plate in the most perpendicular position that the L4–L5 access space will allow. A depth measurement is taken to determine the length of the fibular graft. A 12-mm anterior cruciate ligament (ACL) reamer is then used to overdrill the K-wire and make a channel for the fibular allograft (Fig. 48-13). The fibular graft is prepared to the appropriate length using a burr, and the cortex is contoured so that it is able to freely pass through a 13-mm guide. Allograft bone is packed into the fibular medullary canal. Once the fibular dowel is

Figure 48-11 Postreduction lateral plain radiograph.

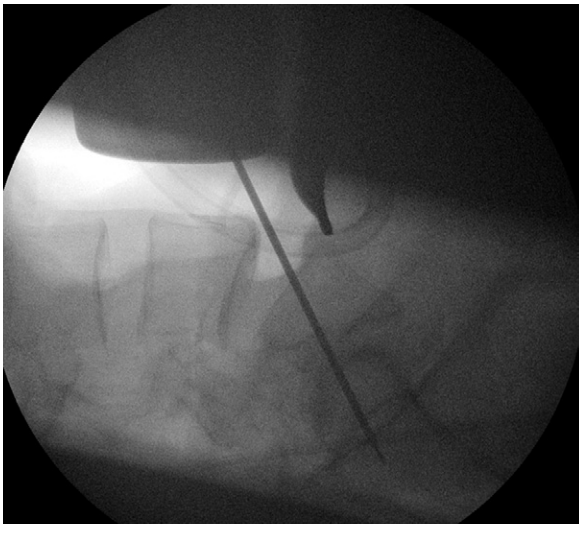

Figure 48-12 The K-wire is drilled into the L5 body, across the L5–S1 disk, and into the body of S1.

Figure 48-13 A 12-mm anterior cruciate ligament reamer is then used to overdrill the K-wire to make a channel for the fibular allograft.

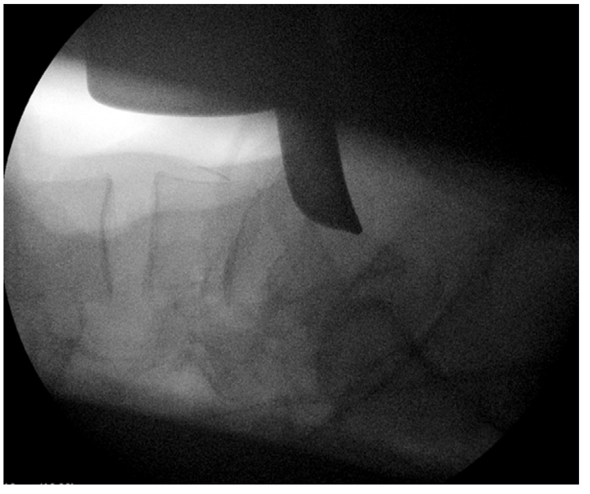

Figure 48-14 Once the fibular dowel is adequately prepared, the K-wire is removed, and the fibula is tapped into the channel using a mallet and impacter.

adequately prepared, the K-wire is removed, and the fibula is tapped into the channel using a mallet and impacter (Fig. 48-14). Any remaining fibular graft that is prominent in the L4–L5 space is burred down so that it is flush with the end plate of L5. Subsequently, the L4–L5 disk space is treated with a standard anterior lumbar interbody fusion (ALIF) procedure (Fig. 48-15).

Posterior Surgical Technique

Once the anterior portion of the case is completed, the patient is turned prone so that the posterior decompression and fusion can be performed. Posterior exposure is done to stabilize the levels that require fusion, always ending with S1 (Fig. 48-16).

SPONDYLOPTOSIS

The safest surgical treatment for patients with a dislocated L5–S1 segment (spondyloptosis) is an in situ posterior fusion. However, if the deformity is a major cosmetic issue, the surgeon can consider a spondylectomy. It should be noted that in a series of 30 patients, 23 of the patients had some temporary clinical deficit in the L5 root that ranged from 6 weeks to 3 years duration following reconstruction. All but two have recovered fully, and only two of the patients wear an ankle-foot orthosis (AFO) on a regular basis. No patient has had any problem with bowel, bladder, or neurologic deficit, but one patient does have retrograde ejaculation.[25,26]

An anterior approach is performed retroperitoneally, and dissection is performed laterally to identify the L4 and L5 nerve roots. An L4–L5 diskectomy is performed, taking the

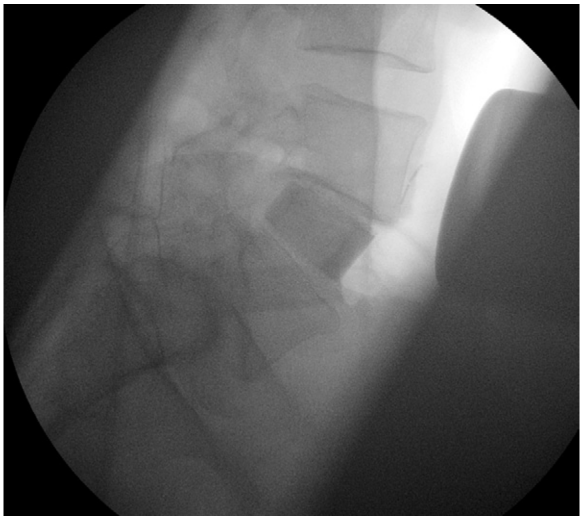

Figure 48-15 Any remaining fibular graft prominent in the L4–L5 space is burred down, so that it is flush with the end plate of L5. Subsequently, the L4–L5 disk space is treated with a standard anterior lumbar interbody fusion procedure.

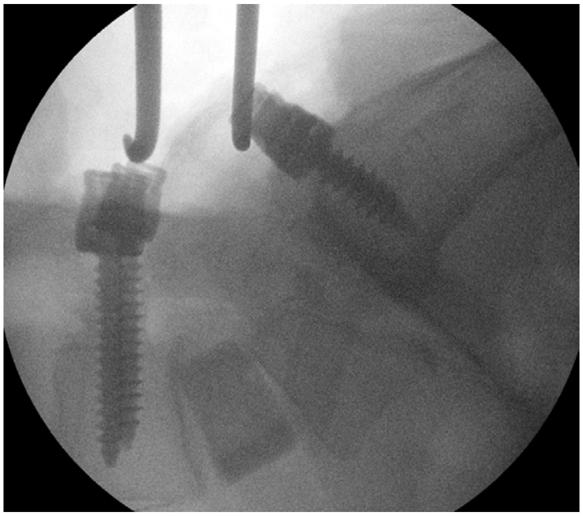

Figure 48-16 Posterior exposure is done to stabilize the number of levels that require fusion, always ending with S1.

PLL. Next, the L5 vertebrectomy is performed with osteotomes and rongeurs. Now the L5–S1 disk is visualized, and a diskectomy is performed. The L4 body should be in close proximity to the sacrum. The anterior approach is closed, and the patient is carefully placed into a prone position. A standard L4–S1 midline approach is performed with decompression of the L5 lamina, transverse processes, pedicles, and inferior and superior facets. The L4 and L5 roots are identified, and an interbody fusion is performed, followed by an instrumented posterior fusion.

Care must be taken when instrumenting L4. We recommend holding the spinous process of L4 by a towel clip and with a steadying force, while the pedicle screws are being placed. Once the instrumentation is placed, a posterolateral fusion is performed.

Conclusion

Spondylolisthesis is a common spinal condition with a variety of clinical presentations. The surgeon must carefully evaluate each surgical candidate to determine the best option for each. In general, we recommend in situ fusion with the posterior instrumentation for low-grade slips. In the setting of high-grade slips, in situ fusions or a reduction and fusion can be performed. Lastly, in the setting of spodyloptosis, an in situ fusion or spondylectomy can be performed, depending on the goals of surgery.

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49 Lumbar Facet Screw Fixation Techniques

JOHN S. CLAPP, JOSHUA P. HERZOG, and THOMAS D. CHA

Overview

The technique for ipsilateral lumbar transfacet fixation (ILTF) was first described by King[1] in 1948. It was modified in 1959 by Boucher,[2] who reported the results of transfacet fixation that used longer screws to obtain primary fusion in the lumbosacral spine. In 1984, Magerl[3] described another open technique for transfacet fixation in which screw entry starts in the contralateral lamina and then passes through the ipsilateral facet joint. Numerous clinical studies describe the outcomes of open transfacet fixation.[1-6] However, pedicle screw fixation, first introduced by Roy-Camille in 1963, has become the standard for stabilization of the lumbar spine and is used much more commonly than open transfacet fixation.

The advantage for transfacet fixation is the smaller footprint required for insertion, which increases the bony surface area available for fusion and provides the potential for percutaneous insertion. Standard placement of pedicle screws requires a significant amount of soft-tissue dissection, which can increase the morbidity associated with the procedure.[7-10] Additionally, exposure of the cephalad facet joint capsule introduces the potential for disruption, which may lead to adjacent segment degeneration. Ipsilateral transfacet fixation provides an alternative method for posterior stabilization following an anterior interbody procedure, especially because the failure of fusion of stand-alone anterior lumbar interbody fusion (ALIF) has been reported to be up to 24%.[11-13]

Translaminar facet screws have been shown in biomechanical studies to be equivalent to pedicle screws in resisting motion in all three planes when used with a load-sharing interbody implant.[14] Studies that compare transfacet to pedicle screw fixation following ALIF show similar load fluctuations in the disk space in a one-level interbody fusion and equivalent biomechanical properties in two-level interbody fusions.[15,16] Translaminar facet screws have been shown to provide added construct stability for resisting extension and axial rotation when combined with anterior interbody fusion.[17] The stability of transfacet fixation is not compromised after repetitive cycling in biomechanical studies.[18]

Best and Sasso[19] compared clinical outcomes of transfacet fixation versus pedicle screw fixation as an adjunct to anterior interbody fusion for patients with diskogenic low-back pain and found that transfacet screws required less operative time, less blood loss, and fewer additional operations for hardware removal. Tuli and colleagues[20] demonstrated decreased hospital stays when comparing translaminar fixation with pedicle constructs.

Transfacet fixation serves as an alternative method for posterior stabilization as an adjunct to anterior interbody fusion with the potential advantages over pedicle screw fixation of less dissection, a lower profile, less blood loss, reduced cost, reduced operative time, and shortened hospital stay. Familiarity with multiple techniques provides the spinal surgeon with options for the many different scenarios encountered both in primary, revision, and salvage scenarios.

Anatomy Review

When placing transfacet screws, a variety of options are available. These include direct facet fixation or translaminar fixation, which can be done through an open or minimally invasive percutaneous approach.

The standard approach for open placement of transfacet fixation is the posterior midline approach. The extent of the dissection is less than what is commonly done for pedicle screw placement. It is important to remember that the spinous process and lamina are contiguous with the inferior facet and serve as a guide or reference point for translaminar facet screw placement. Likewise, the superior facet is continuous with the pedicle and transverse process of the caudal level (Fig. 49-1). When considering open or less invasive techniques, it is important to have an understanding of the orientation of the facets throughout the lumbar region. Figure 49-2 demonstrates the variation in facet joint surface angle for each level in the lumbar spine. Because of the sagittal orientation angle of the facets at L1–L2 and L2–L3, placement of direct facet screws is challenging. Likewise, the coronal orientation of the L5–S1 facet creates difficulty in placing translaminar facet screws.[21]

Indications

- Adjunct to stable anterior column (interbody fusion or significant degenerative disc disease)
- Posterior fusion (without neural decompression)
- Salvage procedure when pedicle fixation is not an option
- Cephalad adjacent-level fusion: allows for additional level of fusion without having to remove adjacent pedicle screw-and-rod construct

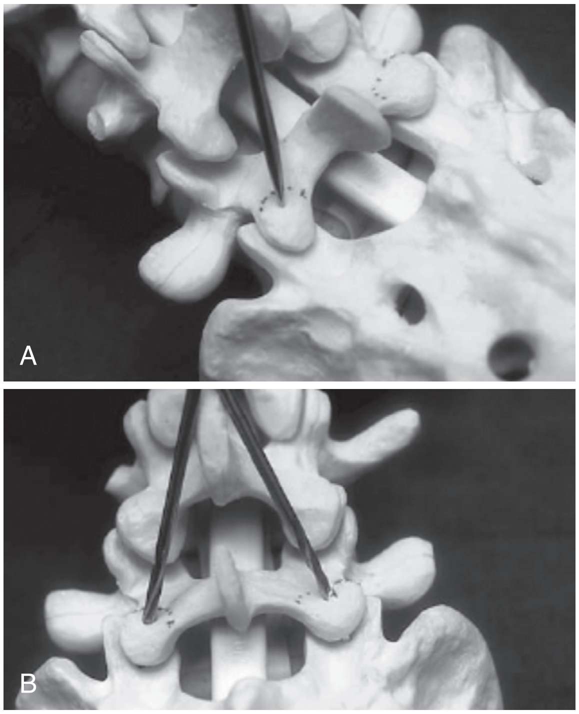
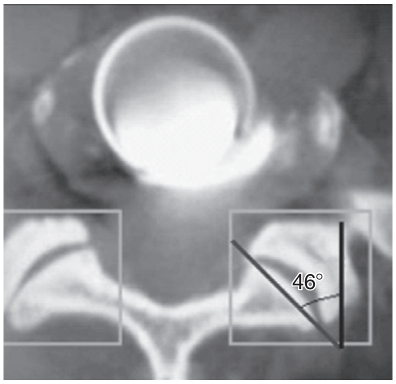


Figure 49-1 Anatomic model demonstrates the ideal starting point for an ipsilateral L5–S1 transfacet screw, starting in the middle aspect of the inferior facet and angled as close to perpendicular to the joint as possible.



Level	Angle
L1-L2	25 (15-47)
L2-L3	28 (17-51)
L3-L4	37 (15-57)
L4-L5	48 (13-70)
L5-S1	53 (36-70)

Figure 49-2 Average angles of the surface of the facet joint relative to the spinous process throughout the lumbar spine.

Contraindications

- Inadequate bone stock
- Deficient posterior elements
- Concomitant neural decompression (laminectomy or facetectomy)
- Isthmic spondylolysis
- Degenerative spondylolisthesis higher than grade II

RELATIVE CONTRAINDICATIONS

- Significant deformity
- Osteoporosis/osteopenia
- Prior surgery through the intended level of fixation

Operative Technique

EQUIPMENT

- Cortical screws (4.5 fully threaded or 4.0 cannulated)
- Radiolucent operative table
- Fluoroscopy
- Oscillating drill
- Protective drill sleeve
- Image guidance
- Decorticating instruments when performing a posterior lateral fusion (burrs, curettes, osteotomes)

PATIENT POSITIONING

- The patient is prone with adequate padding of potential sites of compression.
- Close attention to lordosis is important when positioning the patient on the table. Hip flexion contractures or inadequate lordosis during positioning can result in iatrogenic flat back syndrome.

APPROACH

- A posterior midline approach is used.
- Incision and soft-tissue dissection can be minimized by localization with fluoroscopy.

TECHNIQUE

Open Technique Direct Facet Screw Placement

The dissection is limited to the level of interest. The spinous processes, laminae, and facet joints are exposed in their entirety. For a single-level fusion at the L3–L4 level, the spinous process and lamina of L3 and the L3–L4 facet joint are exposed. Care is taken not to disrupt the facet capsules cephalad and caudad to the level of interest. If a decompression is required at the same level, the surgeon must preserve an adequate amount of the facet to allow for fixation. An alternative would be to place the facet screws before decompression.

The facet capsule is opened, and the cartilaginous surfaces of the respective facets are removed. This can be done with a high-speed burr or a curette. After decorticating, the space is packed with bone graft material.

For the direct approach, the trajectory starts at the junction of the pars interarticularis and the inferior facet (see Fig. 49-1). The goal is to ultimately place the screw perpendicular to the joint surface, with final purchase into the bone of the adjacent pedicle. Remember that each level has a different orientation of the facet surface (see Fig. 49-2). A 3.2-mm drill bit, 4.5-mm tap, and 4.5-mm cortical screw are used for this technique. This screw can be placed as a neutralization screw or lag screw; if a lag screw is intended, overdrilling of the inferior facet is required.

Open Translaminar Technique

A similar approach is taken as previously described for direct facet screw placement. After achieving adequate exposure, the starting point is identified at the junction of the spinous process and lamina (Fig. 49-3). A starting point

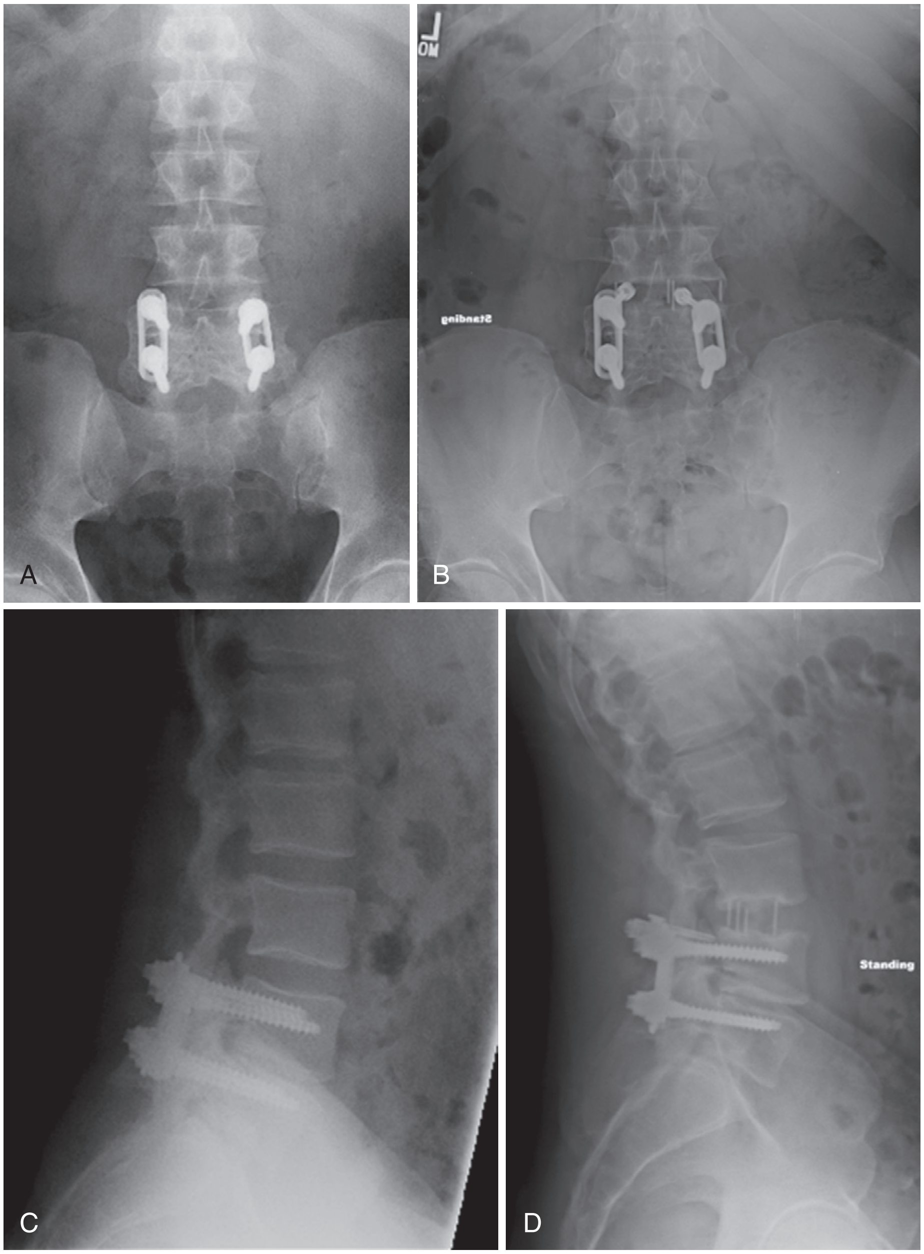


Figure 49-3 This patient with adjacent level disease was treated by anterior interbody fusion (extreme lateral interbody fusion) and supplemental posterior stabilization with ipsilateral transfacet screw fixation. (Courtesy Frank Phillips, Midwest Orthopedics at Rush University Medical Center.)

is created for the screw at the spinolaminar junction using a 3.0-mm burr. A 3.2-mm drill bit is directed toward the contralateral facet joint, and care is taken to maintain a path within the cortices of the lamina. With an open technique, prevention of a breach is facilitated because the path can be directly visualized. A Woodson or Penfield instrument can also be used to palpate the ventral surface of the lamina to detect violation into the epidural space.

When choosing an initial starting point for the first screw, it is important to leave enough bone to accommodate the path for a second screw. The second screw is placed on the contralateral side at the spinolaminar junction. The starting point is more cephalad or caudad with the same trajectory. After drilling, the pathway is measured and tapped before placement of a 4.5-mm cortical screw. Unlike the direct technique, this screw should not be placed in a lag fashion because of a risk of spinous process fracture and loss of fixation.

Percutaneous Translaminar Facet Fixation

Preoperative axial images are used to measure the facet angle at each level being instrumented. The screw trajectory is perpendicular to this facet angle, and axial images are also used to plan the skin incision (see Fig. 49-3). The line of the screw trajectory is drawn from the facet to the skin. The distance from the midline to the point where the line crosses the skin is measured and is used when making an incision. An anteroposterior (AP) fluoroscopic image is used to determine the caudal trajectory of the screw. A line is drawn from the superior pedicle of the level above, diagonally crossing the midline toward the superior lateral quadrant of the inferior pedicle; for example, at the L3–L4 level, a line is drawn from the midpoint of the *right* L3 pedicle diagonally toward the superior lateral quadrant of the *left* L4 pedicle.

A stab incision is made at the intersection of these two lines (see Fig. 49-3). A bone biopsy or Jamshidi needle is inserted through the skin and is docked at the spinolaminar junction. The lateral trajectory of the screw is determined by measuring the angle of the lamina on axial images (see Fig. 49-2). The inner stylet is then withdrawn, and a K-wire is inserted through the trocar and is then advanced with a K-wire driver and using fluoroscopic guidance toward the superior lateral quadrant of the targeted pedicle. A lateral view can be used at this point to guide the trajectory of the wire toward the posterior one third of the pedicle. The trocar is withdrawn, and the guidewire is measured and drilled. A cannulated 4.0-mm lag screw is placed over the guidewire.

PEARLS

- Compress the spinous processes together to create lordosis.
- Palpate the ventral side of the lamina with a Penfield dissector to ensure appropriate trajectory when using the freehand technique.
- When using bilateral translaminar screws, planning for the starting points and trajectories of both screws should be considered.
- Preoperative axial imaging can be used to measure facet angle when planning screw placement.
- Lag technique should be avoided when using translaminar screws because of the risk of fracture.
- In cases where significant lateral recess or foraminal pathology exists that would require extensive decompression and removal of a large portion of the facet, this technique may not be possible if there is inadequate bone left for screw purchase.

CLOSURE

- Closure is dependent on the technique used.
- *Open:* If a large dead space exists, a gentle closure of the muscle underlying the fascia can be done. Closure of the fascial layer is done with interrupted absorbable suture followed by a subcutaneous interrupted layer. Finally, the skin can be closed with either staples or suture based on the surgeon's preference.
- *Percutaneous:* Closure of the skin is done in the surgeon's preferred fashion.

Postoperative Regimen and Care

- Surgeon dependent
- Standard postoperative fusion protocol (surgeon preference)
- No brace required

Complications

- Lamina fractures
- Canal violation or neurologic injury
- Facet fractures
- Failure of fixation
- Inadequate decompression of neural elements
- Nonunion

Conclusions

Lumbar facet screw fixation provides an alternative to pedicle screw fixation that leaves a smaller footprint for insertion, maximizes bone surface area for fusion, and allows for minimally invasive insertion. Clinically, it is most commonly used as an adjunct to anterior interbody fusion to complete circumferential fusion constructs.

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SECTION E

Lumbar Sacral Pelvic Junction

50 Surgical Anatomy, Approaches, and Biomechanics in the Lumbosacral Pelvic Junction

JONATHAN N. SELLIN

Overview

The lumbosacral junction–the confluence of the lumbar spine, sacrum, and ilium—can be afflicted by traumatic, infectious, degenerative, deformative (scoliosis), and neoplastic processes. Surgical management of diseases that affect the lumbosacral junction requires an intricate understanding of lumbosacral anatomy that can present challenges to the surgeon unfamiliar with surgical approaches and techniques applicable to this complicated region.

Classically, the lumbosacral region is accessed by anterior or posterior surgical approaches. Anterior approaches to the lumbosacral junction, whether intraperitoneal or retroperitoneal, can be used to expose the anterior aspect of the lumbar spine and sacrum. Posterior approaches to the lumbosacral junction can be used to expose the posterior surface of the lumbar spine, sacrum, and ilium. Regardless of approach, a detailed understanding of surface, bony, neural, and vascular anatomy, as well as lumbosacral biomechanics and spinopelvic fixation, are essential for the surgeon management of diseases of the lumbosacral junction.

Anatomy

SURFACE ANATOMY

Anterior approaches to the lumbosacral junction require understanding of the anatomy of the anterior abdominal wall. At the midline, the anterior abdominal wall, from superficial to deep, consists of the skin, subcutaneous fat, Scarpa fascia, rectus abdominis, the rectus sheath, transversalis fascia, peritoneal fat, and peritoneum. In the lateral abdominal wall, the rectus abdominis is replaced by three layered muscles: from superficial to deep, these are the external oblique, internal oblique, and the transversus abdominis. Moving lateral to medial, the investing fascia of these three muscles condense to form the rectus sheath, which surrounds the rectus abdominis (Fig. 50-1).

At the midline, between the right and left rectus muscles, the rectus sheath forms a fascial condensation called the *linea alba*. Above the umbilicus, the internal oblique fascia splits to invest the anterior and posterior surface of the rectus abdominis; the external oblique fascia travels anterior to the rectus abdominis in the anterior rectus sheath, and the transversus abdominis fascia travels posteriorly to form the posterior rectus sheath.

Below the umbilicus—starting at the *linea semicircularis of Douglas,* or *arcuate line* of the abdomen—all three layers of fascia pass anterior to the rectus abdominis to form the anterior rectus sheath, leaving only transversalis fascia between the rectus and the peritoneum (Fig. 50-2). The *linea semicircularis* is not to be confused with the *linea semilunaris,* which is the lateral border of the rectus abdominis, where the external oblique, internal oblique, and transversus abdominis fascia invest the muscle that forms the rectus sheath. The inferior epigastric vessels course between the muscles of the abdominal wall and the transversalis fascia. They travel in oblique fashion from lateral to medial and thus are rarely at risk in midline anterior approaches, although caution must be paid to these vessels in more lateral approaches. Deep to the peritoneum are the abdominal and pelvic viscera, most prominently the large and small intestine, and the urinary bladder. From the surface, the L3–L4 disk space can be found on level with the umbilicus, the L4–L5 disk space at the level of the superior iliac crest, and the L5–S1 disk space midway between the umbilicus and pubic symphisis (Fig. 50-3).

BONY ANTATOMY OF THE LUMBOSACRAL JUNCTION

Lumbosacral iliac stability depends on the posterior bone and ligaments of the ilium and sacrum.[1] The dorsal surface of the sacrum can be divided into three zones, as defined by bony anatomy. Moving in a lateral-to-medial direction, zone I is lateral to the dorsal sacral foramina and includes the lateral sacral crest. Zone II, the transforaminal zone, includes the bony surface that surrounds the dorsal sacral foramina. Most medial is zone 3, the region medial to these foramina, ending at the median sacral crest. In zone 3, along the midline, the distal sacrum opens at the sacral hiatus, an opening through which the final sacral nerves exit (Fig. 50-4).

The sacrum has three prominent articulations: Above, it articulates with the fifth lumbar vertebral body at the *lumbosacral joint.* Laterally, the ilium articulates with the sacrum's auricular process at the *sacroiliac joint.* Inferiorly, the sacrum articulates with the coccyx at the *sacrococcygeal joint.* In the anteroposterior (AP) plane, the lumbosacral joint rests anterior to the sacroiliac joint, transmitting the spine's axial load to the superior surface of the sacrum, which is tilted forward; the result is a rotatory force that drives the sacral promontory forward and the apex backward. The axis of this rotary force passes through the center

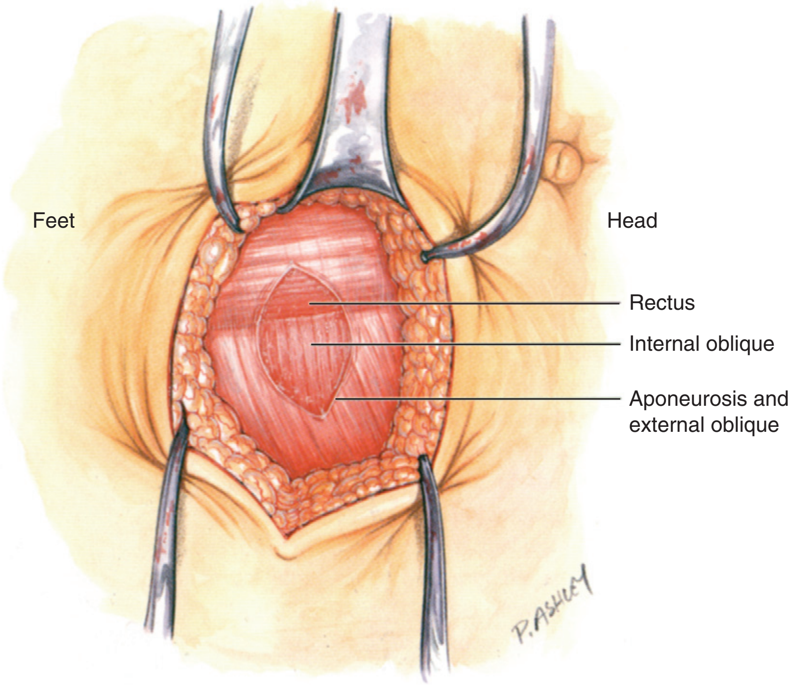

Figure 50-1 Anterior rectus sheath is divided to expose the external oblique muscle. (From Adams P, Cotler H: Alternative anterior lumbar exposures. In Albert T, Balderston B, Northrup B, editors: *Surgical approaches to the spine,* Philadelphia, 1997, WB Saunders, pp 157–171.)

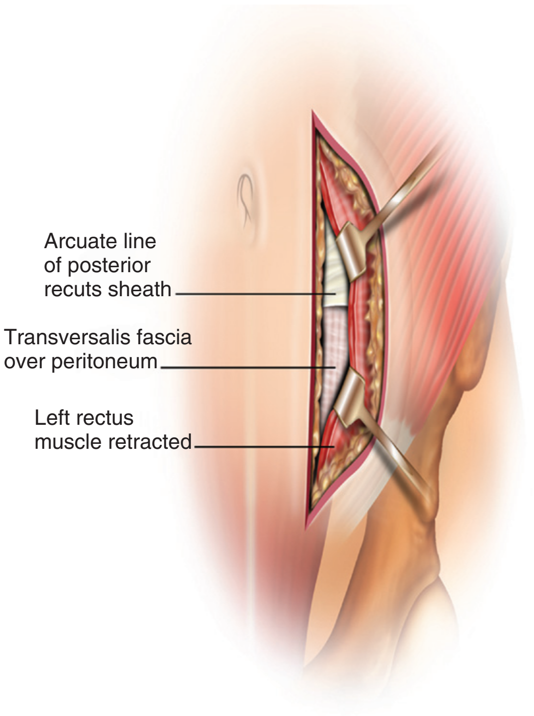

Figure 50-2 Blunt dissection along the fibers of the rectus abdominis muscle medially expose the posterior sheath. The arcuate line marks the transition at the lower end of the incomplete posterior rectus sheath to the peritoneum.

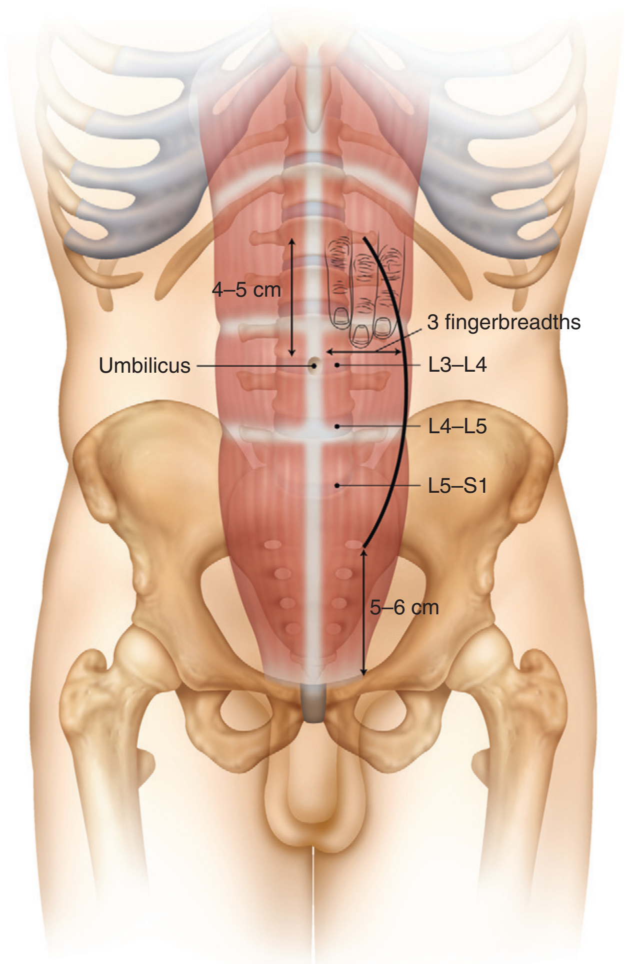

Figure 50-3 Skin incision for the anterior retroperitoneal approach. The umbilicus corresponds to the L3–L4 intervertebral disk level, and the superior iliac crest is at the L4–L5 level. The L5–S1 level is located midway between the umbilicus and pubic symphysis.

of the second sacral vertebra, and the sacrum's rotary predisposition is restrained by ligamentous forces.

The two strongest ligaments in the sacrum are the *interosseous ligament*, a band of short fibers that connects the ilial and sacral tuberosities, and the *posterior sacroiliac ligament*, which passes from the sacral tubercles to the ilial tuberosity and posterior superior iliac spine counter to the natural forward tilt of the upper sacrum. The sacrotuberous ligament connects the ischial tuberosity to the anteroinferior sacrum and coccyx, and the sacrospinous ligament connects the ischial spine to the lateral sacrum and coccyx; these ligaments resist the natural posterior tilt of the inferior sacrum and coccyx. The iliolumbar ligament passes from the L5 transverse process to the inner lip of the iliac crest, and it resists the natural tendency of the fifth lumbar vertebra to slide anteriorly over the sacral promontory (Fig. 50-5).

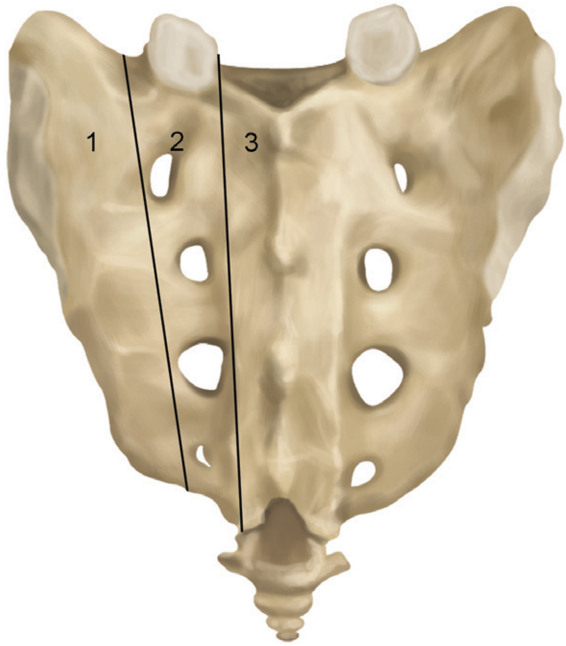

Figure 50-4 Figure outlining the three zones of the sacrum. Zone 1 is lateral to the sacral foramina, zone 2 is transforaminal, and zone 3 is the region medial to the foramina.

The sacroiliac joint itself is a synovial joint formed by the articular surfaces of the sacrum and ilium; the sacral articular surface is covered by hyaline cartilage, and the ilial surface is covered by fibrocartilage. The articular surface of the sacrum has a characteristic earlike shape, and its surface irregularities articulate with complementary irregularities on the surfaces of the ilial articular process. The sacroiliac joint terminates inferiorly at the S2 level.

The body's weight is transmitted from the lumbar spine to the sacrum through the lumbosacral joint then from sacrum to ilum through the sacroiliac joint.[2] In sitting and standing positions, the sacroiliac joint is the principal transmitter of force between the pelvis and spine. Surgical disruption or resection of the sacroiliac join, as in total sacrectomies, can weaken this link and result in sacroiliac instability with poor weight bearing in the upright position that will affect the patient's ability to sit, stand, or walk. Sacroiliac stability is little affected by sacral resections as long as the sacroiliac joint is spared.[2,3] Furthermore, sacroiliac stability can withstand resection of up to 50% or more of the sacroiliac joint, a finding corroborated by cadaveric data from Gunterberg and colleagues.[4,5] Therefore during partial sacrectomies, the lower sacrum can be removed up to the S2 level—where the sacroiliac joint ends and the posterior sacroiliac ligament terminates—without introducing instability into the pelvis.

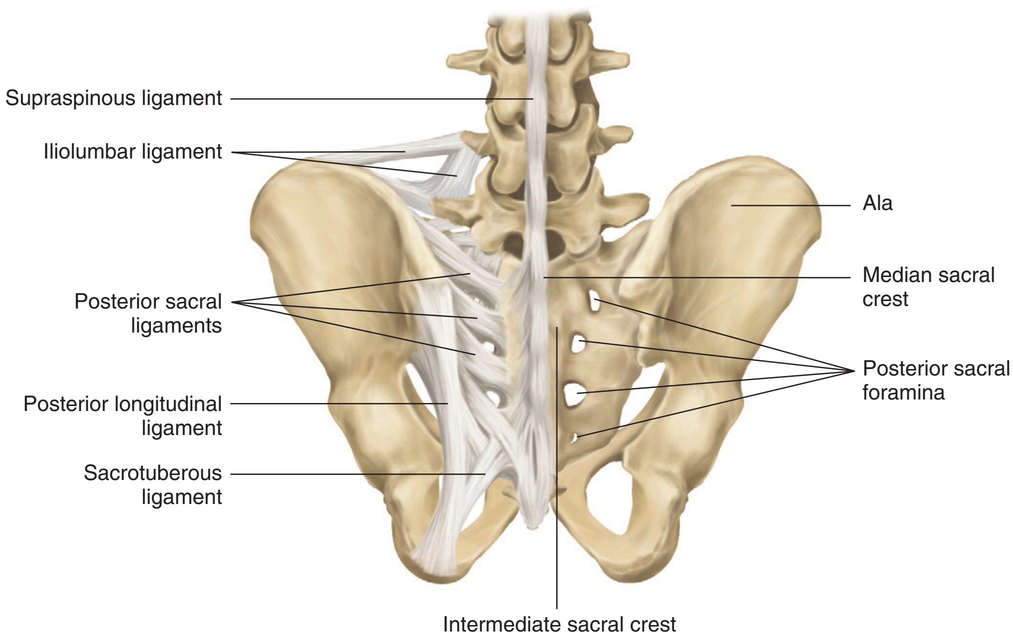

Figure 50-5 Lumbosacral spine and pelvis. The osteologic and ligamentous structures are identified.

BIOMECHANICS OF LUMBOSACRAL JUNCTION

The lumbosacral junction represents an important point of transition between the spinal column, the pelvis, and the lower extremities. Increased attention is being paid to the interrelationship between the pelvis and the spine in maintaining appropriate sagittal balance, and many argue that isolated analysis of the spine alone is insufficient.[6]

One of the guiding principles in analysis of spinal deformity is the concept of *sagittal balance,* which is influenced by several spinopelvic parameters. The most common measurements taken to assess sagittal balance are angles of thoracic kyphosis and lumbar lordosis, calculated using the Cobb method. Aside from actual measurements of the curvature of the spine, global spinal alignment can be assessed using the plumb line method, measuring on a full-length sagittal radiograph the horizontal offset from the posterosuperior corner of the S1 vertebral body to a plumb line drawn from the C7 vertebral body. This distance, known as the *sagittal vertical axis* (SVA) *offset*, has been reported in asymptomatic adults to have a normal range of 0.5 cm (± 2.5 cm; Fig. 50-6).[7] SVA increases with sagittal plane "anterior imbalance."

A more recently developed assessment of global sagittal balance is the *T1–T9 global spinopelvic inclination,* measured as the angle between the vertical plumb line and a line drawn from the center of the T1–T9 vertebral body and the center of the bicoxofemoral axis (Fig. 50-7). Both the SVA and T1 spinopelvic inclination have been demonstrated to correlate significantly with health-related quality of life (HRQOL) measurements, with T1–T9 global spinopelvic inclination actually showing greater correlation.[6] Thus anterior sagittal imbalance correlates with self-reported disability.

Analysis of sagittal imbalance in the spine is likely incomplete if not coupled with similar analysis of the pelvis. Analysis of the pelvis in the sagittal plane commonly uses three angular measurements: the *pelvic incidence* (PI), *pelvic tilt* (PT), and *sacral slope* (SS). These three measurements exist in an algebraic relationship, such that PI = PT + SS (Fig. 50-8).

The *pelvic incidence* is defined as the angle between a perpendicular line passing through the midpoint of the sacral plate and a line connecting this midpoint to the axis of the femoral head. PI is unique among the pelvic parameters in that it is a morphologic parameter, meaning that it is unique to the morphology of an individual pelvis and remains constant even with changes in pelvic position or inclination. As the only fixed value in a chain of interrelated measurements, the PI significantly influences the many positional parameters involved in sagittal balance. Most importantly, the PI has been closely linked to the degree of lordosis in the lumbar spine, such that low values of PI imply flattened lordosis, and high values imply pronounced lordosis with larger sagittal curves.[8,9] Various formulas have been proposed for prediction of lumbar lordosis that use the pelvic incidence along with other pelvic parameters.[6,8,9]

The *sacral slope* is defined as the angle between the horizontal and the sacral plate. Unlike the PI, the SS is a positional parameter, meaning that its value is fluid, and it varies in a given patient as that patient's pelvis moves in space. The SS is a surrogate for the orientation of the pelvis.

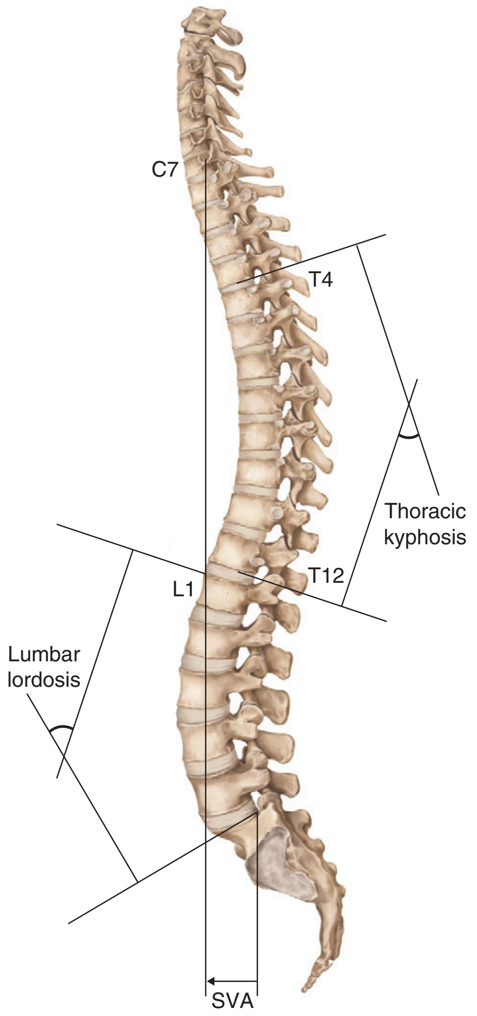

Figure 50-6 Regional spinal radiographic parameters. Thoracic kyphosis is measured from the superior end plate of T4 to the inferior end plate of T12. Lumbar lordosis is measured from the superior end plate of L1 to the superior end plate of S1. SVA, sagittal vertical axis.

Lumbar lordosis is closely related to pelvic orientation and is thus influenced by the SS, which is in turn influenced by the PI, a connection that underlies the relationship between PI and lumbar lordosis as described above.

The *pelvic tilt* is defined as the angle between the vertical and a line from the midpoint of the sacral plate to the axis of the femoral head. PT is a positional parameter commonly thought to act in compensatory fashion; when the spine tilts forward, the body recruits compensatory mechanisms in an effort to bring the spine over the pelvis. One such mechanism is *pelvic retroversion,* rotation of the pelvis backward around the hips. This retroversion manifests itself as an increase in pelvic tilt. Schwab and colleagues[6] demonstrated that PT is increased in patients with anterior sagittal imbalance—age-related changes, loss of lordosis, or increase of kyphosis—and is decreased in patients with posterior sagittal imabalance. PT is also the only pelvic parameter found to be significantly correlated with HRQOL indices, which once again underscores the importance of pelvic parameters in the clinical assessment of spinal deformity.

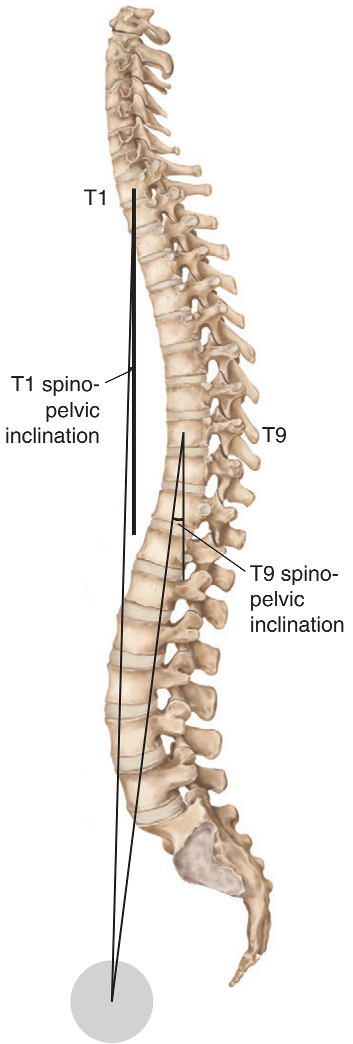

Figure 50-7 Global radiographic parameters. *Sagittal vertical axis* is defined as the horizontal offset from the posterosuperior corner of S1 to the vertebral body of C7. *T1 and T9 spinopelvic inclination* is defined as the angle between the vertical plumb line and the line drawn from the vertebral body center and the center of the bicoxofemoral axis.

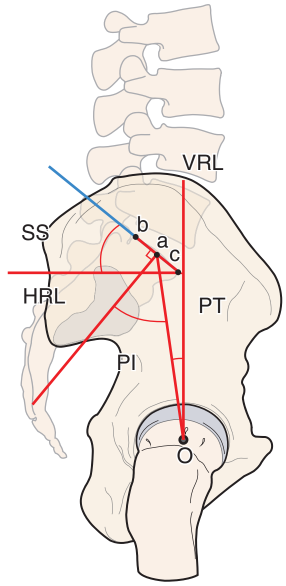

Figure 50-8 *Pelvic incidence* (PI) is defined as the angle between the line perpendicular to the upper sacral end plate at its midpoint and the line connecting this point to the axis of the femoral head. PI = pelvic tilt (PT) + sacral slope (SS.) *a,* midpoint of the sacral end plate; *b,* posterior edge of the sacral end plate; *c,* anterior edge of the sacral end plate. *HRL,* horizontal reference line; *VRL,* vertical reference line.

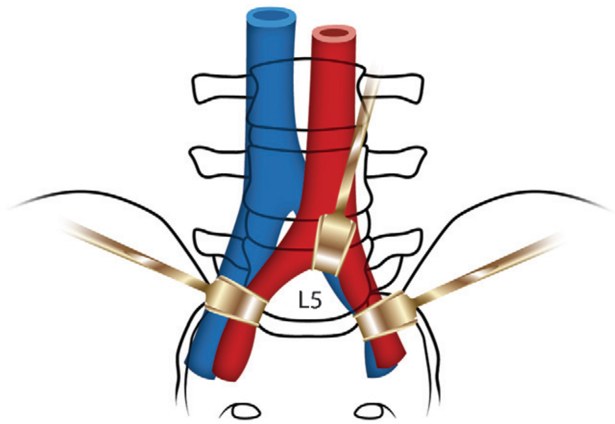

Figure 50-9 Bifurcation of the aorta at the L4–L5 disk level. The bifurcation point is retracted cephalad and two branches bilaterally.

VASCULAR ANATOMY

Intricate understanding of vascular anatomy is important for anterior approaches to the lumbosacral region, because vascular injuries are one of the most feared complications associated with surgical interventions in this area.

The aorta most commonly bifurcates into the common iliac arteries at the caudal L4 vertebra, just left of midline (Fig. 50-9). The common iliac arteries run inferolateral on the medial surface of the psoas muscle to their bifurcation into the internal and external iliac arteries at the level of the lumbosacral articulation, anterior to the sacroiliac joints. The common iliac veins run superomedial to terminate in the inferior vena cava (IVC) posterior to the right common iliac artery at the L5 level.

The right common iliac artery is longer (5 cm) than the left (4 cm) owing to its origin at the aortic bifurcation just left of the midline. Just lateral to the right common iliac artery are the IVC, the termination of the right common iliac vein, and the right psoas. Medial to the artery are the right common iliac vein and the termination of the left common iliac vein, both of which pass beneath the right common iliac artery to join the IVC.

The shorter left common iliac artery is crossed by the inferior mesenteric artery that courses from its origin in the aorta above. To the left of the left common iliac artery is the psoas muscle; on the right is the left common iliac vein.

Both common iliac arteries are crossed anteriorly by the right and left ureter, respectively, as well as the right and left ovarian arteries in women. The ureters, loosely imbedded in the retroperitoneal space, cross the common iliac arteries at the level of the sacroiliac joint. Sympathetic nerve branches cross both arteries as they descend into the superior hypogastric plexus between the common iliac vessels. Anterior to both common iliac arteries are the sigmoid colon and mesocolon.

Descending from the posterior aorta, the middle (or median) sacral artery descends on the midline down the anterior surface of the L4–L5 vertebrae and sacrum. The lateral sacral arteries arise from the distal common or internal iliac artery, posterior division. These sacral arteries contribute a significant vascular supply to presacral tumors. The middle sacral artery is often sacrificed in anterior approaches to the lumbosacral junction.

The internal iliac arteries branch from the common iliac artery at an acute angle, making a dorsocaudal descent into the pelvis, which it supplies. The anatomy of the artery is variable, but it generally divides into an anterior and posterior branch, which give rise to its many branches, all of which will not be covered in this discussion. The first major branch is the iliolumbar artery, which exits at the posterior aspect of the internal iliac artery then ascends rostrolaterally, crossing over the lumbosacral trunk. As mentioned above, one or more lateral sacral arteries branch from the internal iliac artery. Next, and most prominently, the superior gluteal artery exits the internal iliac artery as its largest branch, passing through the upper sacral plexus en route to its exit through the greater sciatic foramen, superior to the piriformis muscle (Fig. 50-10). More distally, the inferior gluteal artery passes through the lower sacral plexus on its own path to the greater sciatic foramen, inferior to the piriformis muscle.

The venous anatomy of the lumbosacral junction echoes the arterial, with far more variability. Two constant variations from the arterial anatomy are the drainage of the middle sacral vein into the left common iliac vein, instead of the IVC, and the drainage of the iliolumbar veins into the common, not internal, iliac veins.[5] These iliolumbar (or ascending lumbar) veins, which arise from the posterior aspect of the common iliac veins at the L5 level, are of particular interest to the surgeon, because they must be isolated and controlled during anterior lumbosacral approaches.

NEURAL ANATOMY

The right and left sacral plexi are formed by the confluence of the lumbosacral trunk, which travels inferolaterally along the ventral sacrum, with the S1–S3 ventral rami emerging from the ventral sacral foramina (Fig. 50-11). This confluence of nerves forms at the sacroiliac joint on the level of the S2 foramina just anterior to the piriformis muscle. The superior and inferior gluteal nerves are the most proximal braches of the plexus, and these leave the pelvis through the greater sciatic foramen above and below the piriformis muscle, respectively (Fig. 50-12). The largest branch of the sacral plexus is the sciatic nerve, which forms at the level of the S3 foramina and exits the pelvis through the greater sciatic foramen inferior to the piriformis. Smaller motor and sensory branches also form in the sacral plexus and pass out of the pelvis with the sciatic nerve. Emerging in the inferomedial sacral plexus, contributions from the ventral rami of S2 to S4 join to form the pudendal nerve, which among other functions innervates the striated muscle of the rectal and urethral sphincter and the coccygeal and levator muscles of the pelvic floor. The pudendal nerve is the only nerve to both exit and enter the pelvis, leaving via the greater sciatic foramen, hugging the sacrospinous ligament, and returning via the lesser sciatic foramen. The fourth and fifth sacral roots and the coccygeal roots form an inconsistent coccygeal plexus that supplies the perianal region.

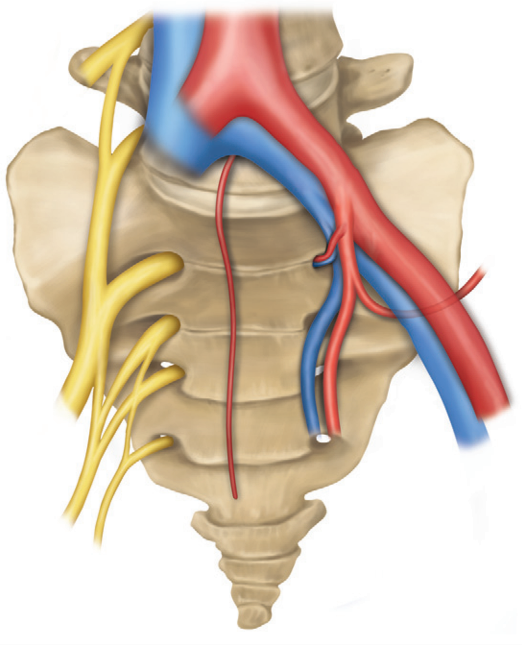

Figure 50-10 The neurovascular structures located on the anterior aspect of the sacrum.

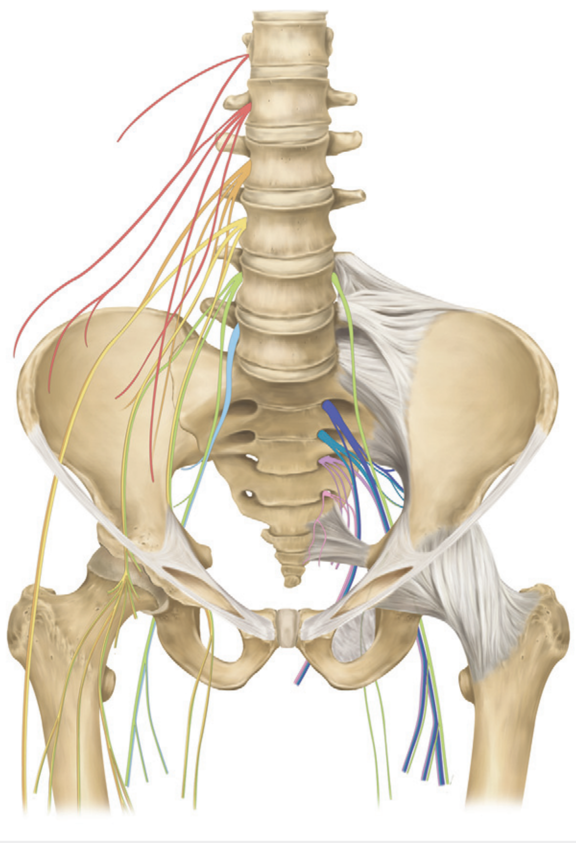

Figure 50-11 Pictorial depiction of nerves of the lumbar and sacral plexi.

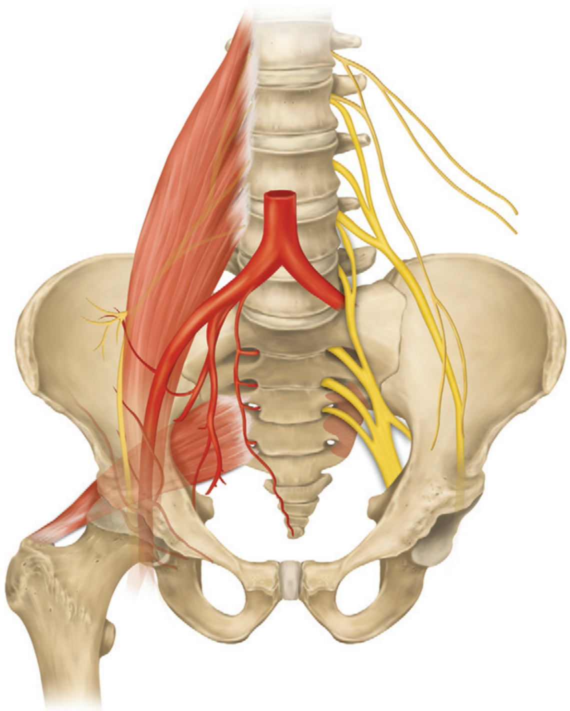

Figure 50-12 Pictorial depiction of psoas and piriformis muscles, sciatic nerve, spinal nerves, and aorta in relation to the bony pelvis. Note the origin of the piriformis on the anterior aspect of the sacrum.

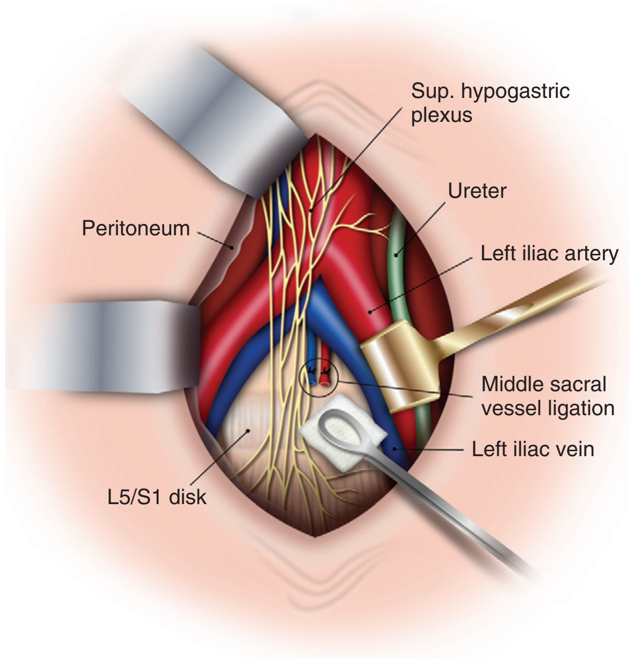

Figure 50-13 Dissection method for superior hypogastric plexus.

The sympathetic chain dispatches preganglionic fibers directly to several of the sacral roots, and its filamentous branches descend into the pelvis and invest the anterior surface of the aorta, lumbar vertebrae, and ventral sacrum as the superior hypogastric plexus. Fibers from the superior hypogastric plexus split inferolaterally at the S1–S2 level to form the hypogastric nerves, which travel to the right and left inferior hypogastric (or pelvic) plexi; these invest the obturator internus at the S2 to S4 levels.

Parasympathetic supply to the inferior hypogastric plexi comes in the form of small branches from the ventral S2 to S4 nerve roots, known collectively as the *pelvic splanchnic nerves*. Both the superior hypogastric and inferior hypogastric plexi contribute small fibers that innervate the organs of the pelvis. Sympathetic input coordinates anterograde ejaculation out of the urethra, and parasympathetic input coordinates the vascular reflexes that sustain that sustain erectile functions.[5] The presence of the superior hypogastric plexus along the anterior aorta to sacral promontory are relevant to the surgeon in anterior approaches to the lumbosacral junction; injury to this plexus can lead to retrograde ejaculation in men (Fig. 50-13).

Approaches to the Lumbosacral Junction

ANTERIOR VERSUS POSTERIOR PATHOLOGY-GUIDED APPROACH

The anterior midline or anterolateral approach to the lumbosacral vertebral bodies provides the surgeon access to lower lumbar and upper sacral vertebral bodies. Midline incisions in the supine patient allow for transperitoneal or retroperitoneal dissection. Oblique flank incisions in the patient positioned in lateral decubitus allow for retroperitoneal dissection.[10] The principal argument for the transperitoneal approach is that the abdominal viscera are more easily retracted than in retroperitoneal dissections. The retroperitoneal approach, however, allows for a more facile plane of dissection, which makes the viscera and the hypogastric nerve plexus less prone to injury. Additionally, retroperitoneal approaches are less likely to provoke postoperative ileus and consequent prolonged hospital stay.

The posterior midline approach allows for direct access to the posterior elements—spinous processes, laminae, and facets—throughout the lumbosacral spine. The transverse processes and pedicles may be reached with greater difficulty by vigorous lateral retraction of the paraspinal muscles. The posterior end plate of the vertebral body and disk space of the lumbar levels can be accessed after laminectomy by lateral retraction of the thecal sac. Carrying the subperiosteal dissection out laterally, the lateral sacrum and sacroiliac joints can be exposed.

The posterolateral approach through a paramedian incision with medial retraction of the paraspinal musculature provides a direct window into the transverse processes and the facet joints that is useful for managing far-lateral disk herniation and for accomplishing posterolateral lumbosacral fusion or for bony fusion of the transverse processes. Additionally, posterolateral approaches allow for varying degrees of exposure of the pedicle and vertebral body.

ANTERIOR APPROACH TO THE LUMBOSACRAL JUNCTION

Classically, anterior approaches to the lumbar spine have been transperitoneal or retroperitoneal.

Midline Transperitoneal Approach

Positioning. In a midline transperitoneal approach,[11] bowel preparation is given to the patient the night before surgery. A nasogastric tube is placed to suction for decompression of abdominal contents. The patient is placed supine on the operating table over the point of flexion at the crease of the table to hyperextend the lumbar spine and open the anterior aspect of the disk spaces to facilitate exposure. A surgical bump can also be used to this effect.[12] The patient may be placed in Trendelenburg position to allow intraabdominal contents to fall away from the surgical field, and some argue for placement of a pulse oximetry probe on the toes of patients to survey vascular flow to the lower extremities.

Incision and Soft Tissue Dissection. Vertical midline incision or the transverse Pfannenstiel incision may be used. The L3–L4 disk space is generally at the umbilicus, the L4–L5 level is halfway between the umbilicus and the pubic symphysis, and the L5–S1 level is two fingerbreadths above the symphysis. Longitudinal midline incisions allow for more extensive exposure of the lumbosacral junction. Incision is made from just above umbilicus at the midline along the linea alba, curving left around the umbilicus, carried down to 2 to 3 cm above the pubic symphysis. Staying true to the linea alba, the surgeon avoids denervation of the rectus abdominis muscle; these receive their nerve supply from the seventh through twelfth segmental intercostal nerves, which course in a lateral-to-medial direction.

A transverse Pfannenstiel incision for limited L5–S1 approaches offers improved cosmesis. Incision is made by palpating the pubic symphysis and making a curvilinear incision 1 cm above, along a natural skin crease; attention must be paid to the inferior epigastric vessels, which may be damaged lateral to the midline.

Incision is carried from superficial to deep through subcutaneous tissue to the rectus sheath. The anterior portion of the rectus sheath is opened, and the rectus abdominis muscle is transected. Posterior to the rectus abdominis, the posterior rectus sheath, transversalis fascia, and peritoneum are intimately adherent. Care must be taken at this stage because of the risk of visceral injury; patients with prior intraperitoneal pathology or surgery may have viscera closely adherent to the anterior abdominal wall. The posterior rectus sheath and abdominal fascia are carefully incised and retracted laterally to expose the peritoneum. Next, the peritoneum is elevated with pickups and is carefully incised; the surgeon's hand should be placed in the abdominal cavity to protect the viscera.

Intraperitoneal Dissection. The small bowel is retracted superolaterally, and the sigmoid colon is identified and retracted to the left. The urinary bladder is protected and retracted inferiorly; large moist sponges and a self-retaining retractor with wide malleable blades are used for retraction and packing of the viscera. The posterior peritoneum is identified, and the aorta, iliac vessels, and sacral promontory are palpated.

Retroperitoneal Dissection. Next, palpate the buoyant texture of the intervertebral disk space of interest. Using a fine needle, infiltrate the retroperitoneal space with saline to create hydrodynamic separation of peritoneum from vascular structures. Elevate the posterior peritoneum delicately with Adson forceps, and make a small longitudinal incision. Metzenbaum scissors may also be used to open the retroperitoneum; retroperitoneal incision should be made lateral to midline to prevent damage to the middle sacral artery before proper control of this vessel. The superior hypogastric plexus is located directly over the L5–S1 disk space, and damage to the plexus can result in retrograde ejaculation in men, thus it is prudent to avoid the use of electrocautery during retroperitoneal dissection to avoid plexus injury. Blunt dissection with sponges can be used to gently separate and mobilize retroperitoneal tissue off the midline. Attention should be paid to the left common iliac vein, which crosses the L4, L5, and S1 levels anteriorly en route to the vena cava; this pale vessel often lies draped across the disk space. The left iliolumbar (ascending lumbar) vein must also be identified. When exposing the L4–L5 level, this vein should always be ligated to prevent unwanted hemorrhage during mobilization or retraction of the left common iliac vein.

For hemostasis, use direct finger or sponge pressure in concert with blunt dissection. Hemorrhage may be controlled with packing and pressure. If necessary, the surgeon should divide and tie to control persistent bleeders.

Once the left common iliac artery and vein are identified, use blunt dissection to sweep retroperitoneal soft tissue and the superior hypogastric plexus from left to right, starting just right of the left common iliac artery. The middle sacral artery and vein, which may be adherent to the L5–S1 disk space, may be bluntly dissected in longitudinal fashion from left to right, or it may be sacrificed.

Thorough dissection allows insertion of Steinmann pins into exposed vertebral body or placement of special Deaver-type retractors, either of which can be used to retract and protect retroperitoneal soft tissue and vascular structures. For additional exposure of the L4–L5 level, the level of the aortic bifurcation and the size of the left iliac vein will guide retraction.

Diskectomy/Osteophytectomy. After exposure of the anterior spinal column, radiograph should be obtained for confirmation of the level. Bony work and disk excision may also be done. Autologous tricortical iliac crest autograft, femoral ring allograft, or synthetic cages are commonly used to achieve interbody fusion. Graft should be tapped into place under direct visualization, with care taken to protect the vasculature and avoid forcing the graft into unreceptive disk space. AP and lateral radiographs should be taken to verify graft position, and blunt nerve hooks may be used to palpate the posterior aspect of graft to determine whether compression of the dural sac has occurred.

Closure. Retractors are removed, and meticulous hemostasis should be ensured; attention should be paid to sources of hemorrhage tamponaded by surgical retraction. Close the peritoneum, muscle, subcutaneous tissue, and skin in the usual fashion. Abdominal viscera should be inspected to ensure no visceral injury has occurred.

Complications. Injury to the great vessels is one of the most feared complications. Venous structures are more commonly injured than arterial structures, with injury to the left common iliac and ascending lumbar vein being the most common. Venotomy should be repaired directly. If this is impossible, ligation may be necessary, and occult venotomies may go unnoticed until retraction is released. Venous or arterial thrombosis is also a concern. Retroperitoneal venous thrombosis may only declare itself postoperatively, in the form of symptomatic pulmonary embolism; arterial thrombosis may result in lower extremity ischemia secondary to hypoperfusion or embolus, a complication that may be detected by pulse oximetry monitoring of the distal lower extremity. Complete iliac or femoral artery thrombosis is potentially devastating and requires emergent vascular surgery.

The ureters can be damaged during the anterior approach, which can result in renal dysfunction; in that event, direct repair and stenting are required. Sympathetic and parasympathetic plexus injury are the most common neurologic complications. The sympathetic chain courses along the lateral lumbar spine and may be injured in anterior approaches cephalad to L5–S1; this results in warmth and flushing in the ipsilateral limb, which is typically benign. Damage to the superior hypogastric plexus, as discussed, can result in retrograde ejaculation, which, although transient, may take up to 2 years to resolve— if it resolves at all. This complication may be more common in transperitoneal, rather than retroperitoneal, approaches; it has been reported in 4% to 20% of male patients following anterior approaches to the lumbar spine.[13] Injury to parasympathetic or somatic nervous structures is uncommon.

Retroperitoneal Approach

In recent years, the retroperitoneal approach to the lumbosacral junction has featured more prominently. In its favor, the retroperitoneal approach can be used to access vertebral levels from L5 to as cephalad as T12, where the transperitoneal approach loses its effectiveness, above L4. The retroperitoneal approach also has in its favor a natural avascular plane that bypasses direct manipulation of the viscera and results in less blood loss, a decreased rate of postoperative ileus, and a decreased incidence of visceral injury. Incidence of injury to the superior hypogastric plexus is also decreased using the retroperitoneal approach.[14]

The anterior retroperitoneal approach can be accomplished through a paramedian longitudinal incision in the supine position, or it may be done through an oblique flank incision with the patient in the lateral decubitus position. Decisions on patient position should generally be addressed on a case-by-case basis with the relevant pathology in mind, but the lateral decubitus position is generally more favorable for more cephalad pathology; the supine position is amenable to classic anterior approaches to the lower lumbar spine, with better visualization of relevant retroperitoneal structures.

Anterior Retroperitoneal Midline Approach

POSITIONING. Position the patient supine on the operating table. Ideally, the patient's lower lumbar spine and anterior superior iliac spine (ASIS) should be at the level of the kidney rests.[15] Surgical bumps can be placed at the ASIS level to facilitate lordosis. To maximize lordosis, both the head and foot of the bed can be lowered, and the patient can be made level with reverse Trendelenburg positioning.

INCISION. A paramedian longitudinal or horizontal incision should be made at the lower lateral border of the rectus abdominis, passing through the skin and subcutaneous tissue. The length of incision depends on the number of levels that require exposure. As with the transperitoneal approach, location of the incision is guided by anatomic landmarks: the superior iliac crest is typically at the L4–L5 level, and L5–S1 is often found several fingerbreadths above the pubic symphysis. If necessary, radiography can be used to clarify the relation of the lumbosacral spine to the pelvic brim.

SOFT TISSUE DISSECTION. Once incision is made, the lateral border of the rectus abdominis should be identified at the semilunar line, where the aponeurosis and fascia of the external oblique, internal oblique, and transversus abdominis invest the rectus abdominis to become the rectus sheath; the rectus sheath is incised just lateral to the semilunar line. Most superficial will be the external oblique muscle, which is dissected in line with the incision. Next, the internal oblique muscle is divided along the same line to reveal the thin layer of transversus abdominis, which is also divided. Deep to the transversus abdominis division, the transversalis fascia is identified. Carefully dissect the outer surface of transversalis fascia to the lateral rectus border, and incise the fascia just lateral to the linea semilunaris to reveal the underlying peritoneum (see Fig. 50-1).

RETROPERITONEAL DISSECTION. Using a sponge or gloved hand, bluntly dissect the peritoneum from the undersurface of the transversalis fascia. Any breaches in the peritoneum should be repaired primarily to prevent later development of abdominal hernias. Carry this avascular plane posterolaterally, bluntly dissecting the peritoneum from the lateral abdominal wall until the psoas muscle is identified. Using a padded Deaver retractor, your hand, or sponge sticks, retract the retroperitoneal fat and intraabdominal contents medially. Sweep the peritoneum and ureter medially to expose the left common iliac artery and vein; failure to retract the ureter medially with the peritoneum increases chance of ureteral injury (Fig. 50-14).

In the upper lumbar spine, the psoas must be reflected onto the anterior aspect of the vertebral body. This dissection can be accomplished with a Cobb elevator, beginning in the midline and carrying the musculature posterolaterally. Once reflected, segmental vessels and the sympathetic trunk should be visualized on the surface of the upper lumbar spine. The segmental vessels should be isolated and ligated to minimize bleeding. In the lower lumbar spine, psoas dissection is less necessary, because this muscle courses inferolaterally from its point of insertion on more cephalad lumbar vertebrae.

As with the transperitoneal approach, palpate and identify the intervertebral disk space of interest. Always obtain radiographic confirmation of the level in question by inserting a 22-gauge spinal needle into the disk space. The body of L5 can often be mistaken for the sacrum, because the L5–S1 disk and sacrum are angled acutely in the horizontal plane.

Once the appropriate level has been isolated, palpate and identify the left common iliac artery and, more importantly, the aortic bifurcation. The L4–L5 disk is typically found in the crotch of the aortic bifurcation; the L5–S1 disk is

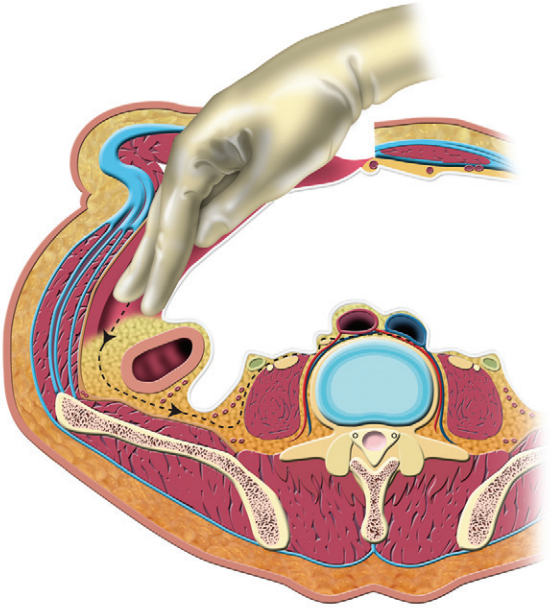

Figure 50-14 Axial section shows the approach of the blunt finger dissection used to reach the anterior aspect of the lumbar spine.

typically found inferior to the bifurcation, along the medial aspect of the left common iliac artery. The remainder of the surgeon's approach will be determined by the exact location of the aortic bifurcation, as well as the venous anatomy, both of which can vary considerably. Take care to identify the left common iliac vein, which rests in the aortic bifurcation at the L4–L5 or L5–S1 disk space. The branches of the left common iliac vein are commonly isolated and ligated to facilitate mobilization of the vessel with improved visualization of the spine. Usually, the left iliac artery and vein require retraction to the left, but anatomic variation may necessitate retraction to the right. Again, identification of the left iliolumbar vein is particularly important; before mobilizing the left iliac artery, the iliolumbar vein must be isolated and ligated. Dissection within the bifurcation of the aorta should proceed in blunt fashion, for which blunt retractors and sponge sticks can be used.

The middle sacral artery and veins are present in the midline, as is the superior hypogastric plexus. To mobilize these structures without damaging them, use blunt dissection to create a plane at the medial border of the left common iliac artery and carry it to the midline, sweeping the prevertebral tissue from left to right off the anterior surface of the lumbosacral disk (see Fig. 50-13). Occasionally, the middle sacral vessels are of formidable size, and they may be retracted or ligated according to surgeon's preference.

To avoid damage to the superior hypogastric plexus, avoid transverse cuts on the face of the disk until all prevertebral tissue has been lifted off the surface of the annulus. Again, always avoid electrocautery in this region to prevent damage to the plexus. Small bleeders are typically encountered in this dissection, but these can usually be controlled by direct finger pressure or hemostatic packing without issue.

To clear the operative field once the retroperitoneal dissection and vascular housekeeping has been completed, Steinmann or Freebody pins can be placed into the vertebral bodies, or special retractors can be used.

DISKECTOMY/OSTEOPHYTECTOMY. A diskectomy/osteophytectomy can be carried out in much the same fashion as described above in the diskectomy/osteophytectomy section of the midline transperitoneal approach.

CLOSURE. Meticulous hemostasis should be ensured, and the peritoneal sac is allowed to fall into place. Transversalis fascia and muscular layers are individually closed with running suture.

COMPLICATIONS. Complications seen in the retroperitoneal approach are similar to those seen in the transperitoneal approach. A greater concern in the retroperitoneal approach, which allows exposure of the cephalad lumbar vertebrae, is damage to the sympathetic trunk that can occur during dissection of the psoas off the anterior vertebral body. Such injury results in warmth in the ipsilateral extremity, which is usually benign and indolent in course.

Anterior Retroperitoneal Flank Approach

LATERAL DECUBITUS POSITIONING. The patient is placed in the right lateral decubitus position for a left-sided retroperitoneal approach.[16] A left-sided approach is commonly chosen to avoid the IVC, which is more easily injured than the aorta and is repaired with greater difficulty. Secure the patient in the lateral decubitus position. Ensure that the operative field is over the break in the table, so that the patient can be jackknifed to widen the space between in the ribs and superior pelvis. Failure to position the patient in a true lateral position may obscure anatomic relationships and disrupt the surgeon's orientation, which will make identification of important structures more difficult. The leg on the operative side of the body (left) is flexed to release tension in the psoas and allow for more facile retraction of this muscle intraoperatively.

LATERAL DECUBITUS INCISION. The anterolateral retroperitoneal approach typically uses a long, oblique flank incision. This incision typically begins midway between the pubic symphysis and iliac crest at the lower half of the umbilicus–pubic symphysis distance, which allows exposure of the lower lumbar and upper sacral vertebrae. This incision can be extended laterally and obliquely in a lazy-S configuration along the iliac crest to the midflank at the midaxillary line, midway between the crest and the lowest rib. More modest incisions can be tailored to particular spinal levels of interest. To access the upper lumbar spine (L1–L3), the incision can begin over the twelfth rib and can be curved anteriorly to end at the level of the umbilicus at the lateral border of the rectus abdominis. To approach the lower lumbar and sacral spine (L4–L5, sacrum), this incision can be started midway between the lower ribs and pelvic brim and curved anteriorly to end below the level of the umbilicus as the lateral border of the rectus (Fig. 50-15).

SOFT TISSUE DISSECTION. Carry the flank incision past the subcutaneous tissue. In line with the incision, divide the external oblique then internal oblique muscle. Next, divide the thin transversus abdominis muscle in the posterior pole of the incision in its approach to the midaxillary line. Toward the midline, the muscular layers of the lateral abdominal wall thin considerably, leaving the peritoneum very superficial at the semilunar line, where the rectus sheath begins. In this area, peritoneum can be entered inadvertently. It is for this reason that the transversus abdominis is divided toward the midaxillary line. If the peritoneum is violated, it should be repaired primarily before proceeding with spinal work.

Once the peritoneum and retroperitoneal space are defined in the posterior aspect of the incision at the midaxillary line, the peritoneum should be dissected bluntly from the overlying transversalis fascia. Moving toward the midline, the dissection can be extended medially by bluntly dissecting peritoneum from the posterior surface of the rectus sheath; the lateral margin of the rectus sheath, as well as the rectus muscle itself, may be partially divided if needed.

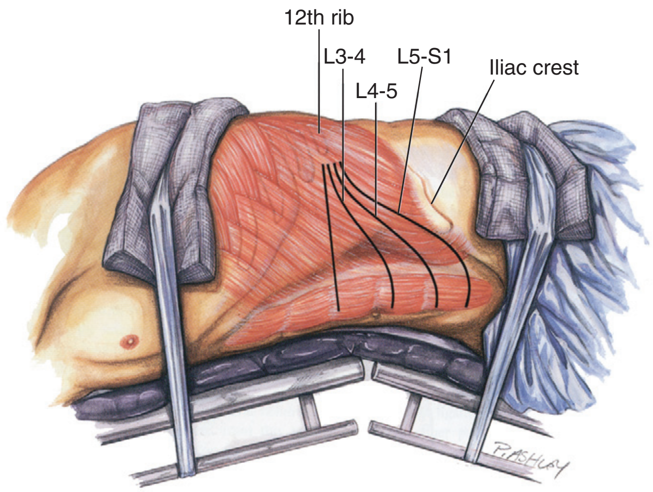

Figure 50-15 Skin incisions, depending on operative level, for the lateral decubitus approach. (From Adams P, Cotler H: Alternative anterior lumbar exposures. In Albert T, Balderston B, Northrup B, editors: *Surgical approaches to the spine.* Philadelphia, 1997, WB Saunders, pp 157–171.)

Next the dissection is carried down to the psoas muscle, which lies just lateral to the spine; care must be taken to isolate the genitofemoral nerve lying on the surface of the psoas (Fig. 50-16). Having identified the psoas muscle, retract the peritoneum and ureter medially as previously described.

RETROPERITONEAL DISSECTION. The surgeon can use a finger to palpate the vertebral bodies and disk spaces for orientation. Radiography should be used to confirm that the appropriate level has been identified. Typically, the L4–L5 disk space is isolated. Retroperitoneal dissection can proceed as previously described.

CLOSURE. Allow the peritoneal sac to fall into place. Close the layers of dissection as described previously.

COMPLICATIONS. Complications found in the flank approach are similar to those found in the anterior retroperitoneal approach. Attention should be paid during soft-tissue dissection to the inferior epigastric vessels, which lie lateral to the midline.

POSTERIOR APPROACHES TO THE LUMBOSACRAL JUNCTION

The posterior approach to the lumbosacral junction can be used to manage a wide variety of pathologies, including degenerative, traumatic, infectious, and neoplastic processes. The posterior approach is particularly advantageous in exposing the sacrum, because the ventral approach requires significant vascular retraction and, with appropriate lateral retraction of the thecal sack, the ventral sacrum is easily accessed posteriorly.[17]

The midline posterior approach is most commonly used because it is extensible and allows for cranial extension to the thoracic and even the cervical spine, and it also permits

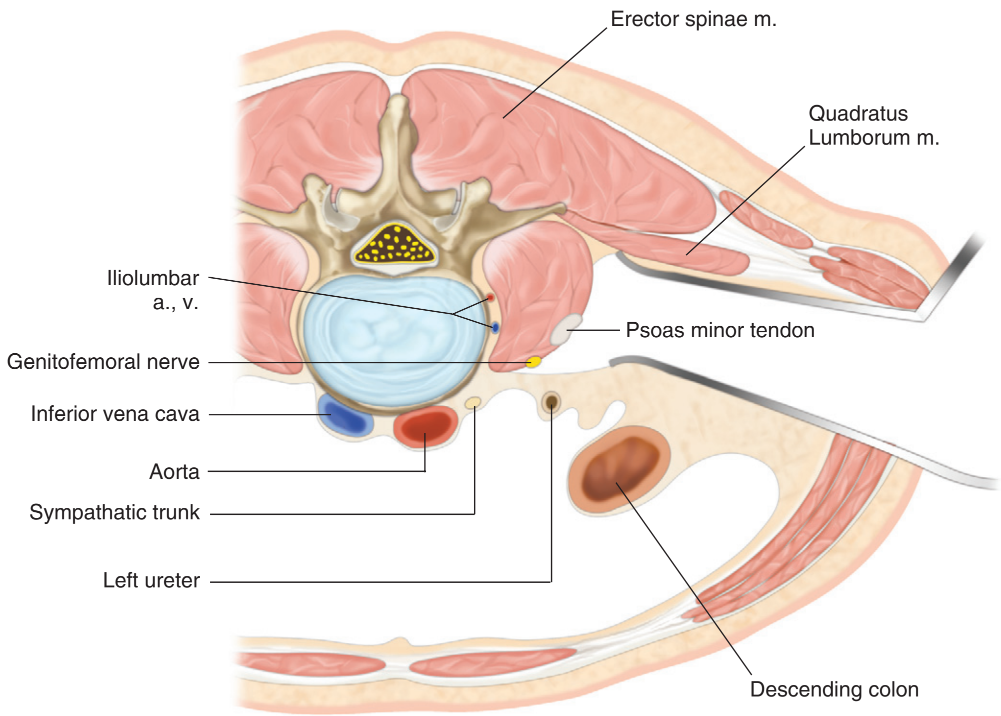

Figure 50-16 Retroperitoneal dissection to expose the psoas muscle and vertebral body.

caudal extension to the sacrum or, rarely, to the coccyx. Extension can be carried laterally to expose the iliac wing and sacroiliac joints.

The posterolateral or paramedian approach, which makes use of a longitudinal paraspinal incision, provides direct access to the transverse processes and the facet joints in the lumbar spine and in the lateral sacrum. This approach is often used in the lumbar spine for far-lateral disk herniations or posterolateral fusion of the transverse processes. In the sacrum, the posterolateral approach is useful for open reduction and internal fixation of vertical sacral fractures that pass through or are lateral to the sacral foramina. Posterolateral lumbosacral fusions are ideally suited to this approach; the transverse process may be removed, and the pedicle and vertebral body are exposed in a limited fashion. Wiltse and colleagues[18] argue that this approach allows for more direct access to the facets, less muscle mass requires medial retraction, and less operative hemorrhage is encountered. Direct plating of open sacral fractures can also be performed through this approach. Arguments against the posterolateral approach consider the difficulty of converting to an extensible midline approach in the lumbar spine.

Transverse incisions can also be used to expose the sacrum. As with the posterolateral approach, the incisions are not extensible but may be suited for reduction and fixation of transverse sacral fractures. Upward- and downward-arched incisions may also be used.

Posterior Positioning

If the surgical plan involves sacrectomy, the patient should receive thorough bowel preparation the day before surgery. The day of surgery, a small vaginal pad should be inserted lengthwise into the rectum.

Place the patient in the prone position; hip pads are placed just distal to the anterior superior iliac spine to avoid pressure on the lateral femoral cutaneous nerve. To decrease venous bleeding, ensure that the abdomen hangs free without pressure. In lumbosacral fusion cases, the lumbosacral junction should be positioned in extension to prevent flat back deformity and to approximate physiologic lordosis. To accentuate this extension, place billows or bolsters under the hips to make the sacrum the highest point on the patient. Before preparation, impermeable adhesive drape should be placed horizontally at the gluteal cleft to prevent fecal microbial contamination.

Posterior Incision: Midline, T-Shaped, Paramedian, or Transverse (Fig. 50-17)

Palpate the spinous processes of the lumbar spine and the midline ridge of the median sacral crest, then mark each process tip with a surgical marker. Connect the dots to create a longitudinal line. The extent of the marking and subsequent incision depend on the extent of surgery. The surgeon should always take care to preserve a fasciocutaneous soft tissue flap to ensure adequate blood supply and prevent necrosis. If the surgeon intends to carry the dissection laterally and expose sacroiliac joints or posterior ilium, the incision can be intersected at the level of the iliac crests to create a T-shaped incision.[19]

If sacrectomy or large tumor resection is planned, a midline longitudinal incision may be complicated by

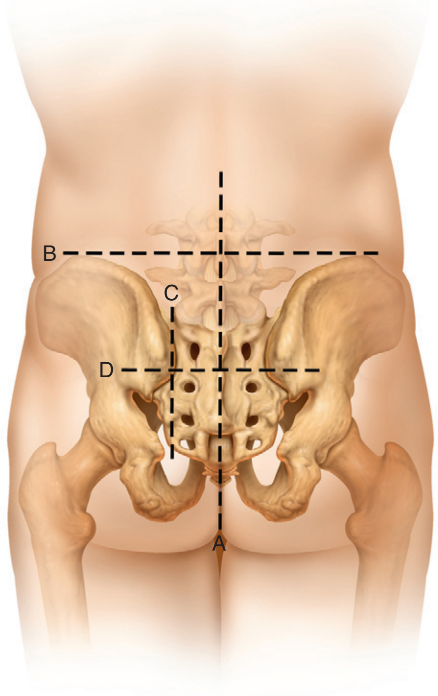

Figure 50-17 *A,* The midline incision is created along the spinous processes of the lower lumbar spine and the midline ridge of the median sacral crest. *B,* This incision can be crossed with a perpendicular incision at the level of the iliac crests to allow more lateral access. *C,* The paramedian incision is aligned with the posterior superior iliac crest. *D,* The location of the incision for a transverse approach is determined by the level of pathology.

inflammatory processes or wound dehiscence in the setting of a major soft tissue defect. Additionally, vertical incisions in extensive resections can injure the anal sphincter and limit lateral exposure of the sacrum. Sacral tumor surgery often requires the inclusion of a biopsy scar in the surgical incision, a process made more difficult with a traditional midline incision. For these reasons, T-shaped incisions may be more suitable for such cases.

Paramedian incisions can be made by palpating and making an incision on line with the posterior superior iliac crest. One variant popularized by Wiltse and colleagues[18] uses one or two incisions 5 cm lateral to the midline and medial to the posterior superior iliac spine. This incision, which can be deepened to the sacrospinalis muscle and the transverse process of the fifth lumbar vertebra, is useful in lumbosacral fusions, because iliac crest graft is easily obtained with the same exposure.

Transverse incisions are placed at the level of horizontal sacral fractures; these should be localized using intraoperative fluoroscopy. The lateral extent of the incision should also be marked using fluoroscopy, with care paid to avoid far-lateral incisions, which can damage the contents of the greater sciatic notch.

For midline incisions with only limited sacral exposure, self-retaining retractors are satisfactory. For more extensive sacral exposures, handheld retractors are more convenient, because they allow for more gentle retraction of skin flaps.

Posterior Midline Approach

Incise the skin and dermis with a scalpel, and use electrocautery to dissect subcutaneous fascia and deep paravertebral fascia. Be sure to recognize any spina bifida defects preoperatively to avoid unintended entrance into the spinal canal with the midline approach.

Once the deep lumbosacral fascia is exposed, the fascia on each side of the midline is incised at the fascia's adherence to the spinous processes. In the lumbar spine, the spinous processes are easily palpated, and the surgical plane is created with ease. However, in the sacrum, the spinous processes that coalesce into the median crest are small and difficult to palpate. Use the decussation of deep fascial fibers as a guide, and incise just lateral to the decussation. Paraspinal muscles can be elevated off the lumbar spine or sacral cortex using Cobb elevators.

To expose the sacral ala, extend the subperiosteal dissection along the superior border of the S1 lamina, where the superior articular process of S1 can be identified articulating with the inferior articular process of L5. Handheld retractors can be used to retract the paraspinal musculature later to this facet joint. Carry the dissection laterally to expose the inferior articular process, which rests contiguous with the posteromedial margin of the sacral ala. At these lateral reaches of the dissection, vigorous retraction may be required to expose the entirety of the sacral ala; Wiltse-Gelpi retractors may be useful in subsequently maintaining the exposure for the remainder of the procedure.

Dissection can be carried lateral to approach the dorsal sacral foramina, which contain many small epidural blood vessels and the segmental dorsal rami, both of which supply the overlying musculature and skin. The surgeon must take care to avoid entry into the sacral foramina, which can result in cauda equina injury or epidural bleeding (Fig. 50-18). Any bleeding in the foramina should be controlled meticulously with bipolar cautery.

Carrying the dissection laterally from the dorsal sacral foramina, the lateral sacral crest is first identified, followed by the posterior superior iliac spine (PSIS). If exposure is carried this far laterally, into zone 1, preservation of nerve branches exiting the dorsal foramina is difficult. Just inferior to the PSIS is the greater sciatic foramen, which contains, among other important structures, the superior gluteal artery and nerve, the inferior gluteal artery and nerve, the sciatic nerve, and the piriformis muscle. If dissection is carried this far distally and laterally, the utmost care must be taken to avoid damaging these structures.

In this area, the gluteus maximus muscle attaches to the lateral border of the sacrum via the posterior sacroiliac ligament. The sacroiliac and sacrotuberous ligament also insert on the lateral sacrum. If dissection requires division of these structures, this should be done as close to the sacrum as possible to allow their approximation before wound closure; failure to do this can lead to ventrodorsal postoperative wound problems.

Carrying the dissection distally at the midline, care must be taken to identify the midline sacral hiatus, through which the final sacral nerves exit. This opening contains no overlying bone, such that cavalier midline dissection in the region can lead the surgeon to dive into the hiatus and damage the exiting nerve roots (Fig. 50-19). Distal dissection can be carried all the way to the coccyx, which is invested with fascial attachments from the anal sphincter inferiorly and anteriorly.

Posterior Paramedian Approach

After incision passes through the subcutaneous tissue, repalpate the PSIS. The posterior sacroiliac will be appreciated extending from the PSIS to insert on the inferolateral sacrum, where it comingles with the sacrotuberous ligament.

Both the paraspinal musculature and the gluteus maximus insert on the posterior sacroiliac ligament: the paraspinal muscles insert on its medial aspect, the gluteus maximus on its lateral aspect; the surgeon should be able to appreciate the decussation of their respective fibers. The paraspinal insertion on the posterior sacroiliac ligament is dissected, the muscle is retracted medially, and the

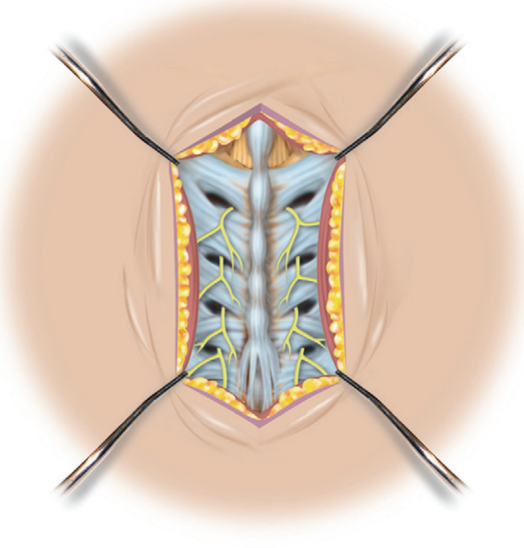

Figure 50-18 The exiting posterior branches of the dorsal sacral rami can be visualized lateral to the sacral foramina with dissection. Inadvertent entrance into the foramina with electrocautery or an instrument can lead to epidural bleeding or nerve injury.

Figure 50-19 With caudal exposure, the surgeon must be cognizant of the sacral hiatus, which is the most distal aspect of the spinal canal.

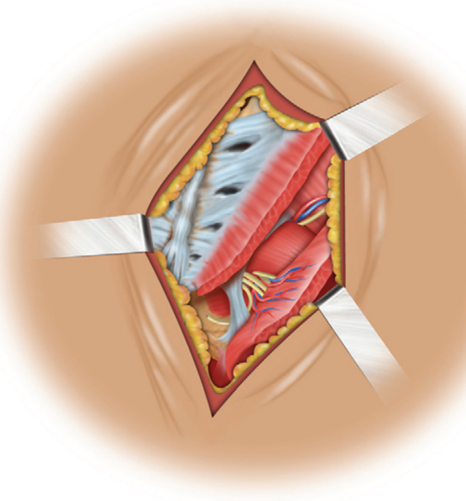

Figure 50-20 The paramedian approach allows more direct lateral exposure. After crossing the subcutaneous layer, the posterior superior iliac spine (PSIS) will be palpable. The posterior sacroiliac ligament extends from the PSIS toward the inferolateral pole of the sacrum and is confluent with the sacrotuberous ligament. Using this approach, the sacral foramina will be first encountered at their lateral aspects.

dissection proceeds toward the midline. In this dissection, the dorsal sacral foramina will be approached at their lateral margin; the same care must be taken during this paramedian approach as in the midline approach (Fig. 50-20).

Dissection can be carried toward the midline to expose the vertical line of the sacral fracture of interest. Further medial dissection is usually unnecessary.

Posterior Transverse Approach

Incision and subcutaneous dissection is carried to the deep lumbosacral fascia in the usual fashion. The deep fascia is incised longitudinally at the midline, and a periosteal dissection is carried laterally to expose the underlying transverse sacral fracture. In some cases, tears in overlying muscle or fascia secondary to the fracture in question will aid in exposure.

Bony Work and Tumor Resection

Further work upon completion of soft tissue exposure is dictated by pathology.

Closure

Self-retaining retractors should be released every 30 to 60 minutes to prevent muscle necrosis. Retractors are removed, and the wound is liberally irrigated with saline solution. The retractors are reinserted, and the wound, bony borders, and epidural regions are inspected to ensure meticulous hemostasis. Lumbosacral fascia should be closed in watertight fashion with interrupted absorbable figure-eight stitches. The deep subcutaneous fascia, dermal layer, and skin are closed in the usual fashion. Postoperatively, patients should be log-rolled from side to side every couple of hours to prevent skin breakdown in the sacral region.

Complications

Injury to the dorsal sacral rami is expected whenever sacral exposure is carried lateral to the dorsal sacral foramina. Sacral root injuries can occur within the canal in association with pedicle screw insertion, iliosacral screw insertion, or midline decompressive laminectomies. Cavalier exposure of the lateral sacrum can lead to damage of the contents of the greater sciatic foramen. Damage to the superior gluteal artery can result in intraoperative hemorrhage, and once transected, this artery typically retracts into the pelvis, such that emergent anterior exploration of the pelvis may be necessary to control the bleeding artery. Damage to the superior or inferior gluteal nerves can cause denervation of the gluteus muscles and result in difficulty with ambulation.

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51 Surgical Management of Sacral Fractures

USMAN ZAHIR and STEVEN C. LUDWIG

Overview

The surgical management of sacral fractures is challenging. Although they are rare injuries, they often present with a wide variety of injury and fracture patterns. Presentations vary from high-energy traumatic mechanisms to low-energy stress insufficiency fractures in elderly patients with osteoporosis. In the setting of trauma, sacral fractures often occur with pelvic and lower extremity fractures, with or without concomitant neurologic dysfunction.[1]

Sacral fractures occur in approximately 45% of pelvic injuries.[2] The treatment of sacral fractures is influenced not only by the many fracture patterns of the sacrum itself but also by injuries to the pelvis and lumbar spine. Late sequelae of untreated, unstable sacral fractures can lead to significant morbidity and dehabilitation.[3] In this chapter, we review the surgical management of a variety of sacral fractures, injury patterns, and outcomes.

Anatomy

The sacrum plays an integral role in lumbopelvic alignment and stability via strong osseous and ligamentous structures. In addition, the sacrum serves as a weight-bearing platform for the spine and protects the lumbosacral plexus. The sacrum has an overall kyphotic sagittal alignment, from zero to 90 degrees. In conjunction with the sacral inclination angle, this alignment helps determine the compensatory lordosis of the lumbar spine.[4]

The sacrum encases the cauda equina, which passes through the sacrum. Each of the sacral nerve roots passes through individual foramina. The average foraminal diameter increases moving caudally in the sacrum; this helps explain why foraminal entrapment is more common in the upper sacral nerve roots (S1 and S2) compared with the lower roots (S3 and S4).[1]

The anterior rami of sacral roots two through five provide parasympathetic innervation and allow for important bowel, bladder, and sexual function. Unilateral sacral root S2–S4 function is important for maintaining these functions. Bilateral nerve root involvement is more likely to cause neurologic dysfunction.[5,6] Sympathetic ganglia of the inferior hypogastric plexus extend anterolaterally from the L5 and S1 vertebral bodies to the anterior and medial margins of the foramina from S2 through S4. Posterior rami contribute sensory fibers to the cluneal nerves. In a study of 44 patients with sacral fractures, Gibbons[7] also noted that unilateral root injuries did not affect sphincter tone.

In contrast to the thicker, soft tissue structures in the lumbar spine, only a thin lumbosacral fascia and the multifidus muscles lie posterior to the sacrum. This thin, soft-tissue envelope does not provide the same level of coverage for spinal instrumentation as seen in the thoracolumbar spine.

Diagnosis

Initial assessment should include a history and physical examination, with particular emphasis on checking for neurologic deficits and associated soft tissue injuries. Sacral fractures are often missed in patients with multiple traumatic injuries. Denis and colleagues[1] showed that patients were more likely to be diagnosed with sacral fracture if an associated neurologic deficit was present. In their study, 51% of patients without neurologic deficit had sacral fracture correctly identified (76% of patients with neurologic deficit).

One factor that affects missed diagnoses is the difficulty in assessing sacral fractures with standard radiographs.[8,9] In most instances, a computed tomographic (CT) scan with coronal and sagittal reconstructions can help identify most patterns, in conjunction with any associated lumbar and pelvic ring injuries (Fig. 51-1). Magnetic resonance imaging (MRI) may help in cases of occult fractures. In the assessment of sacral fractures, attention should be directed to the level and type of sacral fracture, involvement of the lumbosacral junction and sacroiliac joint, and any pelvic ring injury.[10]

Patterns and associated pelvic CT views that are important in the diagnostic assessment of sacral fractures are listed below.[10]

- Axial CT view: anteroposterior (AP) sacral fracture displacement
- Coronal CT view: vertical sacral fracture displacement
- Sagittal CT view: AP translation and kyphotic angulation
- Axial, coronal, and sagittal CT views: degree of central canal involvement and foraminal encroachment

Classification: Sacral Fractures

Several classification systems are used to describe sacral fratures.[1,7,11] For the purposes of this chapter, the Denis

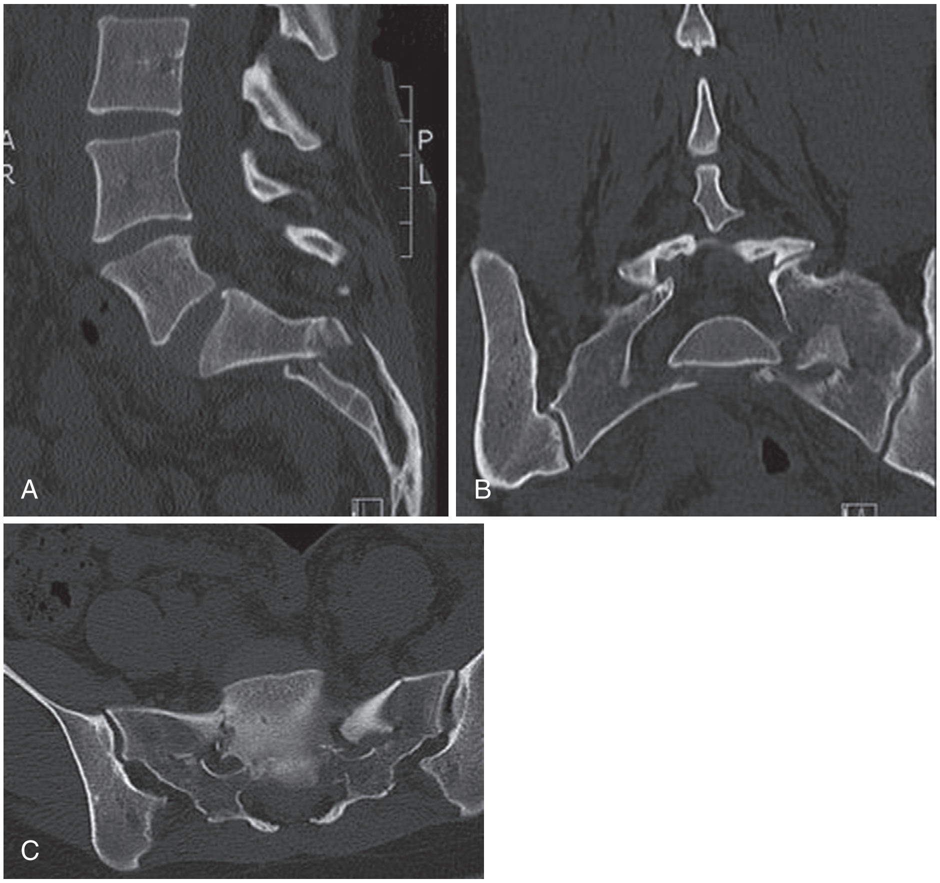

Figure 51-1 Radiographic assessment of a displaced transverse sacral fracture (T type). **A,** Sagittal reconstruction. **B,** Coronal reconstruction. **C,** Axial reconstruction.

classification system and subsequent subtypes are used and are shown in Figure 51-2.[1,12,13]

DENIS CLASSIFICATION

The Denis classification system (see Fig. 51-2) was developed after studying sacral anatomy in 39 cadaveric specimens in conjunction with a retrospective study of 236 patients with sacral fractures.[1] This retrospective multicenter study remains the largest study to date to assess sacral fractures. The Denis system is based on the direction, location, and level of the sacral fracture and is divided into three anatomic zones: zone 1 fractures are lateral to the neural foramen, zone 2 fractures involve the neural foramen, and zone 3 fractures are medial to the neural foramen. Fractures in zone 1 include the region of the ala and are reported to be the most common. In the multicenter study by Denis and colleagues,[1] approximately 50% of the fractures were zone 1 fractures. In 6% of the cases, zone 1 fractures resulted in neurologic injury to the lower lumbar nerve roots; zone 2 fractures involve the neuroforamina. In the study by Denis and colleagues, the zone 2 fracture pattern was the second most common pattern (34%), but it had a higher rate of associated neurologic injury (28%) that often involved the L4, S1, and S2 nerve roots. Zone 3 fracture patterns are those that affect the central sacral canal. In the study by Denis and colleagues,[1] zone 3 fractures were the least common (16%) but had the highest rates of associated neurologic injury (57%).

The Denis classification does not specifically include the level of the sacral fracture, which plays a significant role in neurologic function. Upper transverse fractures that involve S1–S3 have a greater likelihood of urologic dysfunction compared with lower transverse sacral fractures at S4–S5. One postmortem and pathoanatomic study showed the presence of transsected sacral nerve roots in 35% of displaced transverse sacral fractures.[14] Transverse fractures, discussed subsequently, are considered to be a subtype of Denis zone 3 injuries.

ROY-CAMILLE SUBCLASSIFICATION AND STRANGE-VOGNSEN AND LEBECH MODIFICATION

The Roy-Camille subclassification and subsequent modification by Strange-Vognsen and Lebech divides the Denis zone 3 category into transverse fracture types in the sagittal plane on the basis of angulation and displacement.[12,13] This classification is shown in Figure 51-2, *C*, and it categorizes injuries from the least severe (type 1), involving simple angulation, to the more severe patterns, with angulation and complete displacement (type 3). The type 4 pattern includes pure axial-loading injuries and was added by Strange-Vognsen and Lebech.

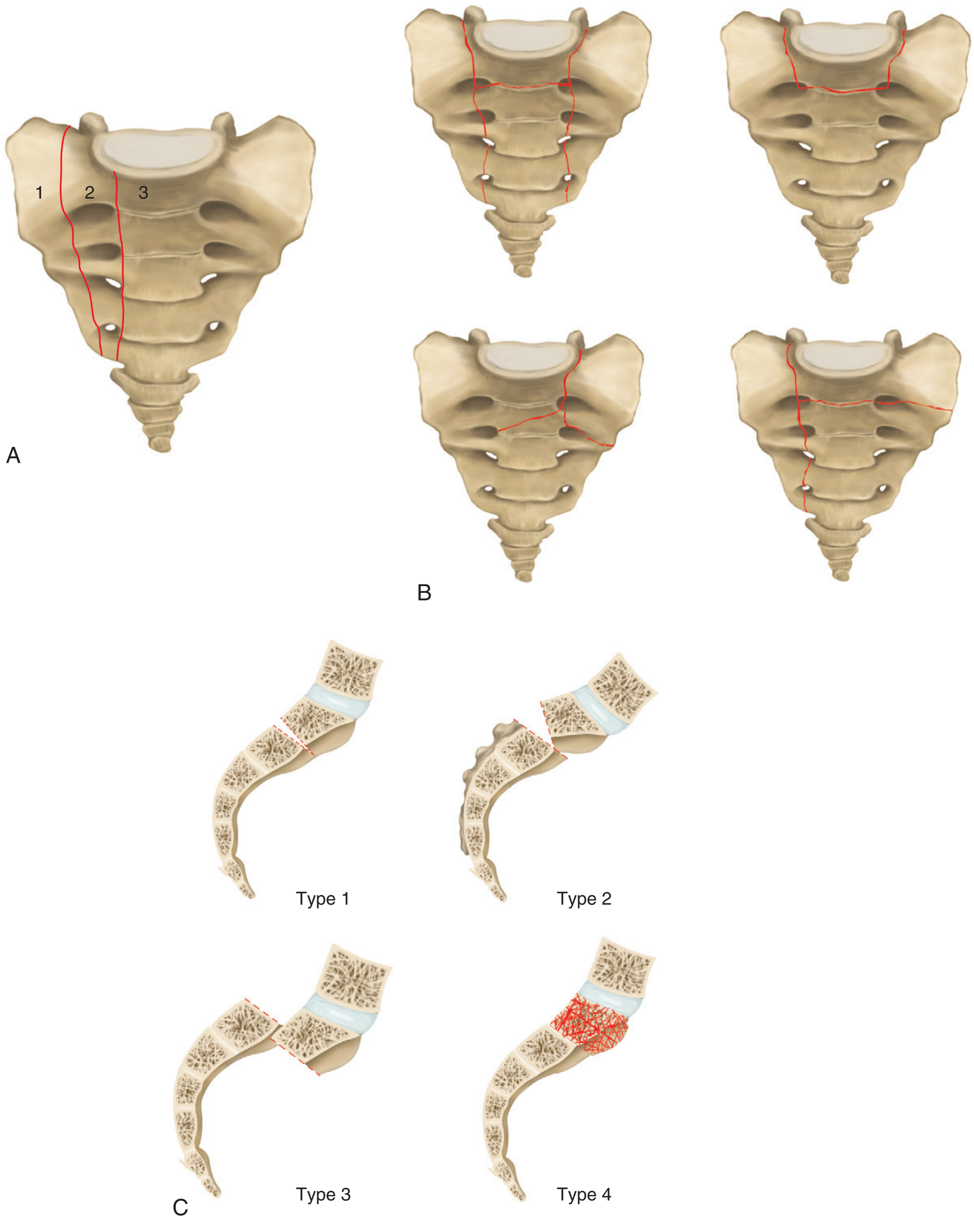

Figure 51-2 Classification of sacral fractures and associated subtypes. **A,** Denis three-zone classification system. Zone 1: fracture line is lateral to the neuroforamina. Zone 2: fracture line passes through the neuroforamina. Zone 3 includes injuries that extend into the spinal canal and any complex fracture patterns. **B,** Denis zone 3 complex fracture subtypes: H-type, U-type, λ-type, and T-type fracture patterns. **C,** Roy-Camille subclassification of Denis zone 3 fractures modified by Strange-Vognsen and Lebech.[1,12,13] Type 1 fractures are angulated but without translation. Type 2 fracture patterns are both angulated and translated. Type 3 injuries show complete translation and displacement. Type 4 injuries are comminuted fractures that occur secondary to axial compression. (Modified from Vaccaro AR, Kim DH, Brodke DS, et al: Diagnosis and management of sacral spine fractures. *Instr Course Lect* 53:375–385, 2004.)

- Type 1: Fractures that are angulated but without translation
- Type 2: Fracture patterns that are both angulated and translated
- Type 3: Injuries that show complete translation and displacement
- Type 4: Comminuted fractures secondary to axial compression

ISLER CLASSIFICATION OF LUMBOSACRAL INJURIES

Lumbosacral injuries usually are a result of high-energy trauma. Patterns may range from subluxation injuries to complete dissociation. Lumbosacral injuries should be considered in patients who come to medical attention with displaced transforaminal fractures, and patients should be evaluated with CT scans.[15] Isler[16] classified lumbosacral injuries (Fig. 51-3) on the basis of a major fracture line involving the lumbosacral junction in relation to the L5–S1 facet, thus potentially affecting lumbosacral stability. In this classification, type 1 fractures are lateral to the facet, type 2 fractures pass through the facet, and type 3 fractures are medial to the facet. Type 1 fractures are usually stable, but type 3 fractures are associated with instability and often necessitate operative intervention.

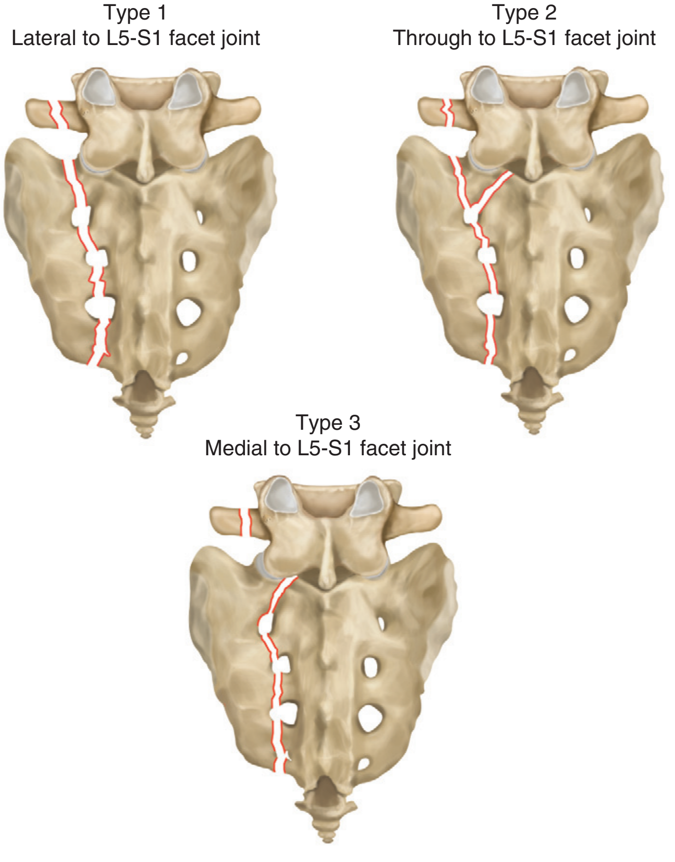

Figure 51-3 Isler classification of lumbosacral injuries. (Modified from Isler B: Lumbosacral lesions associated with pelvic ring injuries. *J Orthop Trauma* 4(1):1–6, 1990.)

Surgical Management

Treatment of sacral fractures should address mechanical instability and neurologic impairment. Although most sacral fractures can be treated nonoperatively, for unstable fracture patterns, several surgical options are available, the goals of which are to provide early mobilization and pain relief.[1] Broadly speaking, management consists of surgical stabilization and/or neural decompressive procedures (Table 51-1). Surgical treatment is usually performed in patients with unstable sacral fracture patterns, a concomitant pelvic ring injury, and/or neurologic dysfunction with radiographic evidence of compression (Fig. 51-4).[17] In certain cases, surgery may be considered for patients with multiple traumatic injuries, if surgery can assist with early rehabilitation. Goals of treatment include fracture stabilization and realignment, improved neurologic function, and reduction of morbidity.[17]

Surgical stabilization procedures (see Table 51-1) traditionally included open reduction and internal fixation with sacroiliac plating or bars.[18-21] Percutaneous iliosacral screw fixation and lumbopelvic stabilization are now more commonly used as surgical options.[22] In cases of neurologic compromise, the surgeon may perform a limited laminotomy/foraminotomy, laminectomy, or neurolysis as needed.

Because of the morbidity associated with anterior approaches, most surgical treatments for sacral fractures can be addressed via minimally invasive percutaneous or open posterior approaches. Pelvic ring injuries that have associated unstable sacral fractures should first have the anterior pelvic ring injury addressed surgically before embarking on posterior stabilization techniques (see Fig. 51-4).

SURGICAL TIMING

The timing of surgery in patients with sacral fractures is largely based on the patient's overall medical condition, associated extremity injuries, and soft tissue status. Delayed surgical stabilization may affect the surgeon's ability to obtain quality reduction. In cases of closed reduction and percutaneous fixation for pelvic ring disruptions, Routt and

Table 51-1 Surgical Management of Sacral Fractures

Surgical Goal	Surgical Procedure
Posterior stabilization	Open lumbopelvic segmental fixation Minimally invasive lumbopelvic stabilization Posterior tension band plate fixation Posterior alar plate fixation Iliosacral screw fixation
Neural decompression	Laminectomy Laminotomy Foraminotomy Lumbosacral neurolysis
Anterior sacral and pelvic stabilization	Anterior sacroiliac plate Anterior pelvic ring stabilization

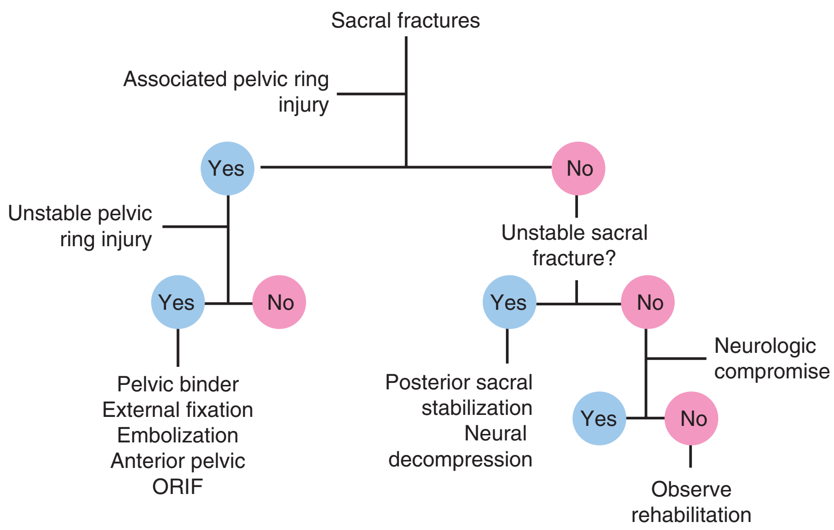

Figure 51-4 Sacral fracture management algorithm. ORIF, open reduction internal fixation. (Modified from Vaccaro AR, Kim DH, Brodke DS, et al: Diagnosis and management of sacral spine fractures. *Instr Course Lect* 53:375–385, 2004.)

colleagues[23] showed that delaying surgery for more than 5 days for unstable Denis zone 1 and 2 fractures resulted in less accurate closed reduction.

APPROACH TO SURGICAL STABILIZATION

Any pelvic ring injuries should be addressed before posterior sacral stabilization procedures are performed. Reduction of the sacroiliac joints is provided by anterior pelvic plating when needed. This also allows for stability when the patient is placed in the prone position for formal posterior sacral stabilization procedures. Once the pelvic ring is stabilized, deciding on the appropriate sacral stabilization procedure largely depends on the sacral fracture pattern.

Although posterior iliac screws can be useful in treating vertical sacral fractures and sacroiliac joint disruptions, they are less suitable for horizontal unstable sacral fracture patterns, which are more amenable to lumbopelvic stabilization. Open lumbopelvic stabilization allows for concomitant neural decompression in cases of nerve compression from bone impaction. Percutaneous sacroiliac screw fixation should not be performed if reduction is not achieved via closed means.

Use of isolated percutaneous sacroiliac fixation techniques in unstable sacral fractures may not effectively prevent the development of a kyphotic deformity alone. However, percutaneous sacroiliac screws placed in conjunction with lumbopelvic procedures for vertical unstable fractures may provide additional stability. This technique, described as *triangular osteosynthesis*, was studied by Schildhauer and colleagues.[24] The biomechanical study showed that for unstable transforaminal sacral fractures, triangular osteosynthesis provided greater stability than iliosacral screw constructs alone. In a retrospective study, this combined technique allowed for early weight bearing.[24] In a 1-year follow-up study of 58 vertically unstable transforaminal sacral fractures treated by this method, operative reduction was maintained at follow-up in 95% of patients.[25] Late complications noted were asymmetric L5 tilting and L5–S1 facet joint distraction. Sacral screw fixation and sacroiliac screw techniques are a focus of Chapters 53 and 54, respectively.

POSTERIOR STABILIZATION TECHNIQUES

Lumbopelvic Stabilization

Lumbopelvic stabilization is a treatment option for unstable injuries involving the sacrum. The goal is to transfer weight loads from the trunk to the iliac wings of the pelvis, thereby reducing the forces at the sacrum. Proximal stability is provided by pedicle screws into L5 and often into L4. This construct is linked distally to the sacrum via S1 screws. Two long iliac screws are placed into the pelvis between the posterior superior iliac spine (PSIS) and anterior superior iliac spine (ASIS) from posterior to anterior. Iliac screws help stabilize the lumbosacral segment relative to the pelvis. Cadaveric studies have shown superior biomechanical strength of lumbopelvic constructs compared with sacroiliac screw constructs.

Indications

- Sacral fractures in conjunction with unstable pelvic ring injuries
- Stable Denis zone 1, 2, and 3 injuries
- Unstable sacral fracture patterns
- Roy-Camille type 2, 3, and 4 injuries
- Sacral fractures in conjunction with lumbar spine fractures

Operative Setup and Equipment

- Position: prone on an Jackson table
- Neuromonitoring: somatosensory evoked potentials (SSEPs), electromyography (EMG)
- Equipment: fluoroscopy

Surgical Technique: Open Lumbopelvic Stabilization

- Surgical approach: A standard posterior midline incision is made from the distal lumbar spine to the sacrum, with lateral exposure of the transverse processes of L5 and L4. The sacral ala and PSIS are identified for S1 and iliac screw fixation, respectively.
- Pedicle screws, lumbar spine: Top-loading polyaxial screws are placed into L5; depending on the degree of sacral instability, they may also be placed into L4 for a stronger construct.

- Pedicle screws, sacrum: Top-loading polyaxial screws are placed into the sacral ala bilaterally.
- Iliosacral screws: C-arm fluoroscopy is placed for the obturator outlet view; the x-ray beam is perpendicular to the plane of the sacrum and is then tilted 35 degrees cephalad. The starting point should take into account the position of the L4–S1 screws, thus allowing ease of rod passage. To avoid neuroforaminal compromise, these screws are fully threaded transfixation screws and are not placed in compression. The longest possible screws are selected to allow for maximum purchase within the ilium (Fig. 51-5, *A*). Figure 51-5, *B*, shows an example of lumbopelvic fixation.
- Decompression: Sacral decompression can be performed in cases of neurologic compromise and in the presence of any evidence of impacted bone fragments in the sacrum affecting the lumbosacral nerve roots.
- Dural tear repair: Dural tears are repaired with 7-0 Gore-Tex suture.
- Figure 51-6 highlights lumbopelvic fixation in a case of T-type sacral fracture.
- Figure 51-7 highlights lumbopelvic fixation in a case of chronic unstable pelvic ring injury and posterior sacral nonunion.

Minimally Invasive Approaches. One of the limitations of open approaches to the sacrum is the limited soft tissue coverage, as previously noted. Percutaneous approaches may be used with the goal of reducing problems related to soft tissues.[26,27] Future studies will be needed to determine the effectiveness of minimally invasive approaches in reducing postoperative morbidity in the setting of sacral fractures.

Open Reduction Internal Fixation

Indications

- Unstable sacral fractures
- Sacral fractures in conjunction with unstable pelvic ring injuries
- Open sacral fractures
- Cauda equina syndrome

Percutaneous Sacroiliac Fixation

Indications

- Sacroiliac joint dislocations
- Sacral fractures in conjunction with unstable pelvic ring injuries
- Stable Denis zone 1, 2, and 3 and Roy-Camille type 1 injuries

Relative Contraindications

- Highly unstable Denis zone 2 fractures, vertical shear injuries
- Denis zone 3 and Roy-Camille type 2, 3, and 4 injuries
- Anomalous transitional lumbosacral anatomy (mainly an issue for percutaneous sacroiliac screw placement)
- Any failure of reduction by closed methods

Complications

- Poor biomechanical strength of sacroiliac screws that may result in instrumentation failure
- Failure to recognize a concomitant pelvic ring injury (anterior)
- Neurovascular injury with screw placement

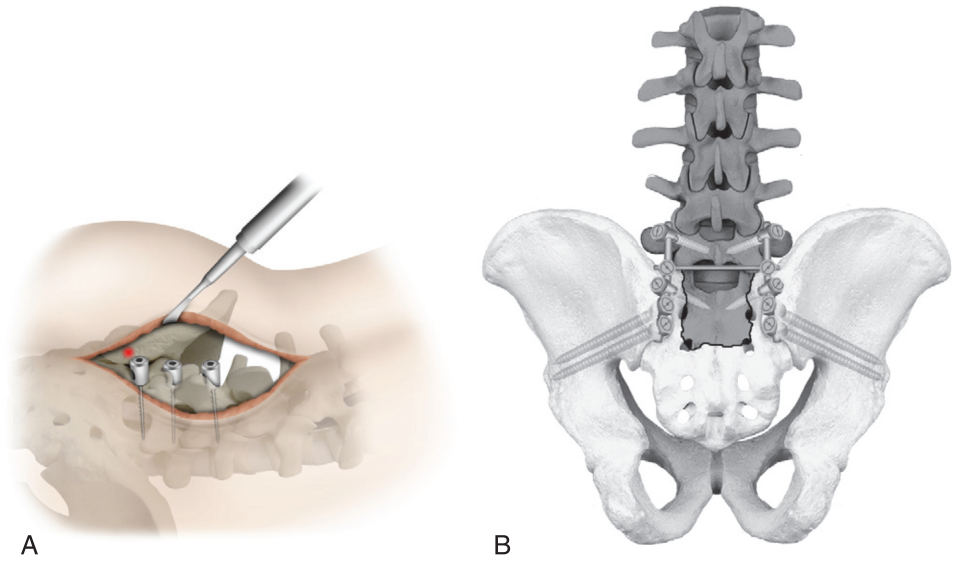

Figure 51-5 Lumbopelvic fixation. **A,** Screw trajectory into the ilium is performed under fluoroscopic guidance. The obturator outlet view is used with a starting point along the inferomedial aspect of the posterior superior iliac spine, aiming 1 cm above the iliac notch toward the anterior superior iliac spine. **B,** Lumbopelvic stabilization. (Modified from Vaccaro AR, Kim DH, Brodke DS, et al: Diagnosis and management of sacral spine fractures. *Instr Course Lect* 53:375–385, 2004.)

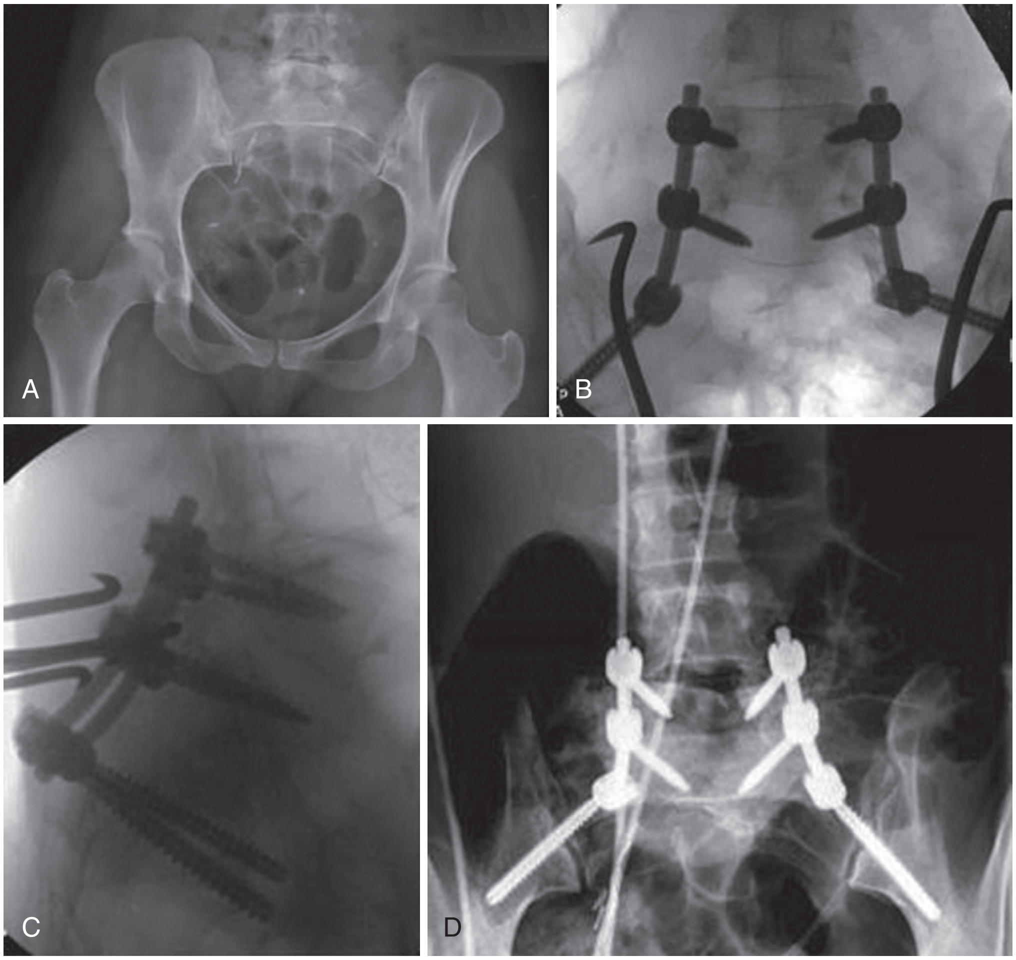

Figure 51-6 Comminuted T-type sacral fracture treated with lumbopelvic stabilization. A 30-year-old woman involved in a high-speed motor vehicle collision sustained a T-type sacral fracture with neurologic deficits affecting the right leg and also causing urinary incontinence. The patient underwent open S1, S2, and S3 laminectomies and a posterior L4–pelvis fixation. **A,** Anteroposterior (AP) view radiograph shows a T-type sacral fracture. **B,** AP view intraoperative fluoroscopic image of the final construct shows lumbopelvic fixation. **C,** Lateral view fluoroscopic image of the sacrum. **D,** Final upright AP radiograph of the lumbosacral spine.

Surgical Outcomes

The many overlapping treatment options that involve sacral fractures and the morbidity that results from a variety of neurologic injuries and associated pelvic ring injuries often render it difficult to compare surgical outcomes; however, retrospective studies in the past have shown improvement of neurologic function regardless of treatment.[1,7,8,22,24,28-31]

Neurologic presentation may range from radicular symptoms secondary to a single root injury to cauda equina syndrome.[29,32,33] Although early mobilization and pain relief are benefits that can be gained from surgical treatment, the role of early neural decompression in the surgical management of sacral fractures with bowel and bladder dysfunction is controversial.[7] Patients often experience improvement in neurologic function regardless of treatment; and in those who undergo decompression, it is unclear whether the improvement was a direct result of the decompression or part of the natural history of recovery.[34,35] Furthermore, patients who do not show improvement in neurologic function may have complete nerve root avulsions.[24] The conclusions from studies thus far are mixed.

Denis and colleagues[1] showed that delays in treatment of longer than 2 weeks resulted in neurologic compromise and overall poor outcomes. Patients with documented foot drop experienced worse results with nonoperative and/or delayed treatments. In another study, patients undergoing surgical decompression for neurologic deficits secondary to the sacral fracture experienced better neurologic improvement and physical function than did patients who were not managed with surgical decompression.[31] Taguchi and colleagues[29] noted a correlation between the displacement of the fracture and neurologic impairment and recommended early decompression and reduction in cases of vertical displacement of more than 1 cm. Although late decompression often did not improve neurologic outcomes, it was noted to have improved a case of chronic radiculopathy.

Other studies have not shown much benefit in neurologic recovery that affects bowel and bladder function. A retrospective study and literature review by Dussa and Soni[36]

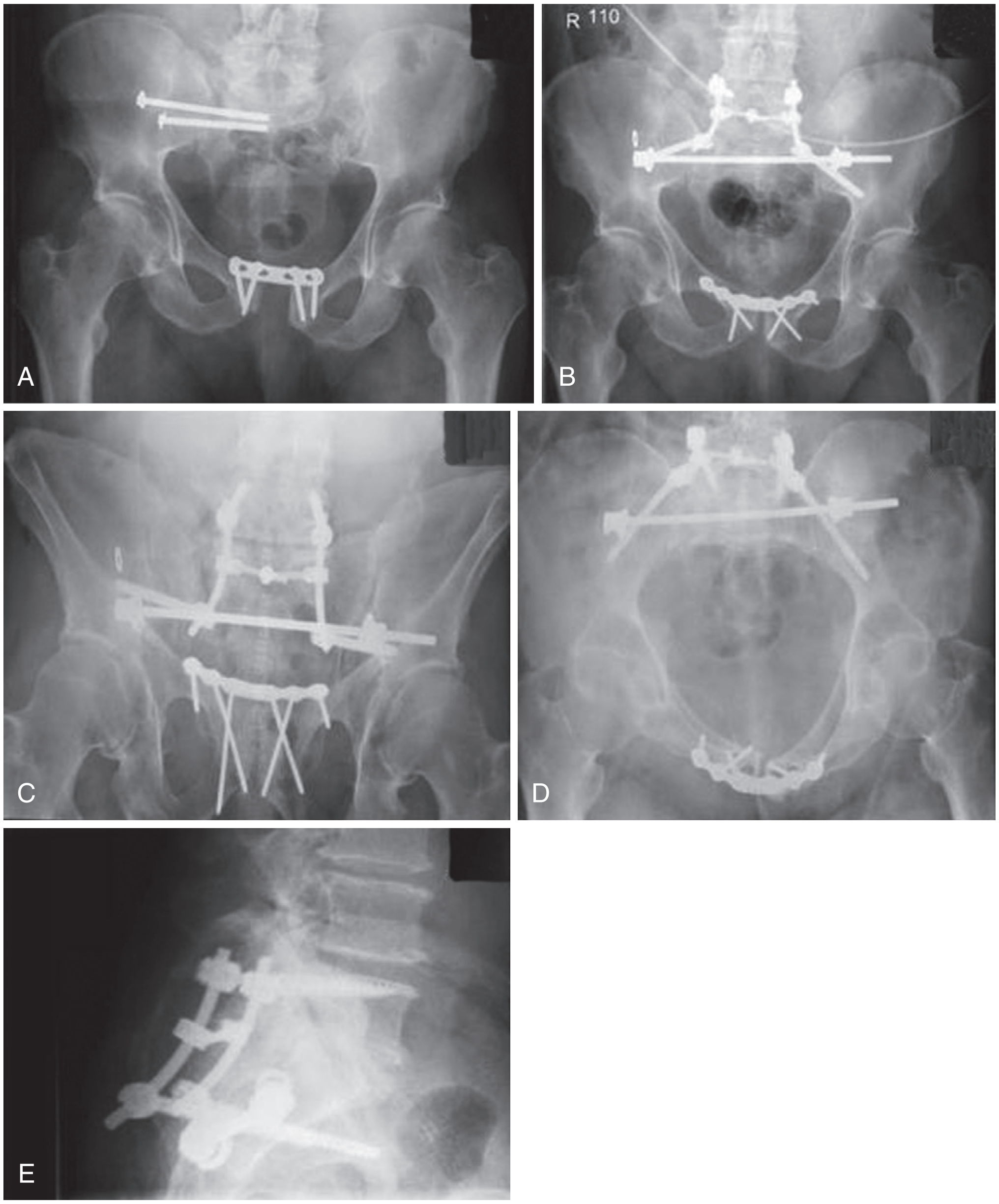

Figure 51-7 Triangular osteosynthesis. Patient came to medical attention with an unstable pelvic ring fracture malunion and posterior sacral nonunion 1 year after undergoing posterior sacroiliac fixation and anterior symphyseal plating. Patient subsequently underwent revision anterior open reduction and internal fixation, revision posterior sacroiliac bar fixation, and open lumbopelvic fixation. **A,** Preoperative anteroposterior (AP) radiograph of the pelvis shows pubic symphysis diastasis. **B,** Postoperative AP radiograph of the pelvis shows L5–pelvis fixation. **C,** Postoperative outlet view. **D,** Postoperative pelvic inlet view. **E,** Postoperative lateral radiograph of the lumbar spine.

showed no statistical evidence of a benefit from either surgical or conservative management on the outcome of bladder and bowel function. They noted that severe angulation, fracture displacement, and neurotomesis resulted in a poor prognosis. Adelved and colleagues[37] recently performed a prospective, longitudinal, single-cohort study of 28 patients with displaced sacral fractures treated with internal fixation to specifically examine long-term functional outcome. They noted that comparing outcomes at 1 year versus 10 years showed no changes in neurologic deficits and bowel function. Urinary and sexual functions, however, were noted to deteriorate with time. Although the literature is mixed, delayed treatment for neurologic injuries may be harder in the chronic setting secondary to scarring.

Complications

Potential complications associated with the surgical management of sacral fractures include infection, wound-healing problems, malreduction, loss of fixation, and persistent lumbopelvic pain.[28] In a retrospective study of 19 patients who underwent surgical treatment for sacral fractures and cauda equina syndrome, 31% had fractures of the connecting rods, 26% had wound-healing problems, and 16% had postoperative infections.[28] Schildhauer and colleagues[24] noted an infection rate of 5.9%, requiring irrigation and débridement and subsequent early instrumentation removal.

In cases of lumbopelvic fixation, much has been reported on prominent instrumentation related to the iliac screws. Sagi and colleagues[25] noted a need for subsequent surgery for prominent and painful instrumentation in all patients. In a study of seven patients who underwent triangular posterior osteosynthesis, Mouhsine and colleagues[30] noted that all patients complained of pain related to prominent iliac screws and required screw removal in all cases at an average of 4 months after surgery. Although not specifically related to sacral fractures, patients undergoing sacroiliac fixation in cases of long spinal deformity have also reported problems related to instrumentation prominence secondary to iliac fixation and loosening.[38]

Conclusions

The sacrum provides the structural foundation for the lumbar spine and the pelvic ring. The surgical management of sacral fractures traditionally consisted of iliac bars and plate fixation but has now evolved to include the use of iliosacral screws and lumbopelvic fixation.[18-21,37] The surgical approach used depends on, among other things, the fracture pattern, presence of neurologic injury, bone quality, associated pelvic ring injuries, and soft tissue considerations.

Sacral fractures are often overlooked and may be missed during the initial evaluation. For this reason, in addition to standard radiographs, CT scans of the lumbar spine and pelvis may help in the diagnosis and assessment of potential unstable fracture patterns. Although many sacral fractures can be treated nonoperatively, identifying unstable fracture patterns for surgical management may help avoid long-term morbidity and may help expedite rehabilitation. Despite treatment, chronic bowel or bladder dysfunction persists in many patients.

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52 Axial Lumbar Interbody Fusion

MATT LAFLEUR and VIKAS PATEL

Overview

Axial lumbar interbody fusion (AXIALIF) is a relatively new, minimally invasive approach to fusion of L5–S1 and L4–L5. This approach allows access to the disk space axially through the body of S1. By making use of this approach, the surgeon can avoid the morbidity usually associated with anterior or posterior approaches, including damage to paraspinal muscles and retraction of the thecal sac and nerve root; it also avoids risk to great vessels and risks of mobilization of the peritoneal contents. The tradeoff is that this approach exposes the patient to risk of rectal injury and presacral hematoma. AXIALIF also limits the surgeon's ability to completely visualize the disk space and may limit the ability to correct the deformity. Thus patients should be selected very carefully for this approach.

Anatomy Review

The relevant bony anatomy for axial interbody fusion includes the sacrum, coccyx, ilia, and the lowest two lumbar vertebrae. The anteriorly concave shape of the sacrum allows axial instrumentation to be placed across the L5–S1 and L4–L5 disks through the anterior cortex of the sacrum.

The ligamentous anatomy of the sacrum and ilia define the access point through the parietal pelvic fascia. The sacrospinous and sacrotuberous ligaments, along with the coccyx, define an arch caudal to the tip of the sacrum. Deep to this arch, the pubococcygeus and coccygeus muscles form a hiatus, which is exploited to gain entry into the pelvis in the presacral space. In this space, the presacral fat layer provides a plane of dissection between the rectum and the sacrum. The midline sacrum is relatively devoid of neurologic structures, however, if dissection is carried laterally, the sacral plexus and sacral nerve roots are encountered. The median sacral artery arises from the aorta above the bifurcation and can be found near the midline of the sacrum along with its associated venous plexus.

The approach to the S1–S2 junction for the AXIALIF procedure exploits the potential space of the presacral space. This space is bordered posteriorly by the parietal pelvic fascia covering the presacral vessels and sympathetic trunk and is bordered anteriorly by the fascia propria of the rectum. The space is contiguous with the retroperitoneum superiorly and is closed by the levator ani inferiorly. A recent anatomic study by Xiang and colleagues[1] confirmed the presence of a rectosacral fascia in 94% of specimens. This fascia arises from the parietal presacral fascia between S2 and S4 and runs anteroinferiorly to join with the fascia propria of the rectum; the rectosacral fascia divides the presacral space into superior and inferior presacral spaces. The authors of this study suggest that the rectosacral fascia be penetrated semisharply, because blunt dissection may rupture the rectum or presacral vessels. This study also divided the presacral space into five layers. From posterior to anterior they are the 1) sacral periosteum, 2) parietal presacral fascia, 3) rectosacral fascia, 4) autonomic nerve fascia, and 5) fascia propria of the rectum (Fig. 52-1). The plane of dissection should be between the parietal presacral fascia and rectosacral fascia inferiorly and the rectosacral fascia and autonomic nerve fascia superiorly.

Pelvic splanchnic nerves arise from the anterior roots of S2–S4, pass anterior to the parietal fascia at the lateral foramina, and run inferolaterally down the pelvic wall. These nerves join with the inferior hypogastric nerve to form the inferior hypogastric plexus, which is found approximately 1 cm from the midline of the sacrum. Branches from this plexus then run medially to enter the mesorectum. Anterior mobilization of the mesorectum is limited by the length of these branches to 19 to 25 mm. These nerves are the limits of safe surgical dissection and define a safe corridor of approximately 2 cm mediolateral and 4 cm anteroposterior.

The great vessels lie far outside the above mentioned corridor. The aorta consistently bifurcates above L5, and the iliac vessels are consistently lateral to the sacral foramina. The vascular structures of concern are the sacral vessels, middle and lateral, and the vessels of the hypogastric plexus. Straying posteriorly through the parietal fascia or laterally into the plexus can put these vessels at risk.

Indications and Contraindications

This technique is indicated for arthrodesis of the L5–S1 disk or L5–S1 and L4–L5 disks. The general indications for arthrodesis at these levels include pseudarthrosis, degenerative disk disease, and grade 1 or 2 spondylolisthesis. Additionally, AXIALIF is an interbody technique that must be supplemented with additional fixation, especially for rotational stability. There are no absolute indications for this procedure, although the implant is well suited to resist shear forces associated with spondylolisthesis after reduction. Relative indications include factors that make other approaches to fusion at this level difficult or impossible. These include:

- Previous anterior surgery, especially with significant scarring or adhesions, provided the presacral space has not been violated

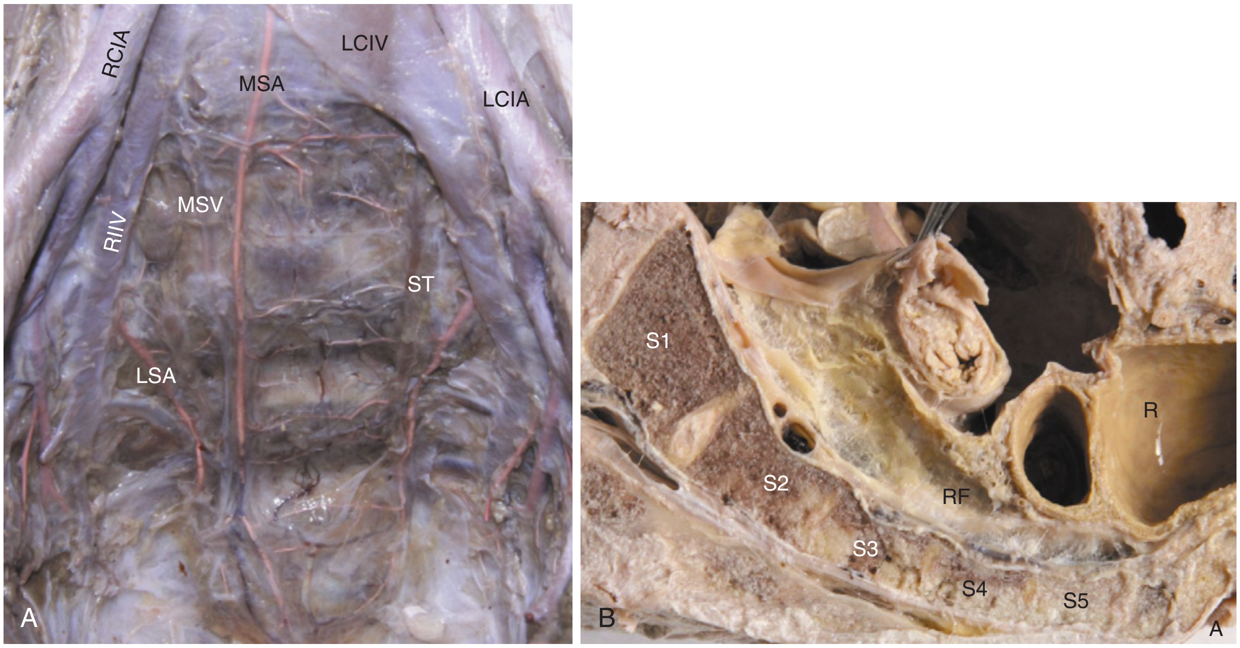

Figure 52-1 **A,** The presacral space: vascular and neurologic structures. LCIA, left common iliac artery; LCIV, left common iliac vein; LSA, lateral sacral artery; MSA, middle sacral artery; MSV, middle sacral vein; R, rectum; RCIA, right common iliac artery; RIIV, right internal iliac vein; ST, sympathetic trunk. **B,** Sagittal view of rectum (R) and rectosacral fascia (RF). (From Li XM, Zhang YS, Hou ZD, et al. The relevant anatomy of the approach for axial lumbar interbody fusion. *Spine*. 2012;37:266-271.)

Figure 52-2 Presacral scarring.

- Severe abdominal obesity
- Abnormal vascular anatomy precluding an anterior approach, as long as the anterior sacrum is free of such vessels

Contraindications to AXIALIF include:

- Previous presacral surgery with significant scarring or rectal adhesion to the sacrum (Fig. 52-2)
- History of pelvic radiation
- Inflammatory bowel disease
- Close approximation of rectum to sacrum on preoperative imaging (Fig. 52-3, *B*)
- Significant deformity of L5–S1 disk level
- Steep L5–S1 inclination or other lumbosacral anatomy that precludes safe screw placement
- Large middle sacral vessels (see Fig. 52-3)

Operative Technique

EQUIPMENT

- Jackson table with leg sling, which allows patient positioning with hips flexed and abdomen free of pressure
- C-arm fluoroscopy

PATIENT PREPARATION AND POSITIONING

Because this procedure is always combined with posterior instrumentation, the authors prefer to complete any decompression and/or reduction maneuvers before beginning AXIALIF. This optimizes positioning for screw placement and minimizes time spent in the prone position after violating the presacral space.

Before surgery, a complete bowel prep is mandatory to reduce risk of infection following a rectal injury. Preoperative imaging is critical for planning the trajectory and excluding contraindications to this procedure (Fig. 52-4). Pelvic magnetic resonance imaging (MRI) is useful to visualize the location of the vessels and bowel. Additionally, antibiotic prophylaxis should be given following the guidelines for elective intraperitoneal colon or rectal surgery. The patient should be positioned prone on a Jackson table with

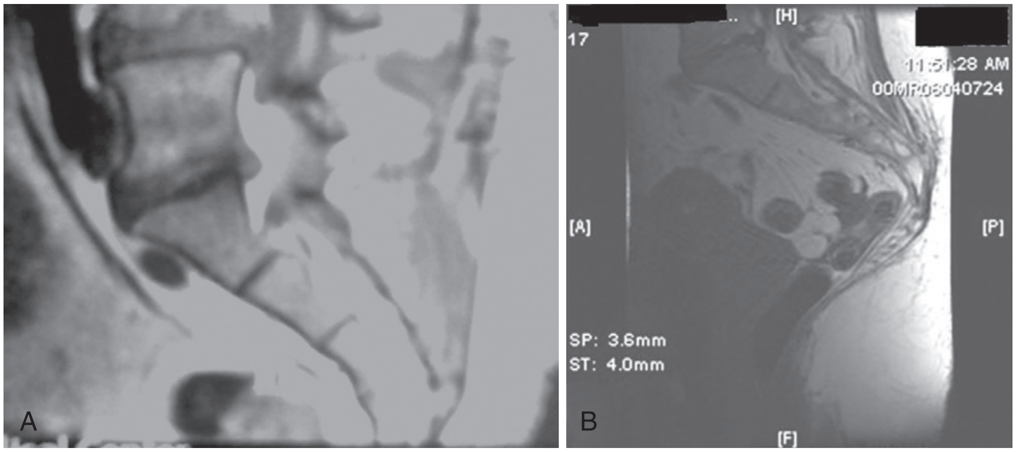

Figure 52-3 **A,** Large presacral vessel on magnetic resonance imaging. **B,** Bowel adherent to sacrum, large vessel.

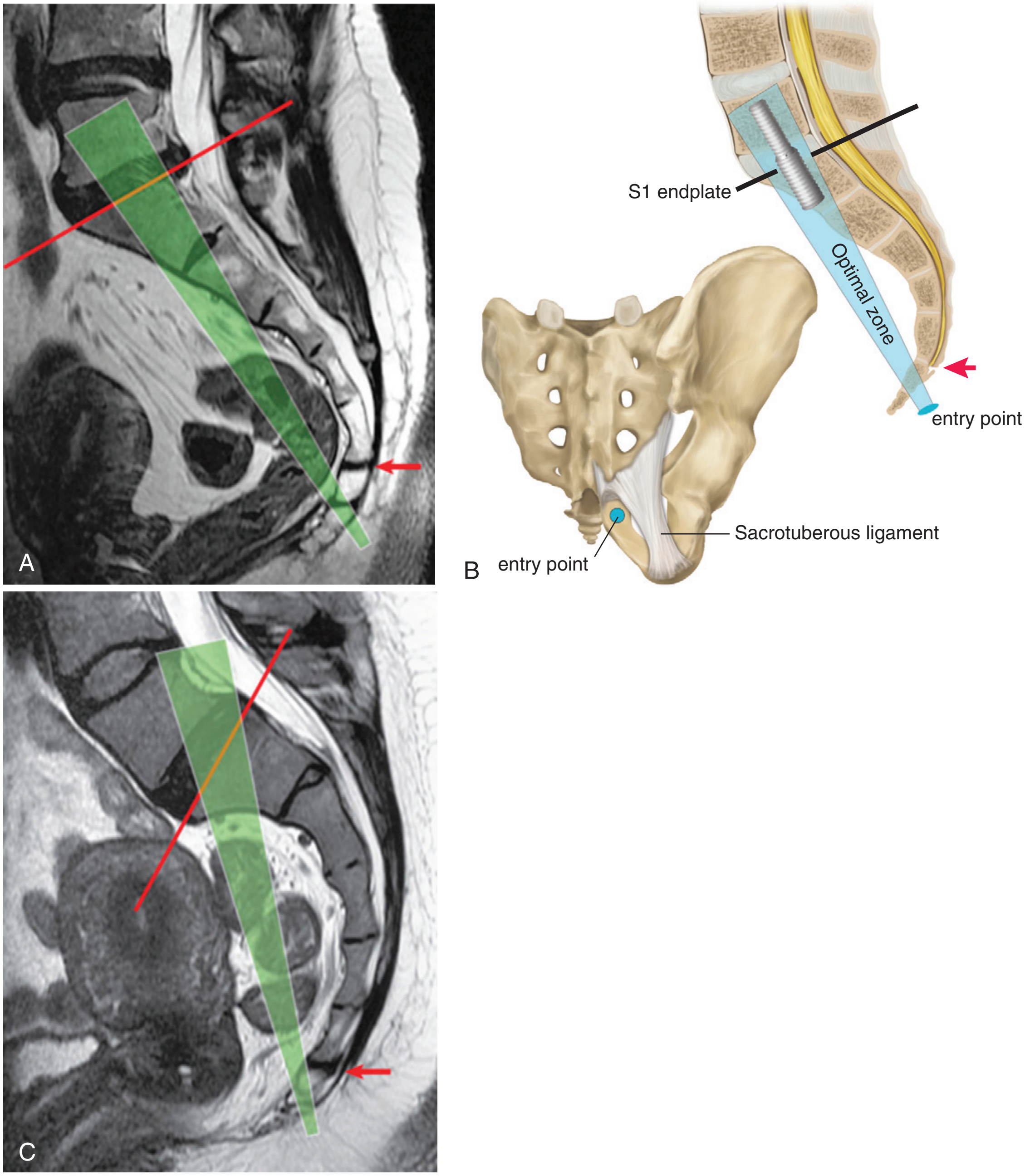

Figure 52-4 Preoperative trajectory planning using magnetic resonance imaging. **A,** Acceptable positioning. **B,** Ideal trajectory. **C,** Unacceptable trajectory.

the hips flexed to facilitate access to the presacral space. The leg sling on the Jackson table, set to the loosest setting, is suggested (Fig. 52-5). Placing the patient in Trendelenburg position can aid access. The anus should be isolated from the sterile field, and the field should allow visualization of the posterior inferior iliac spines and palpation of the ischial tuberosities and coccyx. Treat this procedure as completely separate from any subsequent fixation. We also prefer to scrub the surgical site with chlorhexidine gluconate or Betadine sponges before standard surgical preparation.

APPROACH

The arch created by the sacrotuberous ligament and coccyx is palpated. An incision large enough for the index finger is made 1 to 2 cm distal to the apex of this arch. The incision is oriented transversely beginning at the midline and extending laterally. Blunt dissection is carried out using a Kelly clamp to penetrate the parietal fascia of the pelvis. Dissection is generally anterocranial, aiming toward the midline at S1.

The parietal fascia is penetrated bluntly, and the presacral space is entered. Care should be taken not to penetrate too deeply at this point. The presacral fat and rectum are dissected off of the anterior border of the sacrum using the index finger. The finger is advanced by gently sweeping in the medial–lateral direction with gentle forward pressure. The peritoneum will be encountered at the junction of the rectum and sigmoid colon; this is reflected anteriorly using the finger-sweep method.

Once the peritoneum is released and is mobilized anteriorly, the blunt trocar (Fig. 52-6) can be carefully inserted under fluoroscopy to the anterior cortex of S1 (Figs. 52-7 and 52-8). Care should be taken to stay in the midline, because nerve plexus and vascular structures are located just medial to the sacral foramina. An appropriate starting point is selected in the midline of S1 that will allow a screw trajectory into L5 (and L4 if desired; Fig. 52-9). The blunt

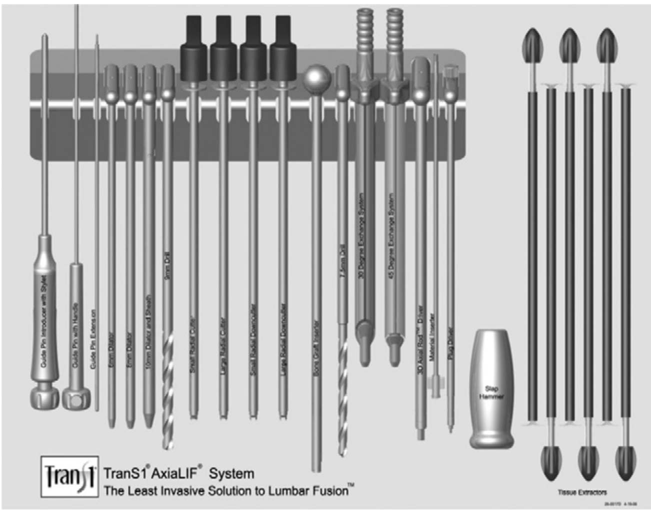

Figure 52-6 First-generation instrumentation.

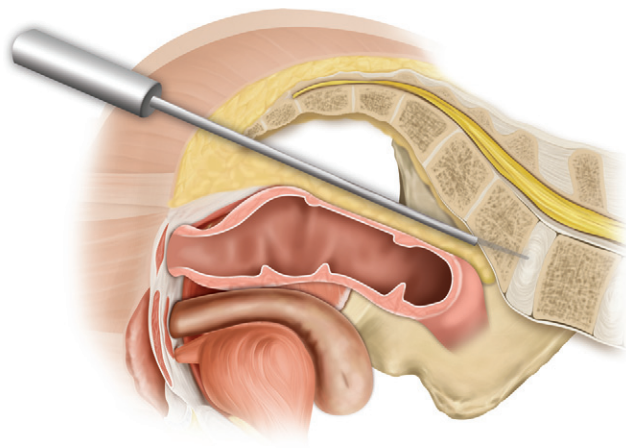

Figure 52-7 Dissection with blunt introducer.

Figure 52-5 Patient positioning.

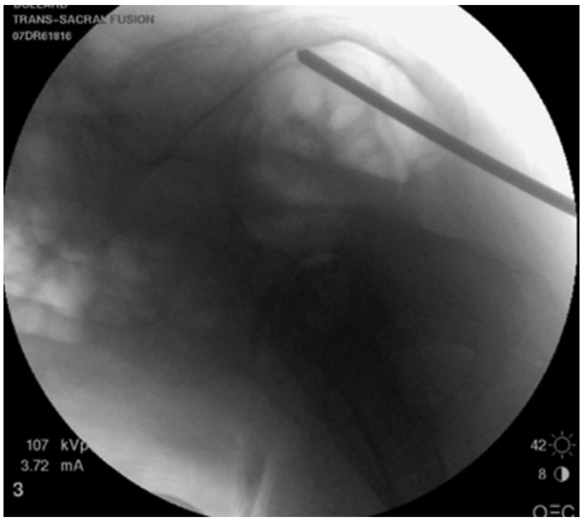

Figure 52-8 Fluoroscopic view of dissection with blunt introducer.

Figure 52-9 Intraoperative trajectory prediction.

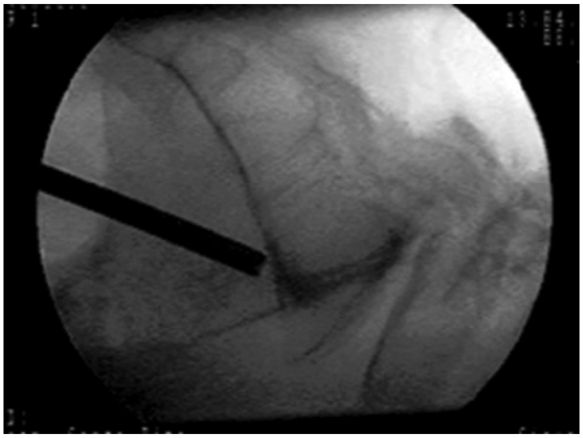

Figure 52-10 Working cannula placement.

trocar is placed solidly against the sacrum, and care is taken to ensure that no soft tissue is incarcerated between it and the bone. A dilator cannula is placed over the blunt guide pin, which is then exchanged for a sharp guide pin. The sharp guide pin is then advanced into the body of S1 and across the disk space into L5, confirming the trajectory with fluoroscopy (Fig. 52-10). Care must be taken during all instrument exchanges to avoid inadvertent removal of instruments, which may cause rectal injury.

Next, a series of dilators is introduced until a final working cannula is placed. The dilators and final cannula penetrate into the body of S1 to protect soft tissue from injury during drilling and diskectomy. Before placement of the final working cannula, the surgeon must again confirm that no soft tissue lies between the instrument and bone. Once the working cannula is secured, the sacrum is drilled up to the disk space, and the guide pin is removed. It is critical for the surgeon to ensure that the cannula is securely and firmly imbedded in sacral bone at all times.

TECHNIQUE OF DISKECTOMY

Diskectomy is performed through the working cannula by use of a nitinol diskectomy blade. This flexible, looped blade is advanced through the working cannula protected in its own sheath. Once the end of the sheath is confirmed in the disk space, the blade is deployed. The instrument is then rotated inside the disk space to cut the nucleus free from the annulus and end plates. Fluoroscopy is used to ensure that the blade remains contained in the disk space at all times. Care must be taken to ensure that the blade does not penetrate anteriorly or posteriorly, which risks injury to the great vessels or thecal sac. The blade is then resheathed and withdrawn.

Blades of various sizes, shapes, and angles are available to ensure adequate removal of disk and preparation of end plates, after which the extractor device is introduced, deployed, and rotated to collect nucleus material; this is repeated as necessary. The disk space can then be irrigated to remove any loose fragments, and bone graft can be introduced through a tube into the disk space.

SCREW PLACEMENT

A second cannula is inserted past the disk space to prevent disruption of the bone graft. The guidewire is reinserted and placed along the final path of the screw. L5 is then drilled, and a dilator is inserted to compact the cancellous bone. Leaving the guide pin in place, an exchange bushing is placed to allow exchange cannula placement. The exchange cannula is placed against the anterior sacral cortex and is secured with a mini K-wire. Implant selection is based on length measurement using the guidewire and fluoroscopy as well as the amount of disk space distraction desired. The screw is then introduced down the cannula and over the guide pin. The screw is advanced under fluoroscopy to ensure proper positioning and distraction of the disk space. The guide pin and exchange cannulas are then carefully removed.

TWO-LEVEL TECHNIQUE

The two-level technique is very similar to the single-level technique. The operation is carried out until bone graft is placed in the L5–S1 disk space. At this point, the dilator sheath is advanced into the L5 body to the end plate. The hand drill is then advanced through the dilator, through the L5 end plate, across the disk space, and into L4. The diskectomy and grafting are then carried out using the same technique as L5–S1. The implant length is measured using the manufacturer's instrumentation, and the screw is then assembled and placed (Figs. 52-11 and 52-12).

CLOSURE

The wound is irrigated copiously and inspected for any evidence of bowel perforation or excessive bleeding. The parietal fascia is made watertight using an absorbable stitch on a small ⅝ circle needle. The skin is closed with Dermabond or similar compound to seal it from contamination (Fig. 52-13).

Postoperative Care

An occlusive dressing is applied to protect the wound from contamination for 5 days. Standard postspinal fusion activity restrictions are recommended.

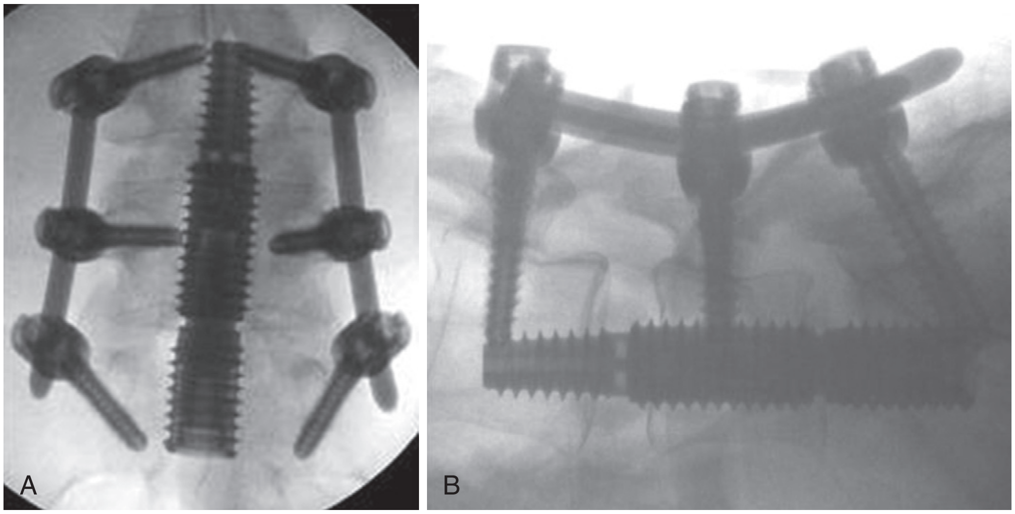

Figure 52-11 Two-level axial lumbar interbody fusion.

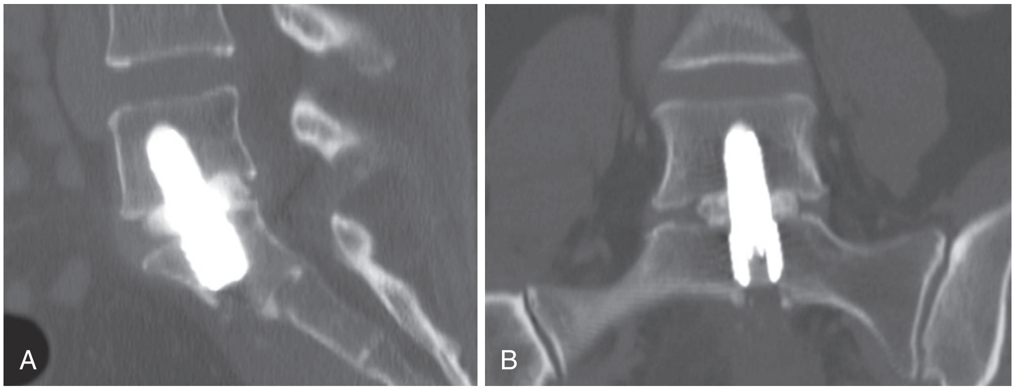

Figure 52-12 Postoperative sagittal and coronal computed tomographic images.

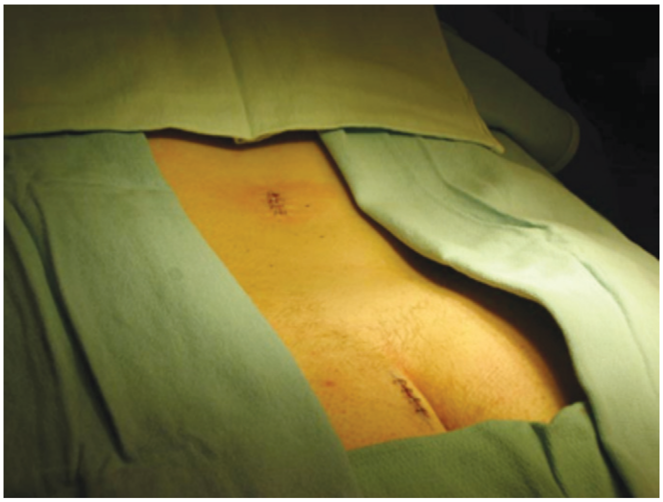

Figure 52-13 Closure.

Complications

Early clinical experience with this technique demonstrated a concerning number of both rectal injury and infection. Advances in technique, specifically careful blunt dissection of the presacral space, and advances in instrumentation have lessened this risk somewhat. The overall complication rates are reported to be from 1.3% to 26.5%.[2,3] This includes rectal and bowel injury, transient hypotension, infection, vascular injury, hematoma, sacral fracture, migration, subsidence, and ureter injury.

Injury to the rectum has been reported at a rate of 0.6% to 2.9%.[2,3] Any rectal injury mandates hospital admission, bowel rest, and serial imaging. High rectal injuries may require intraoperative repair. If the patient subsequently develops systemic symptoms, pelvic drainage and diverting colostomy are required.[5] Rectal injury is perhaps the most serious possible complication of this technique, and care should be taken to minimize the risk. Use of the finger-sweep method of dissection is recommended. Care should be taken when placing the access tube so that no soft tissue is incarcerated between the tube and sacrum, and the surgeon should be vigilant to ensure that no tissue slips out from the tube during the procedure.

Wound infection is another potentially serious complication when using this technique. The proximity of the wound to the anus raises concerns over postoperative fecal contamination of the wound. The rate of superficial infection with AXIALIF is reported at almost 6%.[3] Infections can be best avoided by meticulous tight wound closure and frequent, copious irrigation of the wound. Dermabond or similar skin closure may help avoid postoperative wound contamination; however, the surgeon should ensure that the wound is meticulously cleaned before sealing it. Patient education plays a major role in surgical outcomes, and proper wound care should be reinforced at every opportunity.

Injury to the presacral vessels can result in serious hematoma in the presacral space. The veins in this area lack valves and can contribute to significant hemorrhage. Additionally, traditional methods of control, such as electrocautery and packing, are not available through this approach. Blind application of a topical clotting agent through the cannula is appropriate in such cases. Also, positioning the patient supine in the Trendelenburg position can tamponade the bleeding. Postoperative monitoring of hemoglobin is mandatory, because this may be the only sign of occult bleeding. Pseudarthrosis is also a concern with this technique, because the surgeon cannot visually inspect the end plates to ensure proper preparation. Fusion rates are reported at 94%, which is similar to rates for anterior lumbar interbody fusion.[3,4]

Pearls and Pitfalls

1. Careful preoperative planning is mandatory to ensure that the presacral space is adequate. The surgeon must ensure that the trajectory from the starting point to the L5 body, or L4 body in two-level procedures, is possible.
2. Always include posterior instrumentation to control rotation.
3. The surgeon must become proficient at the L5–S1 technique before attempting the two-level technique.
4. Reduce spondylolisthesis if indicated before interbody graft placement.

   At the time of publication of this chapter, third-generation instrumentation for presacral access was in development. This will likely improve the ease and safety of the access.

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53 Sacral Screw Fixation and Plating Techniques

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Overview

As the terminal segment of the spine, the sacrum is subjected to substantial forces as it transmits axial loads from the lumbar spine to the adjacent ilia via the sacroiliac joints. This relationship leads to several pathologies that are specific to the sacrum, in addition to the extra demands applied as a consequence of surgical treatments. Fixation into the sacrum remains somewhat more challenging than other regions of the caudal spine. The remnant vertebral bodies of the sacrum are relatively small, and the cancellous bone quality is often poor. This leaves comparatively little bone for fixation, and generally only the S1 and S2 segments are amenable to screw placement. Additionally, the sacral instrumentation may be the most distal fixation for long constructs that span the entire thoracolumbar spine, which places great strain upon these two or four screws. These factors have led to the routine use of supplemental iliac bolts to prevent both failure of sacral fixation and sacral insufficiency fractures. In spite of these limitations for fixating to the sacrum, numerous options include pedicle screws, alar screws, posterior sacral plates, and screws combined with intrasacral rods.

Historical Background

Although internal fixation for lumbosacral fusion was described as early as the 1940s, effective sacral fixation involves relatively new technology. In 1948 King described the use of bilateral facet screws for lumbosacral fusions, which allowed early mobilization.[1] These screws were not widely adopted in part because there was a high incidence of early failure and pseudarthrosis.[2]

The first commonly used form of spinal internal fixation was the Harrington rod, used for fusions to the sacrum on many occasions; but fusing to the sacrum proved difficult. The bone of the S1 lamina is thin, and often it would not support a Harrington hook, plus there were concerns of S2 nerve root irritation from the tip of the laminar hooks.[3] This limited fixation led to the development of the Harrington sacral bar, effectively the first iliac bolt. These Harrington bars were transiliac rods that bridged across the posterior superior iliac spine and gave a strong foundation for Harrington constructs to the sacrum.[4] Such bar constructs had much better purchase in bone but also had many limitations: they were prone to migration over time and required a separate skin incision, which often resulted in wound complications. Furthermore, they could freely rotate in the ilium and did little to resist flexion and extension movements.[5] Additionally, long fusions to the sacrum that used this distraction instrumentation system had a pseudarthrosis rate that approached 40%, and it flattened the patient's lumbar lordosis, leading to the now well-known flat back syndrome.[6,7] Because of these limitations, most surgeons strongly avoided long fusions to the sacrum, and short lumbosacral fusions were often not instrumented. The Harrington system was later modified to allow some rod contouring and angling of the distal hook to allow for lumbar lordosis. This helped, but loss of lumbar lordosis was still the norm, and flat back syndrome remained a common occurrence.[8]

Anterior fixation also proved more challenging within the lumbar spine. Dwyer instrumentation was developed and implemented in the late1960s, followed by Zielke instrumentation in the 1970s, principally for lumbar deformity correction and to aid arthrodesis for long fusions.[9,10] These anterior instrumentation systems were effective and rapidly grew in popularity for lumbar deformity, although early series showed loss of lumbar lordosis as a common occurrence. However, the shape of the sacrum and the position of the iliac crest precluded extension of these systems past the lumbosacral junction. Some authors attempted hybrid implant systems, using Zielke or Dwyer instrumentation in the lumbar spine, with anterior lumbar interbody fusion (ALIF) at L5-S1, and applying an anterior staple across the lumbosacral junction.[11] These early staples were conceptually similar to modern anterior lumbosacral plating systems, but they lacked threads or tines and were easily displaced and often migrated. They also were not rigid, therefore they did not provide much stability. Pseudarthrosis was common.

The 1970s saw the first widespread interest in the treatment of spinal stenosis, first described by Verbiest in 1951. Many spine surgeons appreciated the need for concomitant arthrodesis in addition to multilevel decompressions for stenosis.[12] With few fixation options available, surgeons experimented with both Harrington rods and Knodt rods to stabilize decompressions and fusions.[13,14] These implants were not well suited to the task. First, both were distraction systems that typically flattened the normal lumbar lordosis. Second, both systems relied on hooks and supplemental use of sublaminar wires, but with loss of the posterior elements for the decompression, there was no place to apply these hooks or wires; this meant surgeons had to instrument an unaffected vertebra above the decompression.[15] Distal fixation often consisted of supralaminar hooks applied to S1 or hooks tamped into the ala. Supplemental wires could be placed around the S1 or S2 laminae via small drill holes or through the dorsal sacral foramina. Again, implant dislodgement, breakage, and pseudarthrosis were very common.

Effective sacral fixation was not available until the advent of pedicle screws. Roy-Camille was among the first to experiment with the concept of screw-and-plate constructs, and Harrington began using L5 lag screws fixed with wire to a Harrington distraction rod for treating severe spondylolisthesis.[16,17] It would take another two decades before such devices saw widespread use and were popularized in the United States by the work of Arthur Steffee, mostly during the 1980s.[18] Pedicle screws offered the first effective means of capturing quality bone in the sacral bodies via posterior instrumentation; these delivered much more robust fixation than prior hook or wire constructs, and they allowed for multiaxial control for reduction of deformity and maintenance of normal sagittal contours.[19]

The S1 screw is still the only pedicle screw that is amenable to routine bicortical purchase, which greatly enhances pullout strength. However, in spite of the benefits of bicortical purchase, S1 screws are often a weak link in a lumbosacral construct. Much of this is due to sacral anatomy, because the cancellous bone is not dense, and the cortex is often rather thin. The S1 pedicles are usually quite large relative to the lumbar pedicles, and overall screw purchase is often less than lumbar pedicle screws. These weaknesses have led to several additions to enhance S1 screws. These include sacral plates (Chopin plate, Colorado system), S2 alar screws, Jackson intrasacral rods, and routine use of anterior column support and supplemental iliac screws for long fusions to the sacrum (more than three levels).

Sacral Anatomy

The sacrum is a physiologically and anatomically unique component of the axial skeleton. It functions to transmit forces from the mobile spine to the adjacent ilia to convert compressive forces from the lumbar spine to shear forces at the sacroiliac joints. Functionally the sacrum serves as a bipod with forces entering at the sacral promontory, bifurcating, and exiting through the alae and sacroiliac joints. This unique function necessitates unique anatomy. As a result, the sacral promontory and alae must withstand significant stress, and this drives the bony architecture of the sacrum on both a macroanatomic and microanatomic level.

The surface anatomy of the sacrum is unique, and it demonstrates the remnants of key vertebral features from the cephalad spine. It is formed by the fusion of five sacral vertebrae that retain many homologous features of the mobile spine but also exhibit features unique to sacral vertebrae (Fig. 53-1).

The bodies of the sacral vertebrae are highly tapered and rapidly decrease in cross-sectional area, from cranial to caudal. Although the average anteroposterior (AP) length of the S1 body is 50 mm for men and 47 mm for women, at S2 this figure decreases dramatically, to 31 mm for men and 28 mm for women.[20] Sacral vertebrae are also larger in the coronal than in the sagittal plane and have relatively small bodies.

The anterior costal and posterior transverse processes of S1–S3 are very large and broad, fusing to form the paired alae, which contain some of the denser bone found within the sacrum. Because of the fusion of the anterior and transverse processes, each sacral level must contain two foramina to transmit both the ventral and dorsal primary spinal rami. The ventral foramina are much larger, because they convey the substantial root contributions of the sciatic nerve. The comparatively small dorsal roots are accompanied by branches of the sinuvertebral artery and can be a source of brisk bleeding during dissection.

In spite of the substantial forces transmitted through the sacrum, much of the sacral cancellous bone is of low density and poor quality. This is consistent with the bipod-like function of the sacrum, because the densest bone is found within the sacral promontory and paired alae, but the remainder of the sacrum has poor quality bone, because it is functionally shielded from stress.

Anterior to the sacrum lie many important visceral structures that include the paired common and internal iliac arteries and veins, paired L5 nerve roots, sigmoid colon, middle sacral artery, and sympathetic plexus. All of these structures may be subject to risk during approaches to and surgical instrumentation of the lumbosacral junction. The safest region of the anterior sacrum is the paracentral portion of the S1 body; the vascular structures bifurcate above the S1 body and trace laterally, traversing far from the midline at the level of S1. The L5 nerve roots also course laterally and lie at the junction of the S1 vertebral body and ala. The only midline structure is the middle sacral artery, which lies directly on the midline of the anterior sacrum. With this in mind, the safest location for implants that exit the anterior aspect of the sacrum is just lateral to the midline within the S1 body. Implants that exit the cortex within the ala place the neurovascular structures at much greater risk. S1 screws are the safest of the bicortical implants, because their tips should lie within the medial aspect of the S1 body (Fig. 53-2).

Sacral Biomechanics

Several important biomechanical principals drive the choice of sacral fixation, especially for long fusions. One of the most important is the concept of the *lumbosacral pivot point*, described by McCord and colleagues.[21] Centered within the posterior longitudinal ligament at the level of the L5–S1 disk space, it is a powerful predictor of the efficacy of lumbosacral fixation. As an implant extends further anteriorly from the lumbosacral pivot point, it will provide more construct stiffness and will support a higher load to failure. Implants that remain posterior to the lumbosacral pivot point impart little additional stability; those that extend far anterior, such as iliac bolts, impart substantial biomechanical benefits.

Due to the normal anatomic relation of the sacrum to the lumbar spine in an ambulatory adult, a typical S2 pedicle screw will not extend anterior to the lumbosacral pivot point, whereas an S2 alar screw does extend anterior and is biomechanically preferred. Among the common implants and techniques available for sacral fixation, only S1 pedicle

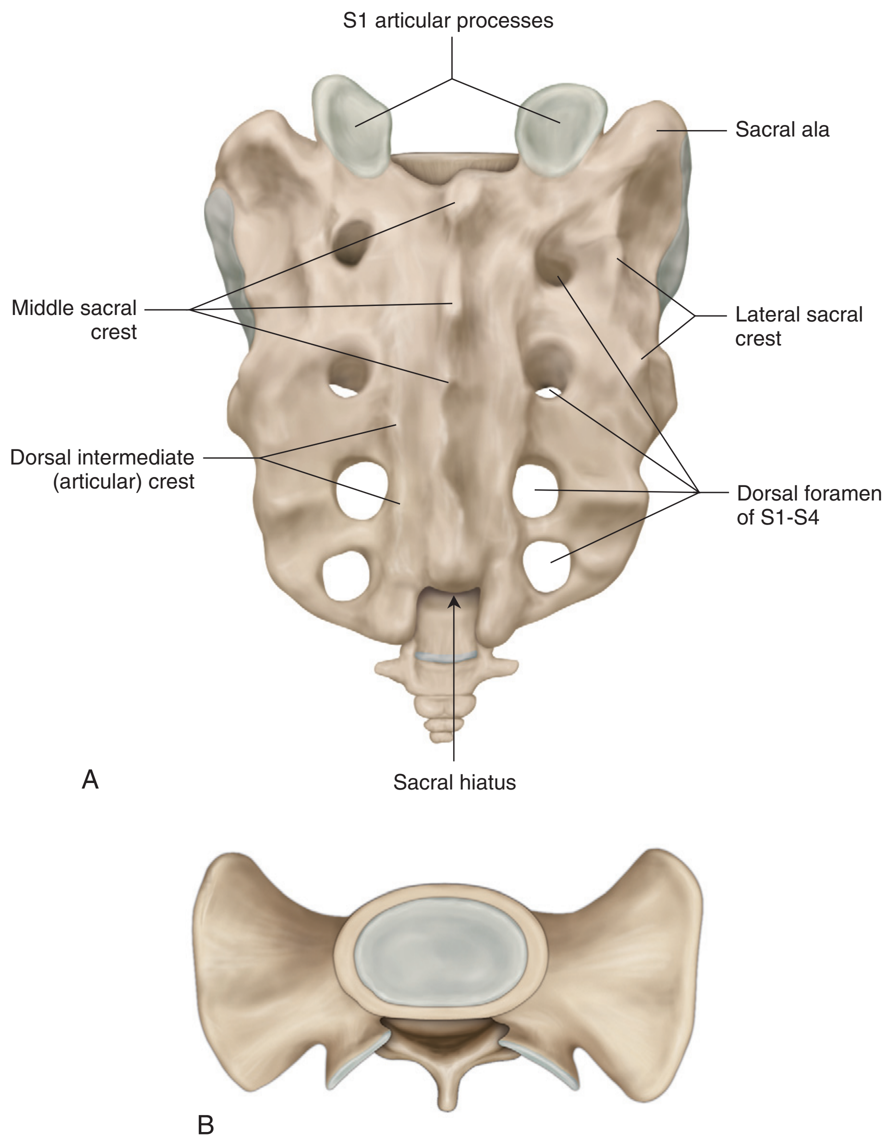


Figure 53-1 Key bony landmarks of the dorsal surface of the sacrum.

screws, S2 alar screws, and iliac bolts will reach or extend anterior to the lumbosacral pivot point.

Triangulation of implants dramatically increases the pullout strength of a construct. Ruland and colleagues[22] found that medially directed and crosslinked S1 pedicle screws outperformed either hooks or stand-alone pedicle screws. This reinforces to the biomechanical benefits of the medial S1 pedicle screw over alar screws or sacral hook constructs.

S1 Pedicle Screws

Pedicle screws placed into the S1 vertebra remain the mainstay of direct sacral fixation in modern spine surgery. The technique for placement is familiar to the majority of spine surgeons, and the quality of fixation is quite good if placed properly; it harmoniously integrates with posterior instrumentation of the lumbar spine, provides direct sacral fixation, and is relatively safe.

Several important details are required for placing S1 screws properly for both maximum fixation and safety. Placement of S1 screws is much like placement of lumbar pedicle screws, but a few anatomic factors can make placing an ideal S1 pedicle screw more difficult than screws at more cranial levels. The wide interpedicular distance at S1 and the need to medialize the tip of the screw to capture the dense bone of the promontory both necessitate a very medial projection of the S1 screw. However, the iliac crest can block the ideal path for the screw, especially in men with large iliac crests (Fig. 53-3 and 53-4).

INDICATIONS FOR S1 PEDICLE SCREWS

- Arthrodesis for L5–S1 spondylolisthesis
- Reduction of L5–S1 spondylolisthesis
- Arthrodesis for degeneration of L5–S1 disk and facets
- Spinal deformities that require fusion to the sacrum
- Supplemental fixation for ALIF or anterior resections for tumor or infection

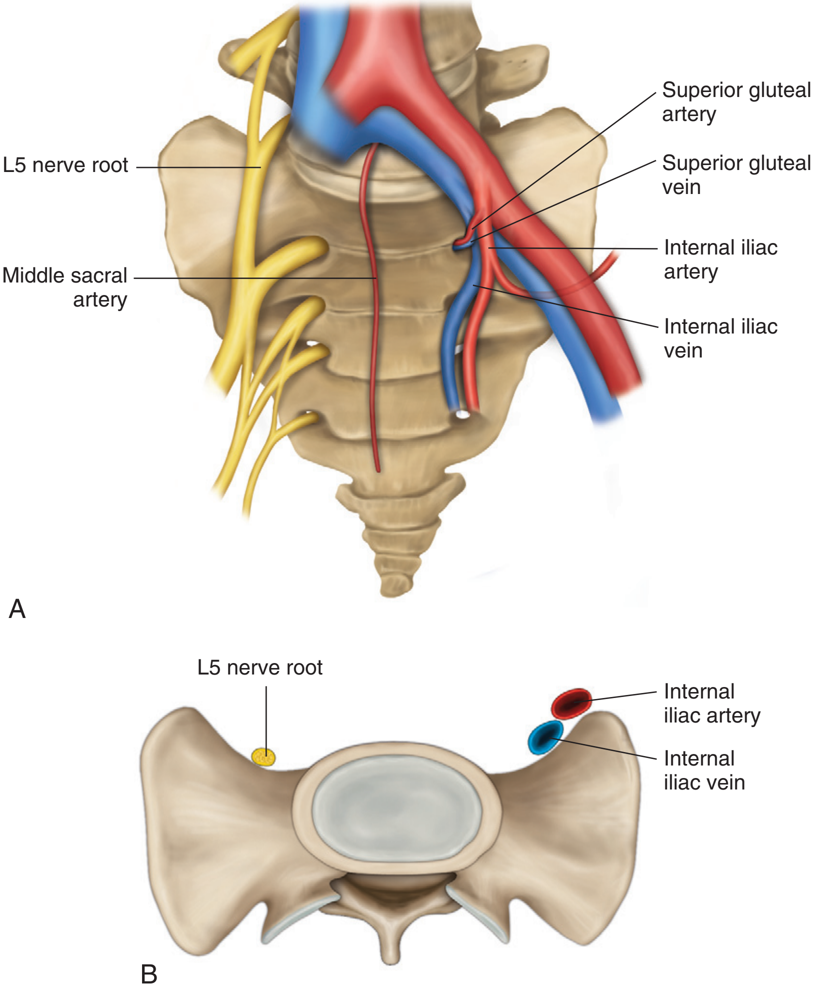


Figure 53-2 Neurovascular structures located on the anterior aspect of the sacrum.

- Trauma of the lumbosacral junction or caudal lumbar spine
- Arthrodesis for failed prior diskectomy
- Arrthrodesis for instability of the L5–S1 segment
- Stabilization following extensive bilateral facetectomy of L5–S1

RELATIVE CONTRAINDICATIONS FOR S1 PEDICLE SCREWS

- No absolute contraindications
- Comminuted sacral fracture
- S1 fracture
- Extensive osteolysis of the sacrum
- Large space-occupying lesion of the sacrum with violation of the S1 pedicles or body
- Pedicles smaller than 4 mm

OPERATIVE EQUIPMENT

- Radiolucent operating table with appropriate frame for prone positioning
- Intraoperative radiography or fluoroscopy
- Electrocautery and bipolar electrocautery
- Self-retaining retractors
- Pedicle probes (Lenke, Steffee, etc.)
- Fine, ball-tipped pedicle sound
- Leksell rongeurs (small, medium, and large)
- Kerrison rongeurs (2 to 5 mm)
- Hemostatic agents (Gelfoam, Surgicel, Surgifoam, Thrombin)
- High-speed burr
- Osteotomes of various sizes
- Curettes of various sizes
- Monoaxial or polyaxial pedicle screw system

PREOPERATIVE PLANNING

- Advanced imaging, such as computed tomography (CT) or magnetic resonance imaging (MRI), for advanced planning before the procedure is strongly recommended.
- Planning allows the surgeon to confirm the ideal trajectory for implants.
- Measure the size of the pedicles and relative bone quality.
- Confirm the location of anterior sacral neurovascular structures.
- Plan for anatomic factors that may complicate intraoperative localization (sacralized L5 or lumbarized S1).
- Assess for issues that may complicate or compromise exposure (spina bifida occulta at L5 or S1, very large or overly medialized iliac crests)

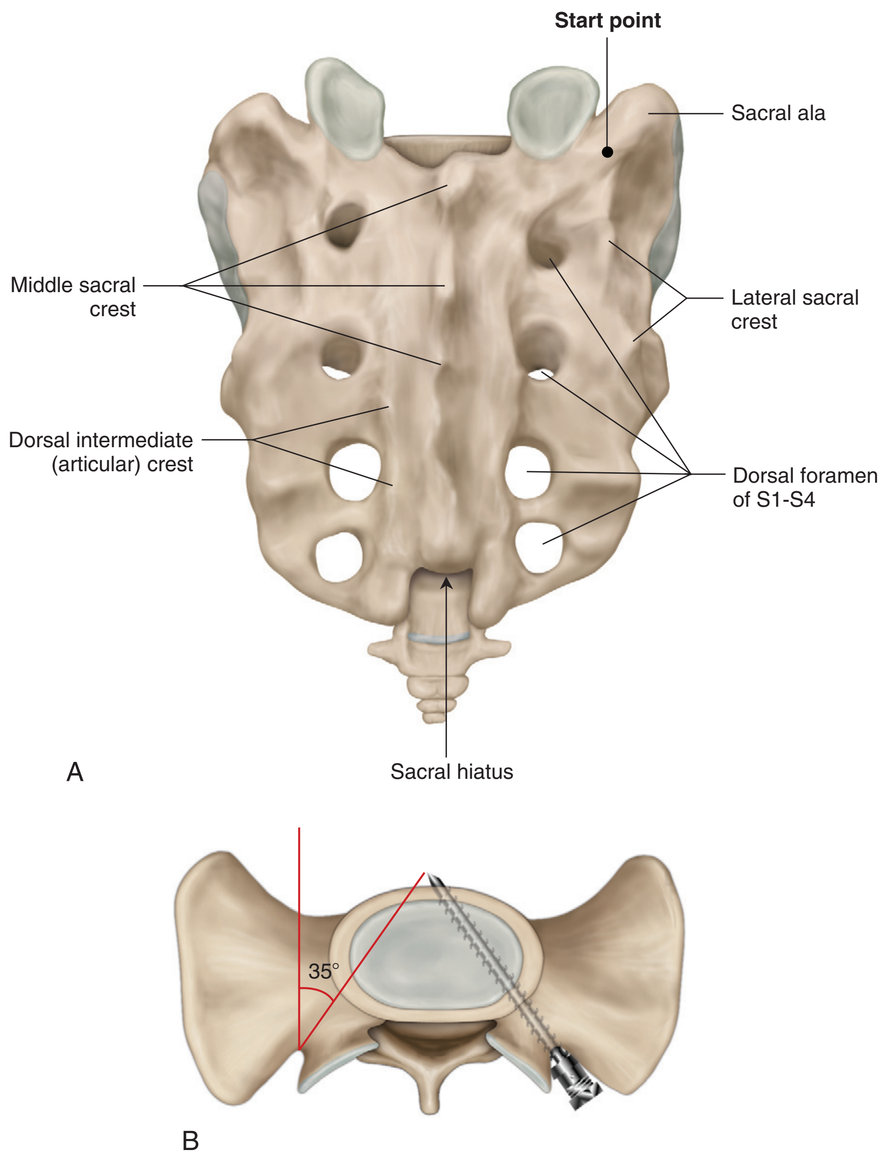


Figure 53-3 Ideal S1 pedicle screw placement.

PATIENT POSITIONING

- A Foley catheter is placed before prone positioning.
- The patient is placed prone on the operating table.
- Bony prominences are padded, and arms are carefully positioned to reduce the risk of neuropraxia.
- Hips should be extended, and the lumbar spine should be resting in anatomic lordosis to prevent segmental kyphosis during fusion.
- Sequential compression devices are placed on bilateral lower extremities to reduce deep vein thrombosis (DVT) risk.
- Intraoperative electromyelograph (EMG) and somatosensory evoked potentials (SSEPs) can be helpful adjuncts.
- The patient's back is sterilely draped caudal to the intergluteal crease and lateral to the iliac crest; the cranial level of draping is highly dependent upon the planned procedure.

SURGICAL APPROACH

- Several possible exposures include the midline, Wiltse, and minimally invasive approach using specialized retractors.
- Choice of approach is based upon the global operative plan, but the chosen approach must allow for exposure lateral to the S1 articular processes.
- The level should be confirmed by intraoperative radiograph or fluoroscopy before instrumentation. Many surgeons localize both before and after skin incision, but a confirmatory radiograph with an instrument applied to a bony landmark is essential for confirmation.
- Dissection should extend lateral to the L5–S1 facet with exposure of the ala, and care should be taken while dissecting near the S1 dorsal foramen, because it can be a source of brisk bleeding. Also note that the interlaminar window of L5–S1 is particularly large, and durotomies

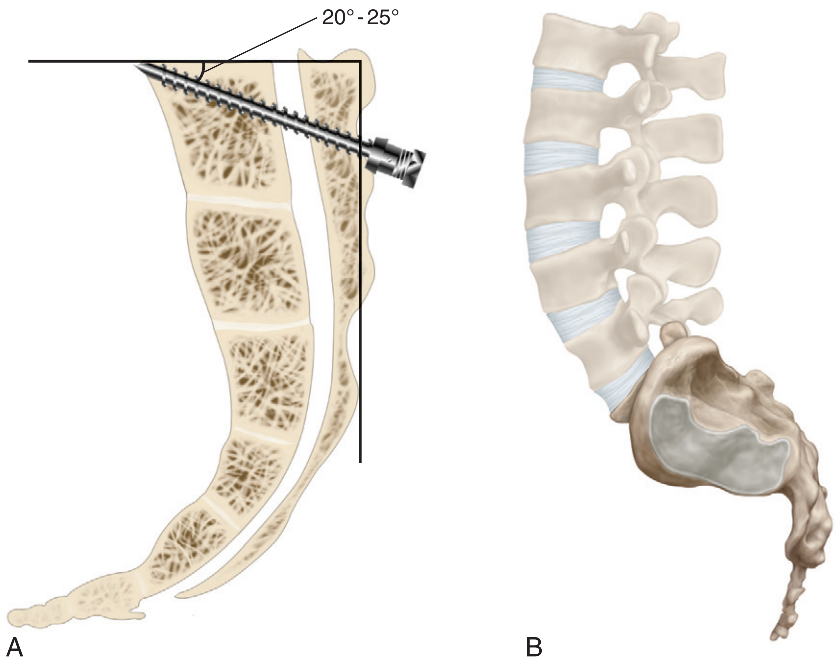


Figure 53-4 Ideal S1 pedicle screw placement.

can occur during dissection if the surgeon strays over the window.
- The iliac crest can overhang the surgical field and may complicate lateral exposure and placement of implants.

SURGICAL TECHNIQUE

- Following exposure of the L5–S1 facet and ala, all bony surfaces are carefully cleaned to maximize visualization of anatomic landmarks.
- The L5–S1 facet can be very large and osteophytic as a result of facet arthopathy; debulking of the facet with a rongeur or osteotome may aid visualization.
- Decompression of the L5–S1 level, if planned, may be carried out before or after placement of the S1 pedicle screws.
- Once critical landmarks are visible, a pilot hole is made using a rongeur or high-speed burr. The ideal starting point is at the confluence of the S1 articular process and ala, just distal and lateral to the S1 articular process.
- After creation of the pilot hole, the pedicle probe is inserted and angled 30 to 35 degrees medial and 15 to 25 degrees cepahald from the dorsal axis of the sacrum. Medial direction may be limited by the iliac crest, especially in large men. In these cases, medialize the tip of the probe as much as the anatomy will allow.
- The pedicle probe advanced under constant pressure and significant force should not be required, even in young patients.
- The probe should advance for 30 to 40 mm; if significant resistance is encountered early, the probe may need to be redirected more cepahalad or medially.
- If an end point is reached after advancing 30 to 40 mm, the anterior cortex should be broached by tapping the probe with a mallet.
- A pedicle sound is advanced into the probe path, and patency of the path is confirmed.
- The surgeon should palpate for breaches and then confirm the length of the tract with the pedicle sound and a Schnidt clamp.
- Following confirmation of screw length, the pedicle tract should be tapped as necessary.
- A screw of the appropriate length is advanced through the tract, taking great care to ensure proper screw direction. Pedicle screw screwdrivers are often bulkier than pedicle probes, and their bulk may force the tip of the screw laterally. Insertional torque may noticeably increase as the screw reaches the anterior cortex.
- Sacral screws that are medialized 10 degrees or less will function as alar screws and can still effectively purchase the sacral bone; the drawback of alar screws is the risk to nearby neurovascular structures, including the L5 nerve root and iliac vessels. The bone of the ala is also much less dense than the promontory, and pullout strength will be less than with a true S1 screw. The anatomy of the sacral body is also more consistent than that of the sacral ala, and some patients have a small or unusually shaped ala, a condition called *sacral dysmorphism.*
- Caudal breaches place the S1 nerve root at risk; this is easy to do if the surgeon does not direct the pedicle probe in a cephalad direction during insertion. Cephalad breaches may also occur into the L5–S1 disk space, although the dense bone of the sacral end plate makes this less common; additionally, screws that perforate the sacral end plate do have good pullout strength, although they may be shorter than the ideal length.

Jackson Intrasacral Rod Technique

The Jackson intrasacral rod technique is a powerful adjunctive method of sacral fixation that reduces the strain on S1 screws without fixation into the ilium. Its low profile is ideal for patients with thin, soft tissues that may break down over iliac bolts. The procedure is technically demanding and requires perfect rod contouring and caudal-to-cranial rod insertion. If used for long fusions to the sacrum, the need for caudal-to-cranial rod placement may be a significant limitation. In these cases, the use of separate cranial and caudal rods joined by a domino or other rod connector may be very helpful. Biomechanical testing has shown it to provide robust fixation for bending resistance than rotation and is very dependent upon sacral bone stock. The technique requires fluoroscopy and closed-top S1 screws with a low-profile head. This allows for countersinking into the sacrum and assists guiding of the rod into the proper portion of the sacrum (Figs. 53-5 through 53-7).

INDICATIONS FOR JACKSON INTRASACRAL ROD

- Arthrodesis for high-grade L5–S1 spondylolisthesis
- Reduction of L5–S1 spondylolisthesis

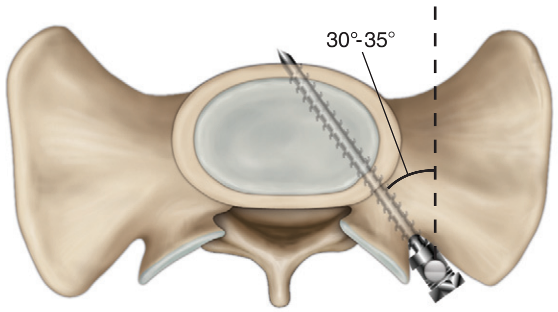


Figure 53-5 Ideal Jackson intrasacral rod placement from axial and dorsal views.

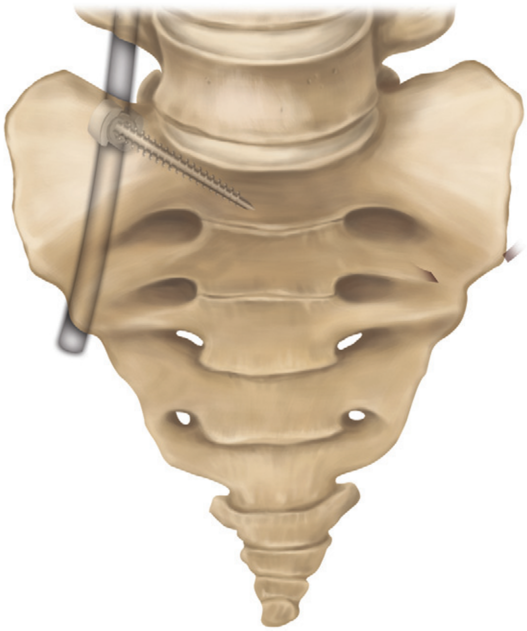


Figure 53-6 Ideal Jackson intrasacral rod placement from anterior aspect.

- Lumbosacral arthrodesis with significant lumbosacral kyphosis
- Arthrodesis of L5–S1 with significant sacral osteopenia
- Spinal deformities that require fusion to the sacrum
- Trauma of the lumbosacral junction or caudal lumbar spine
- Arthrodesis for instability of the L5–S1 segment
- Stabilization following extensive bilateral facetectomy of L5–S1

RELATIVE CONTRAINDICATIONS FOR S1 PEDICLE SCREWS

- No absolute contraindications
- Comminuted sacral fracture
- S1 fracture
- Extensive osteolysis of the sacrum
- Large space-occupying lesion of the sacrum with violation of the S1 pedicles or body
- Pedicles smaller than 4 mm

OPERATIVE EQUIPMENT

- Radiolucent operating table with appropriate frame for prone positioning
- Intraoperative radiography or fluoroscopy
- Electrocautery and bipolar electrocautery
- Self-retaining retractors
- Pedicle probes (Lenke, Steffee, etc.)
- Fine, ball-tipped pedicle sound
- Leksell rongeurs (small, medium, and large)
- Kerrison rongeurs (2 to 5 mm)
- Hemostatic agents (Gelfoam, Surgicel, Surgifoam, thrombin)
- High-speed burr
- Osteotomes of various sizes
- Curettes of various sizes
- Specialized Jackson intrasacral curette
- Screw-and-rod system that contains monoaxial pedicle screws with closed heads
- Rod benders

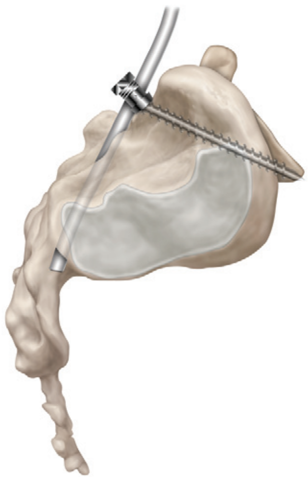


Figure 53-7 Ideal Jackson intrasacral rod placement from lateral view.

PREOPERATIVE PLANNING

- Advanced imaging is strongly recommended, such as CT or MRI, for advanced planning before the procedure.
- Planning lets the surgeon confirm the ideal trajectory for implants.
- Measure the size of the pedicles and relative bone quality.
- Confirm the location of anterior sacral neurovascular structures.
- Plan for anatomic factors that may complicate intraoperative localization (sacralized L5 or lumbarized S1).
- Assess for issues that may complicate or compromise exposure (spina bifida occulta at L5 or S1, very large or overly medialized iliac crests)

PATIENT POSITIONING

- The patient is placed prone on the operating table.
- Bony prominences are padded, and arms are carefully positioned to reduce the risk of neuropraxia.
- Hips should be extended, and the lumbar spine should be resting in anatomic lordosis to prevent segmental kyphosis during fusion.
- Sequential compression devices are placed on bilateral lower extremities to reduce DVT risk.
- A Foley catheter is placed before prone positioning,
- Intraoperative EMG and SSEPs can be a helpful adjunct.
- Fluoroscopy should be performed before prepping and draping to ensure that adequate intraoperative views can be obtained.
- The back is sterilely draped caudal to the intergluteal crease and lateral to the iliac crest; the cranial level of draping is highly dependent on the planned procedure.

SURGICAL APPROACH

- Several possible exposures include midline, Wiltse, and minimally invasive approaches using specialized retractors.
- Choice of approach is based upon the global operative plan, but the chosen approach must allow for exposure lateral to the S1 articular processes and proximal sacrum.
- The level should be confirmed by intraoperative radiograph or fluoroscopy before instrumentation. Many surgeons localize both before and after skin incision, but a confirmatory radiograph with an instrument applied to a bony landmark is essential for confirmation.
- Dissection should extend lateral to the L5–S1 facet with exposure of the ala, and care should be taken while dissecting near the S1 dorsal foramen, because it can be a source of brisk bleeding. Also note that the interlaminar window of L5–S1 is particularly large, and durotomies can occur during dissection if the surgeon strays over the window.
- The iliac crest can overhang the surgical field and may complicate lateral exposure and placement of implants.

SURGICAL TECHNIQUE

- Following exposure of the L5–S1 facet and ala, all bony surfaces are carefully cleaned to maximize visualization of anatomic landmarks.
- The L5–S1 facet can be very large and osteophytic as a result of facet arthopathy; debulking of the facet with a rongeur or osteotome may aid visualization.
- Decompression of the L5–S1 level, if planned, may be carried out before or after placement of S1 pedicle screws.
- Once critical landmarks are visible, a pilot hole is made using a rongeur or high-speed burr. The ideal starting point is at the confluence of the S1 articular process and ala, just distal and lateral to the S1 articular process.
- Following creation of the pilot hole, the pedicle probe is inserted and angled 30 to 35 degrees medial and 15 to 25 degrees cepahald from the dorsal axis of the sacrum. The medial direction may be limited by the iliac crest, especially in large men. In these cases, medialize the tip of the probe as much as anatomy will allow.
- A pedicle probe advanced under constant pressure and significant force should not be required, even in young patients.
- The probe should advance for 30 to 40 mm; if significant resistance is encountered early, the probe may need to be redirected more cepahalad or medially.
- If an end point is reached after advancing 30 to 40 mm, the anterior cortex should be broached by tapping the probe with a mallet.
- A pedicle sound is advanced into the probe path, and patency of the path is confirmed.
- The surgeon should palpate for breaches and then confirm the length of the tract with the pedicle sound and a Schnidt clamp. The screw head will be countersunk, and the assessment of proper length should take this into account.
- Following confirmation of screw length, the pedicle tract should be tapped as necessary.
- An appropriate length closed-headed pedicle screw is advanced through the screw tract, and the head of the screw is countersunk into the bone until the top of the screw is nearly flush with the dorsal surface of the sacrum.
- A curette is used to expose the cranial aspect of the screw head, including the portion that accepts the rod.
- The special Jackson intrasacral curette or right-angle awl is passed through the screw head and advanced caudally into the sacrum under fluoroscopic guidance.
- The curette should be directed along the long axis of the sacrum in the sagittal plane and slightly lateral in the coronal plane.
- The curette is advanced under constant pressure until the inferior cortex is encountered, just medial to the distal portion of the sacroiliac joint.
- The curette is then advanced through the cortex to create the exit hole.
- The tract is palpated with a pedicle sound, and the length of the tract is measured.
- The rod is then cut to length, incorporating the requirements of the rest of the construct, and is carefully contoured to match the created rod tract.
- The rod is inserted into the closed head of the S1 screw and is carefully advanced through the screw tract under fluoroscopic guidance. Small rotational movements aid the passage of the rod.
- Care must be taken, because creating a new tract with the rod is fairly easy.

- Once the rod reaches and passes the exit hole, a set screw is applied to the S1 screw to lock down the construct.
- The process is then repeated on the contralateral side, and the rod is reduced down to the cranial portion of the construct.
- Reduction of the caudal construct to the cranial construct is a powerful maneuver that can greatly aid the creation of lumbosacral lordosis.

S2 Alar Screws

The vertebral body of S2 is much smaller than the body of S1, typically having roughly 60% of the AP dimensions of S1.[23] The bone quality is also poorer, leaving the surgeon with a dubious combination of short screws with little purchase. With these limitations, most choose to use the S2 screw as more of an alar screw, aiming in a superolateral direction to increase length and capture the alar bone stock (Figs. 53-8 and 53-9). A few biomechanical studies have included S2 screws as a mode of fixation, and most studies have found them to be inferior to iliac screws if testing was performed on cadavers.[24,25] However,S2 screws remain an effective technique to supplement S1 pedicle screws, especially as a salvage technique for those who cannot have iliac fixation, such as those who previously had substantial posterior iliac crest harvested for bone graft.[26]

INDICATIONS FOR S2 ALAR SCREWS

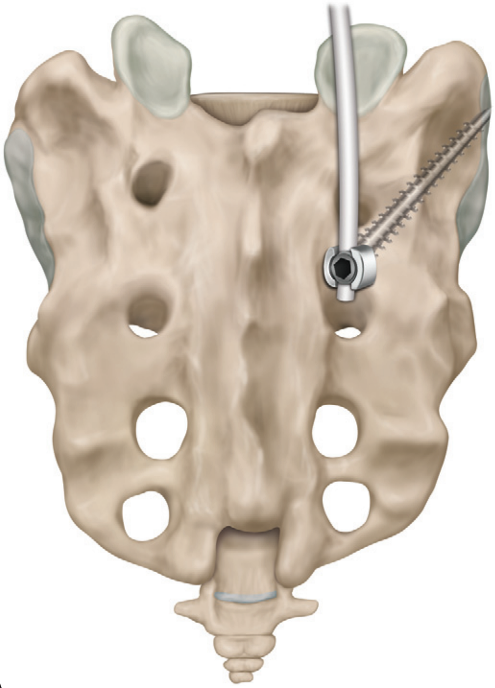
- Prior massive iliac crest harvest that precludes placement of iliac bolts
- Supplemental fixation for reduction of L5–S1 spondylolisthesis
- To supplement or protect S1 screws in long fusions to the sacrum (more than four segments)
- Stabilization following resection of S1 for tumor or infection
- Sacral trauma involving the S1 body or pedicle
- Failure of fixation through S1, including S1 screw pullout or insufficiency fracture of S1

RELATIVE CONTRAINDICATIONS FOR S1 PEDICLE SCREWS

- No absolute contraindications
- Comminuted sacral fracture
- Fracture of the ala
- Extensive osteolysis of the sacrum
- Large space-occupying lesion of the sacrum with violation of the ala or S2 lamina

OPERATIVE EQUIPMENT

- Radiolucent operating table with appropriate frame for prone positioning



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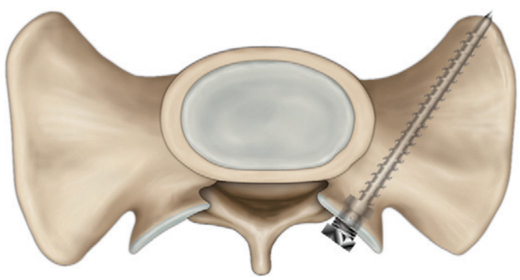

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Figure 53-8 Ideal S2 alar screw placement from axial and dorsal views.

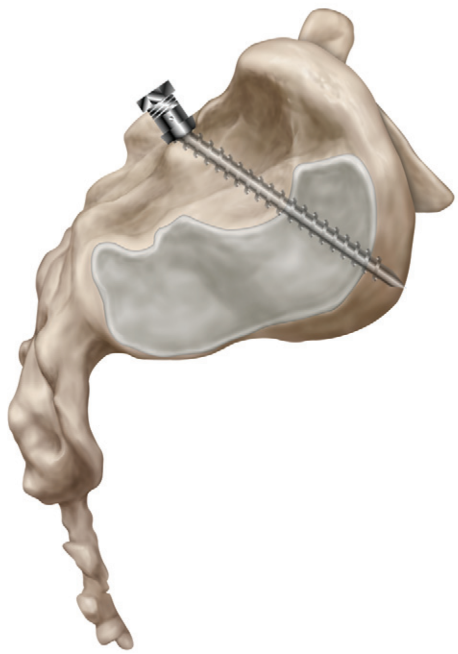

Figure 53-9 Ideal S2 alar screw placement from lateral view.

- Intraoperative radiography or fluoroscopy
- Electrocautery and bipolar electrocautery
- Self-retaining retractors
- Pedicle probes (Lenke, Steffee, etc.)
- Fine, ball-tipped pedicle sound
- Leksell rongeurs (small, medium, and large)
- Kerrison rongeurs (2 to 5 mm)
- Hemostatic agents (Gelfoam, Surgicel, Surgifoam, Thrombin)
- High-speed burr
- Osteotomes of various sizes
- Curettes of various sizes
- Screw-and-rod system with polyaxial pedicle screws

PREOPERATIVE PLANNING

- Advanced imaging, such as CT or MRI, is strongly recommended for advanced planning before the procedure.
- Planning lets the surgeon confirm the ideal trajectory for implants.
- Measure the ala and estimate relative bone quality.
- Confirm the location of anterior sacral neurovascular structures.
- Plan for anatomic factors that may complicate intraoperative localization (sacralized L5 or lumbarized S1).
- Assess for issues that may complicate or compromise exposure (spina bifida occulta at L5 or S1, very large or overly medialized iliac crests).

PATIENT POSITIONING

- The patient is placed prone on the operating table.
- Bony prominences are padded, and arms are carefully positioned to reduce the risk of neuropraxia.
- Hips should be extended with the lumbar spine resting in anatomic lordosis to prevent segmental kyphosis during fusion.
- Sequential compression devices are placed on bilateral lower extremities to reduce DVT risk.
- A Foley catheter is placed before prone positioning.
- Intraoperative EMG and SSEPs can be a helpful adjunct.
- The patient's back is sterilely draped caudal to the intergluteal crease and lateral to the iliac crest; the cranial level of draping is highly dependent upon the planned procedure.

SURGICAL TECHNIQUE

- Posterior exposure of the sacrum is performed; exposure should extend from the L5–S1 facet cranially to just distal to the S2 dorsal foramen caudally.
- Lateral exposure should extend to the tip of the ala caniolaterally and laterally, to the lateral sacral crest.
- Bony surfaces should be carefully cleaned so that key landmarks can be identified, particularly the dorsal intermediate crest and dorsal foramina.
- The dorsal foramina of S1 and S2 are identified as key landmarks for screw placement, but care must be taken to avoid brisk bleeding from the accompanying sinuvertebral arteries.
- A pilot hole is created using a high-speed burr or a Leksell rongeur; the starting point is midway between the S1 and S2 dorsal foramina on the lateral edge of the foramina.
- A pedicle probe is introduced into the pilot hole and is directed superolaterally toward the apex of the ala.
- The proper angle varies among patients but is typically 50 to 60 degrees cranial and 30 to 40 degrees lateral from the posterior axis of the sacrum.
- The pedicle probe is advanced under constant pressure and generally advances easily with mild to moderate effort.
- Once the far cortex is encountered, the pedicle probe can be gently tapped through with a mallet.
- The tract is then palpated with a ball-tipped pedicle sound, and the length is measured using the pedicle sound and a Schnidt clamp.
- Typical screw lengths are 35 to 50 mm if bicortical purchase is achieved.
- The tract is tapped as necessary, and a screw is inserted, taking great care to ensure that the screw is directed properly.
- Bicortical purchase is biomechanically superior for alar screws but is riskier, because injury to neurovascular structures is much more common with bicortical alar screws than with bicortical S1 screws.
- Screw tracts that are too short are usually not aimed sufficiently cranial or lateral.

Chopin Plate/Colorado II Sacral Plate

The established limitations of stand-alone S1 pedicle screws or alar screws led to a combined fixation system originally termed a *sacral block*. This implant was developed and reported by Chopin in 1991 and combines an S1 pedicle screw with an alar screw placed into one sacral plate with one fixation point. The concept of two divergent sacral screws has been biomechanically validated and compared to a single S1 screw. The two divergent sacral screws granted superior fixation with higher loads to failure and improved stiffness of the construct.[27] The Chopin plate has been adopted by the Colorado II plate system (Medtronic, Minneapolis, MN) as an available alternative to S1 pedicle screws, and it can still be used in conjunction with iliac screws. The disadvantages of the Chopin plate include slightly more dissection for placement of the plate and more constraint for the placement of the S1 pedicle screws and alar screws. Additionally, the screw–plate system is of a conventional design (nonlocking), and the potential for sequential screw pullout and failure exists as it does for independent screws. Nevertheless, this system remains superior to S1 pedicle screws alone or alar screws alone (Figs. 53-10 and 53-11).

INDICATIONS FOR CHOPIN PLATE/ COLORADO II SACRAL PLATE

- Arthrodesis for L5–S1 spondylolisthesis
- Reduction of L5–S1 spondylolisthesis
- Arthrodesis for degeneration of L5–S1 disk and facets with sacral osteopenia
- Spinal deformities that require fusion to the sacrum
- Supplemental fixation for ALIF or anterior resections for tumor or infection

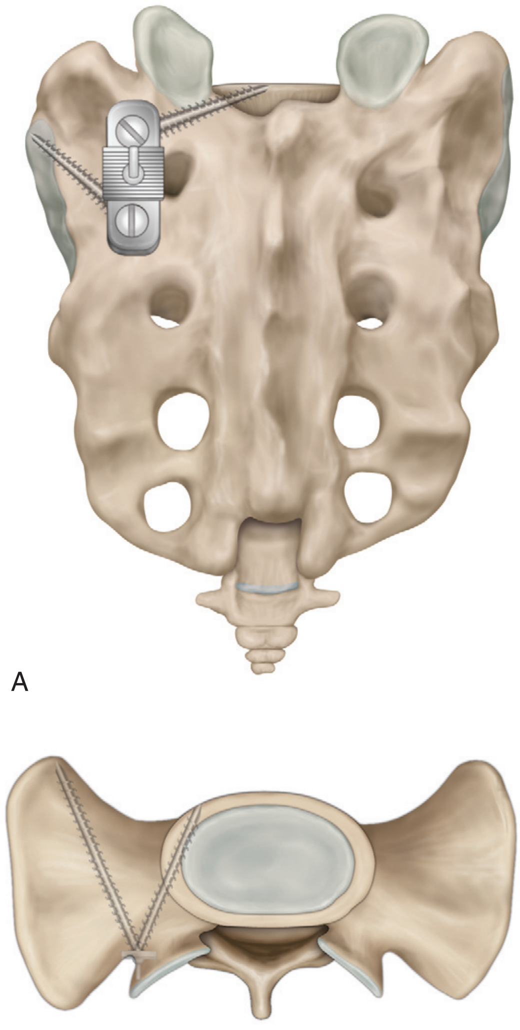

Figure 53-10 Ideal Chopin plate placement from dorsal and axial views.

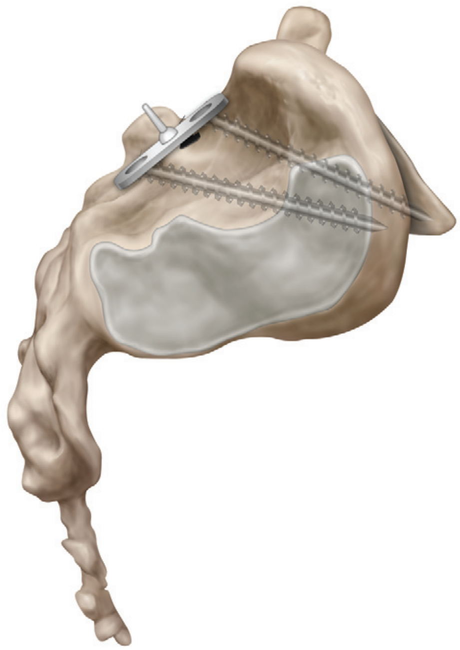

Figure 53-11 Ideal Chopin plate placement from lateral view.

- Trauma of the lumbosacral junction or caudal lumbar spine
- Arthrodesis for failed prior diskectomy
- Arthrodesis for instability of the L5–S1 segment
- Stabilization following extensive bilateral facetectomy of L5–S1 with osteopenic sacrum

RELATIVE CONTRAINDICATIONS FOR S1 PEDICLE SCREWS

- No absolute contraindications
- Comminuted sacral fracture
- S1 fracture
- Alar fracture
- Extensive osteolysis of the sacrum
- Large space-occupying lesion of the sacrum with violation of the S1 pedicles or ala
- Pedicles smaller than 4 mm

OPERATIVE EQUIPMENT

- Radiolucent operating table with appropriate frame for prone positioning
- Intraoperative radiography or fluoroscopy
- Electrocautery and bipolar electrocautery
- Self-retaining retractors
- Pedicle probes (Lenke, Steffee, etc.)
- Fine, ball-tipped pedicle sound
- Leksell rongeurs (small, medium, and large)
- Kerrison rongeurs (2 to 5 mm)
- Hemostatic agents (Gelfoam, Surgicel, Surgifoam, thrombin)
- High-speed burr
- Osteotomes of various sizes
- Curettes of various sizes
- Chopin plates or Colorado II pedicle screw system
- Monoaxial or polyaxial pedicle screw system

PREOPERATIVE PLANNING

- Advanced imaging, such as CT or MRI, is strongly recommended for advanced planning before the procedure.
- Planning allows the surgeon to confirm the ideal trajectory for implants.
- Measure the size of the pedicles and relative bone quality.
- Confirm the location of anterior sacral neurovascular structures.
- Plan for anatomic factors that may complicate intraoperative localization (sacralized L5 or lumbarized S1).
- Assess for issues that may complicate or compromise exposure (spina bifida occulta at L5 or S1, very large or overly medialized iliac crests).

PATIENT POSITIONING

- The patient is placed prone on the operating table.
- Bony prominences are padded, and arms are carefully positioned to reduce the risk of neuropraxia.
- Hips should be extended, and the lumbar spine should be resting in anatomic lordosis to prevent segmental kyphosis during fusion.

- Sequential compression devices are placed on bilateral lower extremities to reduce DVT risk.
- A Foley catheter is placed before prone positioning.
- Intraoperative EMG and SSEPs can be a helpful adjunct.
- The patient's back is sterilely draped caudal to the intergluteal crease and lateral to the iliac crest; the cranial level of draping is highly dependent upon the planned procedure.

SURGICAL APPROACH

- Several possible exposures include the midline, Wiltse, and minimally invasive exposures using specialized retractors.
- Choice of approach is based upon the global operative plan, but the chosen approach must allow for exposure lateral to the S1 articular processes and for exposure of the ala that meets or exceeds the Chopin plate footprint.
- The level should be confirmed by intraoperative radiograph or fluoroscopy before instrumentation. Many surgeons localize both before and after skin incision, but a confirmatory radiograph with an instrument applied to a bony landmark is essential for confirmation.
- Dissection should extend lateral to the L5–S1 facet with adequate exposure of the ala for placement of the alar screws and to accommodate the plate footprint.
- The iliac crest can overhang the surgical field and may complicate lateral exposure and placement of implants, particularly the S1 screws.

SURGICAL TECHNIQUE

- Following exposure of the L5–S1 facet and ala, all bony surfaces are carefully cleaned to maximize visualization of anatomic landmarks.
- The L5–S1 facet can be very large and osteophytic as a result of facet arthopathy; debulking of the facet with a rongeur or osteotome may aid visualization and may allow for proper fitting of the plate.
- Plate placement begins with creation of the S1 screw tract using standard S1 screw technique.
- A pilot hole is created using a rongeur or high-speed burr. The ideal starting point is at the confluence of the S1 articular process and the ala, just distal and lateral to the S1 articular process.
- Following creation of the pilot hole, the pedicle probe is inserted and angled 15 degrees medially and 15 to 25 degrees cephalad from the dorsal axis of the sacrum.
- The pedicle probe is advanced under constant pressure; significant force should not be required, even in young patients.
- If an end point is reached after advancing 30 to 40 mm, the anterior cortex should be broached by tapping the probe with a mallet.
- A pedicle sound is advanced into the probe path, and patency of the path is confirmed.
- The surgeon should palpate for breaches and then confirm the length of the tract with the pedicle sound and a Schnidt clamp.
- Following confirmation of the screw length, the pedicle tract should be tapped as necessary.
- The Chopin or Colorado II sacral plate is then applied to the sacrum, oriented longitudinally so that it sits relatively flush on the sacrum. The proximal hole of the plate should directly overlie the pilot hole for the S1 screw.
- The S1 screw is then screwed down through the plate; it should not be overtightened to avoid tilting the plate.
- The plate itself assists with orienting the alar screw; a starting awl is used to make the pilot hole, and a pedicle probe is advanced through the plate and into the ala.
- The pedicle probe should be directed 30 to 35 degrees anterolateral and advanced under constant pressure.
- The alar screw should not penetrate the sacroliac joint.
- The length of the screw path is checked, and the alar screw is placed through the plate and into the ala.
- The S1 and alar screws are tightened in an alternating fashion to ensure that the plate stays well applied to the bone.
- The sacral plate can then be connected to the remainder of the fixation in the usual fashion.

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54 Iliac Fixation

IOANNIS AVRAMIS and MUNISH GUPTA

Overview

The lumbosacral junction of the spine is a high stress area; it is the transition from the highly mobile lumbar spine to the rigid pelvis. As a result of this high stress, the lumbosacral junction is prone to instrumentation failures and pseudarthrosis. When performing a lumbar fusion, the lumbar–sacral junction then becomes a transition from two rigid areas of the axial skeleton, increasing the risk of pseudarthrosis. Failure of instrumentation of S1 pedicle screws from pseudarthrosis or before fusion has led to the use of iliac screw fixation for long fusions. Long fusion to the sacrum, which is considered to L2 or higher, is an indication for pelvic fixation as reported by some authors.[1-5] The indications for iliac screws has been extended to pathology or fusion constructs; this places high stresses at the L5–S1 motion segment when fusion is desired at that level.

The first modality for fixation to the pelvis was body casting, which had numerous complications and was poor at stabilizing the pelvis. This was followed by Harrington rod fixation to the sacrum with hooks. Both techniques had pseudarthrosis rates near 50%.[1,3,6-8] Using the next development in spinal fixation, Luque instrumentation, King attached the longitudinal construct to the posterior superior iliac spine (PSIS) using rods with a 90 degree bend at the distal ends and threaded tips of the rods that were passed through the ilium and secured with washers and bolts to the outer table; however, pseudarthrosis rates continued to be high.[9]

The next advance in instrumentation was the Cotrell-Dubousset system with alar and iliosacral screws, yet pseudarthrosis rates of 33% and instrumentation-related complications of 44% continued. Iliosacral screws are placed by starting on the outer cortex of the ilium, crossing the inner table, and entering the S1 pedicle above the sacroiliac joint. A connector attaches near the tip of the screw and links the screw to the longitudinal rods.[10,11]

Iliosacral screws were replaced by the Galveston technique, which is currently used by some surgeons. The Galveston technique provides a more rigid fixation across the lumbosacral junction by inserting a contoured rod at the PSIS in the ilium. This technique decreased instrumentation-related complications and prominence; however, the technique is technically demanding.[12-14]

Currently the most widely used technique for fixation into the pelvis is the iliac screw or bolt. It is derived from the Galveston technique; however, a screw is placed in the ilium as opposed to a contoured rod. Iliac screws are placed by inserting a polyaxial screw into the ilium between the inner and outer tables. The use of iliac screws and cross connectors has reduced the technical demands of pelvic fixation and has allowed for variability in screw diameter and length and in pullout strength from the screw threads.[15,16] Published pseudarthrosis rates of L5–S1 with the use of iliac screws have been as low as 5%.[15]

Recently, the S2 alar iliac screw has been used in place of the standard iliac bolt. The main advantages of this technique are decreased hardware prominence and no longer needing a cross connector to attach to the longitudinal rods. The screw is inserted through the sacrum into the ilium starting inferior and lateral to the S1 dorsal foramen (Fig. 54-1). Early studies show good results without disruption of the sacroiliac joint; however, long-term studies have not been published.[17,18]

Indications

- Long fusions to the sacrum, as in neuromuscular scoliosis treatment
- Flat back deformity that requires corrective osteotomy (Fig. 54-2)
- Correction of pelvic obliquity
- Grade 3 or higher spondylolisthesis as a result of the high stress at the S1 screws[4,19,20]
- Sacral fractures with spinopelvic dissociation
- Lumbosacral fusions in patients with osteoporosis, as in adult scoliosis

Surgical Techniques

EQUIPMENT

The equipment required for placement of iliac bolts starts with a well-padded radiolucent bed that allows prone positioning of the patient and should include the necessary instruments for standard midline exposure of the spine, including Bovie cautery, Cobb elevators, towel clips, and retractors. A large Leksell rongeur and sharp Cobb elevator are needed to prepare the insertion site. A T-handled or Steffee broach, ball-tip probe, and of course the implant with an appropriate tap are also needed. Crosslinks are also required to attach the iliac bolt to the longitudinal rod.

PATIENT POSITIONING AND INCISION

The patient is positioned prone on the operating table and is padded appropriately before sterile prep and draping; the feasibility of obtaining intraoperative radiographs or fluoroscopy should be assessed. Radiographic guidance is not needed for iliac bolt insertion by this technique; however, it can be used for trajectory verification until the surgeon is comfortable with the technique. If preforming an osteotomy, the ability to position the lumbar spine over the break of the operating room table and use the table controls to obtain correction should also be taken into consideration.

A midline incision is made followed by subperiosteal dissection of the soft tissues overlying the spinal column with exposure of the transverse processes in the lumbar spine. Once dissection and possibly placement of lumbar instrumentation is achieved, dissection for placement of the iliac bolts can be addressed. The incised midline fascia is towel-clipped back together using one or two clips. Dissection in the plane superficial to the fascia is carried out from the midline, using palpation of the PSIS to guide the level and amount of dissection, which should be as minimal as possible (Fig. 54-3). Using palpation, the fascia is then incised with Bovie cautery over the PSIS approximately 5 cm, and the periosteum is dissected off the PSIS both laterally and medially (Figs. 54-4 and 54-5). The medial dissection is carried out until it communicates with the midline dissection. The lateral dissection is carried out to the edge of the outer table, at which point a sharp Cobb or periosteal elevator can be used to expose the outer table along the trajectory of the iliac bolt. This allows clinical guidance of the broach and screw during placement; an arcade of bone can be palpated, and the screw trajectory should follow this arcade (Fig. 54-6).

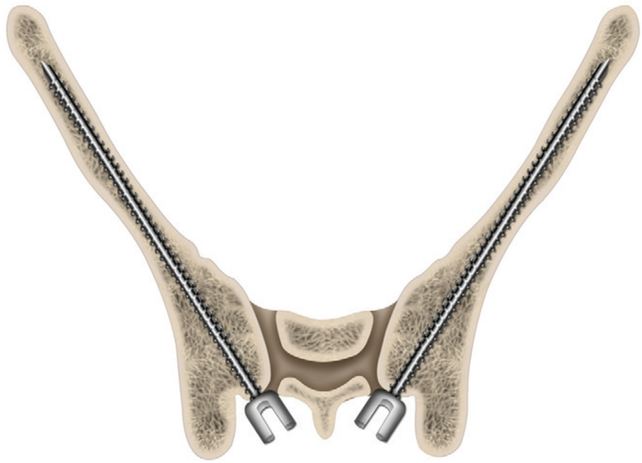

Figure 54-1 Diagram of the axial view of the S2–iliac screw.

SCREW INSERTION

With the PSIS exposed and the outer table dissected to allow for palpation and visual guidance of the broach and screw trajectory, insertion of the iliac bolt can proceed. A large rongeur is used to remove approximately a 1 cm cube of bone from the PSIS; this allows access to the cancellous bone and helps to recess the polyaxial head of the bolt to reduce instrumentation prominence. A T-handled or Steffee probe is then used to dilate a screw path, and the trajectory

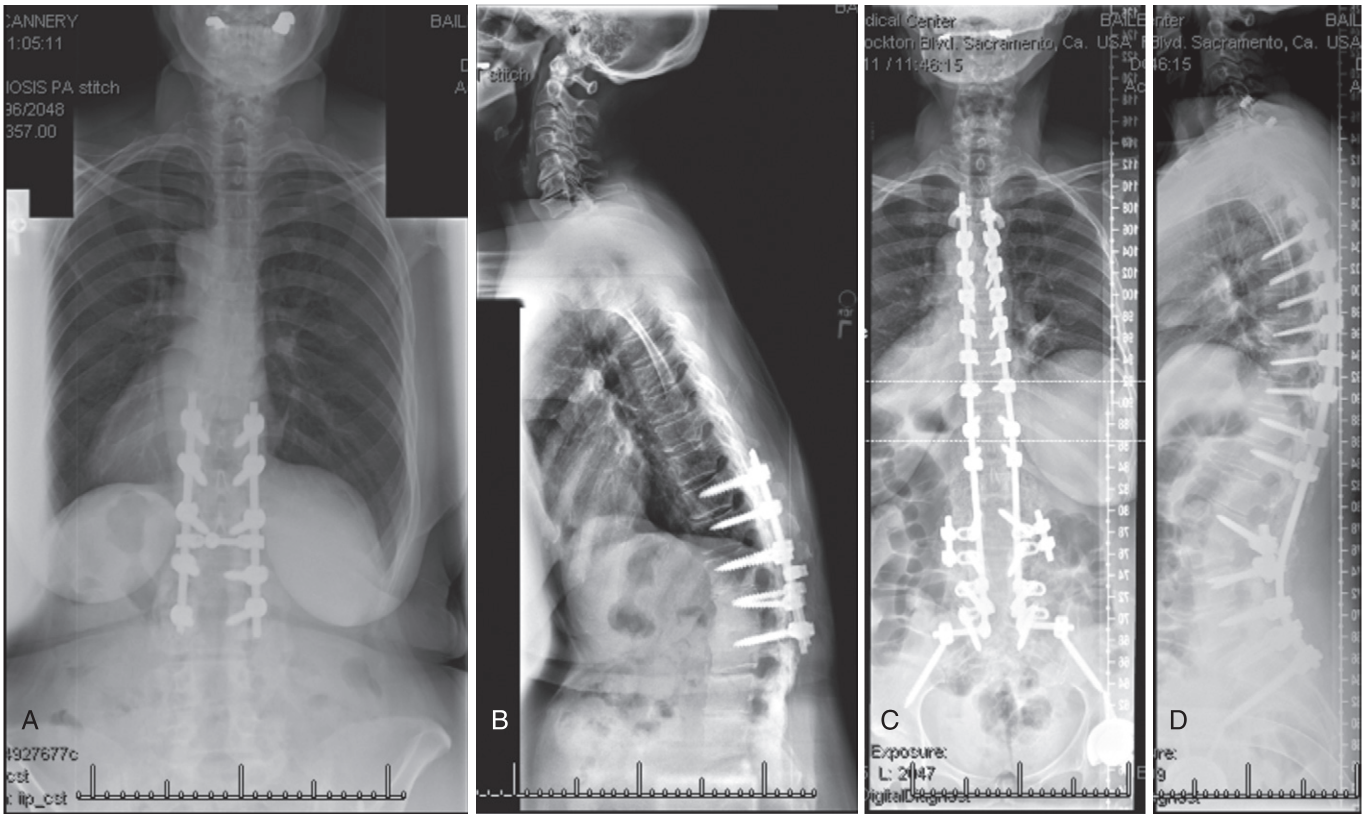

Figure 54-2 Preoperative and postoperative radiographs of flat back deformity correction using T4–pelvis posterior spinal fusion and instrumentation with L3 pedicle subtraction osteotomy.

Figure 54-3 Diagram of prone patient with midline and two lateral fascial incisions for iliac bolt placement.

Figure 54-4 Diagram of incision of midline fascia with towel clip and planned lateral incisions for iliac bolt placement.

is guided by visualization of the outer table and palpation of the arcade of bone (Fig. 54-7). This arcade of bone represents the thickest bone in this region of the pelvis, and placing the bolt here decreases the chance of inner or outer table breaches. Using rotation more than a longitudinal force, the broach is advanced to approximately 8 cm, and the tract is palpated and measured with the ball-tip probe to ensure a cylinder of bone with a floor. The tract is then tapped with the appropriate size tap, and the screw is inserted. The iliac bolt size is usually 8 by 80 mm in average-sized adults and adolescents; smaller children tolerate a 6 mm screw, and the length should be determined using a ball-tip probe and a ruler.

The structures at risk during iliac bolt placement are the acetabulum and the sciatic notch. Within the sciatic notch lie the superior gluteal artery and the sciatic nerve. By exposing the outer table, which allows for visualization and

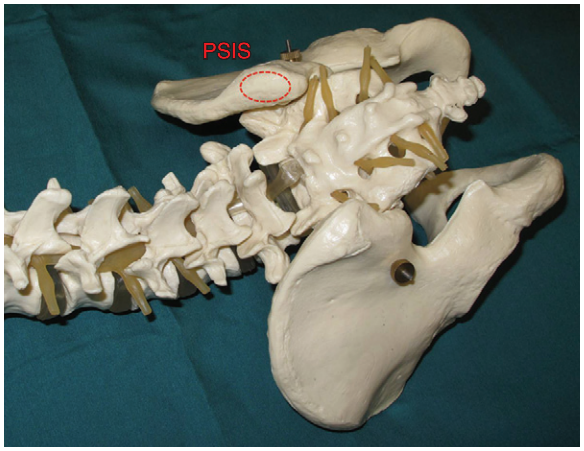

Figure 54-5 Exposed posterior superior iliac spine (PSIS) is the starting site for the iliac bolt; it can be easily palpated through the fascia to guide the lateral fascial incision.

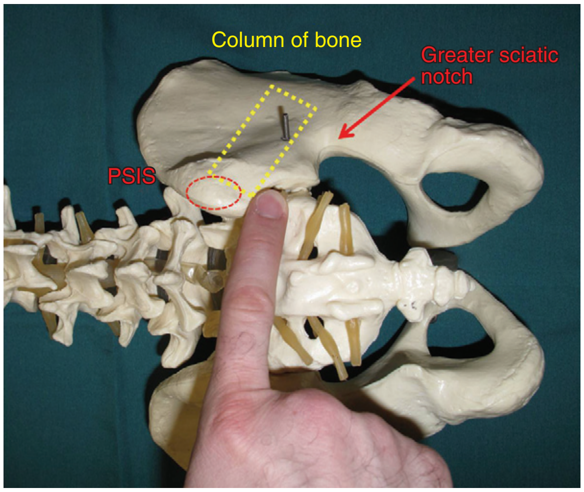

Figure 54-6 Exposure of lateral iliac wall can help the surgeon visualize the iliac bolt trajectory, and palpation of the column of bone superior to the greater sciatic notch can also guide screw placement down this column of bone. PSIS, posterior superior iliac spine.

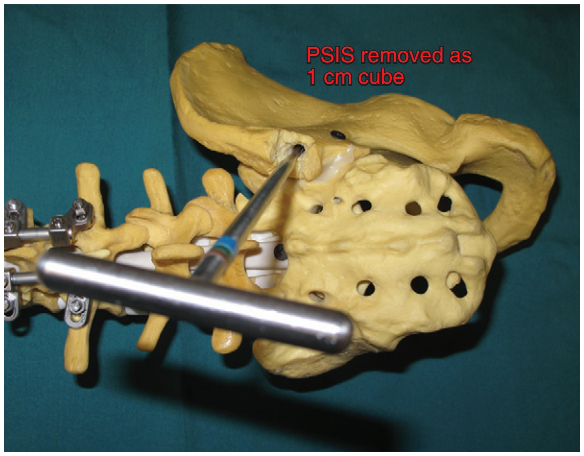

Figure 54-7 Insertion of T-handled broach. PSIS, posterior superior iliac spine.

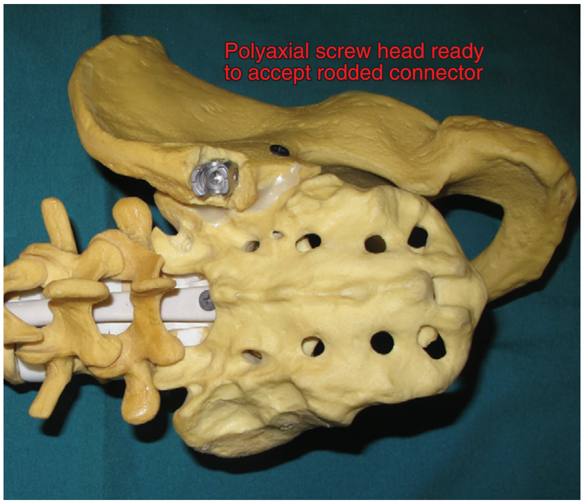

Figure 54-8 Insertion of iliac bolt.

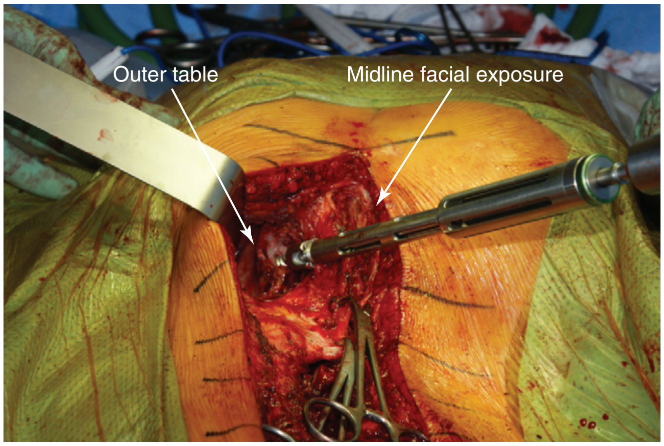

Figure 54-9 Lifting fascial slip between the midline and lateral fascial incisions over the iliac bolt polyaxial head to visualize the head in the midline wound.

palpation, the sciatic notch can be avoided. The notch can be palpated through the overlying soft tissues, and a finger can be placed there during broaching to ensure the broach is directed superior to the notch. Violation of the acetabulum can be avoided by using more rotation than longitudinal force when inserting the broach; the thick cortical bone of the dome of the acetabulum can be palpated and differentiated from the cancellous bone with the broach and more easily so with the ball-tip probe. In osteoporotic patients, in whom the cortical bone will not be as strong and easy to differentiate, alternating between the ball-tip probe and the broach is helpful.

FUSION SITE PREPARATION

There is no fusion across the sacroiliac joint, hence no decortication is necessary lateral to the sacrum. The sacral ala and lamina of S1 are decorticated using a high-speed burr after irrigation and before application of bone graft.

CONNECTION TO THE CONSTRUCT

Once the screw has been inserted, the laterally incised fascia can be placed superior to the iliac bolt, and the screw head will be visualized in the midline dissection provided by the medial dissection of the periosteum from the PSIS (Figs. 54-8 and 54-9). The iliac bolts must have a polyaxial head to facilitate connection to the longitudinal rods. A cross connector, usually 40 mm, is used to attach the bolts to the longitudinal rods (Fig. 54-10). Although rarely necessary, the cross connectors themselves can be contoured to allow attachment, for example, if the longitudinal rod is cut too short.

CLOSURE

Once the final correction has been accomplished, and bone graft has been placed, closure of the midline and lateral fascia can be carried out. The midline fascia for long fusions is closed in two parts. The superior two thirds to three fourths are closed with a looped number 1 running absorbable monofilament. The inferior portion has a second running stitch placed, but it is left loose (Fig. 54-11). A Meyerding or similar retractor is used by the ipsilateral surgeon to expose the lateral fascial incision to the contralateral surgeon, who closes the incision with a looped number 1 running absorbable monofilament suture (Fig. 54-12). Once both lateral fascial incisions are closed, the midline fascial suture is tightened in a shoestring fashion and tied (Fig. 54-13). The midline fascial closure is reinforced with an interrupted figure-eight of No. 0 braided absorbable suture, and the subcuticular tissues and skin are closed in a standard fashion.

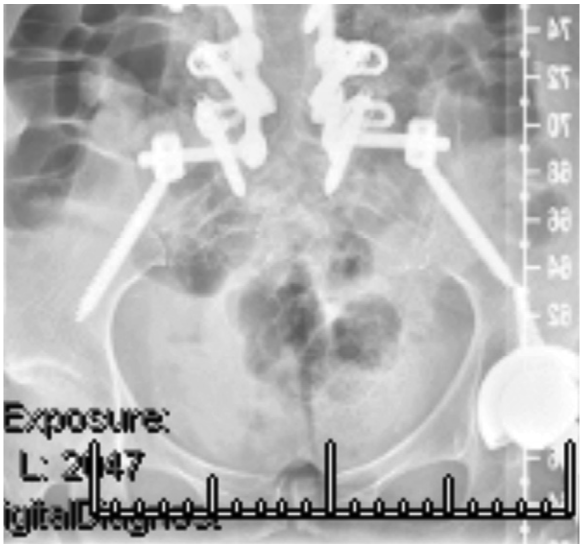

Figure 54-10 Example of the use of a rodded connector from iliac bolt to longitudinal rod with L5 pedicle screws.

ALTERNATIVE TECHNIQUE

The S2 alar iliac screw has been championed by some surgeons, because it results in less hardware prominence and more ease in positioning the screw head in line with the longitudinal rod of the fusion construct. The screw is placed by starting 2 to 4 mm lateral and 4 to 8 mm inferior to the

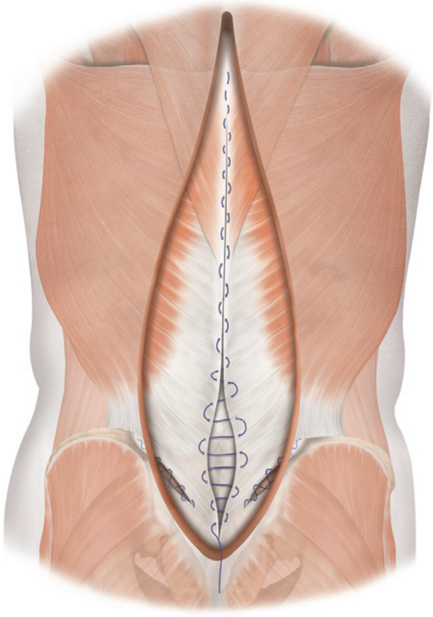

Figure 54-11 Diagram of running suture closure. The proximal two thirds to three quarters of the midline fascia is closed tightly. A running suture is placed in the inferior portion of the midline wound but is left loose to allow mobility of the fascia to close the lateral incisions.

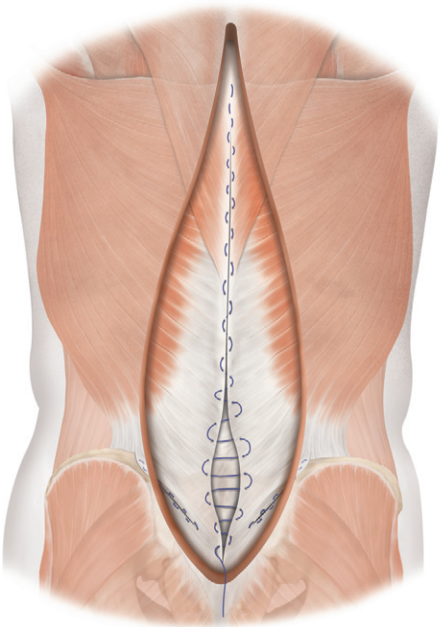

Figure 54-12 Diagram of lateral fascial incisions closed with a midline fascial incision with loose sutures.

S1 foramen. A 2.5-mm drill is used to drill through the S2 ala, across the sacroiliac joint, and into the ilium. Once the ilium has been entered, the 2.5-mm drill is exchanged for a 3.2-mm drill to prevent breakage. The trajectory is 40 degrees lateral and 20 to 30 degrees inferior, and the path should be 20 mm above the greater sciatic notch.[18] Fluoroscopy can be helpful, the teardrop view of the hemipelvis should be obtained, and the screw path should be in the teardrop.

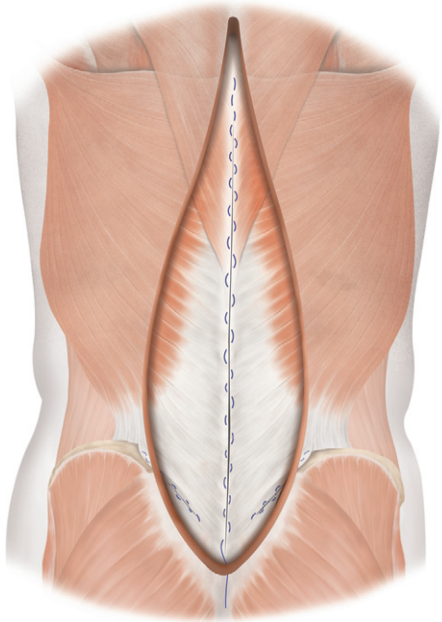

Figure 54-13 Diagram of all fascial incisions closed tightly.

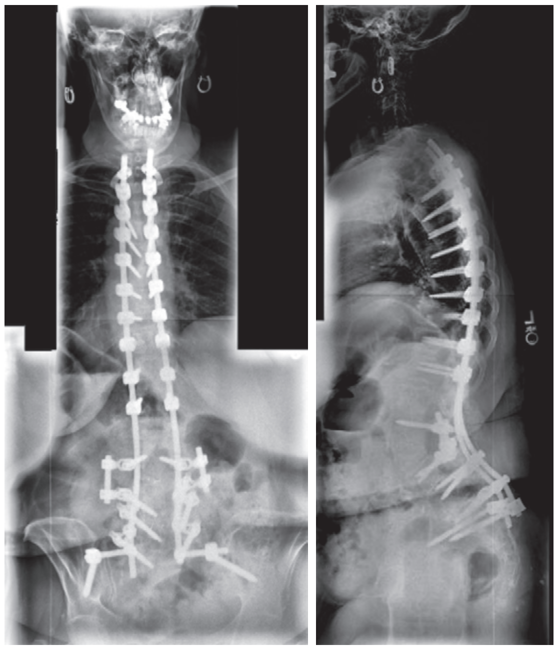

Figure 54-14 Anteroposterior and lateral radiographs of a T4–pelvis posterior spinal fusion and instrumentation following an L3 pedicle subtraction osteotomy.

Postoperative Care

Postoperatively, patients receive prophylactic antibiotics and drain care. No special interventions are required when iliac bolts are used. All patients receive standing radiographs that include the iliac bolts for evaluation and comparison with future radiographs (Fig. 54-14).

Complications

INTRAOPERATIVE COMPLICATIONS

The structures at risk during iliac bolt placement are the acetabulum and the sciatic notch. Within the sciatic notch lie the superior gluteal artery and the sciatic nerve. The superior portion of the greater sciatic notch can be palpated inferiorly to the column of bone in the ilium that the screw path should be in. Palpation of the notch and column of bone in addition to visualization of the column of bone should prevent breaching into the sciatic notch.

POSTOPERATIVE COMPLICATIONS

Instrumentation prominence leading to pain and overlying soft tissue irritation is the most common complication.[21,22] The iliac bolts can be removed once there is certainty that lumbosacral fusion has occurred. Removal before fusion can result in kyphosis and breakage of remaining instrumentation of the sacrum.

Implant loosening despite lumbosacral fusion may be symptomatic and may require screw removal. Loosening in the ilium may be related to motion at the sacroiliac joint, which may also cause loosening of the cross connector; however, if lumbosacral fusion is achieved, this is not problematic. Loosening or breakage without fusion at the lumbosacral junction can occur as at any level in an instrumented spinal fusion. Some authors recommend anterior column support with interbody fusion at L4–L5 and at L5–S1. These interbody grafts are anterior to the lumbosacral pivot point and hence are subject to compression, facilitating fusion and decreasing the chance of iliac screw loosening or breakage as a result of pseudarthrosis and fatigue stress.[12-14,23] Pseudarthrosis rates range from 5% to 17% depending on a host of factors that include the fusion construct, for example, inclusion of S1 pedicle screws and anterior fusion, both of which decreased the pseudarthrosis rate.[15,24,25]

Infection rate as high as 4% was seen in one study, an increase that may be attributed to the necessary soft tissue dissection as well as to the overlying soft-tissue coverage.[15]

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55 Surgical Resection of Sacral Tumors/Sacrectomy and Lumbopelvic Reconstruction

ILSUP KIM and DANIEL H. KIM

Overview

Most tumors of the sacrum are benign aggressive lesions—aneurysmal bone cysts, osteoblastomas, and giant-cell tumors—or low-grade malignancies, such as chordoma or chondrosarcoma. Intralesional resections in the form of curettage provide a complete cure for benign lesions. In contrast, wide resections are necessary for complete disease control in malignant tumors. Surgical procedures for sacral tumors are classified into four types on the basis of extension of tumors and the level of sacral resection (Fig. 55-1).

1. Type I is *low sacral amputation,* or sacrectomy below S2
2. Type II is *high sacral amputation,* or sacrectomy through S1 or S1–S2
3. Type III is *total sacrectomy,* or sacrectomy through L5–S1
4. Type IV is *extended sacrectomy,* or total sacrectomy combined with excision of the ilium, vertebra, or intrapelvic organs

Low sacral tumors, neoplasms that affect levels inferior to the S2 disk, are approached posteriorly, whereas high sacral tumors, neoplasms that affect the S1 and S2 disks, are approached by combined anterior and posterior incisions.[1]

Tumors Involving S3 and Below

This approach is suitable for lower sacral tumors whose superior limit can be reached upon digital rectal examination (Fig. 55-2).[2] A purse-string suture is done around the anus, a modified knee-chest position is set, and a midline skin incision is made. The skin and subcutaneous tissue are prepared and reflected to expose the sacrum, sacroiliac ligament, origin of the gluteus maximus, and medial attachment of the sacrotuberous ligament; the sacral periosteum should not be incised or dissected.[3] These ligaments and muscles are divided on both sides close to their sacral attachment. The insertion of the gluteus maximus muscle is cut up to the edge of the sacroiliac joint (Fig. 55-3). This allows exposure of the inferior roots of the sciatic nerves, piriformis muscle, and posterior margin of the pelvic portion of the tumor.[2]

At the deeper level, the piriformis muscle and the sacrospinous and anococcygeal ligaments are found and divided. The rectum is gently detached from the presacral lamina and from the tumor, which always protrudes anteriorly. The upper level section of the sacrum is decided on the basis of radiologic findings. At the chosen level, a careful digital dissection of the anterior soft tissue is performed on both sides through the greater sciatic notch below the lower margins of the ilium and alae of the sacrum. The bulky tumor usually remains well covered by the periosteum, and careful finger dissection avoids dramatic injury to the gluteal vessels. The pudendal nerves exiting the greater sciatic foramen and reentering the lesser foramen should also be identified and protected, except when they are too intimate with the tumor to be spared (Fig. 55-4).

The lower roots, including S3, are removed en bloc with the tumor mass. The removed specimen includes the sacrum, coccyx, lower sacral roots, and resected surrounding soft tissue. An osteotomy is performed between the S2 and S3 dorsal foramina.[4]

The tumor mass is freed circumferentially and can be removed en bloc. Bleeding from the sacral stump is controlled with bone wax, and bleeding in the presacral soft tissue may be severe. The median and lateral sacral arteries and veins are usually the main sources of this bleeding. In these types of resections, reconstruction is not necessary, because the sacroiliac joints are not excised. For smaller lesions of the midsacrum and distal sacrum, resection of the sacroiliac joint is not required.[3] Wound closure generally can be achieved without a rotational flap or other reconstructive procedures.

It is impossible to dissect the soft tissue of the upper presacrum safely via the posterior approach. A posterior approach to the upper sacrum may cause major vascular injury or inadvertent entry into the rectum, or it may violate the tumor capsule during an attempt to osteotomize the ventral sacrum and sacroiliac joints from behind. These difficulties are best addressed by combining the dorsal sacrectomy via a ventral approach for lesions that require amputation through the level of the sacroiliac joints.

Tumors Involving Proximal Sacrum (Combined Anterior and Posterior Approach)

VENTRAL SACRECTOMY

With the patient supine, the anterior aspect of the sacrum is exposed through a midline vertical incision along the rectus abdominis muscle through all the layers of the abdominal wall except the peritoneum (Fig. 55-5).[3] The

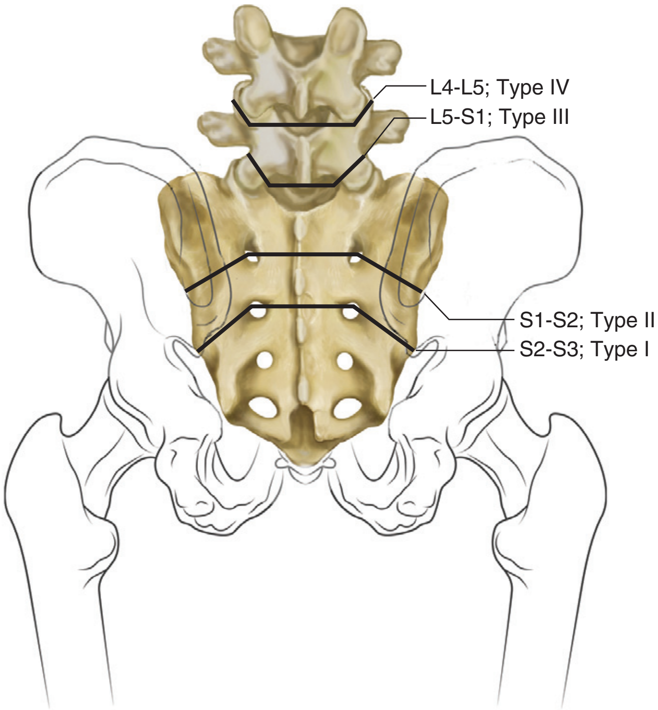

Figure 55-1 Extent of sacral resection.

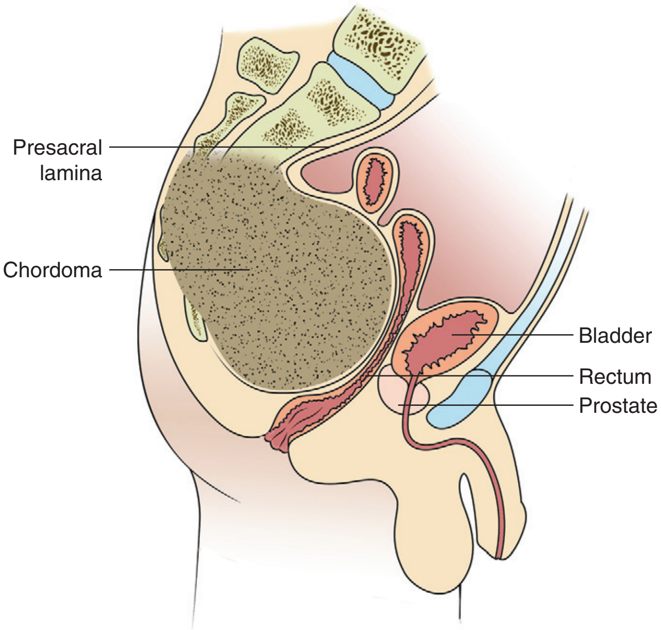

Figure 55-2 Lower sacral lesion.

internal iliac artery along with the mediolateral sacral vessel are ligated and divided on both sides. The ligation of the internal iliac vein can cause congestion of the pelvic and epidural venous plexi. Currently, instead of ligating the internal iliac vein, the segmental veins entering the sacral foramina are ligated while exposing the anterior surface of the sacrum.[5]

The presacral fascia is not opened.[1] The L5–S1 disk is incised and reamed; the mobilized vessels and iliopsoas muscle are retracted, and the nerve root of L5 and the

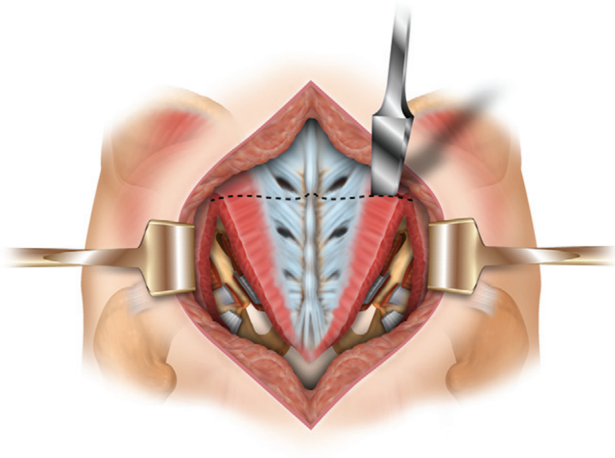

Figure 55-3 Lower sacral resection from behind.

iliolumbar trunk are identified. A chisel cut is made through the internal lamina of the iliac wing 1 cm lateral to the S1 joint bilaterally, marking the level of resection (Fig. 55-6). The lumbosacral nerve trunks from L4 and L5 should be preserved. The S1 through S4 nerve roots are cut on both sides away from the tumor. The rectum is mobilized by blunt finger dissection in the presacral space.

POSTERIOR SACRECTOMY

The patient is set in a prone position. A three-limbed star-shaped skin incision is used, and a lumbosacral flap is lifted from the sacrum and is retracted rostrally (Fig. 55-7). The posterior iliac crest, greater sciatic foramina, and sciatic nerves are exposed bilaterally as are the L3–L5 spinous process, facet joints, and transverse process. The sacral nerve roots are divided after the L5–S1 laminectomy. The dural sac is transected caudal to the L5 nerve roots and is ligated with nonabsorbable sutures. The detachment of the L5–S1 disk from the L5 end plate is completed via a posterior approach (Fig. 55-8). The L5–S1 facet joints are disarticulated. The sacrospinalis muscles are transected transversely, and the gluteus maximus and piriformis muscles are divided. The dorsal sacroiliac ligament, sacrotuberous ligament, and sacrospinous ligament are detached or transected. The superior gluteal vessels and nerves, inferior gluteal vessels and nerves, sciatic nerve, pudendal nerve, and posterior femoral cutaneous nerve should be preserved.

In a posterior sacral osteotomy, the sacroiliac joints or ilium are cut with an osteotome or drill from behind (Fig. 55-9). Bone resection with an osteotome or drill proceeds to meet the ventral osteotomy previously made. For easier cutting, a threadwire saw can be used. If indicated, the resection margin can be extended to the iliac bone. The extent of ilium resection is determined by a sagittal computed tomographic (CT) scan or magnetic resonance imaging (MRI). A shallow groove is cut through the internal cortex of the iliac wing lateral to the sacroiliac joint to mark the level of resection (Fig. 55-10).[6] In the case of an iliac bone resection, the iliac vessel dissection should be complete when a ventral sacrectomy is performed.

After the skin incision, the skin and subcutaneous tissue were reflected. In the next layer, the gluteus maximus muscle layer, the muscle was divided from the midline and

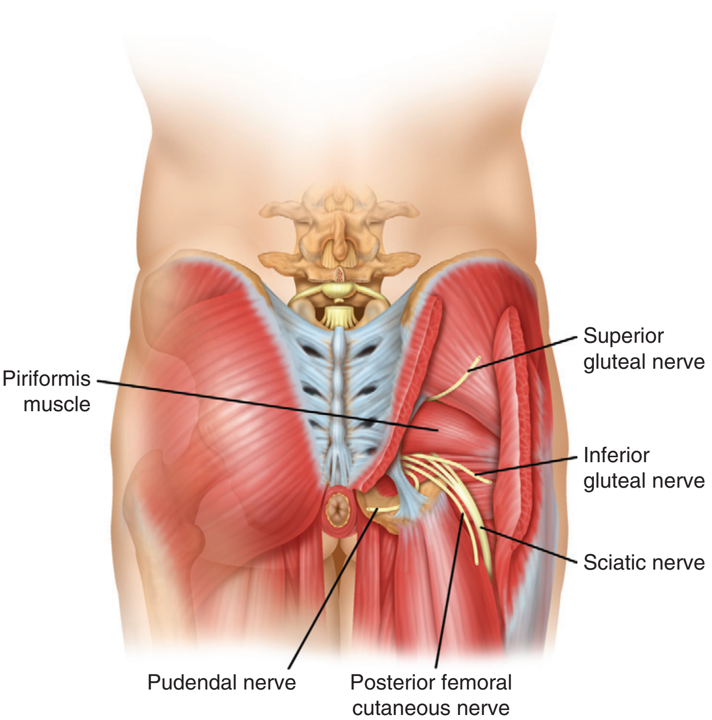

Figure 55-4 After the gluteal muscle is dissected, the piriformis muscle and sciatic nerve are seen.

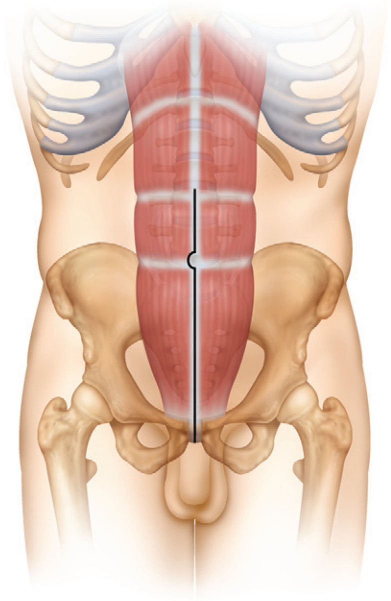

Figure 55-5 Incision for ventral sacrectomy.

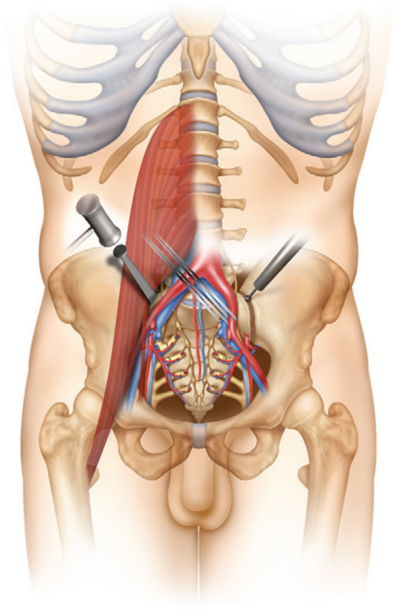

Figure 55-6 Ventral sacrectomy.

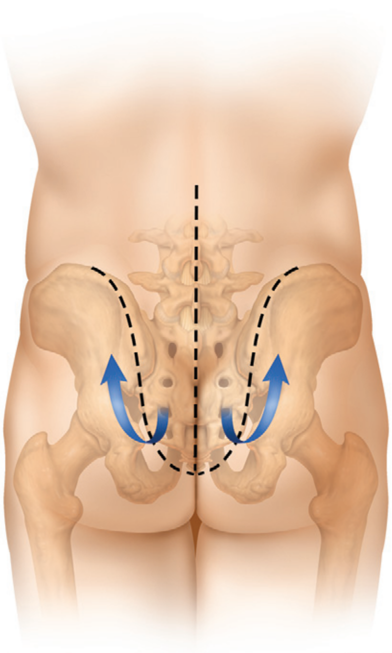

Figure 55-7 Incision for posterior sacrectomy.

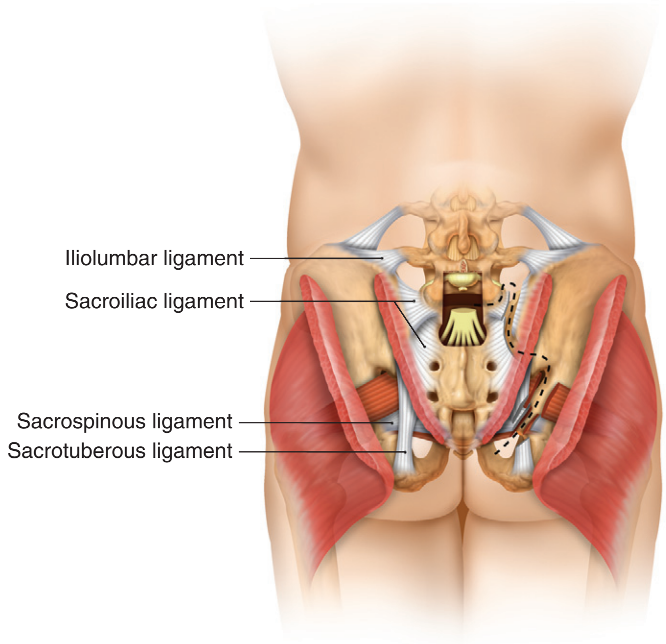

Figure 55-8 Muscle dissection for posterior sacrectomy.

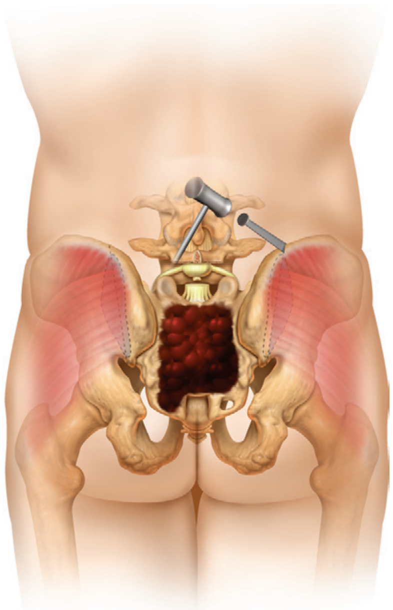

Figure 55-9 Osteotome for dorsal sacrectomy.

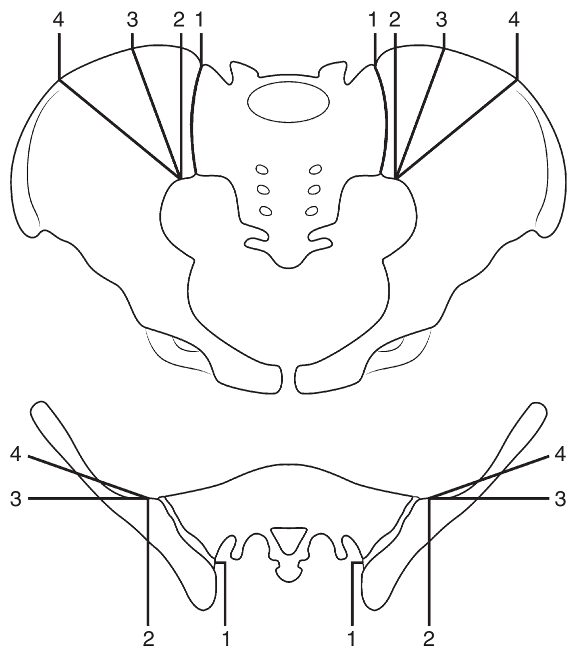

Figure 55-10 Extent of resection for iliac resection; width of resection varies from 1 to 4.

Case Illustration

A 55-year-old woman came to medical attention with a painful mass in her left buttock. CT scan showed that the mass was destroying the lower sacrum and left iliac bone (Fig. 55-11). The mass extended below the sacral level to the coccyx area (Fig. 55-12), and the operation was done with the patient in a lateral decubitus position (Fig. 55-13). The skin incision was started from the midline as a vertical shape and was extended to the left buttock as a horizontal shape (see Fig. 55-13).

Figure 55-11 Left sacral mass in a patient who came to medical attention with left buttock pain.

Figure 55-12 Mass occupying the coccyx and left buttock.

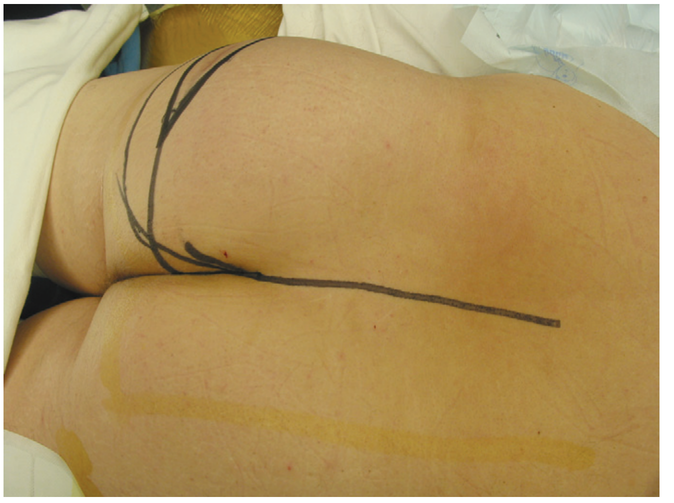

Figure 55-13 Lateral decubitus position and incision.

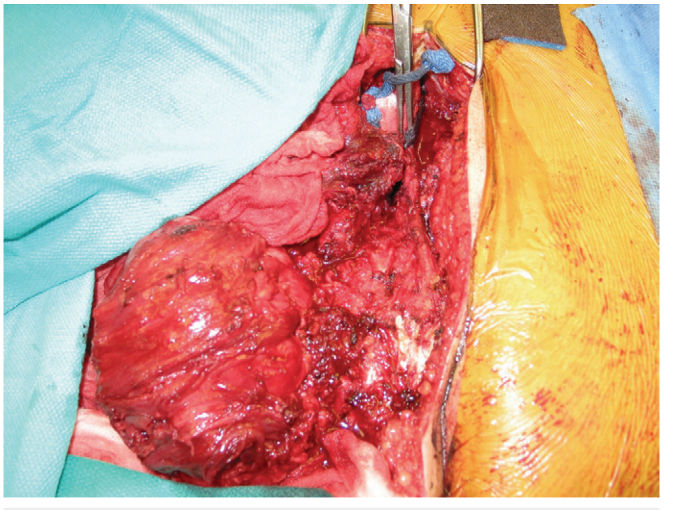

Figure 55-14 After the gluteus maximus muscle is dissected, the mass is exposed.

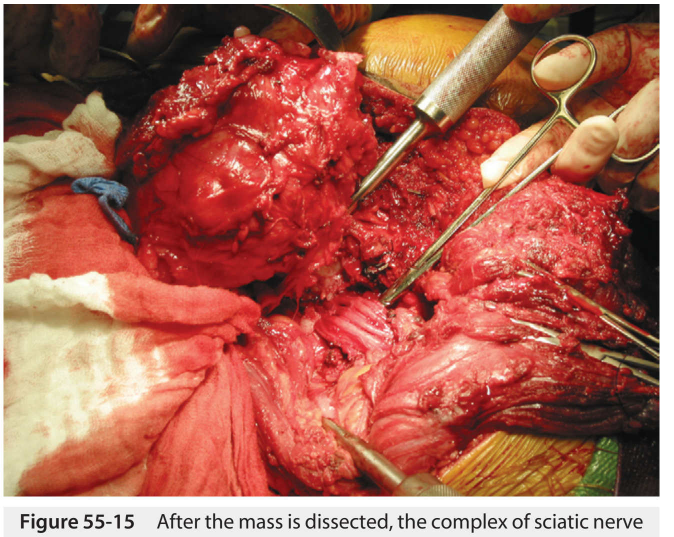

Figure 55-15 After the mass is dissected, the complex of sciatic nerve and inferior gluteal nerve is seen.

reflected to the lateral side (Fig. 55-14). Next, the piriformis muscle was divided. After the gluteus maximus muscle was retracted, the underlying mass was exposed. The tumor mass originated from the lower sacral bone and adjacent iliac bone. The mass was dissected from the surrounding muscle and underlying vascular structures. After the mass was dissected away, the underlying neural structures were found: the sciatic nerve, inferior gluteal nerve, and lateral femoral cutaneous nerve (Fig. 55-15). The mass was removed, including the destroyed left iliac bone (Fig. 55-16).

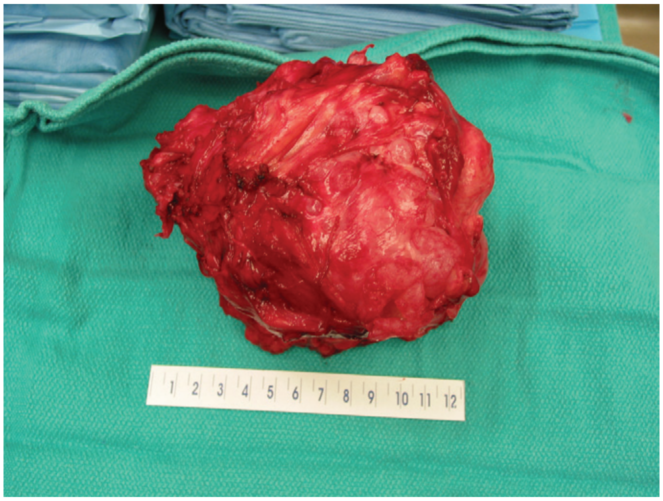

Figure 55-16 The mass was removed en bloc.

Sacral Reconstruction

Resection that involves more than 50% of the sacroiliac joint makes the pelvis unstable, but reconstruction is necessary to restore continuity of the spine and pelvic ring. Various reconstruction methods after total sacrectomy include the use of sacral bars to connect the plates, vertical Galveston rods attached to cross-connecting spinal rods, a threaded transiliac rod, and the use of a custom-made sacral prosthesis.

MODIFIED GALVESTON TECHNIQUE

A bilateral pedicle screw fixation is first done at L3–L5. The portal of entry is the posterior superior iliac spine (PSIS),[7,8] which is directly lateral to the second dorsal foramen of the sacrum. The PSIS is removed with a large rongeur to the level of the sacrum (Fig. 55-17). The probe insertion is directed to a point 1.5 cm above the sciatic notch and between the two cortices of the ilium, and it is tapped into place with a mallet to a depth of 6 to 9 cm (Fig. 55-18). A finger on the outer table palpating the sciatic notch provides tactile landmarks to develop an intracortical path in the thick supraacetabular bone of the ilium. The probe is advanced by rotation into the thick bone (Fig. 55-19). The angle of insertion is usually 20 degrees lateral from the midline on the transverse plane and 30 to 35 degrees caudal to a horizontal plane (Fig. 55-20). A malleable template rod (wire) is inserted with rod contouring.

Rod Contouring

The Galveston rod is composed of three parts: the *spinal, sacral,* and *iliac* segments.[9] Using the tube benders, a 90 degree bend is made between the spinal and sacral segments. The second bending at the sacroiliac junction in the transverse plane depends on the left or right side orientation to the rod, matching the angle of the ilium, and sagittal plane contouring of the spinal segment of the rod. A 6 mm titanium rod is contoured to match the template rod (Fig. 55-21). The rod is inserted into the ilium to a depth of about 4 to 5 cm and is attached to the lumbar pedicle screws, and crosslinks are placed.

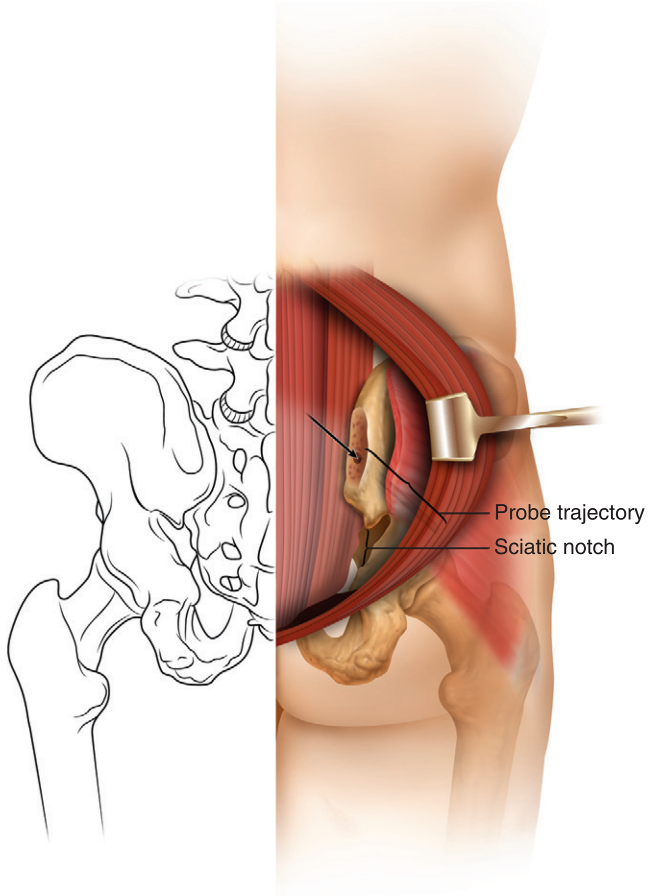

Figure 55-17 Entry point for iliac rod.

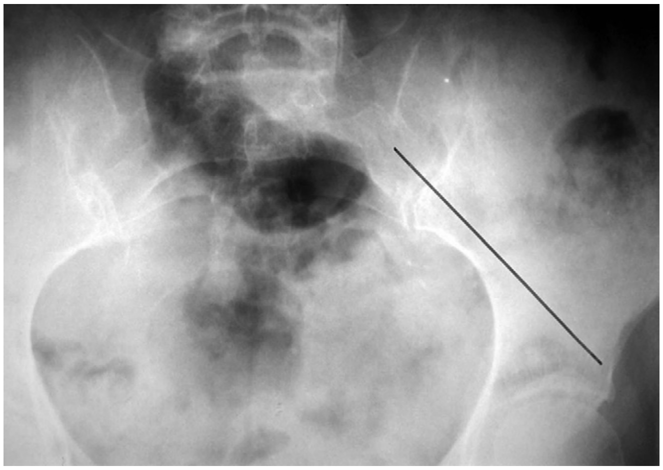

Figure 55-18 Insertion angle of the iliac rod.

DOUBLE ILIAC SCREW FIXATION WITH LUMBAR SEGMENTAL FIXATION

The iliac screw entry points are identified by resecting the PSIS with a curved osteotome (Fig. 55-22).[10] The posterior superior iliac crest should be flush with the sacrum, which places the iliac foundation more anteriorly and improves the soft tissue coverage over the ilium. The resection results

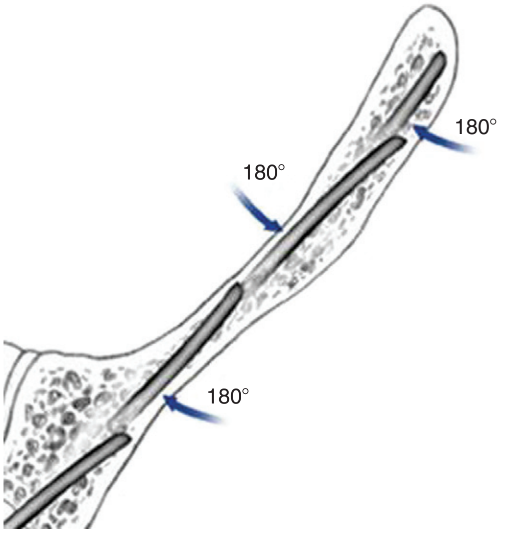

Figure 55-19 Rotation method of iliac rod advancement.

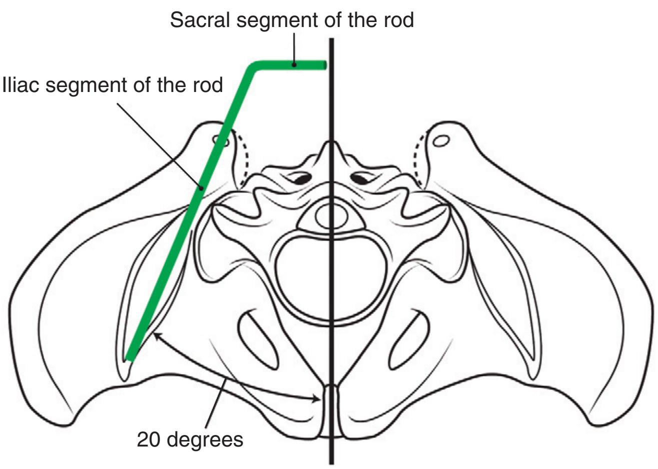

Figure 55-20 Axial view shows the insertion angle of the iliac rod.

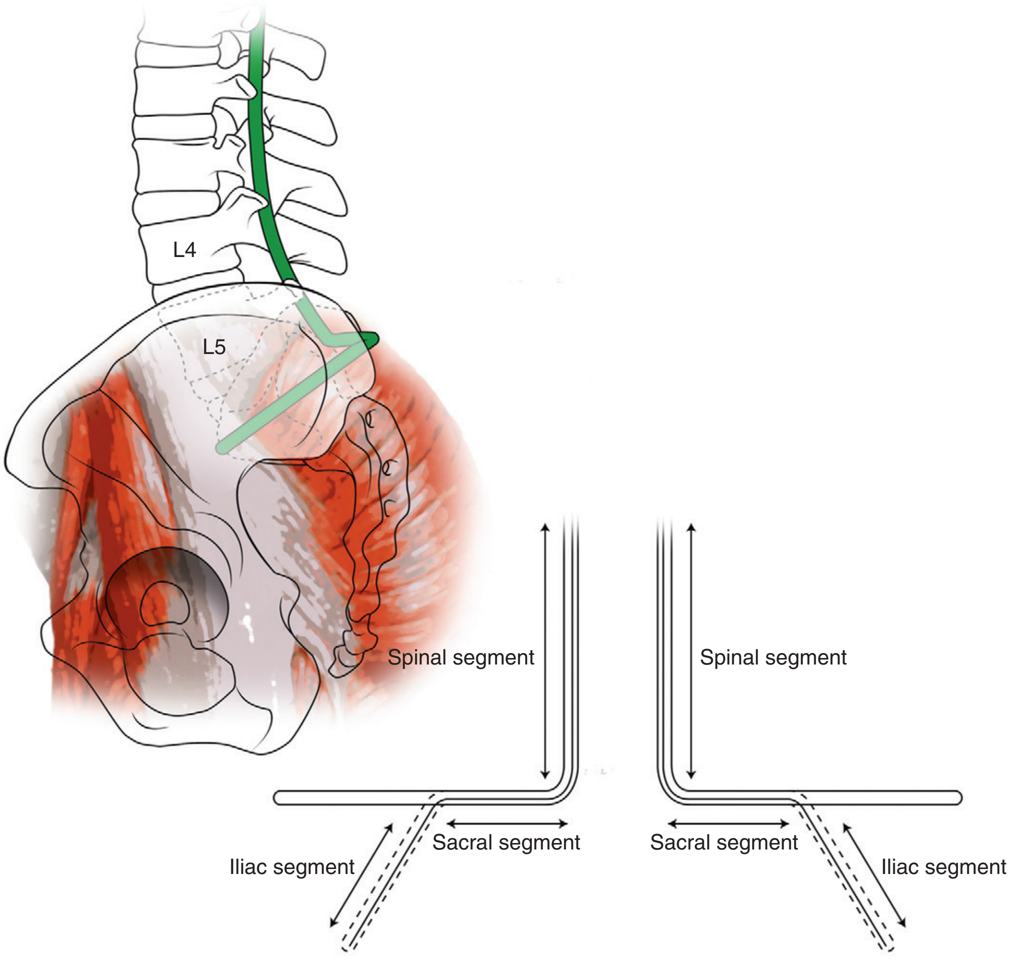

Figure 55-21 The bending angle of the Galveston rod.

in an oval-shaped cancellous starting point for both the superior and inferior iliac screws.

With the fingertip of the opposite hand in the superior aspect of the sciatic notch, the iliac starter probe is introduced into the inferior portion of the oval cancellous area and is inserted between the two cortical plates of the ilium. The iliac probe is then advanced further between the two cortical plates of the ilium to just above the sciatic notch. The inferior iliac screw path is tapped, and the iliac screw is inserted into the inferior ilium. The inferior iliac screw

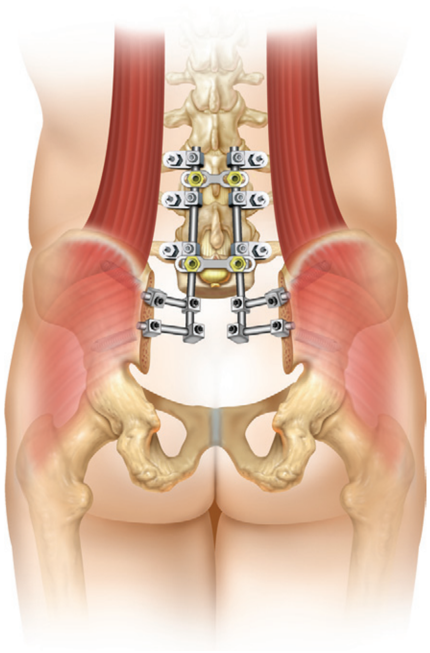

Figure 55-22 Double iliac screw.

Figure 55-23 Preoperative anteroposterior view of an osteolytic lesion.

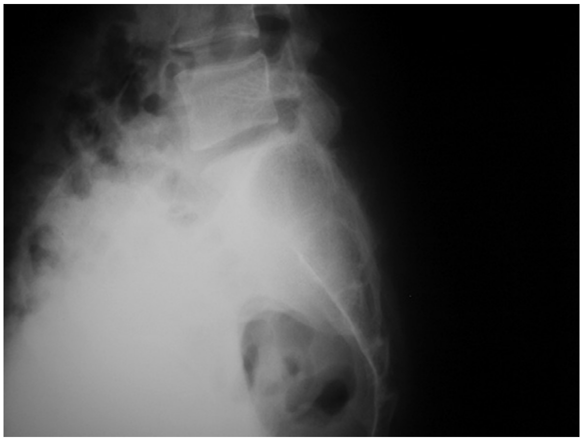

Figure 55-24 Preoperative lateral view of an osteolytic lesion.

must be long enough to endure weight loading and is 70 to 75 mm in length.

The second iliac screw insertion site is identified at the superior end of the oval cancellous area. An iliac starter probe is inserted into the superior end of the oval cancellous regions with a slight cephalad inclination. The iliac probe is then inserted to widen the path in the ilium. The superior iliac screw path is tapped, and the iliac screw is inserted into the superior ilium with a slight cephalad inclination.

Case Illustration

Case 1

A sacral chordoma patient came to medical attention with back pain and bilateral leg pain. A radiograph was taken upon initial examination, and an osteolytic lesion was seen on the S1 vertebral body (Figs. 55-23 and 55-24). The tumor mass shows low signal intensity on the T1-weighted image and high signal intensity on the T2-weighted image (Figs. 55-25 and 55-26). It grew circumferentially to compress the cauda equina (Fig. 55-27). On angiography, feeding vessels were seen from both iliac arteries (Fig. 55-28).

After a ventral removal of the tumor mass, double iliac screw fixation was done posteriorly (Figs. 55-29 and 55-30). Pedicle screws were inserted in bilateral L4 and L5, and two iliac screws were inserted into the right ilium and one into the left ilium (Figs. 55-31 and 55-32).

Case 2

This is another type of double iliac screw; the rod is L-shaped (Fig. 55-33). Two iliac screws are connected with a short, straight rod. The L-shaped rod and the straight rod are connected (Figs. 55-34 and 55-35).

TRIANGULAR FRAME RECONSTRUCTION

After placement of pedicle screws into the L3–L5 vertebral bodies, the spinal column is pulled down, and L5 is affixed to the bilateral ilium; this is done with sacral rods in the L5 vertebral body and by spinal instrumentation connecting the spine and the pelvis (Fig. 55-36).[10] This procedure is followed by massive bone grafts using autogenous fibulae and bone chips or cancellous allografts.

TRANSILIAC ROD PLACEMENT

Posterior transiliac rod insertion requires exposure of both outer tables of the ilia (Fig. 55-37).[11] The thoracolumbar fascia is incised along the posterior iliac crest and over the posterior spine. The gluteus maximus is released from the more medial aspect of the posterior iliac spine and thoracolumbar fascia and is reflected laterally. The entry point of the rod is approximately 2 cm lateral to the tip of the PSIS at the thickest part of the ilium and 2 cm above the greater sciatic notch. A hand drill is used to pass the bar through both iliac wings; the rod must be visualized as it passes

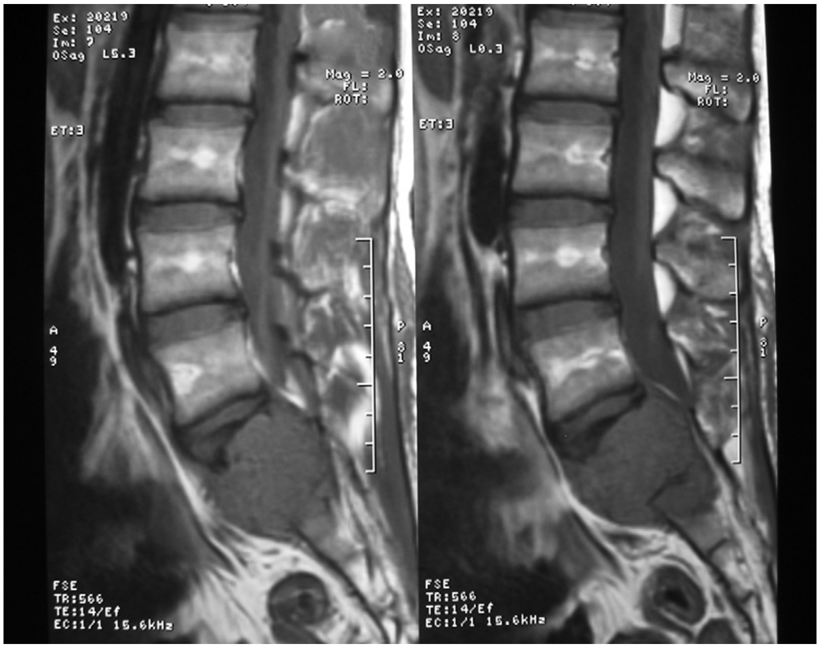

Figure 55-25 Low-signal upper sacral mass on T1-weighted sagittal magnetic resonance imaging.

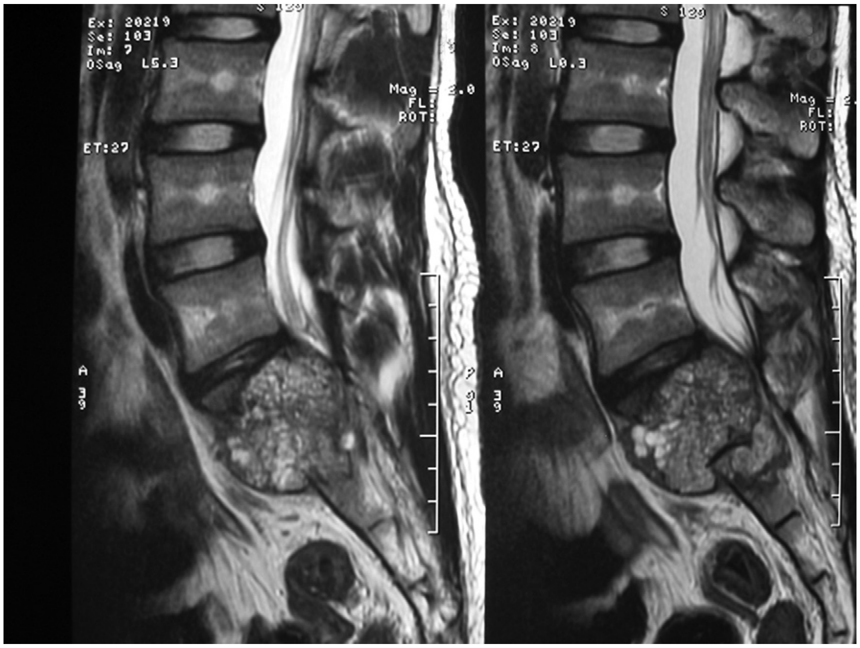

Figure 55-26 Low-signal upper sacral mass on T2-weighted sagittal magnetic resonance imaging.

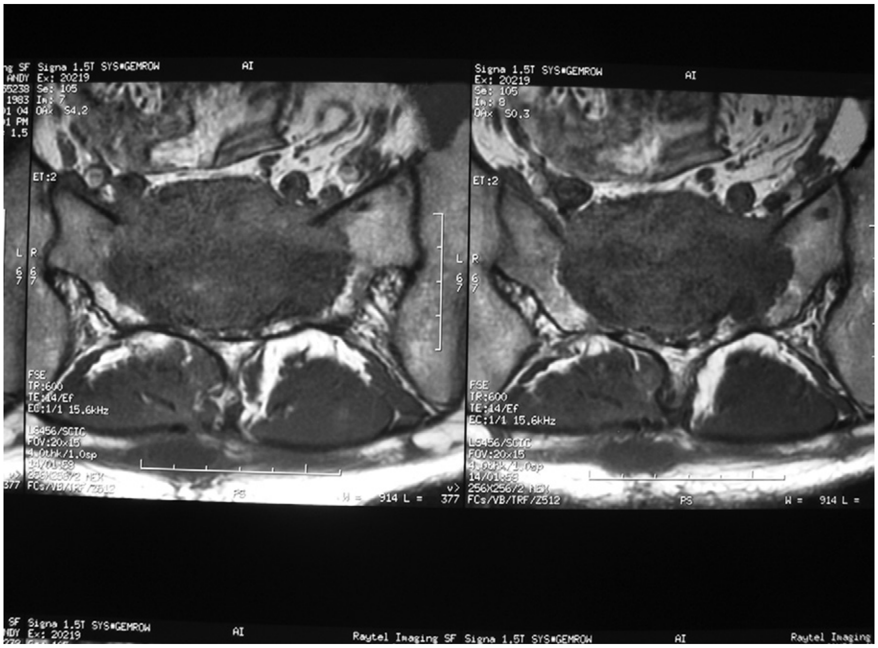

Figure 55-27 Axial view of upper sacral mass. Circumferentially bulging appearance and cauda equina compression are seen.

Figure 55-28 Angiographic appearance of sacral chordoma.

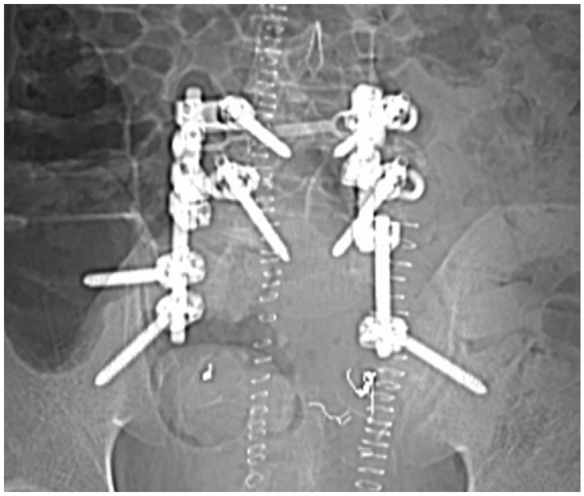

Figure 55-29 After total sacrectomy, double iliac screws are applied.

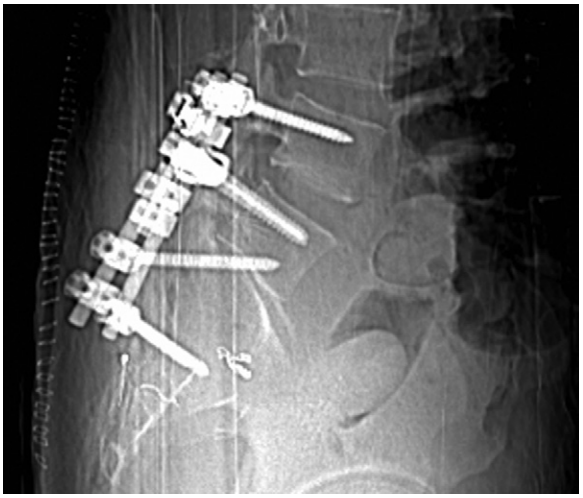

Figure 55-30 Lateral view of double iliac screw insertion.

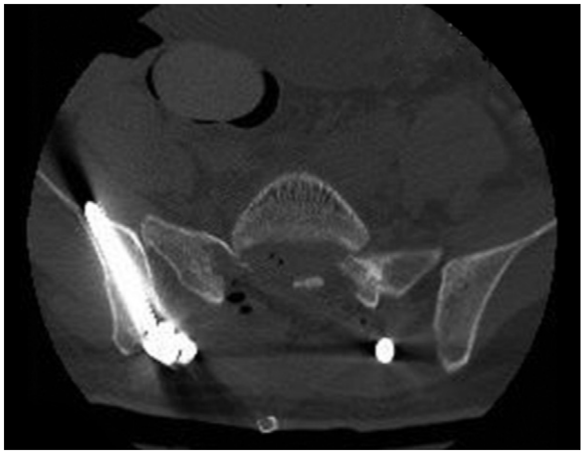

Figure 55-31 Computed tomography scan shows the direction of the upper iliac screw.

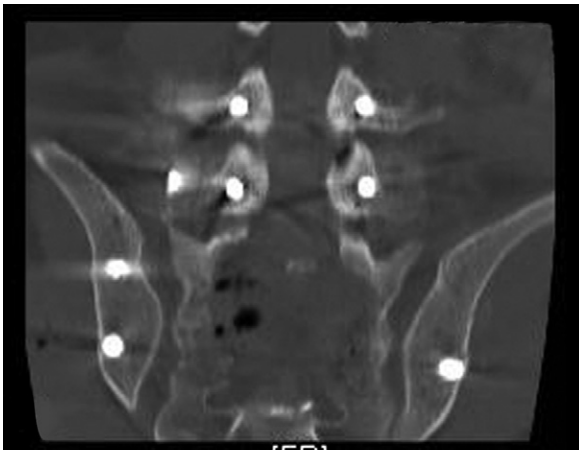

Figure 55-32 Coronal view confirms intracortical location of the iliac screws.

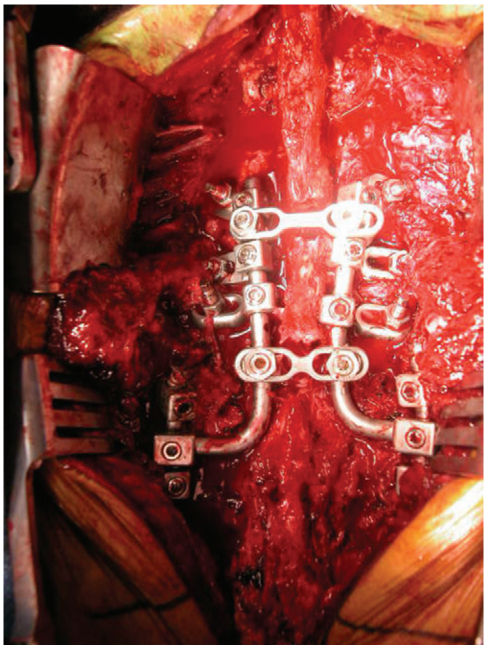

Figure 55-33 Operative view of lumbopelvic fixation.

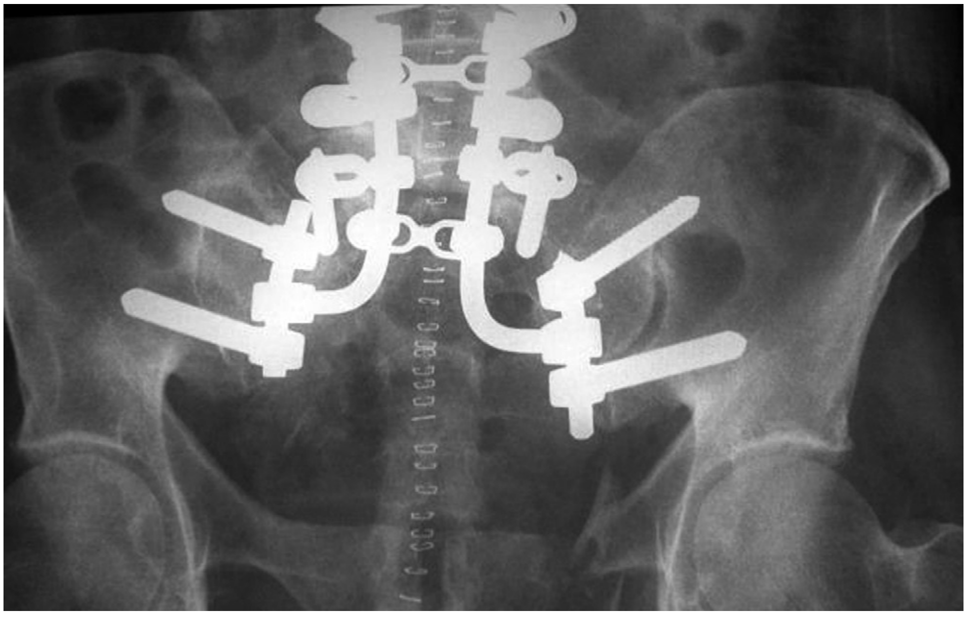

Figure 55-34 Anteroposterior view of the lumbopelvic fixation.

Figure 55-35 Lateral view of lumbopelvic fixation.

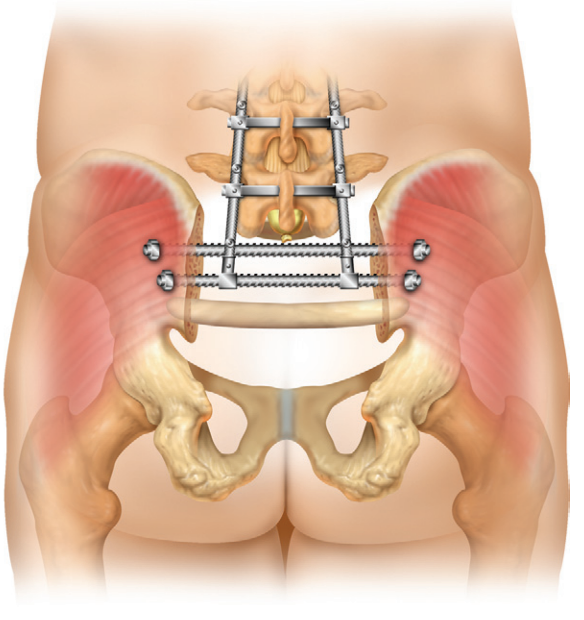

Figure 55-36 Triangular frame.

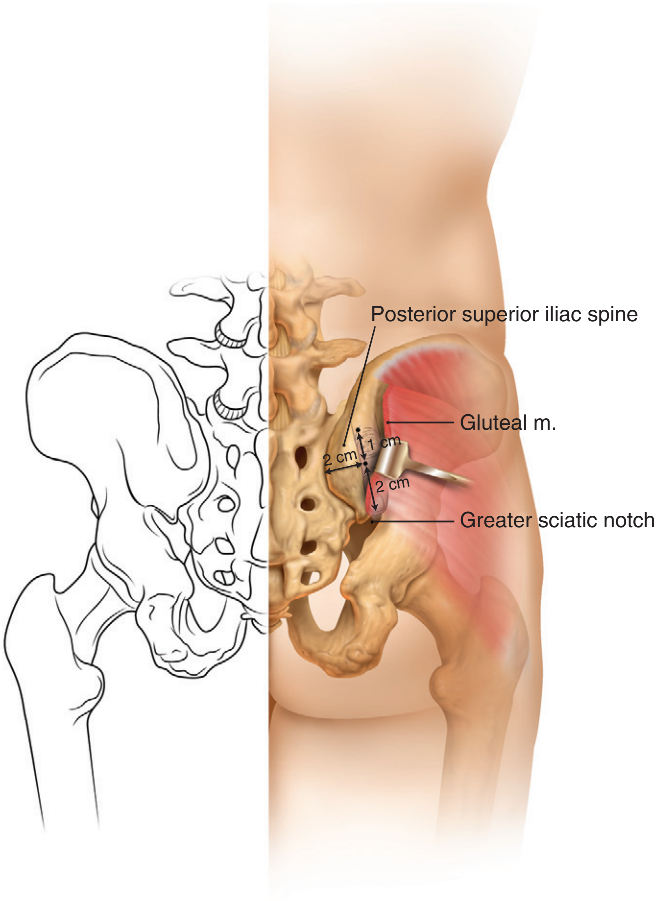

Figure 55-37 Dissection for the transiliac rod placement.

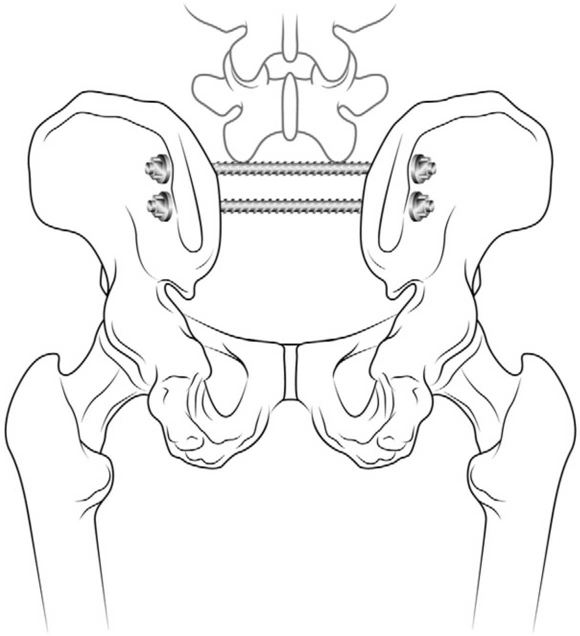

Figure 55-38 Transiliac rod placement.

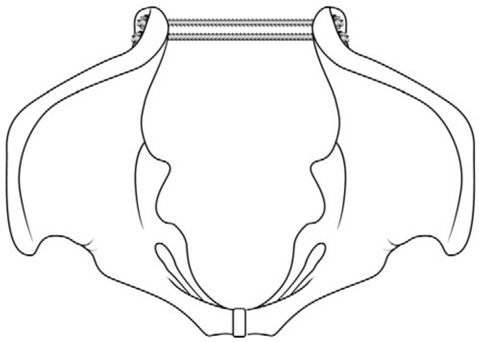

Figure 55-39 Axial view of transiliac rod.

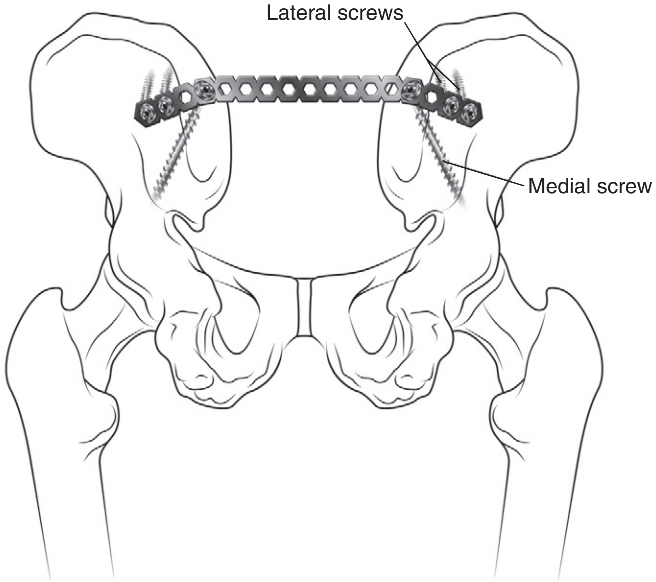

Figure 55-40 Posterior iliosacral plating, posterior view.

dorsal to the sacral lamina (Fig. 55-38). Posterior transiliac bar fixation requires two large rods to be placed through each posterior tubercle. The superior one is at the L5–S1 junction, and the inferior one is at the S2 level. The threaded sacral bars from the Harrington rod system (6.3 mm thick) are the most commonly used implant. After the rod is safely passed through both ilia, washers and nuts are applied to secure the rod in place, and the ends of the rod are then cut in situ (Fig. 55-39).

POSTERIOR ILIOSACRAL PLATING

Posterior iliosacral plating requires the same approach and exposure as for the placement of transiliac bars. A straight, 10 to 12 hole, 4.5 or 3.5 mm reconstruction plate is used (Fig. 55-40). The plate is secured to each iliac wing; the most medial screw is placed obliquely between the two tables. A 6.5-mm cortical screw (>80 mm) between the iliac tables provides excellent purchase. Two more screws are added on each side of the plate to further secure it to the ilium (Fig. 55-41). The screws on each side should be left loose and then sequentially tightened. The plate contoured across the posterior aspect of the sacrum is anchored to the iliac wings through the posterior tubercles in a tension band configuration. The optimal position of the plate is just below the posterior spine and just above the greater sciatic notch. The reconstruction plate is contoured in situ to the outer table of the iliac crest with the use of a pointed ball pusher and mallet. This plate can be used as a support for transiliac rods.

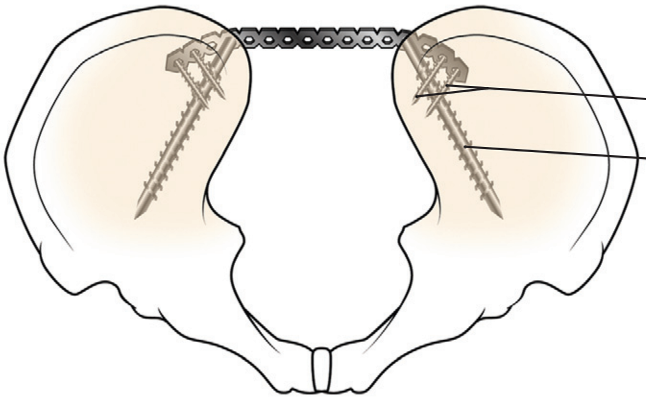

Figure 55-41 Posterior iliosacral plating, axial view.

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SECTION **F**

Spinal Deformity

56 Surgical Approaches to Cervical Kyphosis and Deformity

RAHUL BASHO, BECK DEAL MCALLISTER, BRANDON J. REBHOLZ and JEFFREY WANG

Overview

The delicate balance among the curves of the spinal column has allowed man to accomplish a unique feat among living organisms: upright bipedal ambulation. When examining human embryology, it is clear that the predominant curve of the nascent spinal column is one of kyphosis from the thoracic and sacral segments. The lordotic compensatory curves of the cervical and lumbar spines develop secondarily and allow for balancing of the occiput over the pelvis, a necessity for balanced upright gait. Any factors that alter the alignment of these curves, or their relationship to one another, has clinical consequences in regard to balance, ambulation, pain, and load sharing. The normal lordotic curvature of the cervical spine has been measured in various studies, but no general consensus exists on a range of "normal values." To measure the kyphosis in the cervical spine, a tangent is drawn to the posterior cortex of the most cephalad and caudad vertebral bodies of the curve, typically the C2 and C7 vertebral bodies. The angle formed by the intersection of these two tangents, theta, is the degree of cervical kyphosis (Fig. 56-1).

Gore and colleagues[1] evaluated the values of cervical kyphosis from C2 to C7 in osteoarthritis patients and found 16 to 22 degrees of lordosis in men and 15 to 25 degrees of lordosis in women. Ganju and colleagues[3] define normal values of cervical lordosis as being from 10 to 20 degrees. Irrespective of the true value, when evaluating the cervical segment, the global overall alignment of the patient's spinal column must be taken into account. A plumb line drawn from the C2 body and extended caudally should pass through the S1 body and rest just anterior to the S2 vertebral body (Fig. 56-2).

Biomechanical evaluation of the spinal column underscores the importance of both alignment and secondary stabilization structures. The vertebral bodies themselves primarily resist compressive forces and bear 36% of the axial load. The posterior bony elements, facet joints, and soft tissues resist predominantly tensile loads and bear approximately 64% of the axial load.[2] Loss of integrity of either one of these stabilizing structures results in altered load-bearing mechanics and eventual loss of normal sagittal alignment. When devoid of all osteoligamentous attachments, a cadaveric spinal column fails at much lower loads than those observed in vivo. During flexion, extension, and other activities of daily living, the forces in the cervical spine can approach 1200 N. Cadaveric studies have demonstrated failure of the cervical column with vertical loads of as little as 10 N when all osteoligamentous attachments are removed. To withstand these physiologic loads, the cervical spine must have anatomic alignment and intact musculature. This allows appropriate load bearing and distribution to occur. In the lordotic cervical spine, the weight-bearing axis of the head falls behind the vertebral bodies, thus decreasing energy expenditure by the paraspinal muscles.[3]

In the kyphotic cervical spine, the weight-bearing axis is translated anteriorly, and the force acting upon the spinal segments induces a bending movement. The increased forces acting upon the anterior column results in compression of the disks and places more stress upon the posterior tension band. Distribution of forces in this manner will result in continued worsening of kyphosis (Fig. 56-3).

Etiology

Because normal cervical lordosis depends on a delicate balance of forces and alignment between the anterior and posterior columns of the spine, disruption of either of these two regions can result in kyphotic alignment. The anterior column may lose its integrity as a result of trauma, tumor, spondylosis, spondyloarthropathies, or metabolic abnormalities. Patients with advanced spondylosis of the cervical spine will have collapse of their disk spaces and will gradually develop kyphosis, whereas changes in patients with a traumatic injury occur quite suddenly.

Postlaminectomy kyphosis is the most commonly encountered form of cervical kyphosis, and it results from complete disruption of the posterior tension band (Fig. 56-4). The incidence of postlaminectomy kyphosis has been reported from 6% to 30%.[4-8] Kaptain and colleagues[9] performed a retrospective review to examine patients who underwent cervical laminectomy for myelopathy and found an overall incidence of 21% for postlaminectomy kyphosis within a 4-year follow-up period. Patients with preoperative loss of lordosis were twice as likely to develop postoperative kyphosis.

Clinical Presentation

Patients with cervical kyphosis typically present with complaints of shoulder and neck pain. This is due to the cervical and back musculature attempting to maintain sagittal alignment. In severe cases, patients may have difficulty with forward gaze and even swallowing. These patients will attempt to compensate through their lumbar spine, and

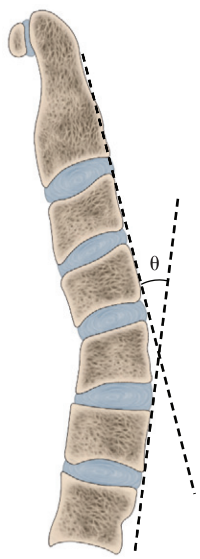

Figure 56-1 The degree of cervical kyphosis.

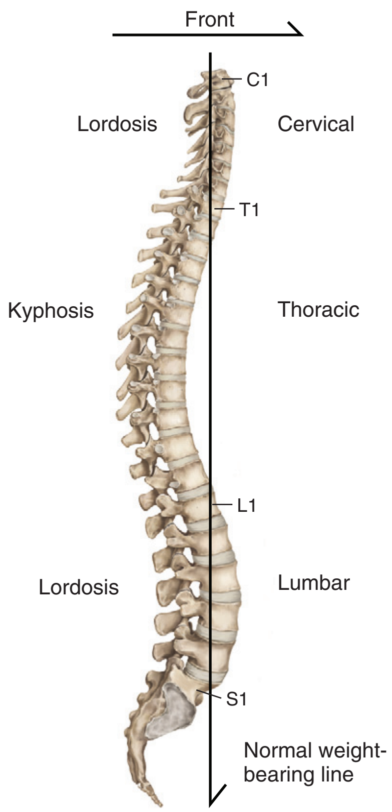

Figure 56-2 A plumb line drawn from the C2 body and extended caudally should pass through the S1 body and rest just anterior to the S2 vertebral body.

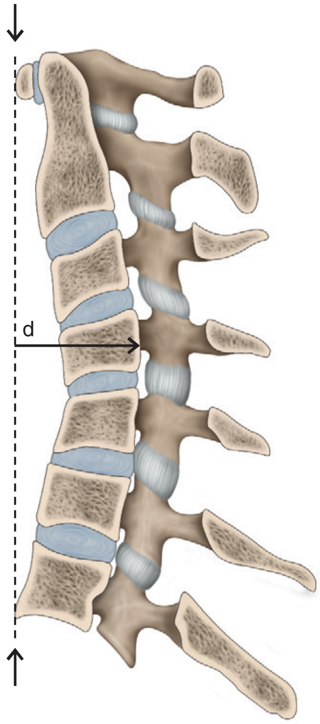

Figure 56-3 Distribution of forces will result in continued worsening of kyphosis. In a kyphotic spine, axial loads cause progression of the kyphosis through a bending moment (*d*) depicted above.

Figure 56-4 Postlaminectomy kyphosis.

lumbar hyperlordosis with concomitant lower back pain is often noted. The presence of cervical radiculopathy and myelopathy is variable, depending on the amount of kyphosis and spondylosis present. Kyphosis leads to draping of the ventral aspect of the spinal cord over the posterior aspect of the vertebral bodies. Studies show that kyphosis in the cervical spine leads to compression of microvascular feeding vessels to the spinal cord, potentially leading to the development of myelopathy.[10]

Clinical Evaluation

A complete neurovascular examination should be completed with emphasis on long-tract signs such as Hoffman or Babinski signs or clonus. A detailed and complete radiographic workup is essential to determine key facts about the deformity, such as 1) the origin of the deformity, 2) the severity of the curve, and 3) the flexibility of the deformity and whether it corrects passively. All of this information is essential for surgical planning, and the answers to these questions help determine whether the surgical approach should be anterior, posterior, or a combined intervention.

Initial films should include anteroposterior (AP), lateral, and flexion-extension views of the cervical spine. These dynamic radiographs are of utmost importance, as they allow determination of whether the deformity is fixed or mobile. The patient's global sagittal alignment should be evaluated with a full-length standing lateral radiograph. In patients with severe kyphosis, we position them supine on an examination table to assess whether the deformity will correct passively and to what degree. In addition, a thin-slice CT scan of the cervical spine should be obtained to evaluate the facet joints posteriorly. If the facet joints are ankylosed, this will likely necessitate some form of posterior intervention. An MRI scan of the cervical spine should be included to assess for any pressure on the spinal cord and neural elements. The presence of large anterior osteophytes will typically require anterior intervention.

Surgical Indications

No firm surgical indications exist for patients with cervical kyphosis. Because not all patients with this condition require surgical intervention, the clinician must adeptly extract and synthesize key information from the history, physical exam, and imaging studies. These key pieces of information allow tailoring of an individualized treatment plan for each patient. In our experience, the presence of myelopathy, radiculopathy refractory to conservative treatment, or progressive deformity with worsening clinical symptoms are all indications for surgical intervention. Patients with severe deformity that interferes with their activities of daily living should also be closely evaluated for surgical intervention.

Surgical Approach: Anterior, Posterior, or Combined?

Once the decision has been made for surgical intervention, the decision for an anterior, posterior, or combined approach must be addressed. Much of this hinges on the key details about the deformity.

- *What is the origin of the deformity?* Anterior column integrity can be compromised by tumor, trauma, or multilevel spondylosis. A deficient anterior column will require an anterior approach. Patients with postlaminectomy kyphosis have a deficient posterior tension band.
- *Are neural elements compressed ventrally?* Ventral compression on the spinal cord and neural elements will likely need to be addressed anteriorly.
- *Is the deformity passively correctable?* This key piece of information must be gleaned not only from the dynamic radiographs but also by having the patient lie supine. A kyphotic cervical spine that corrects passively can be addressed entirely from a posterior approach.
- *Are the facet joints ankylosed posteriorly?* A rigid deformity with ankylosed posterior joints will likely require a combined AP approach.

The answers to the aforementioned questions permit a stepwise approach to surgical decision making. A rigid deformity with no ankylosis of the posterior facets can be addressed anteriorly. If the deformity is rigid, and the facets are ankylosed posteriorly, a combined AP approach will be necessary. Lastly, in the absence of ventral compression, a passively correctable deformity can be addressed posteriorly alone. The flowchart shown in Figure 56-5 demonstrates this in algorithmic format.

Surgical Techniques

ANTERIOR APPROACH

The utility of the anterior approach to the cervical spine has expanded since its introduction in the 1950s by Smith and Robinson.[11,12] Advances in spinal fixation have allowed surgeons to treat more complex spinal pathology through more limited approaches. The primary indication for ventral-only cervical kyphosis deformity correction is a fixed deformity without ankylosis of the posterior facet joints.

The anterior approach offers several advantages to the surgeon: direct access to the ventral spinal cord is available to decompress the spinal column, and ankylosed segments can be directly released ventrally, assuming the posterior facet is mobile. The anterior approach offers the ability to correct the deformity with reconstruction of the load-bearing anterior column. The anterior approach is associated with less morbidity and mortality than the combined anterior and posterior approach.[13] In cases of postlaminectomy kyphosis, the anterior approach avoids the surgical risk of exposure and instrumentation with an exposed spinal cord. The major disadvantages of this approach are less kyphotic deformity correction than combined approaches,[14-18] loss of correction,[19] graft-related complications, and approach-related complications. In general, the approach is implemented when the posterior facets are not fused.

Anterior Surgical Technique

The patient is positioned supine on a radiolucent table that provides radiographic evaluation of all planned surgical segments. The patient is intubated with the assistance of fiberoptic guidance to reduce the amount of cervical extension prior to decompression. Our current practice is to perform the procedure with neuromonitoring. A roll is placed under the patient's shoulders, and a donut roll is placed under the head with several towels. This allows for varying amounts of extension to be attained after decompression is performed.

The cervical spine is approached by standard methods, utilizing either an oblique incision along the anterior sternocleidomastoid or a transverse incision. The decompression is performed with diskectomy, corpectomy, or a

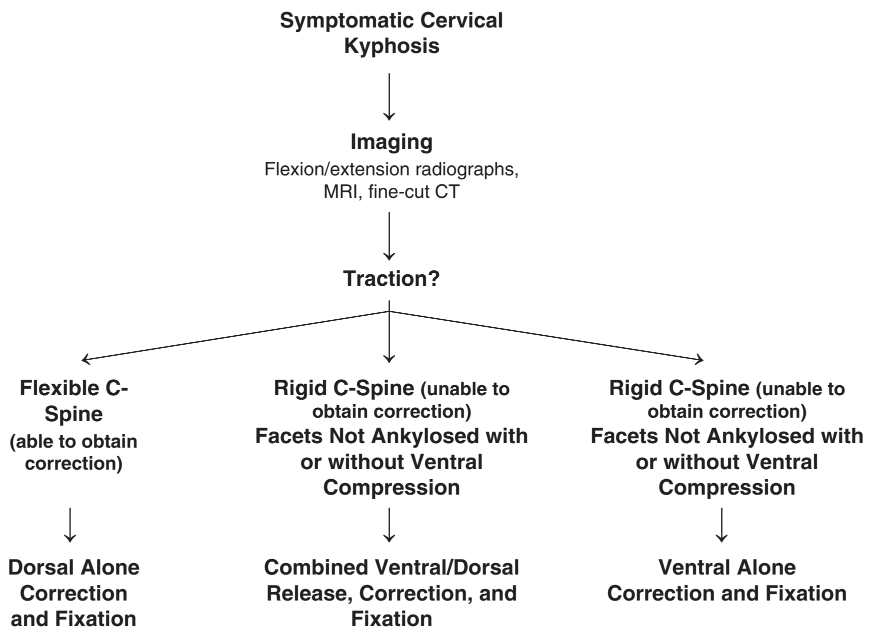

Figure 56-5 Algorithm for surgical approach.

combination based on preoperative imaging. It is paramount to adequately release the uncovertebral joints and to ensure mobility of the posterior facets prior to attempting correction of the deformity. If present, intermediate vertebral bodies should be left during the decompression to provide intervening points of fixation during reconstruction. As described by Steinmetz and colleagues,[20] an intermediate vertebral body is a vertebral body that has cerebrospinal fluid present posterior to the vertebral body on T2-weighted MRI sagittal imaging. This implies a lack of compression at this level, and the vertebral body may be left for additional fixation.

After decompression and anterior release is complete, attention can be turned to kyphotic deformity correction. The previously placed towels or donuts are removed to increase cervical lordosis. Distraction posts are then placed in a convergent manner, such that as distraction is performed, the cervical spine is corrected into a lordotic position (Fig. 56-6).

The posterior longitudinal ligament (PLL) may be left intact as long as no disk fragments are evident that could cause spinal cord or nerve compression. The PLL can be used to aid in restoration of lordosis as the anterior column lengthens in relation to the posterior column.[21] Bone graft should be placed after contouring to maintain lordosis. In diskectomy, the graft should be trapezoidal in shape with the larger segment in the anterior cervical spine. Anterior cervical plating is generally from the most cephalad vertebral body to the most caudal vertebral body involved in the kyphotic deformity. The cervical plate is then secured first at the most cephalad and caudal vertebral body. If present, the intermediate vertebral bodies are then drawn to the implant, recreating cervical lordosis.[11,21] Steinmetz and colleagues[17] advocated the use of dynamic cervical plating in older populations. The advantage of dynamic plating is that it controls sagittal plane deformity while allowing for minimal subsidence in the axial plane. This decreases the stress on the construct, thereby decreasing graft- and plate-related complications.[17]

The wound is thoroughly irrigated and is closed over a small drain brought out through the incision. The patient is placed in a cervical orthosis prior to emergence from anesthesia. The patient may remain intubated overnight, depending on the length of the surgery and the number of levels involved. The cervical orthosis is typically kept for 6 to 8 weeks, depending on radiographic evidence of consolidation of the fusion mass. Cervical radiographs including AP, lateral, and flexion-extension views are obtained at 3 months to evaluate for pathologic motion.

Results

The current literature on anterior-alone treatment for cervical kyphotic deformity correction is composed entirely of retrospective reviews with a relatively small number of patients. Furthermore, available instrumentation has evolved over the last several decades, which has led to significantly different treatment modalities among the studies for the anterior-alone procedures.

Zdeblick and colleagues[14] published their results of 14 patients treated with fibular or iliac graft with a follow-up of 27.9 months. The reconstruction utilized placement of a graft into a 5 mm deep hole centered in the cephalad and caudal vertebral body. Postoperatively, cervical orthosis or a halo-vest was used for stabilization. The average preoperative kyphosis was 45 degrees, which was corrected postoperatively to 13 degrees, with final follow-up revealing 17 degrees of kyphosis (loss of 4 degrees). The average Nurick grade improved from 3.6 to 1.3 at follow-up, and 9 of 14 patients had complete neural function recovery. All patients demonstrated fusion on lateral radiographs with flexion and extension views.

Herman and Sonntag[15] reported on their results treating postlaminectomy kyphosis in 20 patients treated with anterior decompression, bone graft, and anterior cervical plate.

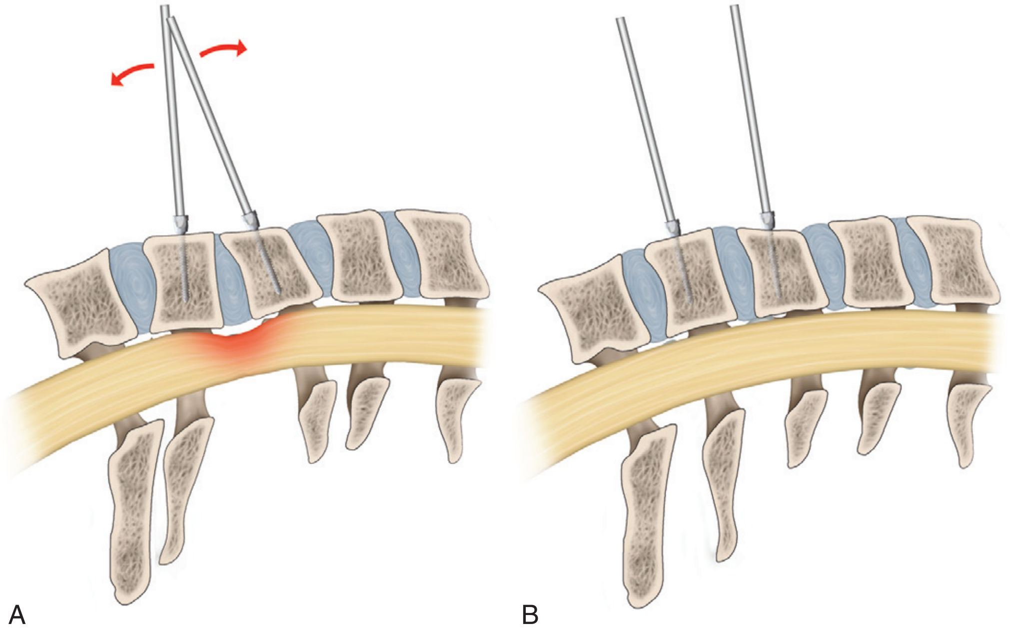

Figure 56-6 **A,** A kyphotic segment and resultant cord compression. Caspar pins are placed in a convergent manner. **B,** Distraction of these pins results in correction of kyphosis.

The mean preoperative kyphosis was 38 degrees, which was corrected postoperatively to 16 degrees of kyphosis. Complete resolution of preoperative symptoms occurred in 10%, and improvement in pain and neurologic function occurred in 55%. Pain improved in 30% of the patients without change in neurologic function. One patient (5%) developed late progressive neurologic symptoms.

Steinmetz and colleagues[17] treated cervical kyphosis with anterior decompression, reconstruction, and dynamic cervical plating in all but two young patients. The average preoperative kyphotic angle was 13 degrees, and the authors were able to obtain a mean of 20 degrees of correction; postoperative measurement averaged 6 degrees of lordosis. Over the follow-up period, an average of only 2.2 degrees of lordosis was lost. Clinical improvement was found in all patients, three of whom had complete resolution of their symptoms. All 10 patients went on to achieve osseous union.

Ferch and colleagues[16] presented their results in 26 of 28 patients treated for cervical kyphosis with a minimum of 18 months follow-up (2 patients died before 18-month follow-up). Cervical kyphosis was addressed with anterior decompression, reconstruction with strut grafts, and static anterior cervical plating. The preoperative local kyphosis was 12 degrees, and postoperative local lordosis of 2 degrees was obtained. Improvement in myelopathy scores, assessed by the modified Japanese Orthopaedic Association Myelopathy Scale, occurred in 41% of patients. No improvement occurred in 56% of patients, and one patient (4%) experienced deterioration. The authors noted that the patient who suffered deterioration was the only patient in whom more that 20 degrees of local correction was attempted. The overall pain scores were not different preoperatively and postoperatively.

Park and colleagues[22] were able to correct preoperative kyphosis by an average of 20.9 degrees to 14.0 degrees of lordosis, with final follow-up showing 9.6 degrees of lordosis in patients with postlaminectomy cervical kyphosis. The treatment consisted of anterior decompression, anterior reconstruction, and placement of a static anterior cervical plate. The mean angle of correction was 30.5 degrees. Improvement of neck disability index, visual analog scale, and Nurick grades was 27.09 to 10.48, 6.22 to 2.3, and 2.52 to 1.04, respectively.

Complications

Zdeblick and colleagues[14] reported that 3 of 14 patients had graft-related complications with dislodgement. The graft dislocations required revision surgery in two of the patients (2/14, or 14.3%). The mortality rate was 14.3%, but the two deaths were not related to the surgical procedure itself. Riew and colleagues[8] reported specifically on the short-term complications of anterior cervical corpectomy in postlaminectomy patients. In this series of 18 patients, a graft-related complication rate of 50% occurred when counting for extrusion, collapse, pseudarthrosis, or progressive kyphosis. The purpose of this paper was to highlight that postoperative immobilization in a halo-vest did not prevent graft-related complications. It is noteworthy that none of the 18 patients were treated with anterior cervical plating techniques. Herman and Sonntag[5] reported vocal cord paresis (15%), pneumonia (10%), deep vein thrombosis (5%), reintubation (5%), graft site wound dehiscence revision (5%), and screw pullout (5%) treated successfully with revision screw and halo vest orthosis for 2 months. Steinmetz and colleagues[7] reported one transient complication of feeling a "lump in the throat" that completely resolved by 6 months. The two long-term complications were of hoarseness in the patient's voice. No graft-related complications were reported in this series. Ferch and colleagues[16] reported two deaths (7%), two patients with prolonged dysphagia (7%), one infection (4%), one hardware loosening (4%), and one persistent neural compression (4%). Park and colleagues[22] had a complication rate of 30.4% in 26% of patients treated. Graft-related complications comprised 14.3% of the complications that included implant displacement, graft dislodgement, and pseudoarthrosis. Other complications included swallowing difficulty, wound infection, dural tear, and pneumonia. Overall, the implementation of anterior cervical plating has helped to decrease graft-related complications; however, this has created the possibility of hardware-related loosening as demonstrated in several series.

Current Practice

The author's current practice is to perform a stand-alone anterior procedure for fixed cervical kyphosis without evidence of posterior facet ankylosis. Careful preoperative evaluation is performed with cervical AP, lateral, flexion-extension, CT, and MR imaging. Attention is focused on levels that need decompression and intermediate vertebral bodies available for supplemental fixation. Reconstruction of the vertebral column is performed with the use of iliac crest or fibular strut graft (greater than two-level corpectomy) with implementation of a dynamic cervical plate for fixation. Cervical orthosis is worn for 6 to 8 weeks postoperatively.

COMBINED ANTERIOR-POSTERIOR APPROACH

A combined AP surgical approach is primarily indicated in patients with fixed cervical kyphosis and ankylosed facet joints. This disease pattern typically prevents adequate decompression and deformity correction through a single approach. Additional consideration for a combined AP approach is given in patients whose deformity involves the cervicothoracic junction, given the physiologic stresses that occur across this transitional area of the spine.[23] To minimize risk of pseudarthrosis and loss of correction, other authors prefer the combined approach when there is a multilevel kyphotic deformity.[24] The combined approach has the potential to decompress the neural elements both anteriorly and posteriorly, to control correction with focused osteotomies as necessary, and to provide rigid internal fixation in a 360 degree fashion.

When considering a combined approach, it is imperative that the goals of surgery and the predominant pathologic features are clearly defined in each individual case. This will allow for optimal sequencing of the overall surgical procedure. Many techniques have been described for the combined approaches, depending upon the specific clinical scenario and surgeon preference. Location of both spinal cord compression and ankylosis, along with extent of kyphosis, need be considered in sequence planning. Regardless of technique, the overall goals are decompression of the neural elements and restoration of sagittal balance. This is essentially achieved through the lengthening of the anterior column and shortening of the posterior column.

Anterior-Posterior Surgical Technique

The surgical sequence is typically anterior–posterior or posterior–anterior–posterior, although posterior–anterior and anterior–posterior–anterior have all been described.[25] Most surgeons prefer that final correction be carried out posteriorly, because this ensures adequate decompression of both the spinal cord and nerve roots at the time of final alignment and fixation. There is a theoretic risk of anterior graft loosening when finishing with the posterior approach, but this has not been observed clinically.[24,25]

Intraoperative neurologic monitoring is performed through the use of somatosensory evoked potentials (SSEPs) and transcranial motor-evoked potentials (TcMEPs). Awake fiberoptic intubation is preferred, although some authors advocate the use of preoperative and intraoperative traction, because there may be correction of the deformity, even if it is not complete.[24] The head and neck must be supported appropriately during the anterior approach, because the deformity typically prevents standard supine positioning. The arms are secured at the patient's sides with gentle traction to facilitate adequate fluoroscopic visualization.

Depending on the number and location of the levels to be addressed anteriorly, a transverse or longitudinal incision may be used. Decompression is performed using diskectomies, corpectomies, or a combination thereof. If the cervical spine is significantly ankylosed, osteotomies must be carried far enough laterally through the uncinate processes to ensure complete anterior release.[25] In cases where the osteotomy must be performed at a focal area of kyphosis, skeletonization of the vertebral artery can be considered to limit the risk of kinking during subsequent correction of the kyphosis.

Instrumented fusion is performed with the use of grafts or cages and a plate. Fusion is augmented with the use of local or remote autograft and/or allograft. Use of bone morphogenetic protein is controversial; because it carries the potential for catastrophic airway compromise, it is not recommended in the cervical spine and is not approved for such applications. A soft drain is left in place, and the wound is closed in the standard layered fashion.

If the anterior surgical correction afforded by multilevel diskectomies or corpectomies provides a significant correction, it may obviate the need for additional osteotomies. In that case, the posterior approach may be performed simply to reinforce the posterior tension band and back up the anterior instrumented fusion with a posterior instrumented fusion.[26] However, more severely rigid kyphotic deformities may require posterior osteotomies. If posterior osteotomies are necessary, they can be performed either at the levels of maximal kyphotic deformity or at the cervicothoracic junction. These posterior osteotomies have the added risk of kinking of the vertebral artery during correction in addition to the risk of neurologic injury. Simmons[27] described the ideal location for osteotomy at the C7 level, where the vertebral artery remains anterior to the transverse processes; the canal is large relative to the cord, limiting potential for injury, and neurologic injury at this level can still allow for meaningful upper extremity function.

To perform the posterior approach, the patient is repositioned prone with the head held in position using the Mayfield tongs. Again, the arms are positioned at the patient's sides with gentle traction to facilitate adequate imaging. A standard midline approach to the cervical spine is performed with subperiosteal dissection to expose the lateral edge of the lateral masses and facet joints. The posterior construct and fusion needs to extend far enough cephalad and caudad to maintain the correction and limit the risk of failure or junctional kyphosis, typically at least one to two levels above or below the osteotomies or deformity. Typical posterior osteotomy options include limited facet osteotomies, Smith-Peterson osteotomies, pedicle subtraction osteotomies, or posterior extension osteotomy as originally described by Urist (Fig. 56-7).[28]

The type of osteotomy chosen should be individualized to the patient's pathology. By performing osteotomies over several levels centered over the area of the kyphosis, gradual correction and substantial correction can be achieved with favorable results.[25] Again, if the correction is too abrupt, there is potential for vertebral artery kinking, which may require anterior skeletonization.

When performing the correction, it is imperative to carefully decompress the nerve roots at the area of extension and to vigilantly monitor spinal cord function. Correction often requires a cosurgeon to unlock the Mayfield tongs and manipulate the head, while the other surgeon maintains a sterile field, directly observing the spine. Meticulous spinal cord monitoring should be performed during correction, and any change in function requires cessation of the correction and return to previous positioning.

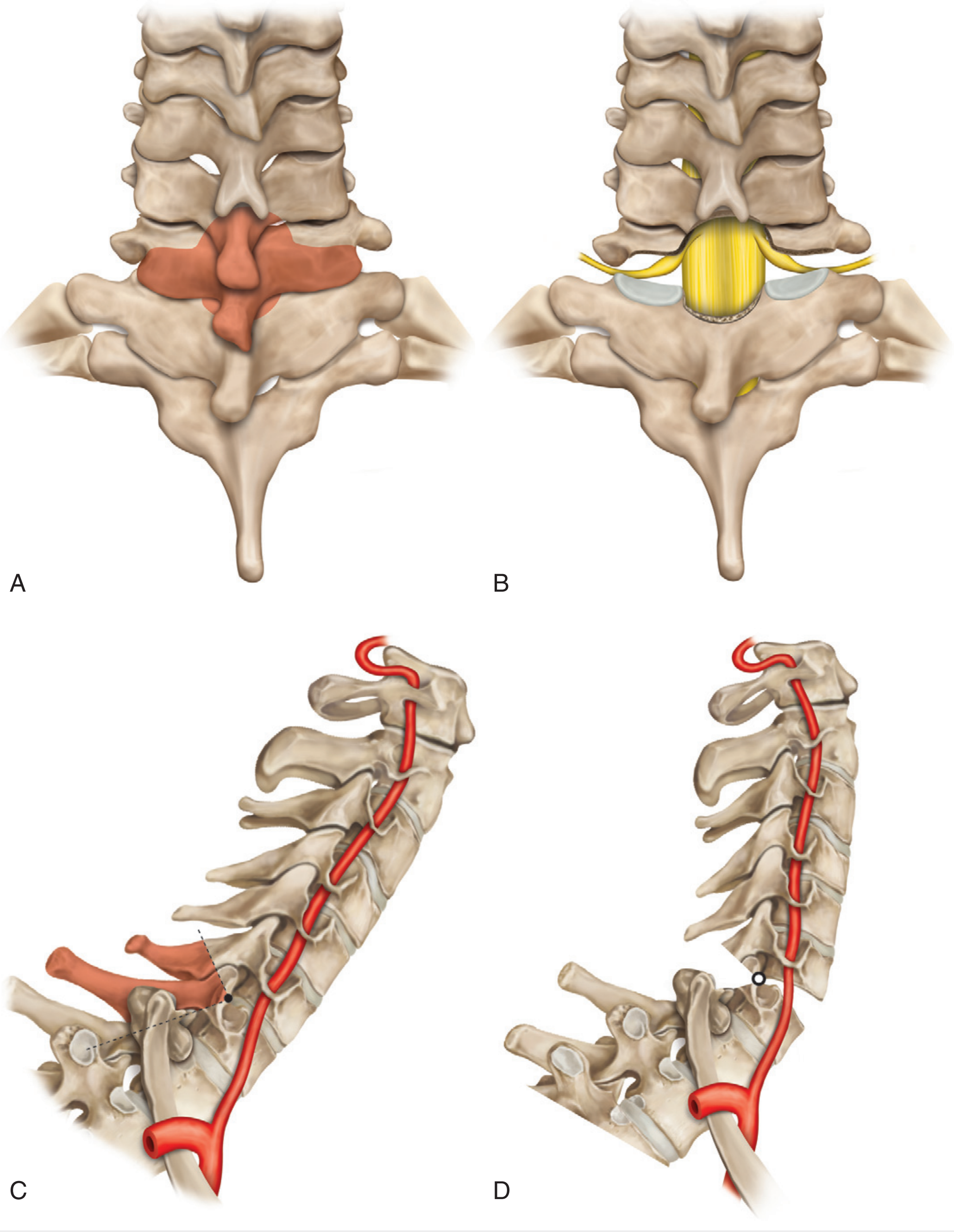

Figure 56-7 Osteotomy options. **A,** The area shaded in red depicts the posterior elements to be removed for correction of kyphosis. **B,** Exposed neural elements after removal of posterior elements. **C,** Lateral view of posterior elements to be removed. **D,** Cervical spine can then be extended about a point (*open circle*) to correct the deformity.

Once correction is complete, the head is again locked in position in the Mayfield tongs. At this point segmental instrumentation can be carried out; this is typically performed using lateral mass or pedicle screws and rods in the subaxial cervical spine and pedicle screws or hooks and rods in the thoracic spine. Bone grafting is typically performed after decortication, using local or remote autograft and/or allograft. Some surgeons will additionally use bone morphogenetic protein, however this is again controversial. A soft drain is placed deep to the fascia, and the wound is closed in a standard layered fashion.

Results

Outcomes for the combined approach are generally favorable for correction and fusion, but this can come at the cost of increased complication risk when compared with a single approach. Mummaneni and colleagues[24] retrospectively reviewed 30 patients with cervical kyphotic deformity who underwent circumferential correction with an average follow-up of 2.6 years. Anterior procedures included diskectomies, corpectomies, and osteotomies at one or more levels with fusion, while posterior operations included decompression and/or osteotomies with lateral mass or pedicle screw fixation. The overall complication rate was 33.3%, and two patients died within 1 month of surgery. Clinical improvement was demonstrated in measured Ishihara indices, Nurick grade, and mean Japanese Orthopaedic Association scores. Fusion rates were 95%, with only one nonunion in a patient with renal disease and osteoporosis.

O'Shaughnessy and colleagues[25] reviewed 16 patients treated surgically for fixed cervical kyphosis and myelopathy followed for a mean of 4.5 years using patient-specific combined approaches. The mean preoperative cervical Cobb angle from C2 to C7 was −38 degrees and improved to 10 degrees at final follow-up, yielding an average correction of 48 degrees. The mean Nurick score improved from 2.4 before surgery to 1.5 at the time of follow-up. According to Odom criteria, outcomes were excellent in 38%, good in 50%, fair in 6%, and poor in 6%. Solid bony arthrodesis and maintenance of correction occurred in all patients, although one patient with severe renal osteodystrophy had a late hardware failure that required revision.

In their review of the literature, Han and colleagues[29] compared the anterior approach alone to a combined approach for the correction of cervical kyphosis and determined that the combined strategy resulted in a greater correction of the deformity and was more likely to restore lordosis. However, the combined procedure involved a higher rate of postoperative neurologic deterioration, complications, revision surgery, and mortality when compared with an anterior-alone approach.

Complications

The common complications of the individual anterior and posterior approaches are implicit in the combined procedures. In their literature analysis of four studies that involved 92 patients who underwent combined corrections of cervical kyphosis, Han and colleagues[29] noted a complication rate of 48.9%. The most common complications were related to dysphagia or dyspnea that resulted in gastrostomy or tracheostomy, respectively (12%); perioperative mortality (7.9%); progression of deformity (4.3%); radicular symptoms (4.3%); and wound dehiscence (4.3%). Other reported complications include durotomy, wound infections, pseudarthrosis, quadriparesis, quadriplegia, construct failure, and dysphonia. Similarly, Hart and colleagues[30] retrospectively evaluated 13 patients who underwent combined procedures across the cervicothoracic junction. They found that complications were common: 9 patients (69%) experienced at least one complication, and the most common complications were dysphagia (46%) and airway edema that required extended intubation (38%). When cervical extension osteotomies are performed, the additional risks of vertebral artery kinking and C8 radiculopathy apply, if the nerve root is not adequately decompressed during the correction.

POSTERIOR APPROACH

Patients with flexible deformities that correct passively are candidates for a posterior cervical fusion. These patients must demonstrate an intact anterior column and no evidence of anterior neural compression. Posterior instrumentation techniques have also evolved significantly over time. Interspinous wiring techniques became outmoded by the superior fixation of posterior screw-and-plate constructs. These have evolved into lateral mass screw-and-rod constructs, which are familiar to most spine surgeons because of their ease of application and strong fixation.

Posterior Surgical Technique

The key to the posterior approach lies in preoperative planning. It is of utmost importance to confirm that the patient has an intact anterior column and no compression of the neural elements anteriorly, and it must be ensured that the deformity passively corrects to the appropriate neutral or lordotic alignment. If these criteria are met, the procedure is similar to a typical posterior cervical fusion.

Once the patient is intubated, baseline SSEPs and TcMEPs are obtained. Mayfield tongs are then attached to the patient's skull, and the patient is placed in the prone position. Using lateral fluoroscopy, the surgeon must confirm that the cervical spine is placed in the appropriate lordotic alignment. At this point, we repeat the SSEPs and TcMEPs to ensure there has been no change from the baseline.

The posterior cervical spine is approached through a standard midline incision, with subperiosteal dissection of the musculature to expose the lateral masses. Depending on the extent of the curve, further exposure in the cephalad and caudad directions may be necessary. Lateral mass screws are inserted using the technique most familiar to the surgeon. We prefer the Magerl technique, angling 30 degrees cephalad and 25 degrees lateral.

In cases of severe chin-on-chest deformity, instrumentation may be required in the occiput, upper cervical spine, and thoracic spine. Instrumentation of the occiput requires meticulous dissection and identification of the external occipital protuberance, the thickest portion of bone. At this protuberance, bone can measure between 12 and 18 mm. Ridges that extend in a medial to lateral direction from the external occipital protuberance are the superior and inferior nuchal lines. Instrumentation should be placed caudal to the external occipital protuberance, and it need not be bicortical; the inner table is only 10% of the total thickness.[31] If need be, C2 pedicle screws can be inserted by performing a small laminotomy and utilizing a number four Penfield No. 4 dissector to mark the medial border of the pedicle. The starting point for the screw should be at the superior medial border of the lateral mass, and the appropriate angulation is 10 degrees medial and 15 degrees cephalad. Once the instrumentation is inserted, the rods are contoured and locked into place. For longer fusion constructs, autograft may be harvested from the iliac crest.

Results

Although data are limited on outcomes of posterior cervical fusion for cervical kyphosis, extensive studies have evaluated the biomechanical strength and variations in technique for such procedures. Dmitriev and colleagues[32] performed a biomechanical study to assess the stabilizing potential of anterior, posterior, and AP constructs in 10 cadaveric cervical spines. Constructs were first instrumented from C3 to C5; after biomechanical testing, the instrumentation was extended to C6, and biomechanical testing was repeated. Although their primary outcome measure was adjacent level kinematics, Dmitriev and colleagues also evaluated the relative biomechanical strength of each construct. In both two- and three-level constructs, AP fixation significantly reduced motion in all planes of loading compared with anterior-only or posterior-only constructs. Comparison of anterior-only and posterior-only constructs revealed biomechanical superiority of the posterior-only constructs. Compared with anterior fixation, posterior fixation reduced motion in all planes of loading for two-level constructs, but this difference was only significant during lateral bending; for three-level constructs, posterior constructs significantly reduced motion in all planes of loading. Thus the authors concluded that posterior instrumentation was biomechanically superior to anterior instrumentation.

Abumi and colleagues[33] evaluated 30 patients with cervical kyphosis who underwent correction and fusion using cervical pedicle screw fixation. Of 30 patients with flexible kyphosis, 17 were managed by a posterior procedure alone, while the remaining 13 patients with rigid or fixed kyphosis had a combined anterior and posterior procedure. All 30 patients had successfully fused at the final 2-year follow-up. Kyphosis improved from an average of 28.4 degrees to 5.1 degrees in the posterior-only group and from an average of 30.8 degrees to 0.5 degrees in the combined group. Two patients developed radicular symptoms that required reoperation, one secondary to a pedicle fracture that required screw removal, the other secondary to iatrogenic foraminal stenosis after kyphosis correction, which necessitated foraminotomy.

Complications

Because of the long constructs often required and the medical comorbidities seen with these patients, complications are often encountered. Deen and colleagues[34] performed a prospective study to evaluate outcomes of patients treated with posterior lateral mass screw-and-rod constructs. A total of 212 screws were implanted in 21 patients, and follow-up extended up to 1 year; CT scanning confirmed accurate screw placement in all cases. Three instances of transient single-level radiculopathy were reported, all of which improved significantly within 3 months. Implant failure, screw backout, and loss of alignment were not reported, and the authors concluded that the use of a screw-rod construct in the posterior cervical spine was a safe and reproducible technique.

Babat and colleagues[35] performed a retrospective review of outcomes in patients with Parkinson disease undergoing spinal surgery. This small, retrospective study included 14 patients who had surgical intervention in all regions of the spine, but both patients who underwent posterior spinal instrumentation developed progressive deformity and required reintervention and surgical revision. The authors concluded that patients with Parkinson had significantly higher rates of instrument-related complications and failure, with junctional kyphosis being the predominant mechanism.

Case Examples

Case 1

A 52-year-old woman came to medical attention with cervical radiculopathy and progressive kyphosis (Figs. 56-8 through 56-14). She underwent an anterior fusion, and then developed progressive collapse of the anterior column. Subsequent posterior fusion did not result in correction of the kyphotic deformity.

The above sequence of radiographs shows that failure to assess spinal alignment will result in fusion in kyphosis. Because the anterior column is fused in kyphosis, this patient will likely require an extensive posterior–anterior–posterior procedure to restore alignment.

Case 2

A 62-year-old man with a history of Parkinson disease came to medical attention with a 1 year history of chin-on-chest deformity (Figs. 56-15 through 56-20). Because he was able to passively correct to some degree of lordosis, the decision was made to perform a posterior cervical fusion. Because of the inherent weakness and atrophy of his paraspinal musculature, the surgeon opted to fuse from the occiput to T4.

Figure 56-8 Initial preoperative lateral radiograph.

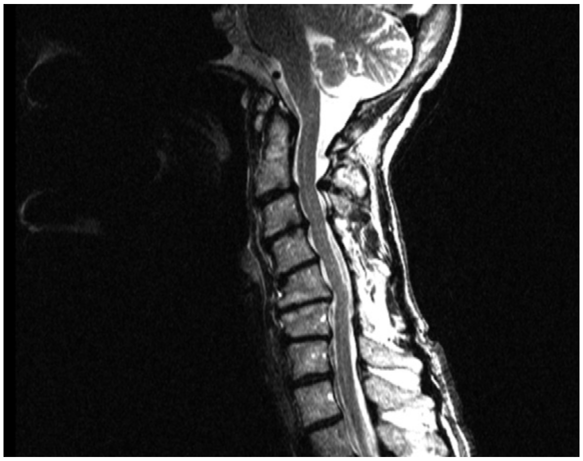

Figure 56-9 Initial preoperative magnetic resonance imaging (MRI).

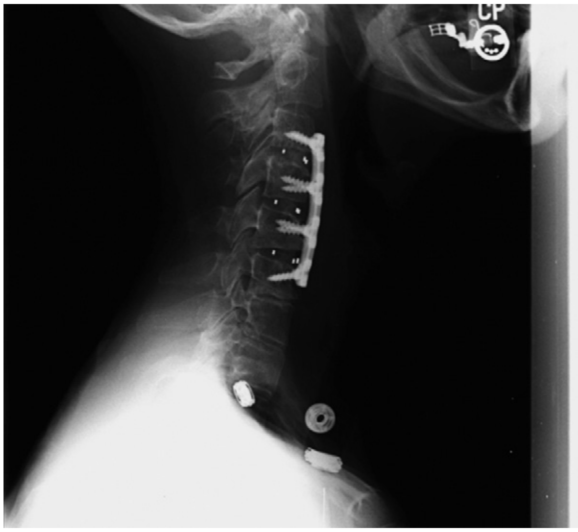

Figure 56-10 Postoperative radiograph shows neutral alignment.

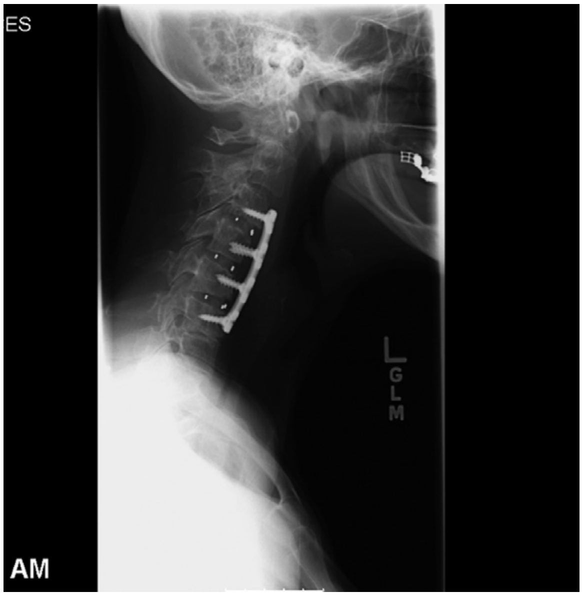

Figure 56-11 One-month postoperative radiograph shows progressive collapse of the anterior column and loosening of the plate.

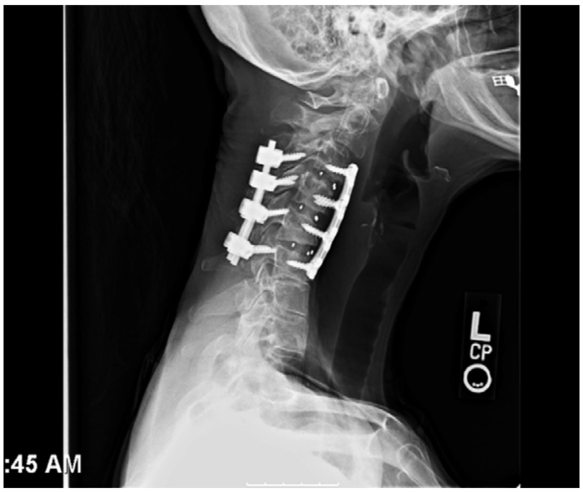

Figure 56-12 Posterior stabilization results in fusion in kyphotic alignment.

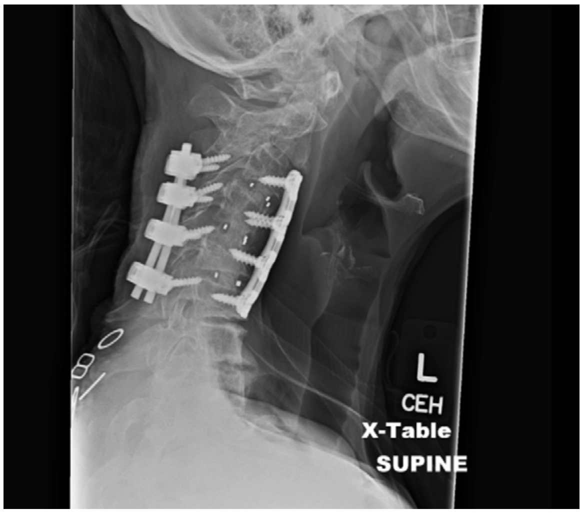

Figure 56-13 Progressive collapse and worsening kyphosis.

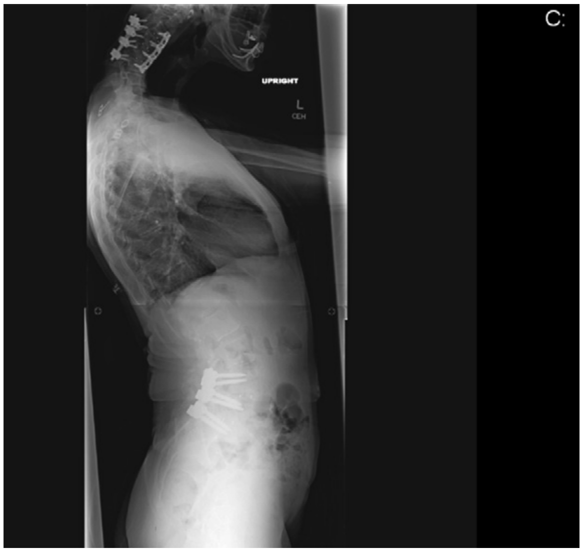

Figure 56-14 Assessment of patient's global sagittal balance shows junctional kyphosis inferior to the construct and compensatory hyperlordosis in the lumbar spine.

Figure 56-15 Severe cervical kyphotic deformity.

Figure 56-16 Correction passively to neutral in the supine position.

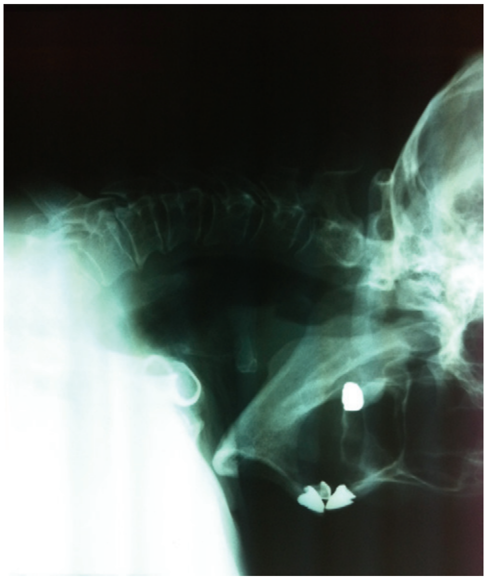

Figure 56-17 Preoperative lateral radiograph.

Figure 56-18 Intraoperative positioning in lordotic alignment.

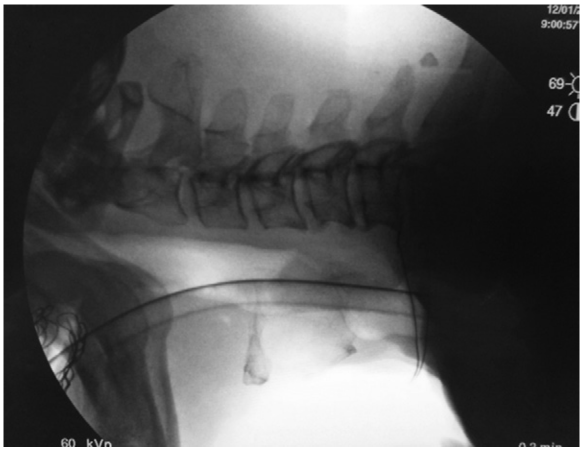

Figure 56-19 Lateral C-arm fluoroscopy confirming lordotic alignment.

Figure 56-20 Postoperative radiograph showing occipitothoracic fusion.

Conclusion

By simply focusing on the trees, it is easy to lose sight of the forest. This adage holds especially true for surgeons addressing cervical kyphosis: the global spinal alignment must be evaluated and taken into account. Treatment of cervical kyphosis requires meticulous preoperative planning and a sound foundation in the biomechanical principles of the spine. Because most cases encountered by surgeons are iatrogenic in nature, an ounce of prevention is worth a pound of cure.

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57 Surgical Management of Scheuermann Kyphosis

ROBERT A. MORGAN AND KIRKHAM B. WOOD

Overview

The posterior-only treatment of Scheuermann kyphosis using segmental posterior shortening and instrumentation has been a treatment option for over 20 years.[1] Early reports detail the poor results with posterior-only surgery, but these were primarily associated with Harrington compression instrumentation.[2,3] This led to advocacy of a combined anteroposterior (AP) approach with anterior releases followed by posterior compression instrumentation and fusion.[4] Loss of correction and pseudarthrosis have been reported.[5,6] However, more recent studies have demonstrated excellent results with pedicle screw instrumentation in association with posterior-only resections and deformity correction.[1] The anterior releases are associated with increased complication rates if performed in a staged fashion,[7] but complication rates are similar between posterior-only surgery and anterior release followed by posterior spinal fusion if performed on the same day.[8]

Indications and Contraindications

INDICATIONS

- Failure of nonoperative management of kyphosis or thoracic pain
- Progressive kyphosis or pain with thoracic deformity greater than 75 degrees or thoracolumbar deformity greater than 40 degrees
- Radiographic wedging of greater than 5 degrees at three levels consistent with the diagnosis[9]

CONTRAINDICATIONS

- Pregnancy
- Metal sensitivity
- Malnutrition
- Vitamin D deficiency

Operative Technique

EQUIPMENT

- Radiograph-compatible operating table
- Imaging system (fluoroscopy or navigation)
- Headlight system
- Retractor system
- Bone graft source
- Posterior instrumentation (implants), longitudinal rods, pedicle screws, and sublaminar, pedicle, and transverse process hooks (discretionary)
- Sublaminar wires (optional)
- Crosslink connectors
- Kerrison rongeur, 1 to 4 mm
- Midas burr
- Leksell rongeur
- Hemovac drain
- Jackson frame
- Spinal cord monitoring with some added somatosensory-evoked potentials (SSEPs) and motor-evoked potential (MEPs) with sphincter monitoring
- Cell Saver (Haemonetics, Braintree, MA) autotransfusion system

PATIENT POSITIONING

The patient is placed prone on the Jackson frame. With severe cases, appropriate padding may be required to safely position the patient initially. A mobile table that allows intraoperative repositioning may be helpful to aid in the reduction maneuver.

A slight reverse Trendelenburg position will keep the patient's eyes from being in a dependent position to prevent facial, periorbital, and airway swelling. Additionally, this will aid in visualization in the upper thoracic spine. General endotracheal anesthesia is used, and arms are positioned at the patient's side with the shoulders taped to allow access for any type of imaging modality to the cervicothoracic junction. This is particularly necessary if navigation is being used. Arms may be positioned in the abducted position, no more than 90 degrees, with the elbows well padded and the shoulders well supported. If navigation modalities are not being used, caution should be exercised with this positioning, because it may place the brachial plexus at risk; neurologic monitoring will be helpful in assessing the brachial plexus throughout the case. The entire back is prepped from the hairline to the buttocks and to the midaxillary lines.

LOCATION OF INCISION

The incision extends from approximately overlying the spinous process of C7, and it is extended caudally to the rostral lumbar spine in the midline. With severe upper thoracic kyphosis, the rostral extent of the incision may need

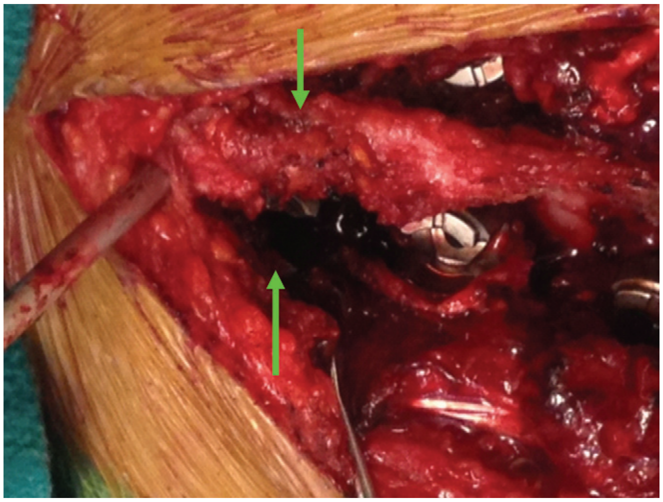

Figure 57-1 Rostral instrumentation consists of transverse process hooks (*up arrow*) placed with limited dissection to maintain robust midline structures (*down arrow*).

Figure 57-2 The spine is exposed with the kyphotic deformity illustrated. (From Geck MJ, Macagno A, Ponte A, Shufflebarger HL: The Ponte procedure: posterior only treatment of Scheuermann's kyphosis using segmental posterior shortening and pedicle screw instrumentation. *J Spinal Disord Tech* 20:586–593, 2007.)

to extend into the subaxial cervical spine to allow for pedicle screw entry.

Local anesthetic with epinephrine may be injected subcutaneously along the incision site to assist with hemorrhage control. Care must be taken that the toxic dose, typically 3 mg/kg for amides without epinephrine, is not reached or exceeded.

INCISION AND SOFT TISSUE DISSECTION

The subcutaneous layer is divided, and hemostasis obtained. The deep fascia is divided in the midline along its connection to the spinous processes at the apex of the deformity. Great care must be taken rostrally not to damage the supraspinous and interspinous ligament complex in an attempt to limit the incidence of proximal junctional kyphosis (Fig. 57-1, *down arrow*).

EXPOSURE OF THE VERTEBRAE

Using a Cobb elevator and electric cautery, longitudinal muscles are exposed and elevated laterally out to the lateral border of the transverse processes and are held with self-retaining retractors (Fig. 57-2).

A permanent radiopaque marker should be used for determining levels definitively. Methods include a needle placed into the spinous process; a clamp placed on the spinous process and a Woodson elevator placed under the lamina; or a curette placed into the pedicle. This will allow fluoroscopy, lateral radiography, or a three-dimensional imaging modality to be able to localize the desired level. It is important to note that severe deformity may preclude lateral radiography from definitively determining the level, and AP radiography may be necessary for level confirmation, particularly in the rostral thoracic spine.

RETRACTOR PLACEMENT

Attention to the midline is important during the dissection so as to minimize bleeding. Self-retaining retractors are placed within the wound at the most proximal and distal aspects and are used to hold back the longitudinal musculature. Usually four retractors are necessary: two angled short retractors used at the ends of the incision and two longer straight retractors introduced over the end retractors and extended into the body of the wound. The retractors should retain longitudinal musculature laterally to allow better visualization of the transverse processes bilaterally, out to the most lateral aspect, from the top to the bottom of the operative field.

Rostral exposure should be limited to prevent excessive soft-tissue destruction in an attempt to limit proximal junctional kyphosis (see Fig. 57-1). The facets must be exposed with the capsule completely resected using curettes or electric cautery. Facets are then excised completely by the surgeon's method of choice. If osteotomes are used for this, they must be sharp, and a high-speed burr may be useful in a more controlled resection of the facets. The spinous processes are resected, and local bone is used for grafting. Beginning in the midline, the ligamentum flavum is then excised with a Kerrison rongeur, proceeding laterally toward the facets. The remainder of the facets are resected with the Kerrison rongeur, and this resection is continued into the foramen at every level. Cephalad and caudad widening of the osteotomy is performed as indicated (Figs. 57-3 and 57-4).

INSTRUMENTATION

Instrumentation is used to assist in manipulating spinal sagittal plane alignment or to shorten the posterior column. Instrumentation levels should extend from T2 or T3 caudally to the first lordotic disk in the thoracolumbar region,

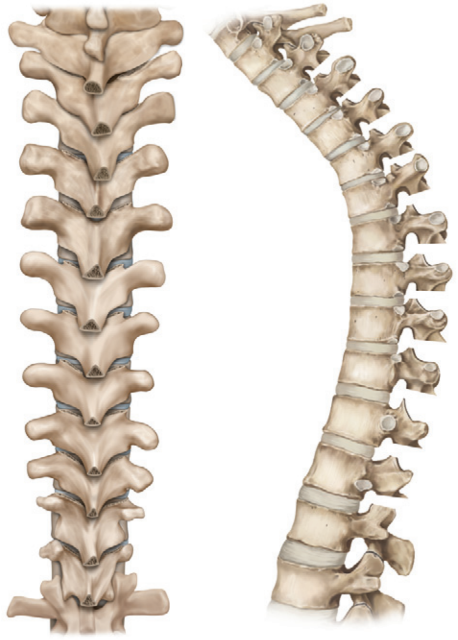

Figure 57-3 Ponte osteotomies. (From Geck MJ, Macagno A, Ponte A, Shufflebarger HL: The Ponte procedure: posterior only treatment of Scheuermann's kyphosis using segmental posterior shortening and pedicle screw instrumentation. *J Spinal Disord Tech* 20:586–593, 2007.)

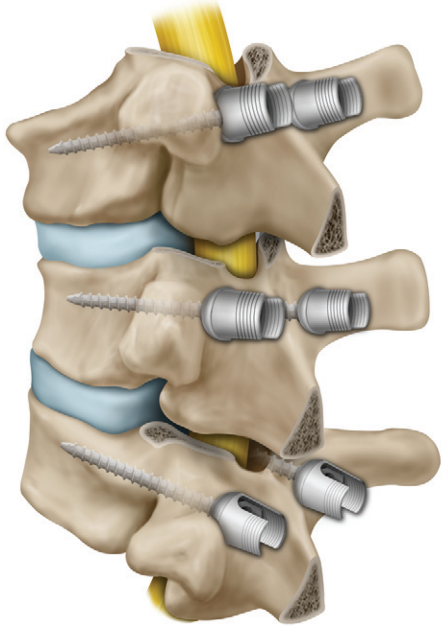

Figure 57-5 Osteotomies with anchors placed. (From Geck MJ, Macagno A, Ponte A, Shufflebarger HL: The Ponte procedure: posterior only treatment of Scheuermann's kyphosis using segmental posterior shortening and pedicle screw instrumentation. *J Spinal Disord Tech* 20:586–593, 2007.)

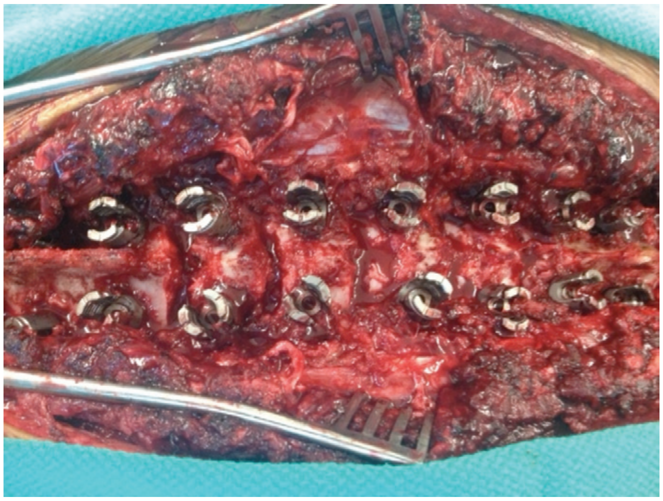

Figure 57-4 Osteotomies at kyphotic levels with instrumentation extending above and below osteotomized levels.

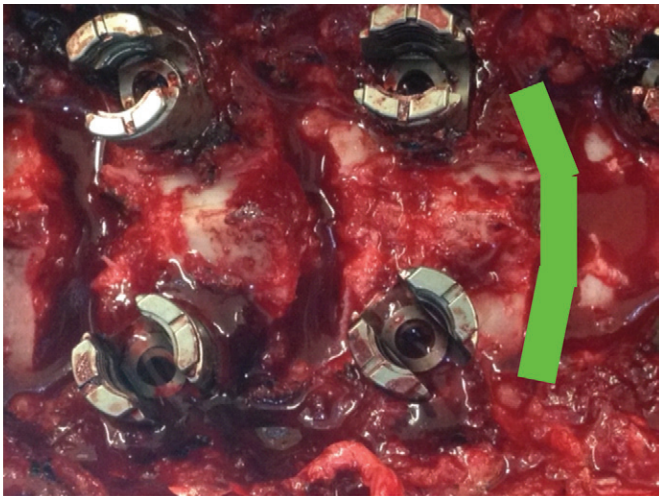

Figure 57-6 Multiple levels of posterior-only osteotomy with complete resection of superior and inferior articular processes, resection of ligamentum flavum, and caudal laminectomy.

typically L1 or L2, as evaluated on preoperative standing lateral radiographs.

Rostral hooks over the transverse process should be considered to limit soft-tissue dissection and proximal junctional kyphosis. For this reason, supralaminar hooks are to be avoided at the most rostral segment. Pedicle screws are the preferred means of fixation, and the rostral and caudal three levels should be fixed bilaterally in this fashion (Figs. 57-5 and 57-6). Subsequent implants across the apex of the deformity may be staggered from side to side to increase segmental exposure and surface area available for fusion mass.

CORRECTION

Rods of sufficient length to allow for a cantilevered reduction are used. These should be of sufficient stiffness to

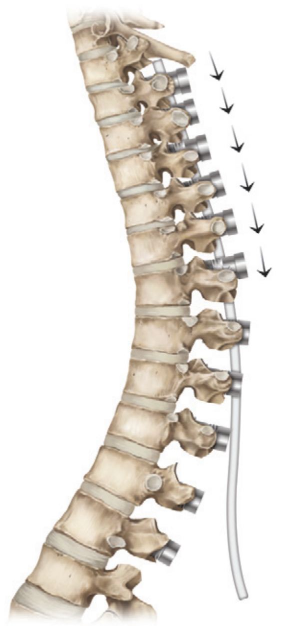

Figure 57-7 Initial rod placement with proximal anchor compression. (From Geck MJ, Macagno A, Ponte A, Shufflebarger HL: The Ponte procedure: posterior only treatment of Scheuermann's kyphosis using segmental posterior shortening and pedicle screw instrumentation. *J Spinal Disord Tech* 20:586–593, 2007.)

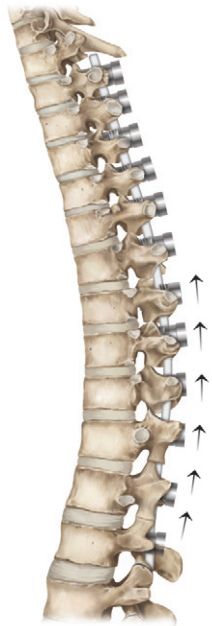

Figure 57-8 Final rod placement with final compression and deformity correction. (From Geck MJ, Macagno A, Ponte A, Shufflebarger HL: The Ponte procedure: posterior only treatment of Scheuermann's kyphosis using segmental posterior shortening and pedicle screw instrumentation. *J Spinal Disord Tech* 20:586–593, 2007.)

hold the correction and not deform under load. This can include quarter-inch stainless steel or cobalt chrome materials. Rod length is estimated by the length of the instrumentation with a subsequent subtraction of approximately 2 cm for posterior column shortening. Bilateral rod placement beginning at the rostral end begins with the rods being placed in the rostral anchors; these anchors are compressed (Fig. 57-7), and the rest of the reduction is a combination of cantilever and compression into the caudal anchors. After rod placement and kyphosis correction, final tightening is performed (Fig. 57-8). Transverse connectors may be used, but these are associated with an increased risk of pseudarthrosis. SSEPs should be attended to during the correction maneuver, and MEPs may be assessed immediately prior to correction, during correction, and following correction to ensure no immediate changes indicative of spinal cord compromise are present. An increase in latency in MEPs or SSEPs of more than 10% or an amplitude drop of more than 50% is an indication to stop the procedure and perform the immediate wake-up test. If the patient fails the wake-up test, or the evoked potentials do not correct, the instrumentation should be removed. If the patient develops a motor deficit postoperatively, consideration for immediate instrumentation removal should occur followed by emergency MRI.

BONE GRAFT

The extensive osteotomies provide a biologically sound method of arthrodesis without extensive additional bone grafting. Crushed cancellous allograft may be mixed as a bone graft extender with the local autograft harvested during the osteotomies. Iliac crest autograft may be harvested through a separate incision.

CLOSURE

A wake-up test at the end of the procedure is recommended if electrophysiologic monitoring is otherwise unavailable, or if an intraoperative electrophysiologic event occurred. A watertight closure of the deep fascia is essential. A quarter-inch hemovac drain is placed deep to the fascial closure, and a No. 7 Jackson-Pratt drain is placed above the fascia in the subcutaneous layer. A two-layer closure of the skin, including a subcuticular layer, is then performed.

Postoperative Care

Bracing is optional and should not be considered protective of weak instrumentation. Hyperextension bracing may be helpful with pain control should this be a problem postoperatively.

Ambulation without a brace is accomplished on the first or second day after surgery. For the first 3 months, patients are on a walking program with lifting restricted to less than 10 pounds and no overhead activity, with no repetitive bending, lifting, or twisting allowed. After 3 months patients are placed in a progressive aerobic activity program that includes jogging, swimming, and bicycling, and they are instructed to avoid contact or collision sports. Fusion-mass consolidation will continue for at least 1 year, at which point full contact sports participation may be continued (Figs. 57-9 and 57-10).

Complications

- Proximal junctional kyphosis may be seen if fusion stops short of an upper end vertebra and may also occur with overcorrection of deformity, because the sagittal balance has shifted too far posteriorly. As a general rule correction should not exceed more than 50% of the preoperative standing lateral Cobb measurement.[10]
- Distal junctional kyphosis may also occur if the distal fusion does not include the first lordotic segment of the upper lumbar spine, and it may also occur with overcorrection.
- The most common complication is wound infection, reported at 3.8%.
- Acute neurologic complication rate is 1.9%.
- Spinal cord injury rate is 0.6%.[4]
- Implant bone failure may be seen with overcorrection or an osteopenic bone. Preoperative assessment of bone quality is critical.
- Hook dislodgement in the caudal spine is not uncommon.
- Implants sometimes fail.
- Pseudarthrosis can be as high as 20% in posterior-only surgery, particularly with nonpedicle screw constructs. If a nonpedicle screw construct is being considered, a combined AP approach should be also considered.
- Correction may be lost.
- Hemothorax or pneumothorax may occur.
- Pulmonary embolism, blindness, and death have also been reported.

Figure 57-9 Clinical pictures of an 18-year-old man with debilitating back pain demonstrate a change in resting posture and improved sagittal alignment.

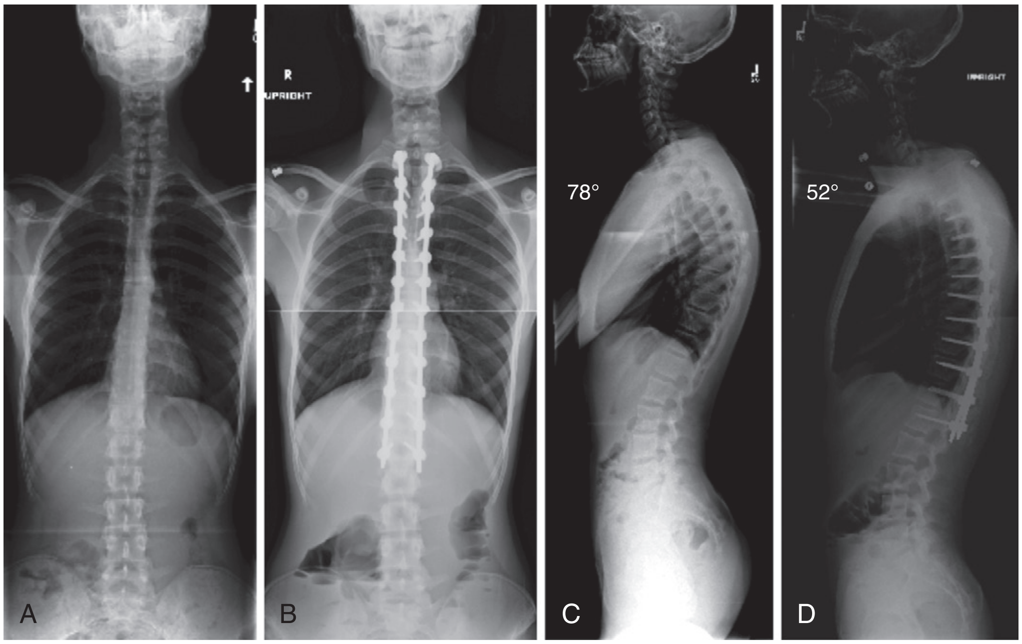

Figure 57-10 Standing radiographs demonstrate implant placement and improved sagittal alignment.

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58 Surgical Approach to Posttraumatic Thoracic Kyphosis

HENRY AHN

Background

Each year in the United States, approximately 150,000 to 170,000 people sustain spinal column fractures; most of these will be caused by trauma, and such injuries can lead to short- and long-term complications. *Posttraumatic kyphosis* is a possible complication of spinal column trauma despite advances in surgical technique and management of spinal fractures. Methods in the management and treatment of this adverse outcome of spinal column fractures involving the thoracic spine are discussed in this chapter.

Normal Sagittal Balance

Recognition of posttraumatic kyphosis requires knowledge of what is defined as "normal." Normal sagittal balance and the contributions of each segment are illustrated in Figure 58-1. A plumb line dropped from the center of the C7 vertebral body on a lateral three-foot standing radiograph should fall over the posterior-superior corner of S1. A plumb line that falls anterior to the posterior-superior sacrum is called a *positive global sagittal balance;* clinically, the patient is pitched forward, a mechanically unbalanced situation. In contrast, a plumb line that falls posterior to the posterior-superior corner is called a *negative sagittal balance.*

Measurement of overall thoracic kyphosis from lateral radiographs proximally is hindered because of overlap of the shoulders. As a result, measurements of thoracic kyphosis can often be measured from T4 to T12, rather than from T1 to T12, and this measurement from T4 to T12 varies from 20 to 50 degrees of kyphosis with a mean of 35 degrees. Each segment in the thoracic spine contributes to this overall kyphosis, beginning with T1–T2, which contributes 1 degree. Each subsequent thoracic segment contributes to increasing amounts of kyphosis up to the apex at T5–T6, which contributes 5 degrees. Segmental contribution of each following level then decreases gradually, until the T11–T12 segment is reached.

In contrast, the thoracolumbar region of T11–L2 is a transition zone between kyphosis and lordosis that measures zero degrees, or slight lordosis. This is followed by the lumbar region, measured from T12 to the superior end plate of S1, at 40 to 80 degrees of lordosis with a mean of 60 degrees—approximately double that of thoracic kyphosis in a balanced spine.

Impact of Spinal Column Trauma on Alignment

Spinal column trauma can lead to focal kyphosis, most commonly in the thoracic and thoracolumbar regions. The magnitude of the focal kyphosis is ideally measured from the superior end plate of the cephalad level and the inferior end plate of the caudal level. The overall sagittal balance may still be normal as a result of compensation from increased lordosis in the lumbar spine.

Overall, vertebral body fractures, such as compression fractures of the thoracic spine, tend to be static and nonprogressive. In contrast, injuries that involve disruption of the posterior ligamentous complex, such as in the case of severe burst fractures or flexion-distraction injuries, can lead to acute progressive kyphotic deformities if the injuries are not surgically stabilized. Kyphotic deformities can also present later, and reasons for late presentation include 1) pseudarthrosis, 2) hardware failure, 3) short-segment stabilization, 4) presence of a laminectomy, and 5) Charcot spine or neuropathic spinal arthropathy in cases of long-term follow-up of patients with spinal cord injury. Deep wound infection needs to be ruled out in the case of pseudarthrosis, and hardware failure can occur as a result of inadequate fixation, owing to such things as poor bone quality, a breached pedicle screw, or an insufficient number of screws. In addition, short-segment fixation has been associated with progressive kyphosis in the case of comminuted burst fractures. Progressive kyphosis can also occur in the setting of laminectomy performed for a fracture. Failure to correct the kyphotic alignment during a revision procedure will lead to increased biomechanical stress on the screws utilized for the revision procedure.

Presenting Symptoms of Thoracic Kyphosis

Patients with thoracic kyphosis may come to medical attention with pain, neurologic deficit, or both. Pain is often localized at the site of the deformity and is due to altered biomechanics from the increased kyphosis, which causes increased strain on the posterior soft tissues. Patients may also complain of pain at adjacent regions because of premature degeneration from increased biomechanical stress, and focal kyphosis greater than 30 degrees may be associated with increased pain. Surgical correction of posttraumatic deformity may or may not reduce pain.

Patients may also present with worsening or new neurologic deficits in posttraumatic thoracic kyphosis because of progression of kyphosis or formation of a symptomatic posttraumatic syrinx. Progression of the thoracic kyphosis can lead to the thoracic spinal cord being "draped and stretched" against the dorsal vertebral body wall. New or progressive deficits may also be due to increased instability, with mechanical stress being transferred directly to the thoracic spinal cord. Alternatively, posttraumatic symptomatic thoracic syringomyelia may also be a cause of late-worsening neurologic function, with estimated rates varying from 1% to 9% of thoracic cord injuries; this can be associated with persistent neural compression as a result of progressive kyphosis. Symptomatic posttraumatic syringomyelia can be treated with correction of the kyphotic deformity and relief of the neural compression, along with a combination of intradural procedures that involve untethering of the thoracic cord, either with arachnolysis and duraplasty or in combination with syringopleural shunting.

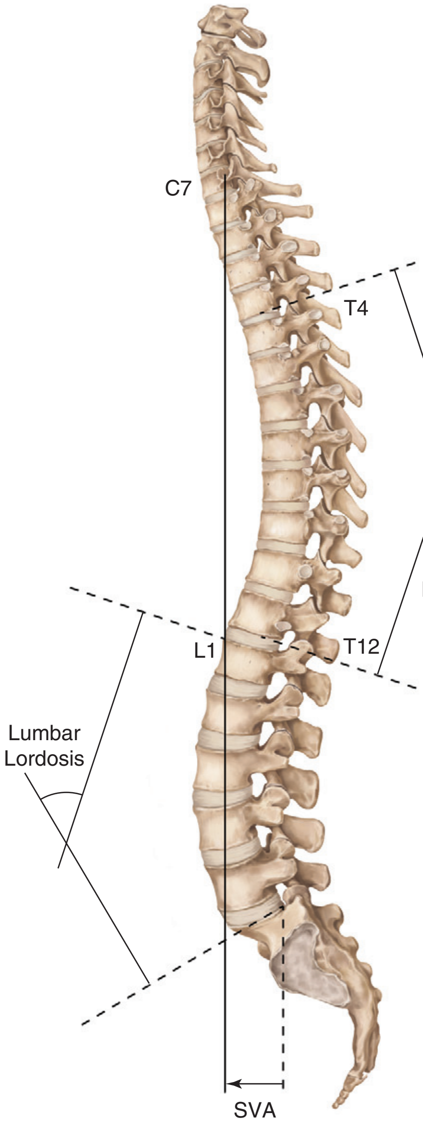

Figure 58-1 Normal sagittal alignment with contributions of segmental levels to overall thoracic kyphosis.

Correction of Thoracic Kyphosis

Not all patients with posttraumatic thoracic kyphosis require surgery. However, indications for correction of posttraumatic kyphosis include 1) significant pain as a result of the deformity or adjacent segment degeneration or pseudarthrosis or 2) new or progressive neurologic deficit. Three-foot standing and supine extension radiographs are performed to characterize 1) the magnitude of the regional kyphosis, 2) the global sagittal alignment, and 3) the flexibility of the curve. A region of flexible kyphosis that corrects on a supine extension x-ray will typically correct with on-table positioning, which could then be maintained with multilevel pedicle screw fixation.

In the setting of fixed or rigid thoracic kyphosis, posterior-only osteotomies that have traditionally been used in nontraumatic spinal deformities, including Smith-Peterson osteotomies (SPOs) and pedicle subtraction osteotomies (PSOs), may be utilized. SPOs involve shortening of the posterior column, through resection of the posterior facets and associated ligamentum flavum and closing of the gap, while increasing the anterior column length (Fig. 58-2). This osteotomy's axis of rotation centers on the posterior vertebral body wall. Rigid fixation is needed, because there is no apposition of bone along the anterior column. For larger posttraumatic deformities or for those involving large regions of the thoracic spine, multiple SPOs can be combined, with each osteotomy correcting 10 to 15 degrees of kyphosis and each millimeter of resected bone translating into 1 degree of correction. Excessive lengthening of the anterior column region from multiple osteotomies can potentially lead to vessel traction or stretching. Pedicle screw instrumentation should be placed prior to an osteotomy, given increased bleeding during this portion of the

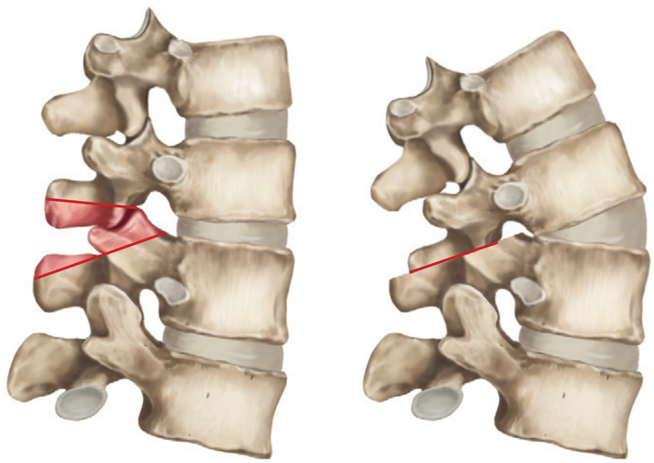

Figure 58-2 Smith-Peterson osteotomy with shortening of the posterior column through resection of the facets and ligamentum flavum, while lengthening the anterior column.

procedure, although there is significantly less blood loss performing an SPO compared with a PSO.

The PSO (Fig. 58-3) can provide kyphosis correction of 30 degrees, which is significantly more than a single SPO. Again instrumentation is done prior to the osteotomy, because blood loss can be significant as a result of epidural and cancellous bone bleeding. Cell Saver (Haemonetics, Braintree, MA) and adequate blood products and hemostatic agents, such as Surgiflo and Recothrombin, are recommended during a PSO. Such procedures have been described extensively in the literature for nontraumatic deformity correction, but they can also be applied for posttraumatic thoracic kyphosis. PSO provides a greater magnitude of correction compared with the SPO, but it also provides bony apposition along the anterior column rather than lengthening or distracting the anterior column.

The PSO (Fig. 58-4) can be started initially with cannulation of the pedicle at the level of the deformity followed by resection of the posterior bony structures at the level of the kyphotic deformity; extension of the decompression proximally and distally to the adjacent levels ensures adequate dorsal decompression to allow for dural sac movement during osteotomy closure. Inadequate decompression above and below the kyphotic segment can lead to bony impingement of the cord during closure of the osteotomy.

This is then followed by vertebral body decancellation via the pedicle in a wedge-shaped pattern that approaches the anterior cortical bone but does not go through it, leaving a thin "eggshell" of cortical bone dorsally, laterally, and anteriorly. The dorsal aspect of the kyphotic segment typically indents into the dural sac; it compresses the spinal cord and needs careful pushing with a reverse Epstein curette anteriorly into the decancellated vertebral body. The osteotomy is then completed laterally, releasing the lateral cortical bone in a wedge-shaped pattern combined with rib head release and rib osteotomy. Significant lateral bleeding may be indicative of injury to a segmental vessel in the "valley" of the lateral vertebral body wall, which requires additional exposure for control of the bleeding. Closure of the PSO hinges on the thin, eggshelled anterior cortex; gentle dorsal pressure is applied to the chest wall in hyperextension, and with a rod in place, compression is applied across the screws immediately cephalad and caudal to the PSO.

Options other than posteriorly based osteotomies include an anteriorly based corpectomy to decompress the spinal cord, with reconstruction of the body with an expandable cage, or a combination anterior and posterior approach. It is difficult to correct a kyphotic deformity from an anterior-only approach, especially with a very rigid posttraumatic deformity.

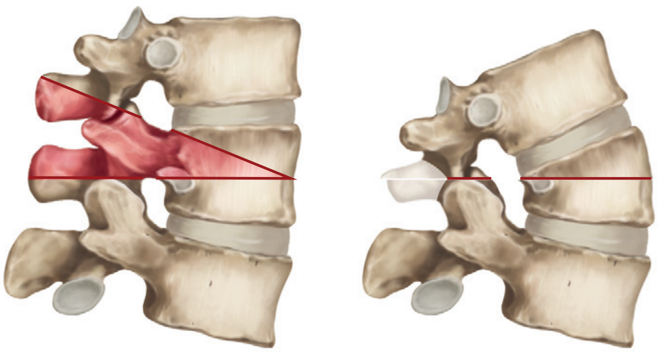

Figure 58-3 Schematic of a pedicle subtraction osteotomy. The PSO results in bony apposition along both the anterior and posterior columns.

Complications Associated with Osteotomies

The most feared and devastating complication after a thoracic osteotomy is paraplegia, especially in the setting of a thoracic-level PSO. Incidence of iatrogenic neurologic deficits in cord-level PSOs is elevated in the setting of posttraumatic kyphosis; according to the literature, it can reach an incidence rate of up to 20%. Multiple factors may be associated with this increased rate of neurologic injury. Posttraumatic kyphosis patients may have already sustained neurologic injury at the time of spinal column fracture or with progression of their kyphosis. Furthermore, with acute angular kyphosis, the spinal cord is typically draped across the dorsal vertebral body wall, which is tenting into the thecal sac and cord, plus scarring and adhesions of the cord and sac may already be present. Also, osteotomy for posttraumatic kyphosis at the thoracic level is technically challenging, and inadequate decompression with resulting impingement of the cord or anterior translation after

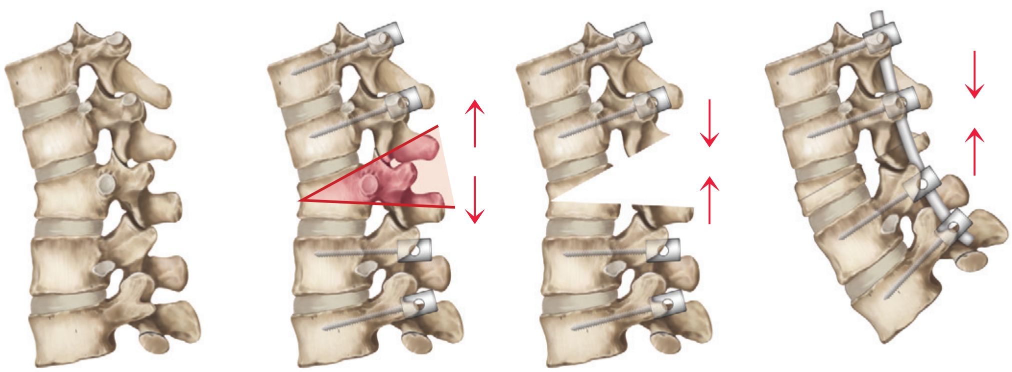

Figure 58-4 Steps to performing a pedicle subtraction osteotomy at the level of the thoracic spinal cord.

osteotomy can lead to iatrogenic spinal cord injury. Bleeding with resulting hypotension can also exacerbate secondary spinal cord damage.

Blood loss can be significant during a PSO for posttraumatic kyphosis. In the absence of any contraindications, Cell Saver is recommended during a PSO. Furthermore, aggressive maintenance of coagulation parameters—such as partial thromboplastin time, international normalized ratio, and calcium levels—during and after surgery can help minimize excessive bleeding after transfusion of large volumes or after resuscitation, causing a coagulopathy.

Another potential major complication is wound infection, both acute and delayed. Wound infection prior to the spine fusing appropriately after an osteotomy can lead to repeat surgeries to debride the spine, followed by long-term intravenous antibiotics and wound vacuum-assisted closure.

Summary

Overall, posttraumatic thoracic kyphosis can lead to significant pain and worsening neurologic deficit. Patients who are symptomatic from their posttraumatic kyphosis can be treated with a posterior-only approach with osteotomies, including a Smith-Peterson osteotomy or a pedicle subtraction osteotomy, depending on the magnitude of the kyphosis and the region it involves. As with most any type of surgery, complications can occur.

59 Anterior Release and Fusion Techniques for Scoliosis

STEVEN W. HWANG, AKASH PATEL, and ANDREW JEA

Overview

Although anterior approaches to the thoracolumbar spine date as far back as the 1930s,[1] first-generation anterior column instrumentation was developed in 1968 by Dwyer and colleagues[2] and was composed of a vertebral screw-and-cable system. The first-generation system corrected deformity in the coronal plane but contributed to significant kyphosis and was prone to instrumentation failure secondary to its nonrigid construct. Subsequently, in the 1970s, Zielke and colleagues[3] designed a screw-and-rod system that improved upon the earlier instrumentation. Innovation has continued since, and various systems are currently available that can typically be divided into single screw-and-rod systems or those with dual screws and dual rods that require a staple.

For awhile, the use of anterior correction for scoliotic deformity gained in popularity and became increasingly more widespread. For select curves, an anterior fusion could be performed while preserving more functional levels than a posterior approach. On average, 2.5 fewer levels were fused to achieve similar radiographic outcomes.[4] Furthermore, anterior correction provided greater axial force, permitted greater improvement of the rotation, and also corrected the hypokyphosis often associated with adolescent idiopathic scoliosis when compared with hybrid constructs. Anterior correction also provided better improvement of compensatory unfused curves, and less decompensation over time was observed with these same anterior constructs.[5,6] However, with the advent of thoracic pedicle screw fixation and posterior direct vertebral body derotation, anterior approaches have become less popular except in select circumstances.

Anterior approaches include the anterior correction and fusion, anterior releases used adjuvantly with posterior instrumentation, or either performed thoracoscopically. This chapter will describe the techniques used to perform open or laparoscopic anterior fusions or releases for scoliotic correction.

Indications

- Lenke type 1 and 5C curves (single thoracic curves or thoracolumbar curves)
- Hypokyphosis (anterior surgery will typically increase kyphosis)
- Significant risk of crankshaft (Risser grade 0, open triradiate cartilage); risk of developing crankshaft phenomenon marginalized by anterior fusions
- High risk of pseudarthrosis (Marfan syndrome, neurofibromatosis, prior radiation, etc.)
- Need for anterior release with rigid, inflexible curves (relative)

Endoscopic indications include the above but are further limited to:

- Single structural thoracic curves
- Curvature less than 75 degrees (relative)
- Between T5 and L1 (ideally T5 to T12)

Relative Indications

Many of the indications are relative, because changing technology and improved techniques have obviated some of the risks and complications from posterior approaches. Although reportedly frequent in skeletally immature children using hook or hybrid constructs, the risk of developing crankshaft phenomenon using pedicle screw instrumentation is thought to be diminished. Furthermore, pedicle screw fixation has improved the rigidity of constructs and may be sufficient in treating etiologies previously associated with unacceptably high rates of pseudarthrosis (i.e., neurofibromatosis). Significant correction can also be achieved with rigid, inflexible curves through adjuvant posterior techniques, such as pedicle subtraction osteotomies or vertebral column resections.

Endoscopic Contraindications

- Less than 2 cm between chest wall and vertebral body

Relative Contraindications

- Severe pulmonary compromise (forced vital capacity <50% predicted)
- Inability to tolerate single-lung ventilation
- Intrathoracic or abdominal pathology (Marfan syndrome, neurofibromatosis, pleural adhesions)
- Significant kyphosis
- Double or triple curves (other Lenke-type curves)

- Long neuromuscular curves
- Severe apical rotation
- Severe osteopenia
- Insufficient vertebral size to support anterior screws

Selection of Level of Fusion

The selection of instrumented levels for an anterior approach typically involves the end vertebrae (EV). The EV represent the vertebrae on the anteroposterior (AP) radiograph that form the Cobb angle, and which end plates are the most angulated from the horizontal (Fig. 59-1). Selection of levels for an anterior release in conjunction with a posterior fusion is typically limited to the few disk spaces that comprise the apex of the scoliotic curve.

Equipment

OPEN

- Neuromonitoring equipment
- Radiolucent operating table, appropriate gel pads, and arm boards

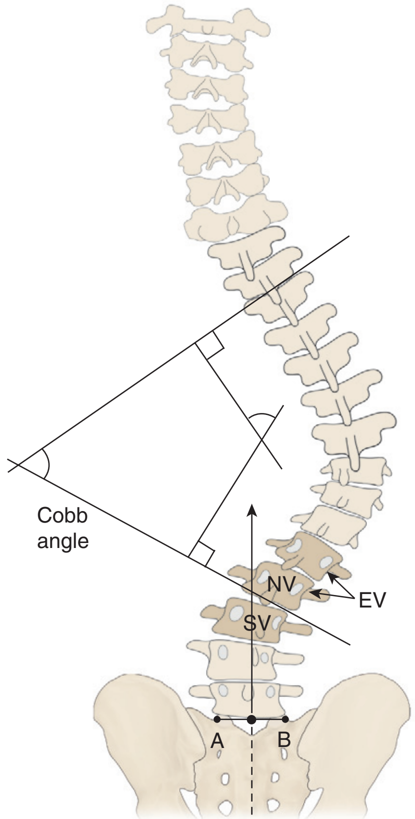

Figure 59-1 Fundamental radiographic parameters. The end vertebrae (EV) represent the rostral and caudal levels, comprising a curve of which the end plates are measured to form the Cobb angle. The EV represent the levels whose end plates are most angulated from the horizontal. The neutral vertebra (NV) depicts the level with the least rotation, where the spinous process is most centered between the pedicles. The stable vertebra (SV) denotes the level bisected by a vertical line drawn from the midsacrum.

- Fluoroscopy/intraoperative imaging
- Double-lumen endotracheal tube
- Chest tube
- Basic instruments (blade, forceps, electrocautery, sutures, Kerrison and pituitary rongeurs, curette, rasp, Steinmann pins)
- Sponges/gauze
- Weck clips
- Kittner dissector
- Rib spreader, rib cutter, Doyen rib raspatory
- Bone graft or interbody device
- Instrumentation (awl, tap, ball-tip probe, screws, rods, etc.)

ADDITIONAL ENDOSCOPIC EQUIPMENT

- Thoracoscope (video tower; light source; 0, 30, and 45 degree scopes)
- Carbon monoxide insufflator
- Access ports
- Harmonic/ultrasonic dissector and electrocautery
- Endoscopic tools (suction, forceps, pituitary rongeur, blades, etc.)

Preoperative and Perioperative Considerations

- *Intubation:* The patient should be intubated with a double-lumen endotracheal tube (ETT), and the lung on the convex side of the curve should be collapsed at the beginning of the case to safely perform the surgery.
- *Blood pressure/mean arterial pressure (MAP):* Hypotension or hemodilution should be avoided, even at the beginning of the surgery, given the potential risk of spinal cord infarction, especially if segmental vessels are ligated. Particular attention should be paid to ensure that the MAP is above 70 to 80 mm Hg prior to correction of the deformity.
- *Neuromonitoring:* Baseline recordings should be obtained prior to incision, and readings should be verified routinely throughout the case.
- *Radiography:* Fluoroscopy should be arranged at the beginning and draped into the field; it can be useful to verify bicortical purchase of screws and localize the vertebral level.

Positioning

LATERAL DECUBITUS (ENDOSCOPIC OR OPEN)

Most commonly, a lateral decubitus position is adopted for a thoracotomy (Fig. 59-2, *A*). Typically, the convex side of the curvature is positioned facing up; however, the surgeon may approach from the alternate side if significant restrictions are present. In the upper thoracic spine, the right brachiocephalic artery and approach has a straighter course and does not risk injury to the thoracic duct and heart. In the thoracoabdominal spine, the artery of Adamkiewicz is often derived from the left side. However, the aorta is also

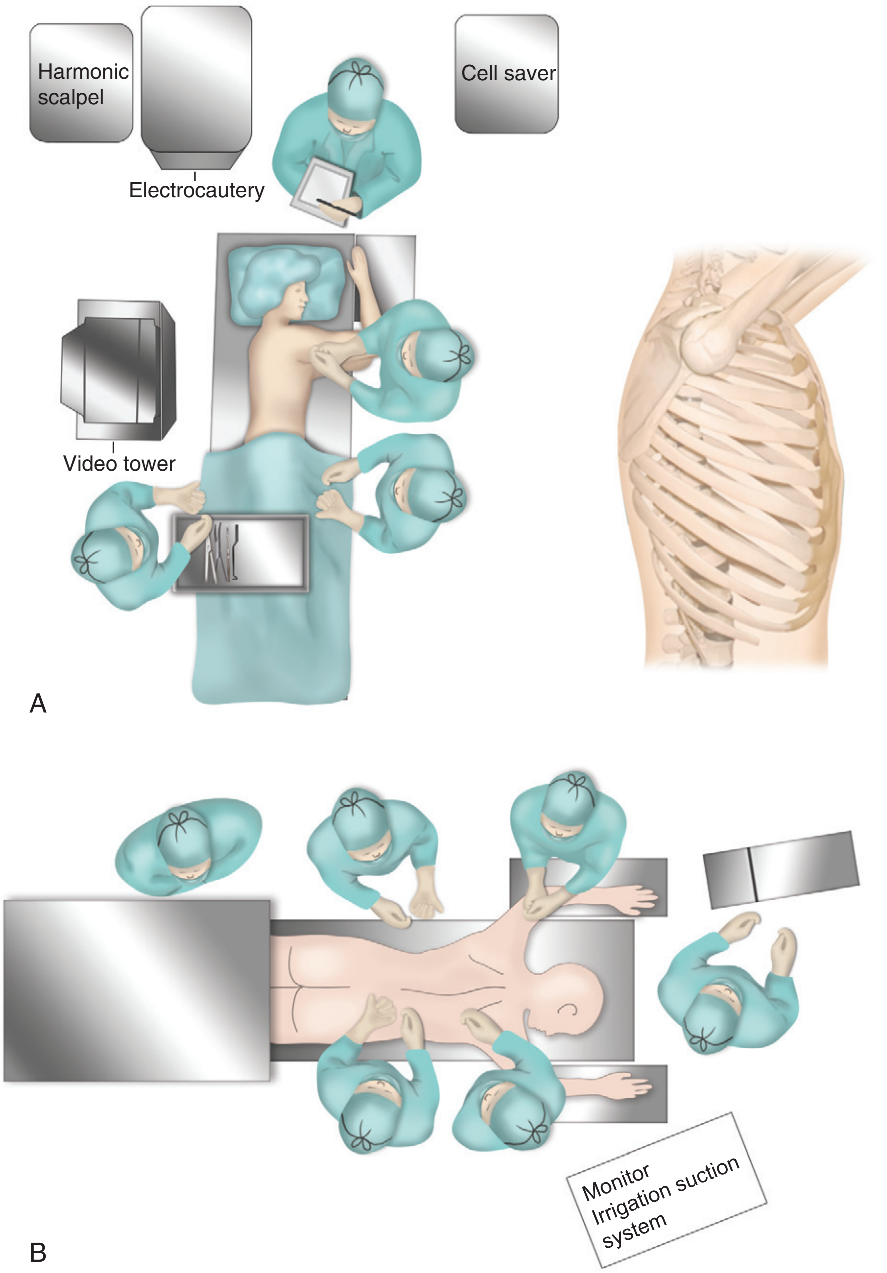

Figure 59-2 Operative positioning. **A,** Patient in lateral decubitis for a thoracic approach with placement of operative equipment. **B,** Illustration of a standard prone position that can be adopted with an anterior release.

situated closer to the left and is often the preferred side for vascular surgeons, because it is easier to mobilize and repair than the inferior vena cava (IVC). It is also important to remember that with significant axial rotation of a right thoracic curve, the great vessels are farther across the vertebral body and closer to the left side; this may narrow the working space and increase the difficulty from a left-sided approach. Routinely, the convex curve side should be placed upward, and a beanbag can be used to help position the patient in lateral decubitus.

A gel roll or padding should be placed under the axilla, and careful attention should be paid to ensure that all pressure points are well padded. The knees are typically slightly flexed, and a pillow is placed between them. The lower arm is usually extended on an arm board, and the more elevated arm is suspended in an armrest flexed at the elbow to rotate the scapula dorsally and rostrally. Tape is placed across the hip; it can be also used to support the shoulder, but caution should be used to avoid having it too caudal, which may restrict the operative field. Surgeons can stand on either side with a screen appropriately placed for proper visualization if thoracoscopy is being used. The diskectomy is easier to perform with the primary surgeon standing on the ventral side of the patient, whereas implantation of instrumentation is easier standing from the dorsal/posterior side.

PRONE (ANTERIOR RELEASE ONLY)

The prone position has been described to facilitate use of anterior releases, followed by posterior instrumentation, without the need to reposition the patient (see Fig. 59-2, *B*). A greater degree of axial rotation facilitates the exposure and permits surgical access to the disk space for anterior releases. However, access to the upper thoracic spine (T1–T4) is limited from this position and should be avoided. The patient can be turned prone, and the pads can be adjusted to the desired configurations. The chest pad can be positioned more caudally to attempt and allow greater kyphosis at the upper thoracic levels. The shoulders are abducted to the sides, and the elbows are flexed at right angles, with special attention given to padding the ulnar nerve.

Operative Technique

INCISION/EXPOSURE

The incision should be verified by fluoroscopy to confirm the anticipated exposure. The convex lung should be collapsed prior to entry into the pleural cavity to avoid injury to the pleura or lung. After the initial port is created, the lung can be insufflated with carbon monoxide; the remaining access ports or a lung retractor can be used.

Upper Thoracic Access (T1–T4)

A curvilinear incision paralleling the underside of the scapula should be adopted and aimed toward the ipsilateral nipple (Fig. 59-3). Each of the muscle groups should be identified and tagged to facilitate reapproximation at closure. The scapula can be retracted to help identify the various muscles, and the trapezius can be divided lateral to its medial attachment. The latissimus dorsi, rhomboid major, and serratus anterior can be divided from their rostral attachments, thus allowing finger dissection of the deep plane of the scapula. The scapula can then be further retracted, allowing access to the upper thoracic spine. Generally, rib resection of the lower rib will allow access to the associated disk space (e.g., resection of the T3 rib will allow access to the T2–T3 disk space).

Single and Double Thoracotomy: Convex

The incision is generally made from the lateral edge of the erector spinae muscle to the costochondral junction of the rib at the desired level. The exposure should be centered over the apex of the curve but may be slightly more rostral, because it is easier to work caudally with the rib angulation. Typically the desired rib is two levels rostral to the target disk space given the caudad angulation of the rib. For a single thoracotomy, the exposure typically parallels the seventh or eighth rib, whereas a double thoracotomy can often be achieved with an incision that extends from the rostral level of T4 in an oblique angle to the costochondral junction of T10 or T11. A thoracotomy can be performed at T4–T5, and a second thoracotomy entry point can be created at T8–T9 from the same incision.

After the exposure is extended past the subcutaneous adipose layer and is appropriately widened, the rib can be dissected. Typically, Bovie electrocautery can be used to longitudinally expose 4 to 6 cm of the rib (Fig. 59-4). The periosteum of the rib can then be dissected circumferentially using a Penfield 1 or Doyen rib dissector (Fig. 59-5). A 4 to 6 cm segment can then be resected using a rib cutter, and the edges can be waxed (Fig. 59-6). The intercostal space can then be divided on the rostral aspect of the rib space. The underlying endothoracic fascia and parietal pleura can then be opened to access the chest cavity.

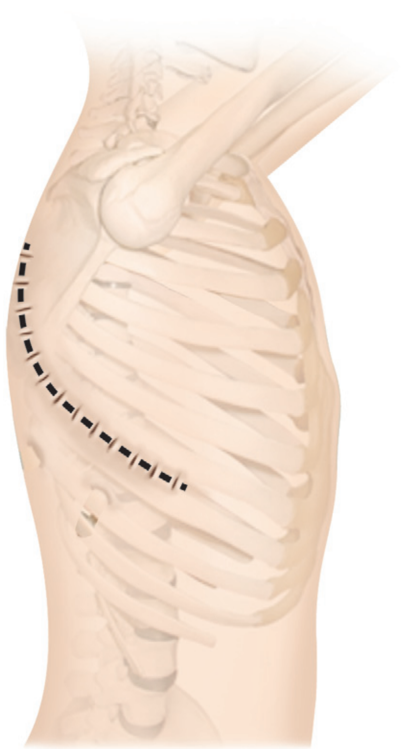

Figure 59-3 Curvilinear incision allows access to the thoracic cavity.

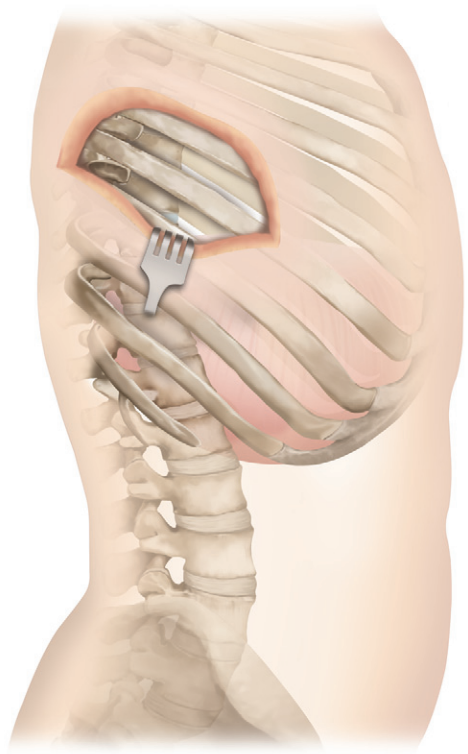

Figure 59-4 Exposure of the ribs and intercostal space.

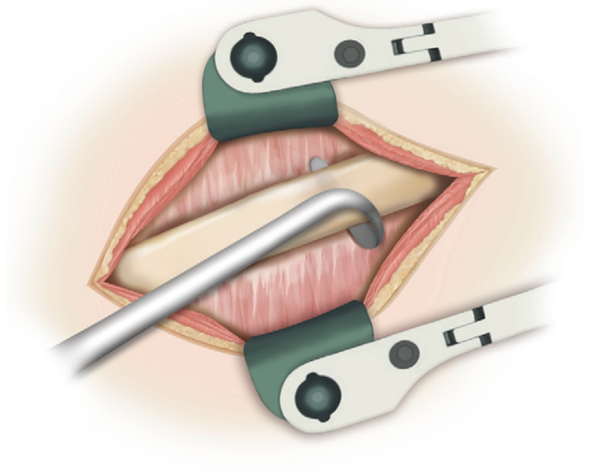

Figure 59-5 Dissection of the rib using a Doyen or rib dissector.

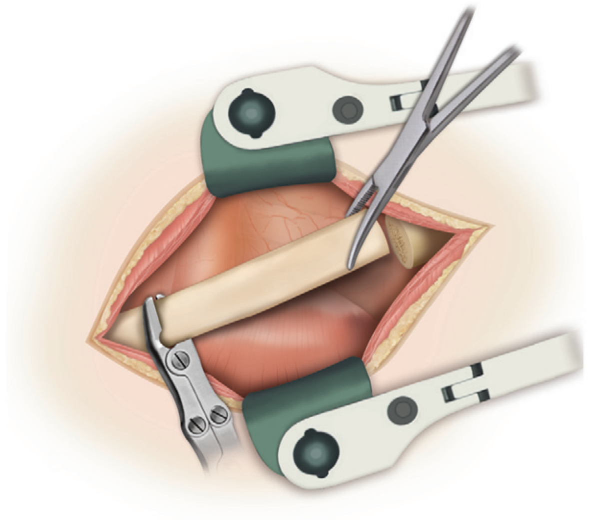

Figure 59-6 A rib cutter can be used to remove the rib, and the edges can be waxed.

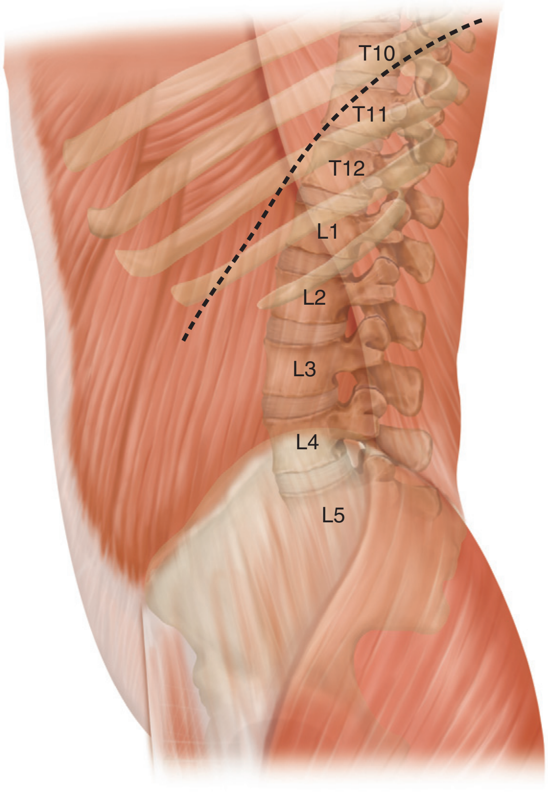

Figure 59-7 Curvilinear incision for thoracolumbar access and underlying musculature.

Alternatively, the surgical exposure can be created without rib resection. The intercostal muscles are divided along the rostral edge of the rib to avoid injury to the neurovascular bundle. This can be achieved by splitting the intercostal muscles, working a hemostat through the endothoracic fascia and parietal pleura until a "pop" is felt as the pleural space is reached. The surgeon can then slide a finger under the intercostal space and use Bovie electrocautery to dissect down to the level of the finger. An opening 4 to 6 cm in length is sufficient to create an adequate working space, which can be widened using a rib spreader.

Endoscopic Access

After the convex lung is collapsed, three to five ports are made in the anterior axillary line to perform the diskectomies; typically each incision allows access to two to three vertebral bodies, and the apex may allow for slightly more. A small incision is made 1.5 to 2.0 cm on or just rostral to the rib. The pleural space can be accessed by splitting the intercostal muscles, or by gently twisting the trocar, until a loss of resistance is felt. After the thoracoscope is inserted, the remaining entry points can be created under direct visualization by angling the scope from within the chest cavity. Localization is then confirmed by fluoroscopy. This can be done by inserting a Steinmann pin through one of the access ports into the disk space and verifying the location using fluoroscopy. Multiple ports can be created using the same approach. The desired location of each entry point can be verified by inserting a needle at the estimated entry point and dripping irrigation through the needle; drops should land against the spine at the desired location. In addition, it should be kept in mind that two to three screws can usually be placed with each entry point.

Similar ports will need to be created after the diskectomy to provide access for the screws and rod. Typically these are made in a similar fashion along the posterior axillary line. A combination of thoracoscopic ports and mini-open thoracotomies can also be utilized at the discretion of the surgeon.

Thoracolumbar (T10–L4) Access

Access to the thoracolumbar spine is typically achieved by making an incision along the rib of T10; the incision should extend from the lateral edge of the erector spinae muscle and course over the rib of T10 (Fig. 59-7). The exposure is extended to the costochondral cartilage of T10, which should be divided and tagged to be reattached later. The thoracic spine can be reached in a similar fashion as previously described, or a retropleural approach can be adopted.

The costochondral cartilage can be followed to the properitoneal fat, which is continuous with the retroperitoneal space caudal to the diaphragm (Fig. 59-8). Finger dissection or a Kittner dissector can then be used to push the peritoneum anteriorly, away from the diaphragm.

The diaphragm then needs to be divided with a cuff of approximately 1 to 2 cm at the attachment to the costal margin (Fig. 59-9). The edges should be tagged for future reapproximation. The crus of the diaphragm can then be identified and divided at its attachment to the anterior longitudinal ligament of L1–L2. The psoas can be slightly undermined and mobilized posteriorly to facilitate exposure of the spine and allow placement of staples and screws.

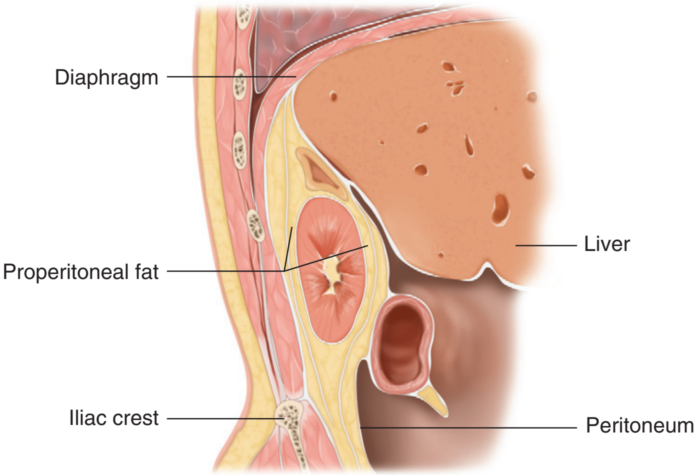

Figure 59-8 Cross-section illustrates the visceral organs and the relationship of the properitoneal fat and the retroperitoneal space.

DISSECTION OF PLEURA

The pleura can be divided in a longitudinal fashion, while being cautious not to injure the segmental vessels, if they are to be preserved. Using a Kittner dissector, the pleura can then be dissected anteriorly and posteriorly to expose the rib head and anterior edge of the vertebral body. A sponge can then be placed between the great vessels and the vertebral body to protect the vessels from inadvertent injury.

REMOVE DISK/VERTEBRAE

Once the disk space is visualized, a long-handled blade can be used to incise the disk space. A large rectangle can be cut into the annulus, and a pituitary rongeur can be used to remove the disk. Often a Cobb periosteal dissector can be used to separate the cartilaginous and osseous end plates to facilitate removal of the disk. The disk space can be finished using a curette or rasp. Fluoroscopy can be valuable to assist in orientation of the borders of the disk space when significant rotation is present. The anterior edge of the vertebral body, the posterior longitudinal ligament (PLL), and

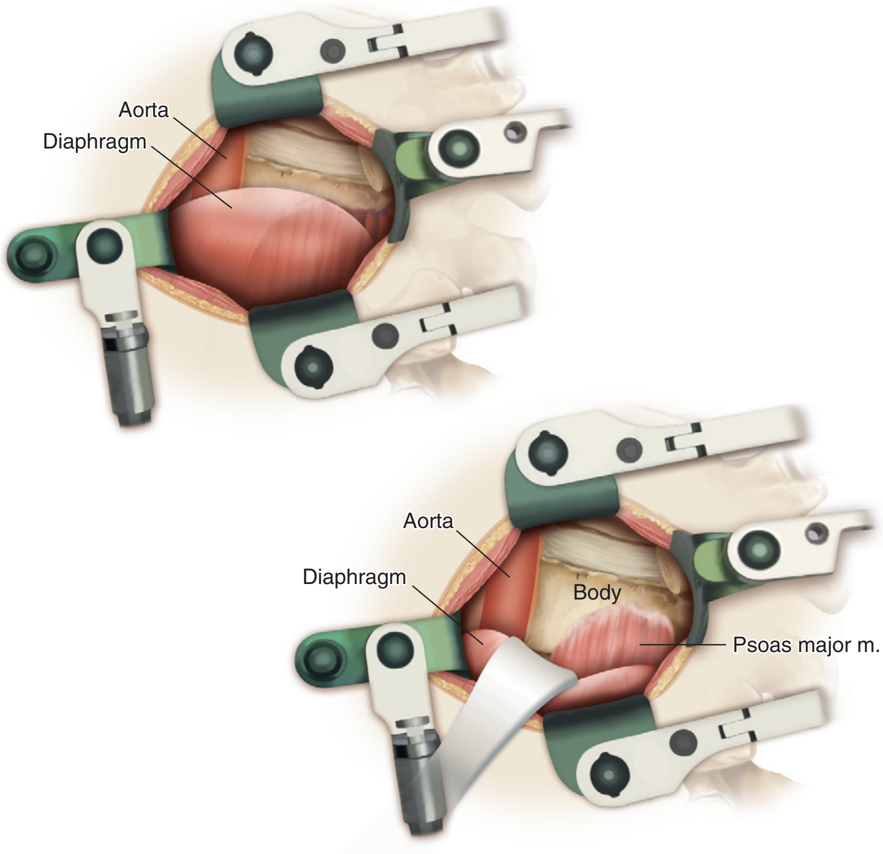

Figure 59-9 Operative view above the diaphragm before and after detachment.

the deep border of the annulus fibrosis should be visualized at the completion of the diskectomy. It is not typically necessary to resect the contralateral border of the annulus fibrosis, nor is it usually necessary to resect the PLL; the thinned annulus fibrosis may provide additional support to hold the graft in position. However, if the bone is less sturdy, release of the annulus may be required to avoid excess stress on the weaker end plates during correction.

If a vertebrectomy is required to achieve sufficient correction, this can be performed after completion of the diskectomies. Furthermore, an asymmetric wedge can be created to allow bone-on-bone interface. Either the osseous margin circumferentially should be removed, or bone the thickness of an eggshell, at most, should be left to allow for correction without overly straining the screw strength.

RIB HEAD REMOVAL

For dual screw-and-plating systems, or for younger patients in whom the vertebral body is smaller, the rib head will often have to be removed to create sufficient working space. Furthermore, the rib head can be used as a marker to delineate the posterior edge of the vertebral body during the diskectomy, but it may also interfere with completion of an adequate diskectomy. The choice of removing the rib head to assist in the diskectomy is left to the discretion of the surgeon. Once the pleura is dissected, the rib head can be removed using a rongeur. The rib head can be a useful marker to delineate the posterior edge of the disk space, and it can be removed after the diskectomy to help orient the surgeon.

GRAFT PLACEMENT

Bone chips or allograft can be packed into the disk space to promote fusion at this time. If a greater extent of correction is desired, a structural graft can be placed into the disk space. Typically adolescent idiopathic scoliosis curves are hypokyphotic in the thoracic spine; therefore morcellized bone graft is sufficient in the thoracic spine, given the weaker end plates, and it can help increase kyphosis. However, in thoracolumbar curves, grafts are routinely required to maintain sagittal alignment. Various graft shapes and sizes are currently available for specific needs. If a vertebrectomy is performed, a cage of desired size can then be fitted into the space. Caution should be used to avoid shortening the spine excessively, because this can result in neurologic compromise.

INTERNAL THORACOPLASTY

If a significant rib hump is present, internal thoracoplasty can be performed to improve the cosmetic outcome. This can be performed prior to completing the diskectomy if additional bone graft is needed, or if the rib head is obscuring the completion of the diskectomy. From the internal exposure, the pleural opening can be extended across the rib head. Subperiosteal dissection can be used similarly to expose 4 to 6 cm of additional rib beyond the rib head at the desired apical ribs, while avoiding injury to the neurovascular bundle. Ribs can be exposed to approximately 4 to 6 cm from the head or to the posterior axillary line. The rib can then be cut and peeled away from the periosteum to the articulation with the transverse process, and the rib head can then be disarticulated; this can be repeated for the remaining apical ribs, however, caution should be exercised not to remove too many ribs, lest a flail chest should develop. Typically, fewer than five ribs can safely be resected.

SEGMENTAL VESSELS

The segmental vessels may not routinely need to be sacrificed, especially with single screw-and-rod constructs. However, with placement of dual screws and plates, the segmental vessels must be ligated. Although varying factors such as unilateral vessels, the number of vessels, and the anatomic level have been associated with spinal cord infarction, no definitive precautions can guarantee avoidance of infarcts. Some have advocated temporarily occluding the segmental vessels and monitoring for changes in neurologic response, but delayed infarcts have also been reported. Overall, as many segmental vessels as possible should be preserved. The vessel should be coagulated and tied off prior to transection, and the tie can be reinforced with a Weck clip at the surgeon's discretion.

SCREW PLACEMENT AND STAPLES

The rotation associated with scoliotic deformity can be confusing; therefore, careful attention must be paid to visualize the anterior edge of the vertebral body, the superior and inferior end plates, and the posterior margin that can be identified through the disk space or by the neural foramen. Single screw placement can be achieved while preserving the segmental vessels by placing the screw near the superior end plate. The position near the end plate is more ideal, because the screw has greater biomechanical purchase; the entry point is at the inferior anterior edge of the rib head (Fig. 59-10). Screws should attain bicortical purchase with approximately 2 mm, or two threads of the tip, beyond the cortical margin. The ventral–dorsal position of the screw can be staggered slightly to help correct the axial rotation of the vertebral body when the rod is implanted. The tract can be started with an awl at the desired location, followed by a tap. The depth of the screw can be verified using a ball-tipped probe, and the screw can be inserted. Blunt-tipped screws are available to avoid injury to the great vessels on the contralateral side.

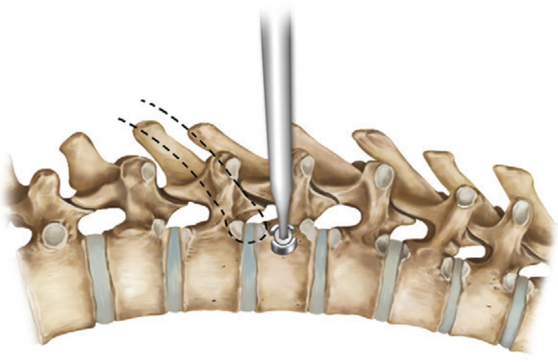

Figure 59-10 Entry point of the posterior screw.

If a dual rod–dual screw system is used, a staple will have to be implanted to guide the screws. The rib head may have to be resected to create sufficient space, after which the staple is positioned in the desired location and is tamped into the vertebral body. An awl can be used to start the tract, and a tap is used to create the screw trajectory. The depth should be measured, and then the screw is placed. Blunt-tipped screws are available to avoid injury to contralateral structures in the thoracic spine. The anterior screw trajectory should parallel the posterior wall of the vertebral body, and the posterior screw is directed slightly forward (Fig. 59-11). The staples can also be positioned to permit correction of axial rotation when the rod is implanted. It is important to note that at this writing, the dual rod–dual screw system was not amenable to a thoracoscopic approach.

ROD REDUCTION/CANTILEVER

Prior to deformity correction, and depending on location of the curve's apex, the axillary roll may be removed to facilitate correction. The desired length of the rod should be measured, and an appropriate segment should be cut. The rod should then be bent into the desired contour. For milder curves, the normal sagittal profile can be bent into the rod. However, larger curves may require the rod to be bent with greater curvature to facilitate insertion and to avoid excess stress on the screws.

Often the curve will be improved from simply reducing the rod into position. The rod should by inserted on one end and sequentially reduced into position using a cantilever technique (Fig. 59-12). Hook holders can be used to align the rod to the screw heads, then the rod can be reduced sequentially. Set screws should be placed loosely to keep the rod in place.

ROD DEROTATION

In thoracolumbar curves, once all the set screws are engaged, the rod can be rotated using a vise grip or rod holder to convert the scoliosis into a sagittal profile, thus creating lumbar lordosis or thoracic kyphosis (Fig. 59-13). The set screws should be sequentially tightened to maintain the derotation. Rod derotation in the thoracic spine will typically create increasing hypokyphosis and is therefore counterproductive.

DIRECT VERTEBRAL BODY DEROTATION

The set screw at the apical or rotated segments can be loosened, and provided that monoaxial or uniaxial screws were used, the vertebral body can be derotated directly by pivoting the screw and then securing it with the set screw (Fig. 59-14). This can be more easily achieved using a dual rod–dual screw system. After one rod is reduced, the other screw can be used to apply axial corrective forces; then, the set screw can be used to maintain the corrected position.

COMPRESSION

Compression between the screws can be sequentially performed to further improve the coronal curvature. Often compression against a rod holder or with the rod holder adjacent to the screw head may minimize the risk of loosening the screw purchase. One screw should be tightened, while the adjacent one is loosened. A compressive force is then applied between both, and the loose screw is tightened. In the thoracic spine, this can be used to create more kyphosis as well.

IN SITU BENDING

Once the set screws are tightened, further correction can also be achieved by in situ bending of the rod. This is mostly

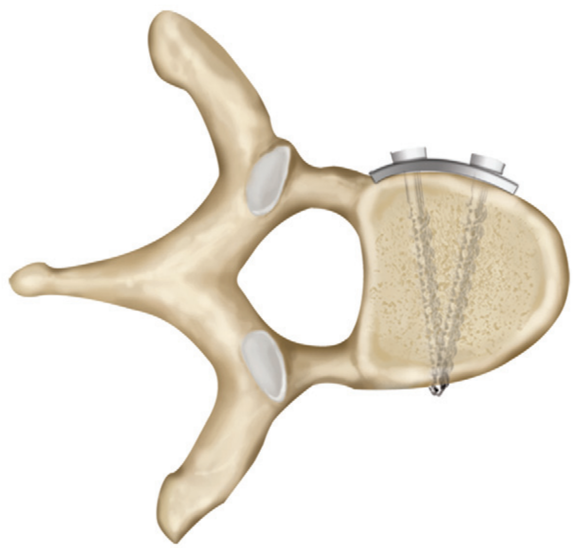

Figure 59-11 Axial view shows the posterior screw parallel to the posterior end plate and an angulated anterior screw.

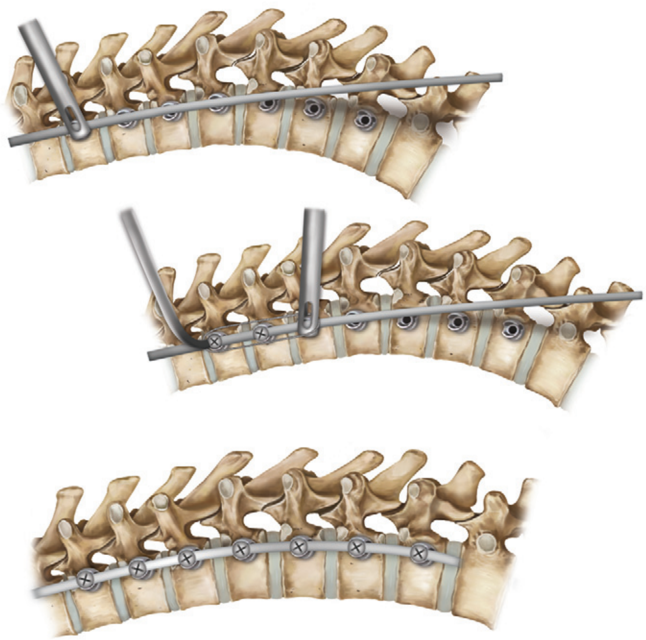

Figure 59-12 Segmental reduction of screws leading to correction of the coronal curvature.

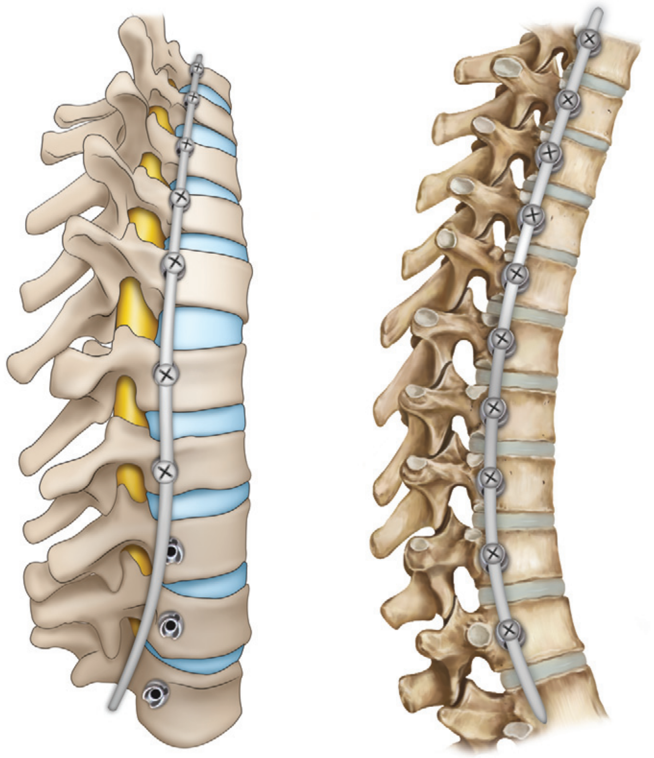

Figure 59-13 Rod derotation converts a coronal curvature to kyphosis. The rod is initially curved in the coronal plane; after the set screws are loosely attached, the rod is then rotated to reduce the coronal curvature while creating kyphosis.

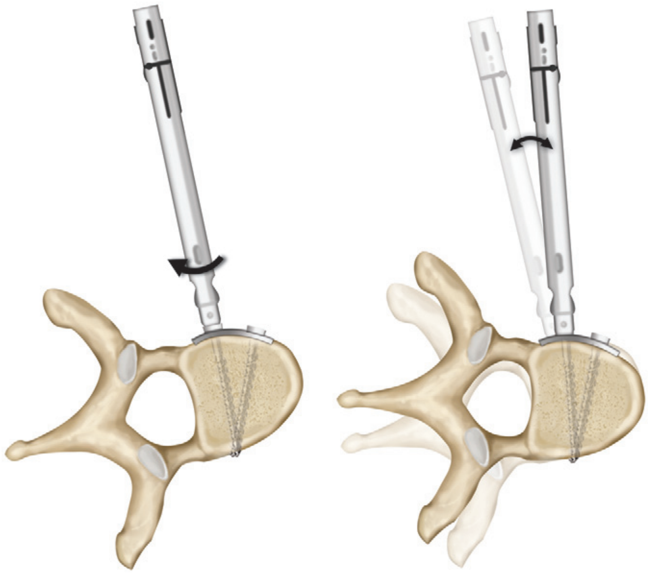

Figure 59-14 Illustration shows how the position of the screw and its alignment when reducing the rod may affect rotation.

used to create a normal thoracic kyphosis or to simulate more lumbar lordosis (Fig. 59-15).

CLOSURE

Closure of the pleura has been postulated to decrease chest tube output, help hold the graft in position, and reduce

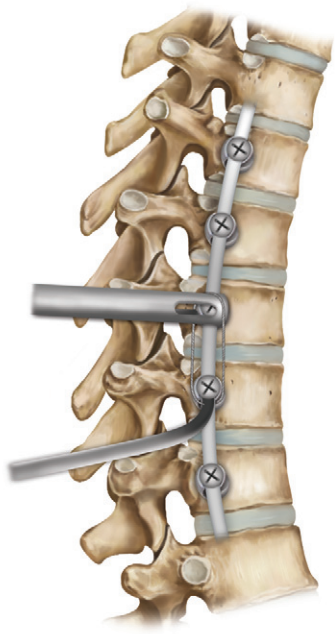

Figure 59-15 Final adjustments can be made by using in situ bending.

adhesion formation. This can be achieved by using a running suture or an EndoStitch device (Covidien, Mansfield, MA) for a thoracoscopic approach. If the diaphragm was divided, it should be reattached using nonresorbable stitches, and a chest tube can be placed and exited through one of the access port entry sites. Large Vicryl sutures can then be placed to reapproximate ribs that have been displaced. The lung should be inspected to ensure that it is not injured, and it should be reinflated. The muscles that were tagged during the exposure can then be reapproximated.

Outcomes

Equivalent results have been reported with the use of anterior fusions and thoracoscopic anterior fusions. Roughly 51% to 69% improvement in the thoracic curvature, as well as increases in the thoracic kyphosis, can be expected with either technique.[7,8] Although overall outcomes are similar, increased blood loss and operative times have been reported with thoracoscopic approaches in some studies, whereas open approaches have been associated with greater blood loss and equivalent operative time in others.[7-9] However, thoracoscopic approaches have been associated with better forced expiratory volume in 1 second and forced vital capacity measures postoperatively and at 2 years when compared with open thoracotomy approaches.[10-12] The addition of thoracoplasty has also been linked to worse pulmonary function test results.[10]

A large series reviewed 599 procedures that involved anterior approaches and found a major complication rate of 7.5% from reintubation, congestive heart failure, deep wound infection, hemothorax, significant blood loss, myocardial infarction, perforated bowel, pneumothorax, pneumonia, hemorrhage requiring reoperation, pulmonary edema, pulmonary hemorrhage, sepsis, respiratory distress, chylous effusion, paralysis, and death.[13] A 32% risk of minor complications was reported that included ileus, atelectasis, superior mesenteric artery syndrome, arrhythmia, infection, dermatitis, esophagitis, Horner syndrome, intestinal ulcers, lung adhesions, meralgia paresthetica, skin ulcers, retrograde ejaculation, syndrome of inappropriate diuretic hormone secretion (SIADH), thigh and knee pain, thrombophlebitis, transient ischemia of the foot, transient paresis, urinary retention, urinary tract infection, and pleural effusions. Overall, pulmonary complications accounted for more than 50% of the complications.

One series of 85 patients treated with open thoracotomy and anterior fusion with 5 years of follow-up found 16% of patients had complications; 4% had severe complications that included implant breakage and progression of the main thoracic curve that required reoperation; and 12% had minor complications that included instrumentation failure that did not require revision surgery and loss of correction of a compensatory curve.[14]

Conclusion

Although anterior approaches to the thoracic spine are safe and provide good outcomes, posterior pedicle screw fixation has become increasingly popular. Anterior spinal fusions minimize the risk of developing crankshaft phenomenon in skeletally immature patients; however, this risk is thought to be significantly reduced with the advent of thoracic pedicle screw fixation. Furthermore, the more powerful correction obtained using pedicle screws has led to questions regarding the benefit of adjuvant anterior releases. Nonetheless, posterior screw constructs may decrease the amount of thoracic kyphosis, thus worsening preexisting hypokyphosis in adolescent idiopathic scoliosis.

Anterior approaches not only more significantly correct the hypokyphosis but may also minimize the risk of developing crankshaft phenomenon in skeletally immature patients. Alternative treatment options for skeletally immature patients include vertebral body stapling or bone tethers that apply a restrictive force on the convexity of the scoliosis, allowing differential growth on the concavity using the Hueter-Volkmann principle. These devices aim to improve the scoliotic curve using the growth potential in younger children, but they either have a narrow clinical indication or are still being investigated.

Overall anterior instrumentation is relatively safe and yields good results. Further analysis and longer evaluation is required to compare anterior and posterior approaches and to evaluate newer technologies to better define the role of anterior surgery in scoliosis.

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60 Anterior and Posterior Treatment for Thoracolumbar and Lumbar Scoliosis

SACHIN GUPTA and MUNISH GUPTA

Overview

Large and rigid scoliotic deformities can be treated with many methods that are constantly evolving. Preoperative traction has been reported by many authors for the treatment of rigid curves that would be otherwise treated with anterior release followed by a posterior fusion. The advantages of traction are gradual correction of a spinal deformity that may not tolerate acute correction in the operating room (OR) without a risk of neurologic injury. The disadvantage is the long hospital stay, the associated expense, and reported complications.[1-4]

Intraoperative traction has also been shown to help reduce the larger curves into more manageable curves on the operating table.[5,6] Intraoperative traction should only be done with neuromonitoring, because changes may be seen even before the incision is made. Lewis describes decreasing the amount of traction placed if neuromonitoring changes occur without permanent sequelae. Halo-femoral traction has been described, which also exposes the patient to a small risk of a distal femoral pin placement.

Intraoperative temporary rod distraction has also been described,[7] which is used to correct large curves in stages to give the curve some time to stretch in between the stages. Neurologic changes can also occur in such procedures, and it is mandatory to have neurologic monitoring. The use of multiple-stage surgery has the drawbacks of increasing the chance of infection, because of going through the same incision repeatedly, and nutritional depletion.

Anterior release for treating rigid deformities has a long history, beginning with anterior débridement for tuberculosis infections.[8-11] Anterior release has been identified to be helpful in achieving greater correction and higher fusion rates.[12] Some advantages include that the disk space provides a very favorable environment for fusion owing to a large area of bleeding bone that provides an ideal bed. The distance the fusion has to occur across is relatively small compared with the distance between the transverse processes. In addition, the bone graft is under compression.

On the other hand, some disadvantages apply when performing an anterior approach in an adult patient. Morbidity is associated with the approach, because cutting the abdominal musculature and sometimes the chest wall may be necessary, depending on the location of the release needed. The musculature frequently stretches, giving at times a rather unsightly, protuberant look to the abdomen. The stretch can result from a combination of cutting the muscle and denervation of the muscle from damaging the eleventh thoracic nerve in thoracoabdominal approaches.[13,14]

Anterior Approaches

THORACIC CURVES

Anterior release in the thoracic spine requires a simple thoracotomy. The rib can be removed during the exposure and can be used as bone graft for the anterior or posterior part of the procedure. The level of thoracotomy can be determined by the rib that best covers the apex of the scoliotic curve. It is generally the rib level above the last level of diskectomy.

Once the thoracotomy is done, the pleura is cut over the convexity of the curve. The segmental vessels are then ligated to expose the disk spaces, and the disk is cut with a scalpel or electrocautery. A thin rongeur is then used to remove the annulus and nucleus pulposus. After a large portion of the annulus is removed, the cartilaginous end plate is removed from the bony end plate with a sharp Cobb elevator. A large pituitary or similar rongeur is used to debulk remnants of cartilaginous end plate and annulus. The posterior annulus is then removed by a sharp curette from the posterior longitudinal ligament (PLL). The PLL has fibers oriented vertically that become visible once the posterior annulus is removed. A distractor in the disk space is very helpful while removing the posterior annulus with a curette, because it shows the edge of the posterior annulus and the bony end plate very clearly. Care should be taken not to damage the bony end plate to avoid bony bleeding that might make the removal of the posterior annulus more difficult.

THORACOLUMBAR SPINE

The thoracolumbar spine can be approached via the thoracoabdominal approach. This approach usually involves cutting through the diaphragm. The superior end of the psoas muscle must be stripped off the spine to expose the disk spaces in the upper lumbar spine.

LUMBAR SPINE

The lumbar approach is reserved for exposing the lumbar spine only, especially the lower lumbar spine.

Anterior diskectomy in the lower lumbar spine is used to obtain correction of the fractional lumbar curve. The diskectomy allows sagittal plane correction of the flat lumbar spine, which is a deformity present in most idiopathic and degenerative lumbar curves.

The psoas muscle must be elevated from the vertebral bodies and the disk spaces. The psoas muscle is carfully retracted posteriorly to avoid injury to the lumbar plexus. The vascular structures are at greater risk during the lumbar approach. Generally, the iliolumbar vein must be ligated to mobilize the great vessels for adequate exposure of the lower lumbar spine segments.

Posterior Approach

The posterior approach is the simplest and most universal approach to the spine. The surgeon must expose the spinous processes, laminae, facet joints, and transverse processes, and an important part of the posterior exposure is identifation of the pars interarticularis; it leads to the pedicle entry point in the lumbar spine and prevents the surgeon from removing too much bone and destabilizing the lumbar segment. It is important to clean the soft tissue from the posterior elements using a curette or a sharp Cobb elevator. This tissue removal aids in identifying landmarks as well as preparing for a posterior element fusion. The hypertrophic facet joints also need resection to identify the pars and the transverse process in order to place the spinal instrumentation. An osteotome is very useful for removing the large hypertrophic facets.

LUMBAR DECOMPRESSION

Lumbar decompression is often needed in treatment of degenerative scoliosis and adult idiopathic scoliosis with degenerative changes in the lumbar spine. The most common levels with spinal stenosis are L3–L4 and L4–L5. The laminectomy is done by removing the spinous processes first; the lamina is then thinned with a high-speed burr, and the thinned lamina is resected with a Kerrison rongeur. The foraminal decompression is performed using Kerrison rongeurs to remove the ligamentum flavum and the superior facet from the lower spinal segment. The laminar resection is done so that the lateral lamina, pars interarticularis, and partial facet joint are preserved.

POSTERIOR RELEASE

Posterior release is an important part of any spinal deformity surgery, and it was described by Shufflebarger.[15] The release includes removal of the interspinous ligament and ligamentum flavum with partial facet resection and removal of the facet capsule (Fig. 60-1). A distractor is used between the lamina to help with the release, especially the lateral part of the canal through the facet joints. Once the posterior release is performed, it is much easier to manipulate the spine into realignment. The posterior release is often referred to as a *Smith-Peterson osteotomy* (SPO) or a *Ponte osteotomy.* The SPO was first described for a posteriorly fused spine.[16] The fusion is removed between the pedicles, but the disks have to be mobile to achieve correction. The Ponte osteotomy was described for treatment of kyphosis associated with Scheurmann disease,[17] and it was used in the thoracic spine. In the Ponte osteotomy, the facets are resected, and the kyphosis is reduced via compression across the resected facet joints. The reasoning was that the posterior column is abnormally lengthened, and shortening it reduces it to the normal curvature.

POSTERIOR INSTRUMENTATION

Posterior instrumentation of the spine is performed with placement of hooks, wires, and screws. In recent years, more pedicle screws have been used than any other implant; but hooks are still useful, such as when pedicle screws cannot be placed or at the proximal end of the construct. The wires can be used on the concavity of the curve, where the pedicles are usually small and deformed; use of pedicle screws has improved the ability to correct spinal deformity (Fig. 60-2). The use of offset connectors allows placement of the pedicle screws as needed without lining them up. The offset connectors allow the variable distance to the rod of the screw to be easily manageable. The rod therefore can be mostly bent in the sagittal plane without having it bent in the coronal plane to accommodate all the screws.

The thoracic screws are placed by first identifying the superior facet. The junction of the facet and the transverse process is identified, and a burr is used to remove the cortex; then a pedicle probe is placed, curving away from the midline, until it passes the 20-mm mark. The pedicle probe is then placed medially and advanced. The ball-tip probe is used to palpate the bony walls of the pedicle and vertebral body before placing the screw. The landmarks and trajectories of the screw placement have been described by Polly and other authors.[18,19]

The lumbar pedicle screws are placed by first identifying the transverse process pars and the facet joint. The transverse process is then decorticated. The junction of the pars, facet joint, and transverse process defines the entry point. The pedicle probe is then used to cannulate the pedicle, facing the curve of the probe medially. The curve can be faced medially, because the pedicles are angulated quite medially in the lower lumbar spine, from L3 down to the sacrum. The pedicle screws are placed after the ball-tip probe is used to palpate the pedicle walls for any perforations.

The hooks can be placed in several positions in the spine: supralaminar, infralaminar, facet, and transverse process hooks may be used. Supralaminar hooks are placed by removing the ligamentum flavum from the superior lamina. A small (2-mm) Kerrison rongeur is then used to square the lamina for resting the throat of the hook. Usually, a small blade is placed in the supralaminar position, because the lamina is angling down toward the spinal cord. Thus the space between the spinal cord and the lamina is smaller. Additionally, only one supralaminar hooks is placed per level, because two may crowd the midline and create stenosis from the two side-by-side hooks. Facet hooks are placed by removing the inferior facet in a square pattern and then placing the hook with a short throat and a wide blade in the facet joint. This position is used for the thoracic level, only because of the anatomy of the facet joint. Infralaminar hooks are used mostly in the lumbar spine to augment

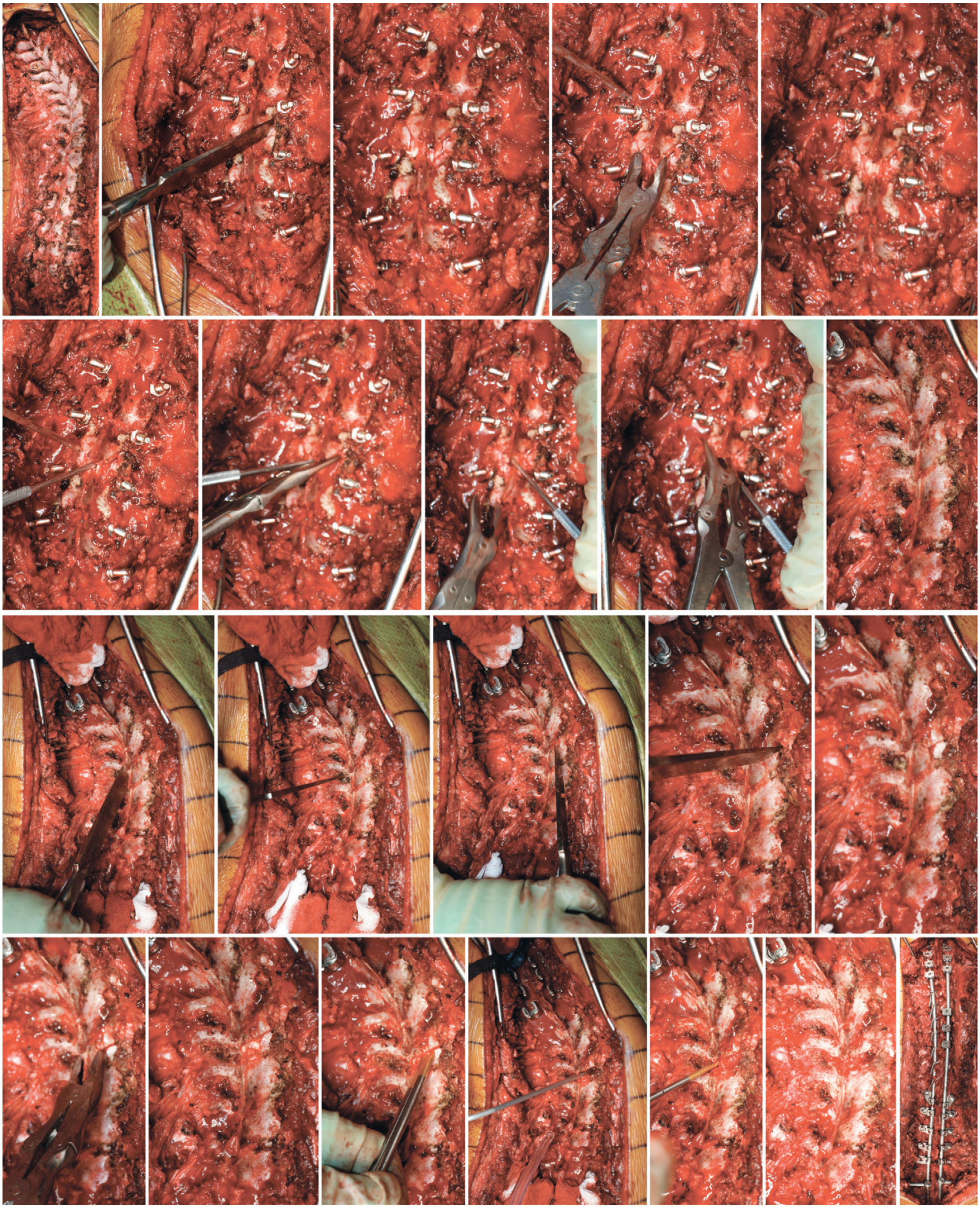

Figure 60-1 The osteotome is used to perform facetectomies in the lumbar and thoracic regions; the cut of the osteotome is oblique in the lumbar area and square in the thoracic region. A large rongeur is used to remove part of the spinous process lamina and ligamentum flavum to expose the epidural fat. The freer elevator is used to protect the dura, while a rongeur is used to remove the part of the facet and facet capsule through the foramen in the lumbar spine. A Kerrison rongeur is used to remove the facet and facet capsule in the thoracic spine.

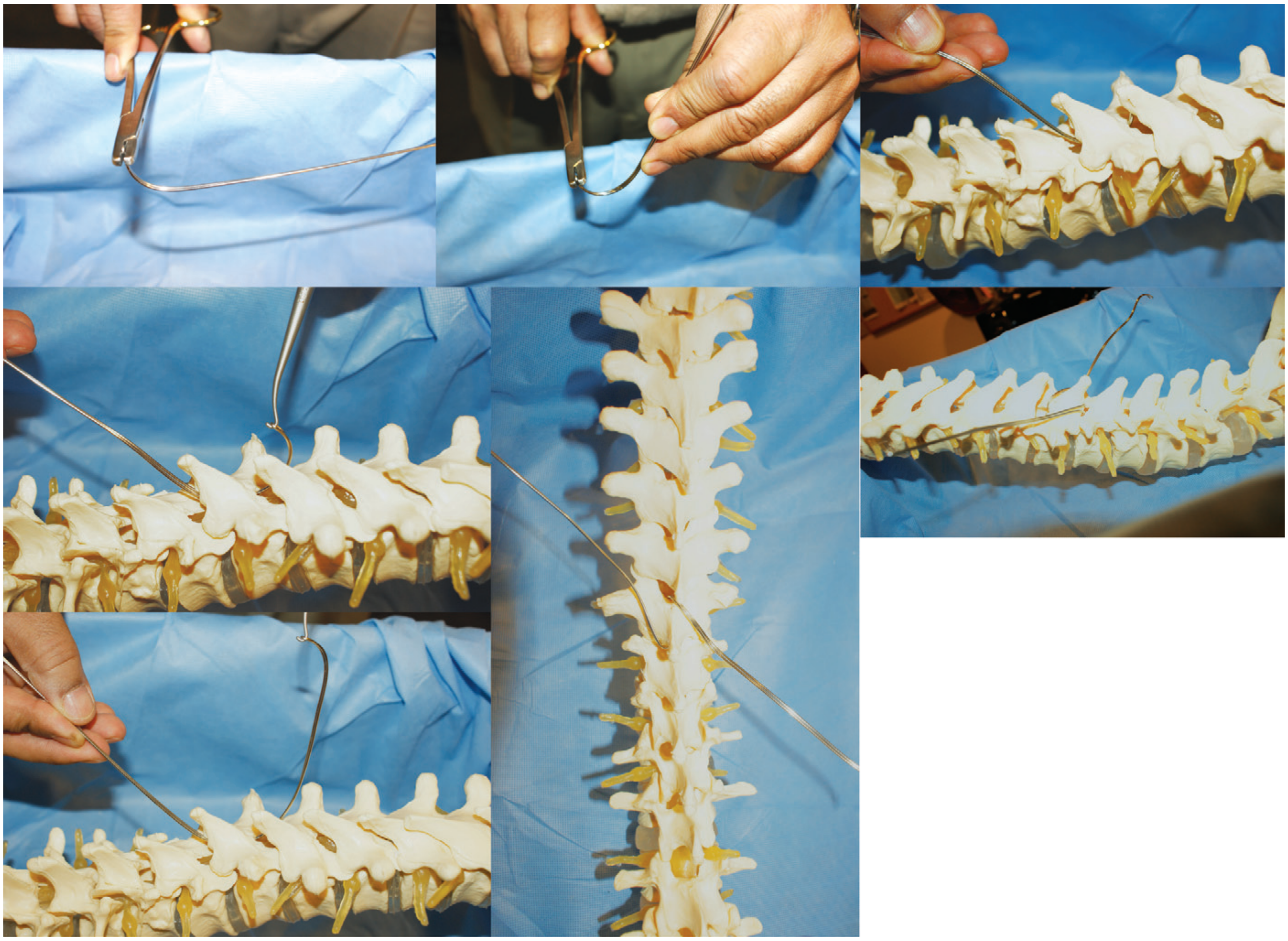

Figure 60-2 A sublaminar wire is a very useful tool. The wire is contoured using a heavy needle holder. The wire is passed beneath the lamina, hugging it, and a wire retriever hook is used to pull the wire out. Constant upward tension is kept on the wire while pulling it through, so it does not impinge on the neural elements. The wire is then molded on to the top of the lamina to prevent the wire from entering the canal.

pedicle screw fixation or when the pedicle anatomy does not permit the safe use of a screw. The hook starter is used to elevate the ligamentum flavum from the inferior portion of the lamina prior to placing the hook. The throat of the hook is usually larger, in the 9.0- to 11.5-mm range. The blade of the hook is also wide. The transverse process hook is still widely used, because it is used at the proximal portion of pedicle screw constructs. The use of the transverse process hook allows keeping the soft tissue from undergoing extensive dissection and keeps the facet joint at the end of the construct from getting disrupted, which is likely to happen when defining the anatomy and placing the pedicle screw.

Iliac screws are extremely useful in providing a strong base for long constructs. Ending a long construct at the sacrum only is prone to failure from splay, pullout, and pedicle fracture. The lumbosacral and thoracolumbar junction have been found to have a higher nonunion rate, although a combination of sacral screws and iliac screws has improved sacropelvic fixation for long constructs. Iliac screws are connected using a rodded connector to the open polyaxial screw. The screw should be at least 7 mm in diameter and 80 mm in length and are usually placed by making a separate fascial incision over the posterior superior iliac spine (PSIS). The outside of the iliac wing is exposed, and the PSIS is removed with a rongeur. A probe is placed through the channel of bone, roughly 1 cm superior to the greater sciatic notch, then the screw is placed.

The sequence of reduction techniques is dependent on the spinal deformity. In adult idiopathic scoliosis, the usual thoracic curves are to the right, and the lumbar curve is to the left. The concave rod is placed first, which is on the left side. The left side also is the convex side for the lumbar curve, therefore the curve is pushed down anteriorly while placing the left rod. This maneuver reduces the lumbar curve and improves lumbar lordosis, because the apex of the lumbar curve is in relative kyphosis. The right rod is then placed. The thoracic spine is generally compressed, and the individual lumbar segments are distracted on the concave side of the lumbar spine. The offset connectors are helpful in attaching the screws to the rod while achieving correction of the deformity (Fig. 60-3).

POSTERIOR-ONLY APPROACH

The posterior-only approach has become the surgical mainstay in treatment of most pediatric and adult spinal deformities. The abundant use of pedicle screws has allowed segmental correction in all planes. The most important

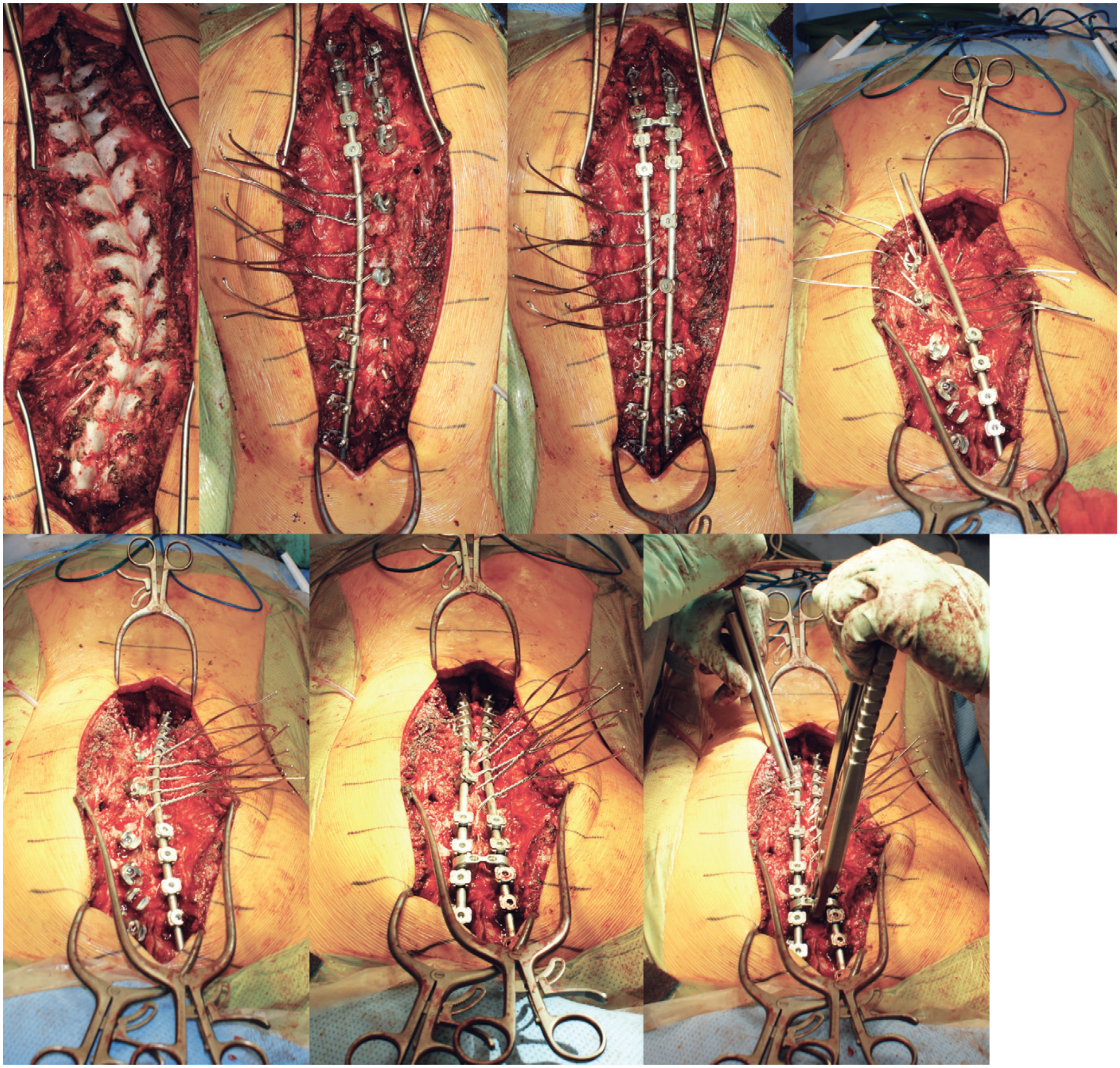

Figure 60-3 The posterior correction is usually started with the left rod. The translation of the spine is accomplished with wires or screws, and the right rod is placed to provide additional correction. The final derotation is performed by using a crosslink and a rod holder as a countertorsion while derotating the lumbar screws.

contribution in the procedures has been the concomitant use of posterior releases that accompany posterior-only approaches to spinal deformity corrections. Many of the pediatric spinal deformities, in combination with thoracolumbar and lumbar deformities, have been well corrected using the combination of aggressive posterior release and segmental instrumentation with combination of wires, hooks, and screws.

Adolescent Idiopathic Scoliosis

Thoracolumbar and lumbar curves in idiopathic scoliosis consist of the Lenke 5 and Lenke 6 curves. Even though Lenke 5 curves were treated widely with anterior spinal instrumentation, starting with Dwyer and Zielke, and finally by dual rod instrumentation, such as the KASS,[20-23] in the recent past, posterior release with posterior instrumentation has been an alternative that has gained wide acceptance. Shufflebarger[24] showed that the posterior-only approach resulted in a shorter hospital stay and fewer complications than anterior instrumentation and fusion for similar corrected Lenke 5 curves, and the author prefers the anterior approach for larger thoracolumbar curves.

Disk removal allows shortening and derotation that is better than posterior-only release and fusion. The dual-rod anterior systems are extremely powerful and have been able to alleviate some of the drawbacks of the anterior approach found early on. The drawbacks were pseudarthrosis and rod breakage with the Zielke system, cable breakage with the Dwyer cable system, and kyphosis along the instrumented segments. Adding structural grafts in the disk spaces in the lower part of the constructs, especially L2–L3, has greatly helped to restore the sagittal plane in these constructs.

The posterior approach for the Lenke 5 idiopathic curves requires a wide posterior release as described by Shufflebarger in adults.[24] The interspinous ligaments, ligamentum flavum, and facet capsule are resected, and a partial facetectomy is performed to achieve correction of the curves. One of the main indicators of such an approach is a thoracolumbar curve that is more than a normal T11–L3 construct placed anteriorly. The other curves that are better treated posteriorly are the ones with significant kyphosis in the thoracolumbar junction.

Neuromuscular Scoliosis

Most neuromuscular curves have signified thoracolumbar and lumbar components. This is frequently associated with significant pelvic obliquity. These patients are well served with a posterior-only approach that requires wide posterior release; posterior segmental instrumentation, with mostly pedicle screws in the lumbar spine; and iliac bolts to help correct the pelvic obliquity. The Galveston technique was first described by Allen and Ferguson,[27] in which the longitudinal rod was contoured and placed in between the iliac wing tables. This technique has been adapted to use iliac bolts instead of rods (Fig. 60-4). The modular nature has helped the assembly of these long constructs; although the assembly is much easier, these constructs have added bulk in the area of the PSIS that can be a problem in very thin patients. The sacroiliac joint is not fused at the time of placement of the iliac construct. The motion across the sacroiliac joint can lead to movement along the iliac screws, and the formation of lucencies and haloes are frequently seen. These haloes are generally not a problem and do not require further surgery in this patient population.

Some severe neuromuscular deformities can be treated with additional anterior procedures, the most common being the anterior release and fusion. This procedure entails multilevel diskectomies and possible reshaping of the wedge-shaped vertebra into a rectangle for gaining correction. Occasionally, the release appears insufficient, and a vertebrectomy can be added at the same setting of the multilevel diskectomy. The apical vertebra is usually resected to gain additional shortening and correction and, more importantly, to correct the pelvic obliquity; residual pelvic obliquity can result in decubiti over the trochanter and ischial tuberosities.

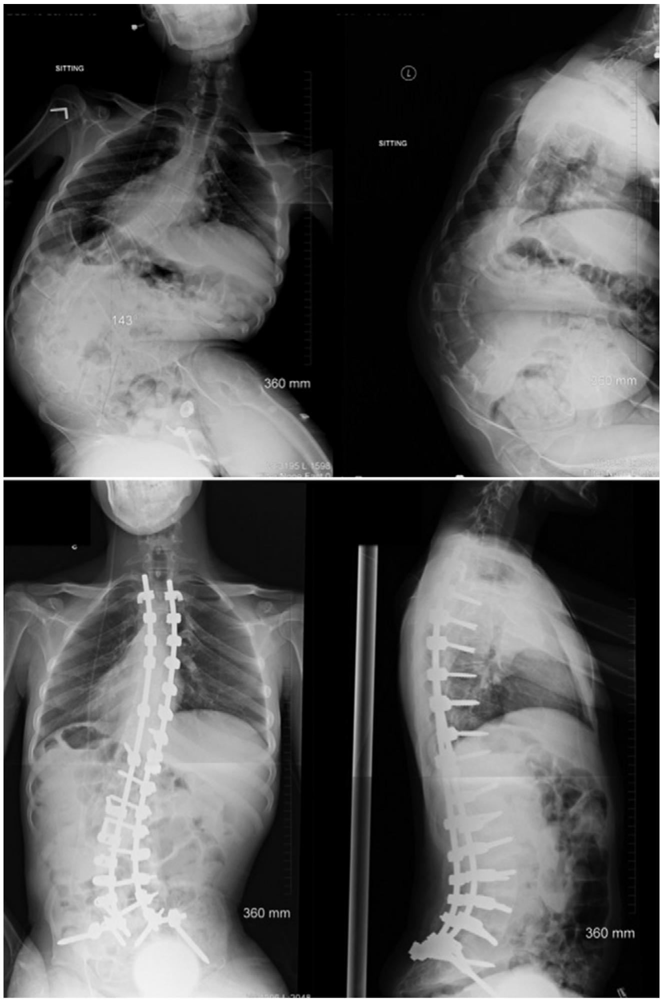

Figure 60-4 This patient had spina bifida, severe spinal deformity, and pelvic obliquity. An anterior release and a vertebral body resection followed by posterior instrumentation and fusion were performed to achieve correction of the spinal deformity of the lumbar spine and pelvic obliquity.

Adult Spinal Deformity

Adult spinal deformity with lumbar and thoracolumbar curves can be very challenging, because these curves are quite rigid, and the bones are the weak link in the bone–metal interface. Adult idiopathic curves are usually larger than degenerative scoliosis curves. Adult scoliosis patients can be divided into three categories:

1. Patients younger than 40 years with adult idiopathic curves
2. Patients with adult idiopathic curves who are younger than 40 years and who have additional degeneration of the lumbosacral junction
3. Degenerative scoliosis patients with small curves that did not exist in their teenage years

The patients that are younger than 40 years are treated similarly to adolescent idiopathic patients. The fusion levels are chosen in a manner similar to those in adolescents. The lumbar and thoracolumbar curves are treated posteriorly in the majority of the cases, and anterior release is added if the curve is large and rigid. No specific number can guide the surgeon to perform an anterior release, and the surgeon's experience and preference are important factors. Curves greater than 70 to 80 degrees that do not bend out more than 50% are considered and may more likely require an anterior release and fusion for achieving greater correction of the spinal deformity. Anterior release and fusion has also been done to increase the chance of fusion.

In recent years, the off-label use of recombinant human bone morphogenetic protein-2 (rhBMP-2 [Infuse]) with

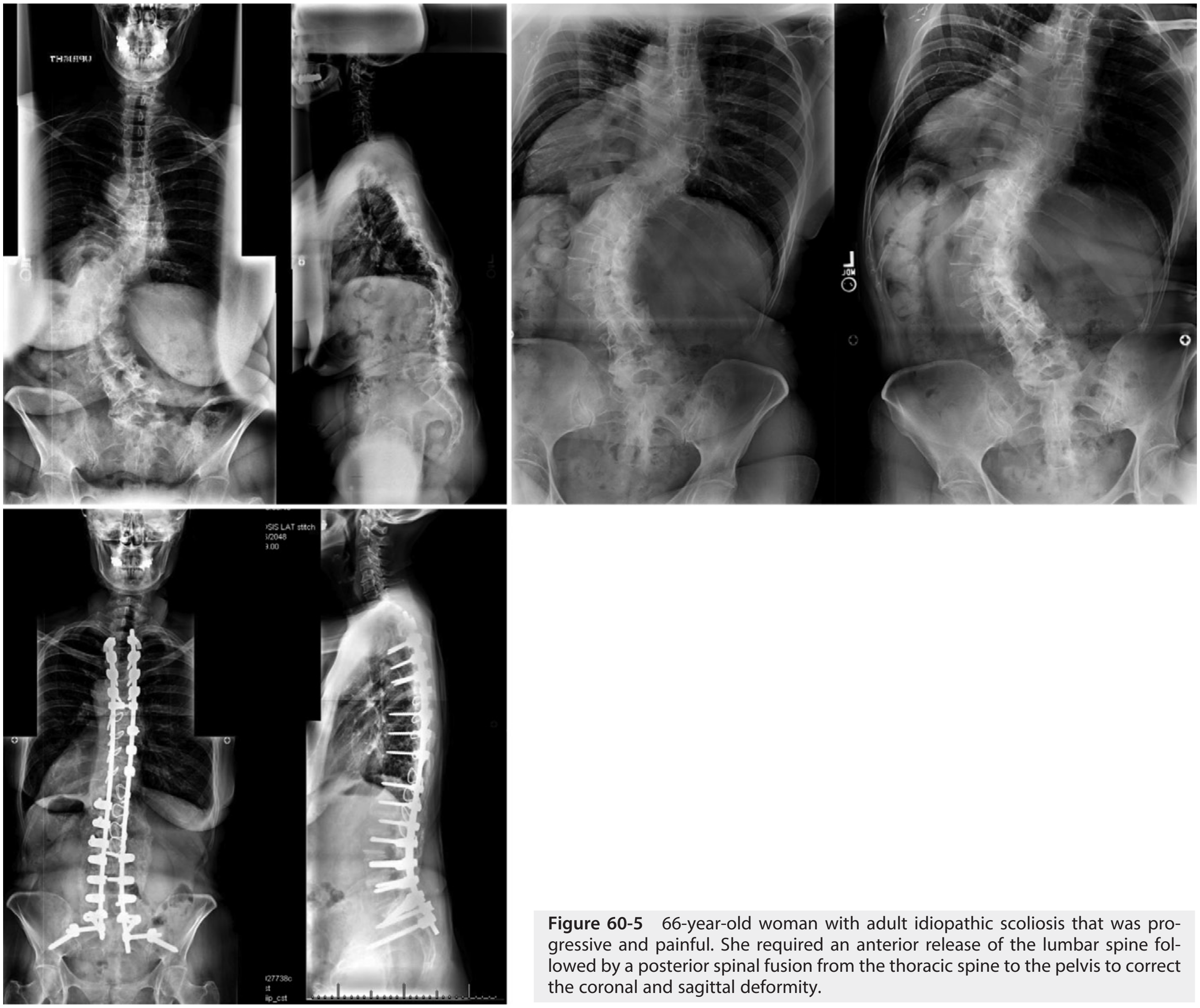

Figure 60-5 66-year-old woman with adult idiopathic scoliosis that was progressive and painful. She required an anterior release of the lumbar spine followed by a posterior spinal fusion from the thoracic spine to the pelvis to correct the coronal and sagittal deformity.

allograft has helped some of these patients achieve excellent fusions without requiring an anterior release or having an iliac crest bone harvest.

Adult idiopathic patients older than 40 years often have additional degeneration at the lumbosacral junction that can require additional fusion levels down to the sacrum with sacral and iliac screws (Fig. 60-5). Higher rates of nonunion are reported in the thoracolumbar junction and the lumbosacral junction in these patients.[25] The nonunion rates can be as high as 17%, reported in one study; nonunions can also appear late. Up to 40% of nonunions can become symptomatic and are detected after the second year. Adding anterior fusion in patients who require fusion to the sacrum has been shown to decrease the rate of nonunion when combined with sacral screws and iliac bolts.[26]

Degenerative Scoliosis

A majority of these patients not only have spinal deformity from the thoracolumbar or lumbar curves, they also have concomitant spinal stenosis, usually in L2–L3, L3–L4, and L4–L5. These deformities are rigid and display a loss of lumbar lordosis. Sagittal imbalance is a major problem in these patients, and the correction for the coronal plane, as well as the sagittal plane, becomes paramount to achieve good clinical outcome and prevent nonunions.

Sagittal plane correction has been achieved by wide posterior release, posterior lumbar interbody fusion, transforaminal interbody fusion, a lateral interbody approach, and the anterior approach. The decision of which approach is used depends on many factors:

1. The physiologic age of the patient, because the average age of presentation of these patients is around 65 years of age
2. Comorbidities that might prevent the anterior approach from being a safe alternative
3. Severity of the coronal and sagittal imbalance
4. Experience and preference of the surgeon

The degenerative scoliosis patient needs a thorough medical evaluation prior to considering any surgical intervention. We often use a chemical cardiac stress test to screen for heart ischemia prior to the surgery. When debilitated by spinal deformity and stenosis, patients are often not exercising or testing the heart.

We prefer to evaluate the need for anterior release based on the sagittal plane deformity and the severity of the coronal plane deformity. Most curves with minor flattening of the lumbar spine and moderate curves can be treated posteriorly; rigid deformities with sagittal and coronal imbalance require an anterior release of the lumbar and lumbar fractional curves prior to posterior instrumentation and fusion (Figs. 60-6 and 60-7). The posterior approach usually requires decompression of the L3–L4 and L4–L5 regions. Posterior instrumentation usually consists of pedicle screws with iliac screws.

Figure 60-6 77-year-old woman with adult idiopathic scoliosis with a long thoracolumbar curve requiring an anterior release and a posterior spinal fusion to the pelvis.

Figure 60-7 Patient with degenerative scoliosis of the lumbar spine, in addition to a spondylolisthesis at L5–S1, was treated with an anterior lumbar release and fusion and posterior instrumentation to the pelvis.

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61 Surgical Treatment of Adolescent Idiopathic Scoliosis: Lenke Curve Types 1 Through 6

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Overview

CLASSIFICATION

The Lenke classification of adolescent idiopathic scoliosis (AIS) is a three-tiered classification system that guides operative management of the spinal deformity (Fig. 61-1). The classification is based upon a numbered scale that describes the proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) curves, combined with a lumbar coronal alignment modifier (A/B/C) and a thoracic sagittal modifier (–/N/+; Fig. 61-2). The combination (e.g., "1BN") assists in the decision-making process when choosing fusion levels.

The classification of coronal deformities relies on Cobb measurements made on upright and side-bending radiographs. The curve with the largest Cobb measurement is deemed the major curve. Minor curves may be structural or nonstructural: curves that remain at 25 degrees or greater on side-bending films are *structural curves* (Fig. 61-3); *nonstructural curves* measure 25 degrees or less on side-bending radiographs. Sagittal alignment also determines structural versus nonstructural curves. A PT curve with hyperkyphosis (T2–T5 sagittal Cobb ≥20°) and/or thoracolumbar (T10–L2) junction kyphosis (≥20°) define structural curves regardless of behavior on side-bending radiographs.

The *lumbar coronal modifier* is determined by the position of the apical vertebra of the lumbar curve relative to the *center sacral vertical line* (CSVL). The CSVL is drawn parallel to the radiograph edge and perpendicular to the floor from the center of the S1 vertebra. If the CSVL falls within the pedicles of the apical vertebra, an "A" modifier is assigned. If the concave pedicle of the apical vertebra touches the CSVL, a "B" modifier is assigned. If the apical pedicle lies lateral to the CSVL, a "C" modifier is assigned (Fig. 61-4). The sagittal profile modifier is determined by the measure of kyphosis from T5 to T12. The normal range is +10 to +40 degrees. Sagittal measurements of 10 degrees or less are assigned a "–" (minus) modifier. Sagittal measurements 40 degrees or more are assigned a "+" (plus) modifier. Measurements between 10 and 40 degrees are assigned an "N" modifier (Fig. 61-5). The curve type (1 through 6) is combined with the two modifiers to classify the deformity.

The major curve is always included in the fusion. The inclusion of minor curves is based on whether they are structural and the clinical appearance of the deformity (e.g., skeletal maturity, lumbar prominence, trunk shift). Thus the classification system acts as a guide in determining appropriate fusion levels.

TYPE I

In this case, the PT and TL/L are nonstructural. As such, fusion of the MT curve is recommended. The upper instrumented vertebra (UIV) is often T2, T3, or T4. Shoulder alignment may help in determining the UIV. The lower instrumented vertebra (LIV) is often one below the lower-end vertebra (LEV). This is often the vertebra touched by the CSVL on the standing preoperative radiograph. In cases with a "B" lumbar modifier, we recommend that some tilt be left in the LIV to allow for a harmonious flow into the unfused lumbar curve. The management of "C" lumbar modifier curves is a matter of debate. When no thoracolumbar kyphosis is evident, we will often perform a selective thoracic fusion, again leaving the LIV tilted to allow for a harmonious confluence between the fused thoracic spine and the unfused lumbar spine. If kyphosis is present at the thoracolumbar junction, the surgeon must fuse both the MT and TL/L curves to minimize the risks of distal junctional kyphosis (DJK). The correction techniques used include cantilever bending, in situ contouring, appropriate compression/distraction, and vertebral column manipulation to achieve rotational correction (Figs. 61-6 and 61-7).

TYPE 2

In the case of a structural PT curve, attention must be paid to preoperative shoulder alignment. The goal of selecting the UIV is to allow for correction, or maintenance, of shoulder alignment. In most instances, the PT curve is apex left, with an elevated left shoulder. In this case, the UIV is often T2, and correction of the PT curve will bring the left shoulder down. The choice of the LIV is similar to that for a type 1 curve.

TYPE 3

This deformity pattern consists of a major MT curve with a structural TL/L curve. As with the aforementioned deformities, selection of the UIV depends primarily on shoulder alignment preoperatively. Often the LIV is the end and stable

CURVE TYPE

Type	Proximal Thoracic	Main Thoracic	Thoracolumbar/Lumbar	Description
1	Nonstructural	Structural (major)*	Nonstructural	Main Thoracic (MT)
2	Structural	Structural (major)*	Nonstructural	Double Thoracic (DT)
3	Nonstructural	Structural (major)*	Structural	Double Major (DM)
4	Structural	Structural (major)*	Structural	Triple Major (TM)**
5	Nonstructural	Nonstructural	Structural (major)*	Thoracolumbar/ Lumbar (TL/L)
6	Nonstructural	Structural	Structural (major)*	Thoracolumbar/ Lumbar-Main Thoracic (TL/L-MT)

*Major= Largest Cobb measurement, always structural.
Minor= All other curves with structural criteria applied.
**Type 4 - MT or TL/L can be major curve.

STRUCTURAL CRITERIA (Minor Curves)

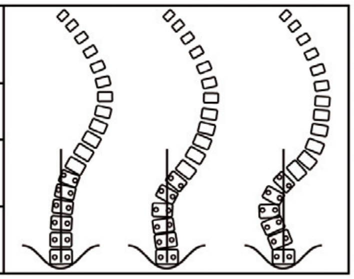
Proximal Thoracic	Side-Bending Cobb ≥25° T2-T5 Kyphosis > +20°
Main Thoracic	Side-Bending Cobb ≥25° T10-L2 Kyphosis > +20°
Thoracolumbar/Lumbar	Side-Bending Cobb ≥25° T10-L2 Kyphosis > +20°

LOCATION OF APEX (SRS Definition)

Curve	Apex
Thoracic	T2-T11/12 Disc
Thoracolumbar	T12-L1
Thoracolumbar/Lumbar	L1/2 Disc-L4

LUMBAR SPINE MODIFIERS

Lumbar Spine Modifier	CSVL to Lumbar Apex
A	Between Pedicles
B	Touches Pedicles
C	Medial to Pedicles



THORACIC SAGITTAL MODIFIERS

Thoracic Sagittal Profile T5-T12	
- (Hypo)	<10°
N (Normal)	10°–40°
+ (Hyper)	>40°

Curve Type (1-6) + Lumbar Spine Modifier (A, B, C) + Thoracic Sagittal Modifier (-, N, +) = Classification (e.g., 1B+)

Figure 61-1 Lenke classification.

vertebrae; these are two separate vertebrae. In such a case, the end vertebra should be made level at the time of correction. For some 3C curves, however, a selective thoracic fusion may be performed to fuse the MT and leave the TL/L with a well-aligned spinal column. Selection of such curves requires comparisons of the Cobb angles, apical vertebral translation (AVT), apical vertebral rotation (AVR), and relative flexibility of the curves. A ratio greater than 1.2 in favor of the MT curve predicts a successful selective thoracic fusion. Attention must be paid to the sagittal alignment of the TL/L curve; thoracolumbar kyphosis in the setting of the above ratios is a contraindication to selective fusion because of the attendant risk of DJK (Fig. 61-8, *A* through *C*).

TYPE 4

The case of three structural curves—PT, MT, and TL/L—is rare. Inclusion of all curves is usually necessary, with the UIV (T2 or T3) selected according to shoulder alignment, as it is with the other deformities. The LIV is often L3 or L4, selected based on the stable and end vertebrae.

TYPE 5

Fusion of the TL/L structural curve is appropriate if the patient is comfortable with the appearance of their trunk and shoulder alignment, because the left shoulder will often elevate following correction. As with selective thoracic fusion of a type 3C curve, similar ratios (>1.2) in favor of the TL/L curve favorably predict a successful fusion of the TL/L curve alone. The UIV is often the upper-end vertebra of the TL/L curve, and the LIV is often the lower-end vertebra, or one below (Figs. 61-9, *A* through *C*).

TYPE 6

This curve type is similar to type 3, however, the TL/L is the major structural curve, and the MT is a minor structural curve. Inclusion of both structural curves is often advised.

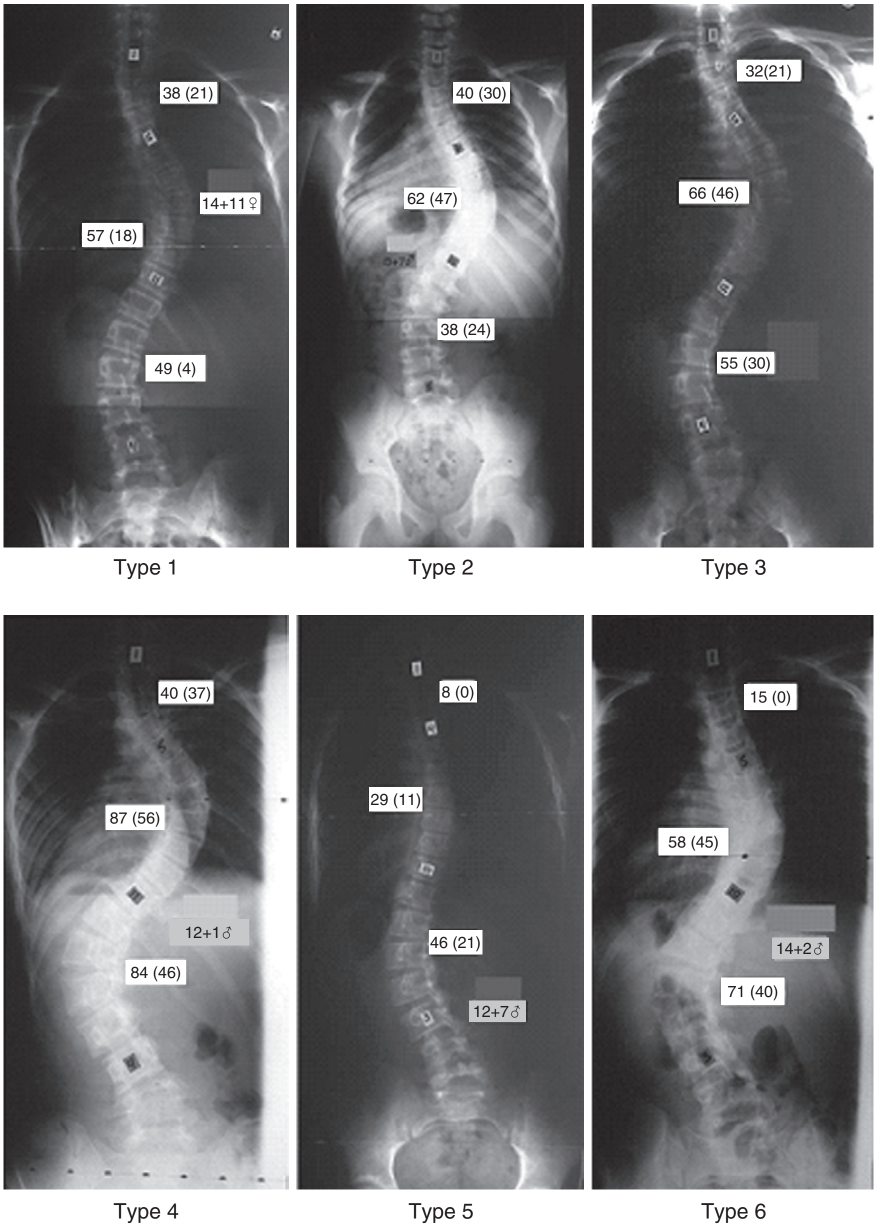


Figure 61-2 The six curve types of the Lenke classification. *Type 1:* main thoracic; *Type 2:* proximal thoracic and main thoracic; *Type 3:* main thoracic and thoracolumbar; *Type 4:* proximal thoracic, main thoracic, and thoracolumbar; *Type 5:* thoracolumbar; *Type 6:* main thoracic and thoracolumbar (major).

Selection of the UIV again depends on shoulder alignment, often at T3 or T4. The LIV is, again, the stable vertebra, often L3 or L4. A selective lumbar fusion is favorably predicted by ratios of Cobb angle, AVT, and AVR greater than 1.2, the same as with type 5 curves.

Indications/Contraindications

Observation of the deformity is recommended for skeletally immature patients with major Cobb angles of 25 degrees or less. In our practice, brace treatment is offered to skeletally immature patients with Cobb angles measuring between 25 and 50 degrees. Skeletally mature individuals with curves of these magnitudes are offered observation alone and are counseled on the risk of progression over time. Operative management of curves is considered for thoracic Cobb angles measuring 50 degrees or greater and for lumbar curves of 45 degrees or greater. In all cases, the decision to operate is made via informed decision making, on the part of the patient and parents, after a discussion of the risks and benefits of nonoperative and operative management.

We would encourage all surgeons to obtain outcomes scores before and after surgery to track the results of their surgeries. In our practice, we routinely obtain Scoliosis Research Society (SRS) 22 scores and some others as indicated by the diagnosis or procedure.

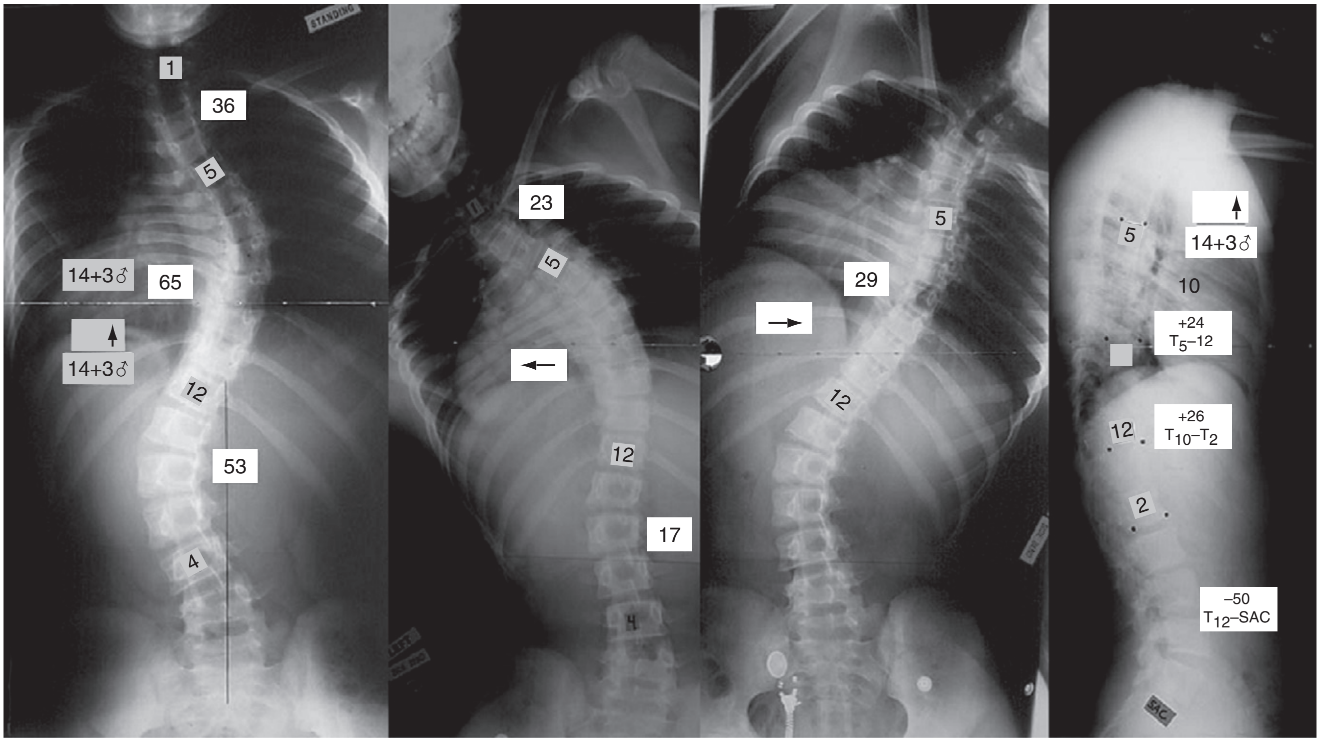


Figure 61-3 Side-bending radiographs of a Lenke Type 1CN curve. The proximal thoracic (PT) and thoracolumbar/lumbar (TL/L) curves reduce to below 25 degrees upon bending to the side.

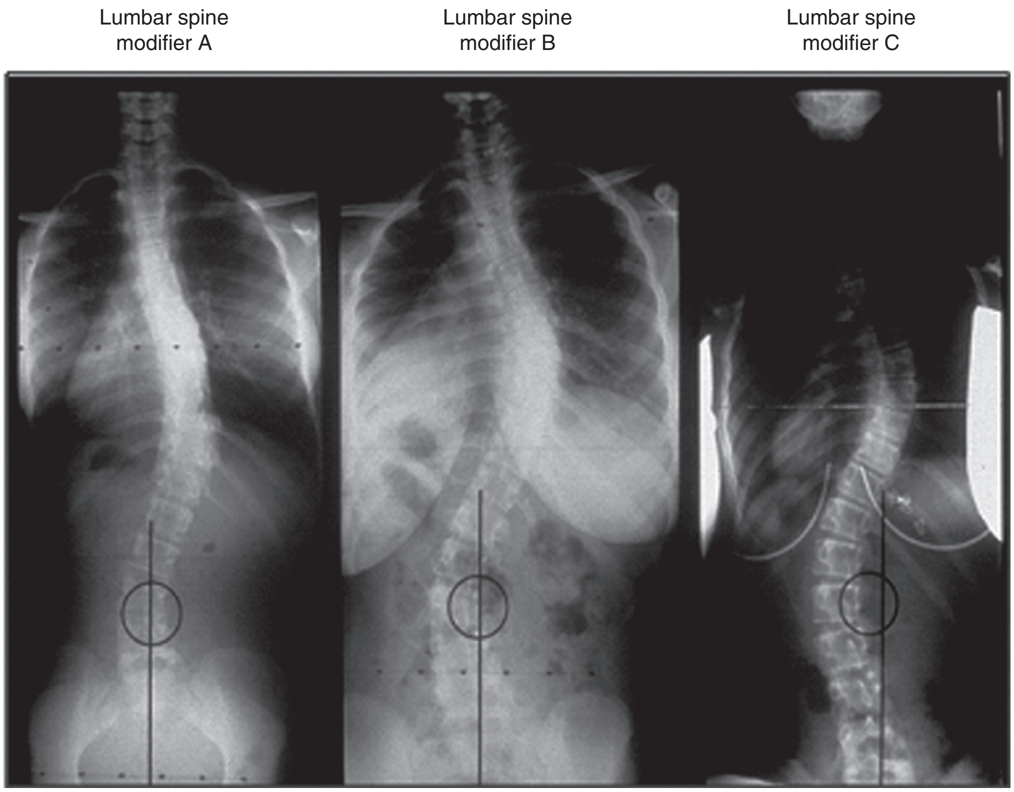


Figure 61-4 Representation of the coronal plane modifier for the thoracolumbar/lumbar (TL/L) curve. **A,** Apex of TL/L curve bisected by the center sacral vertical line (CSVL). **B,** Pedicle of apical vertebra touches the CSVL. **C,** Apical vertebra deviates from CSVL.

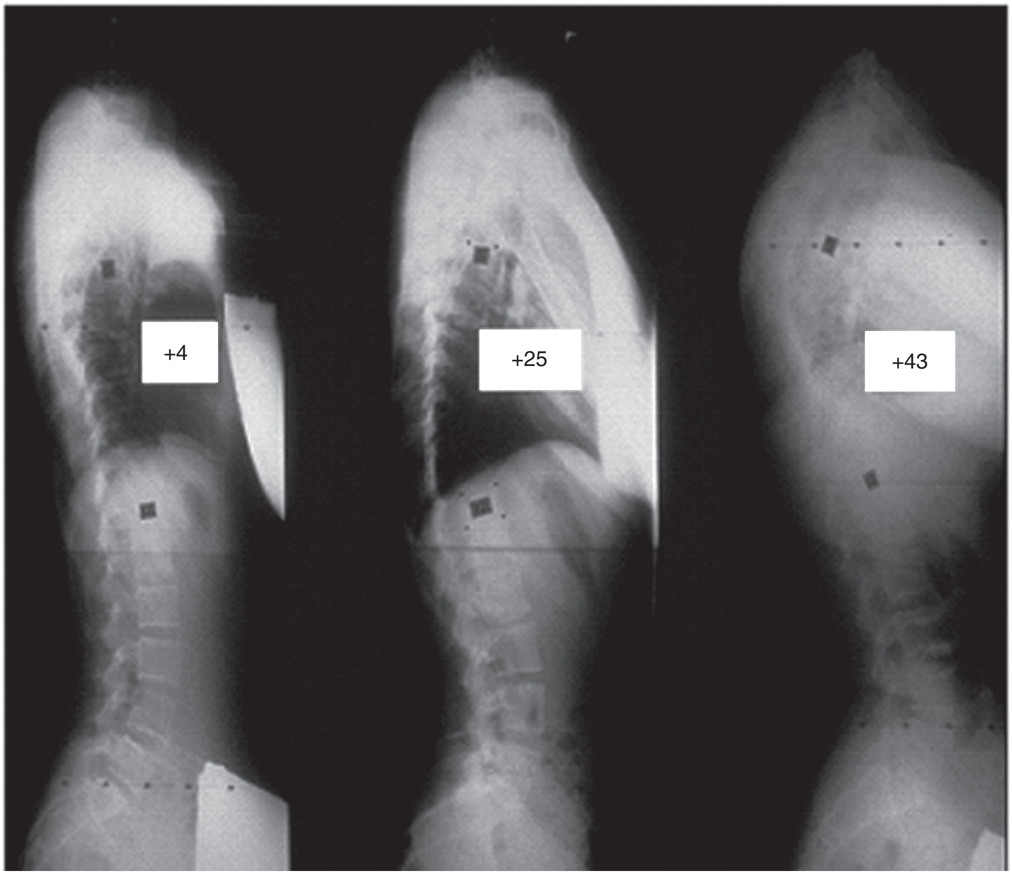


Figure 61-5 Representation of the thoracic (T5–T12) modifier. (–): less than 10 degrees; (N): from 10 to 40 degrees; (+): greater than 40 degrees.

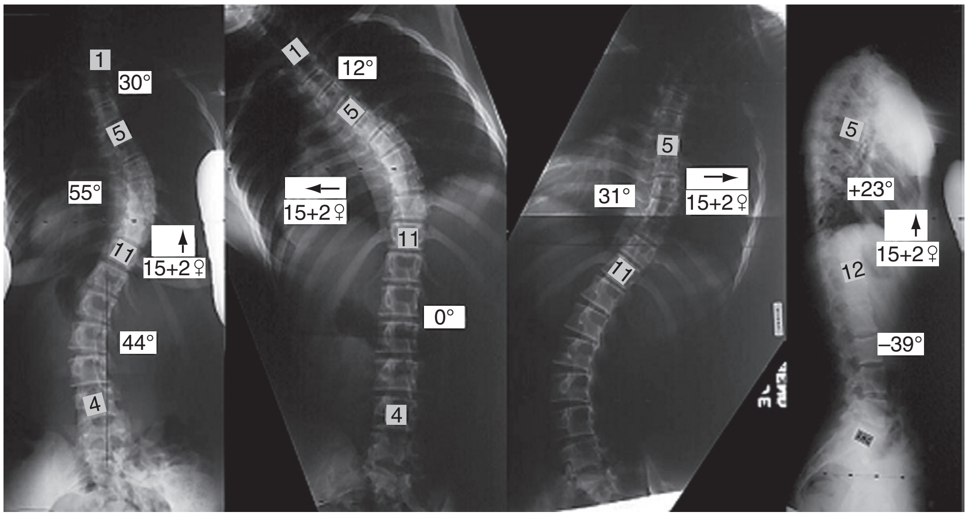


Figure 61-6 Preoperative upright and side-bending radiographs of a type 1BN curve.

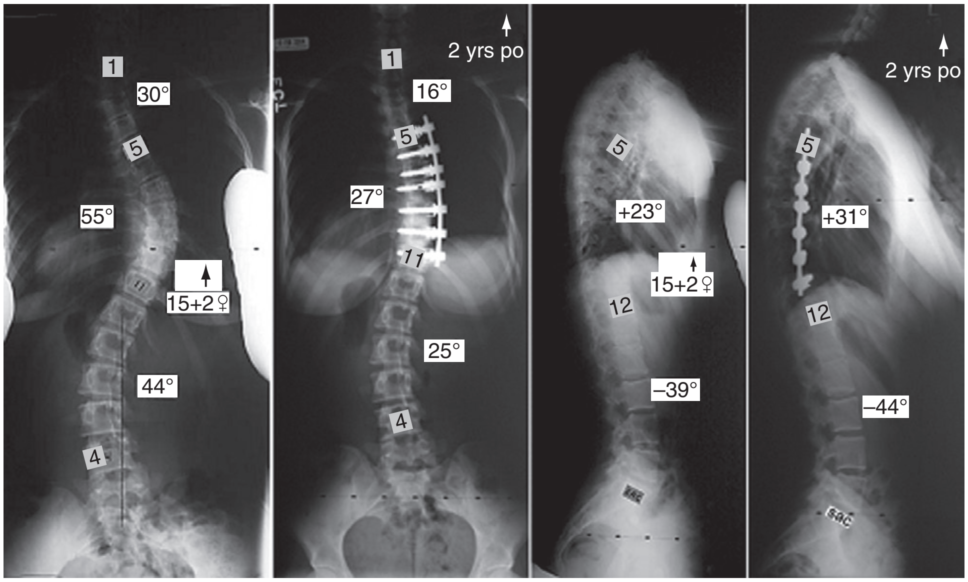


Figure 61-7 Preoperative and postoperative radiographs of a type 1BN curve.

Operative Technique

EQUIPMENT

- Our preference is to use all-pedicle screw constructs when possible. The implants available should include fixed-angle and multiaxial screws, including reduction screws in multiple diameters to accommodate the variable pedicle diameters.
- A variety of hooks should be available: transverse process, laminar, and pedicle.
- In most cases, we use cobalt-chromium rods and avoid stainless steel when possible, because postoperative imaging is suboptimal with stainless steel implants.
- Although local bone graft harvest often yields a significant amount of autograft, we also use cancellous allograft to augment our fusion bed.
- We use a posted Jackson table for these procedures to allow the abdomen to fall between the iliac and chest pads, thereby minimizing intraabdominal pressure and decreasing blood loss.
- In addition to prophylactic antibiotics, we routinely use tranexamic acid as an antifibrinolytic. Patients receive a 50 mg/kg loading bolus, followed by an infusion of 5 mg/kg/hr, continued until wound closure. This dose has been shown safe and efficacious in a pediatric surgical population.
- For cases with an expected duration of 4 to 6 hours, we usually use a padded head holder. For longer cases, Gardner-Wells tongs or a halo may be used to float the face free and minimize the risk of optic nerve ischemia.

POSITIONING

- The patient is placed prone onto a posted Jackson frame. The chest bolsters should leave a handbreadth beneath the axilla. For women, the breasts should lay within the chest bolsters, with both nipples free. Iliac pads are placed just below the level of the anterosuperior iliac spine to minimize the risk of meralgia paresthetica. A second bolster is placed just distal to this on the thigh.
- The legs are placed on pillows on a flat board. This allows for extension of the hips to optimize lumbar lordosis. The pillows are positioned to flex the knees and to float the feet at the end of the table.
- The arms are placed onto padded arm boards in a "90-90" position, with the shoulder abducted 90 degrees and externally rotated 90 degrees. The elbow should be flexed no more than 90 degrees, because that would raise the risk of an iatrogenic ulnar neuropathy.

APPROACH

- A curvilinear incision is made from the spinous process of the level above the planned UIV to the cranial aspect of the spinous process of the LIV. We make this incision just medial to the apical spinous processes. This helps create a straight scar after correction of the deformity, which improves cosmesis.
- A subperiosteal dissection is carried out using a Cobb elevator and electrocautery from the spinous process to the transverse process of the levels within the planned fusion (Fig. 61-10).
- Anesthesia should paralyze the patient to facilitate exposure and minimize blood loss.
- Controlled hypotension aids in reducing blood loss.
- Care must be taken not to disturb the interspinous soft tissues and facet joint capsules at the cranial and caudal adjacent segments.
- Care must be taken not to expose too ventrally at the pars and facet joint, because vessels are routinely found here, and aggravating blood loss may ensue.
- The lumbar transverse processes are exposed if the LIV is at L2 or lower.
- The transverse processes should be exposed, moving from the facet joint and mammillary process laterally. After each transverse process is exposed, a plane is picked between each adjacent process to complete the exposure

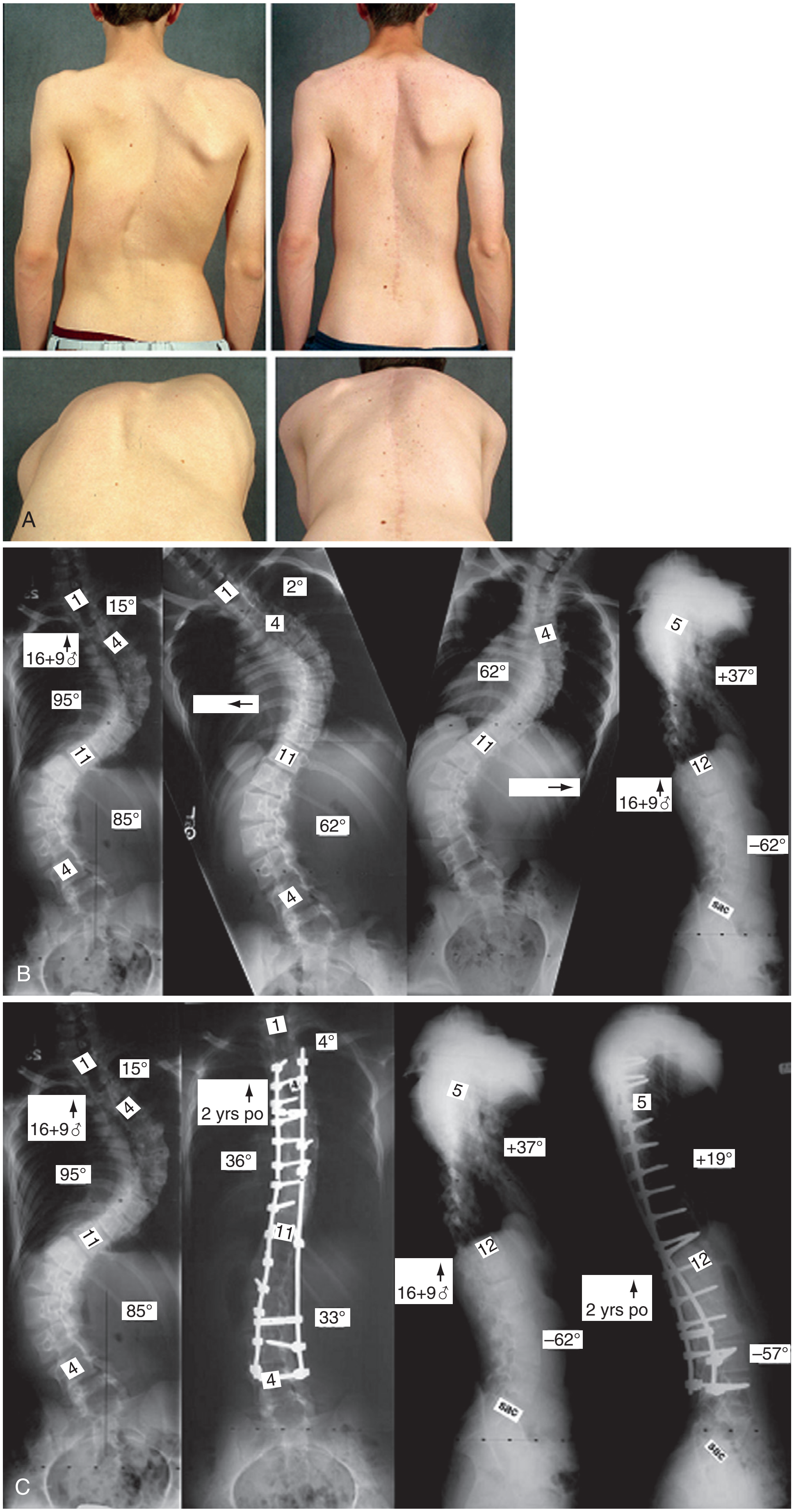


Figure 61-8 Preoperative upright and side-bending radiographs of a type 3CN curve, with clinical photos and postoperative radiographs.

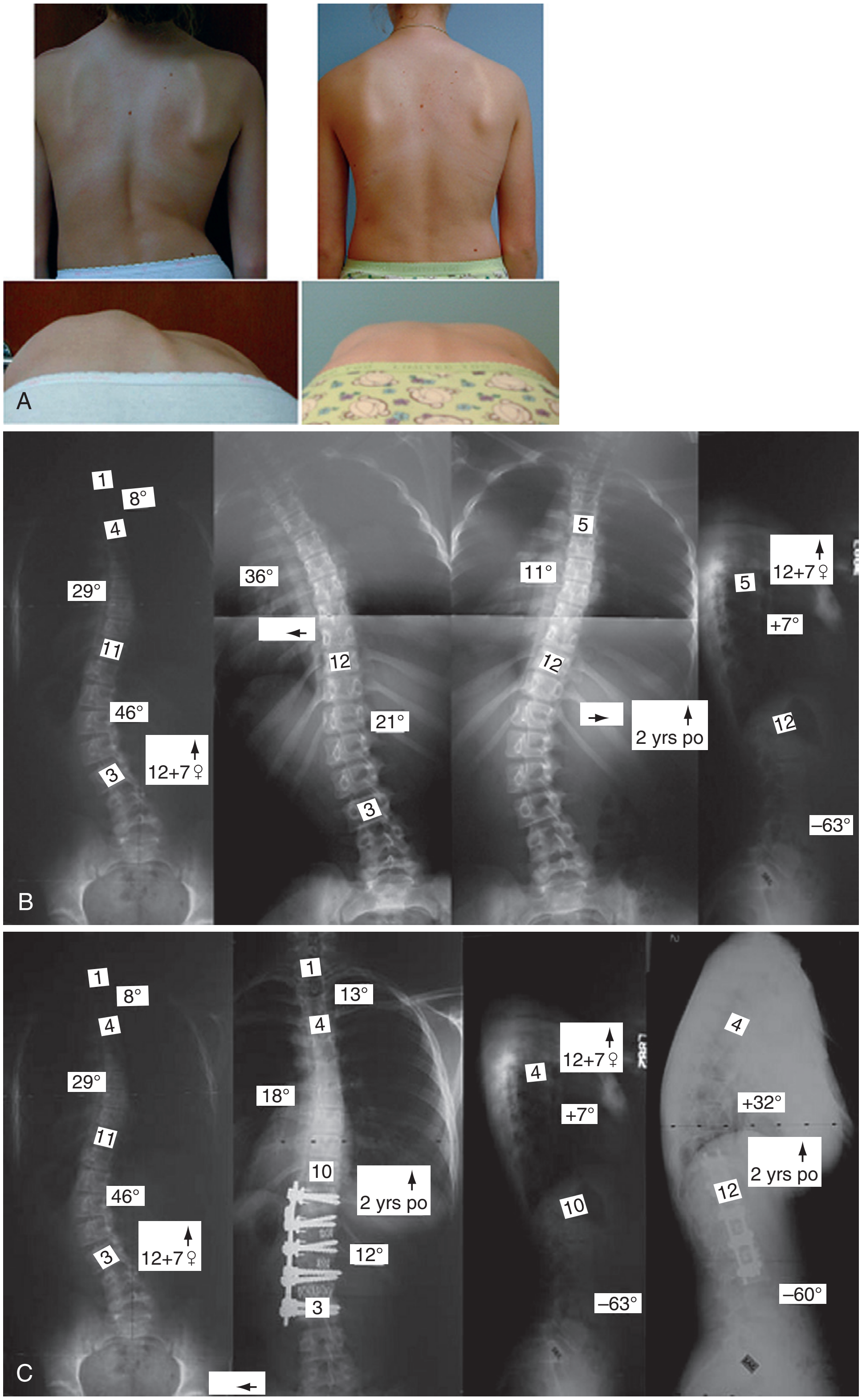


Figure 61-9 Preoperative upright and side-bending radiographs of a type 5C– curve, with clinical photos and postoperative radiographs.

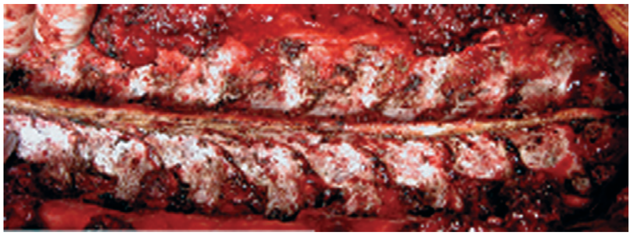


Figure 61-10 Exposed spine following subperiosteal dissection from midline to tips of transverse processes.

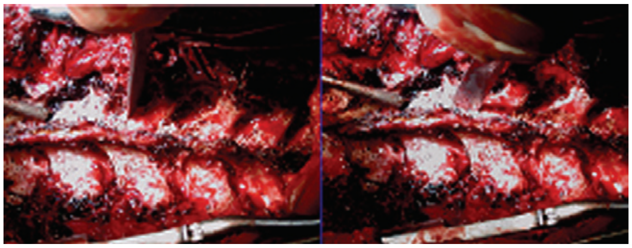


Figure 61-11 Inferior facetectomies performed with a half-inch osteotome.

of the lateral gutter. If the surgeon should attempt to create the lateral gutter without careful exposure of the transverse process, significant bleeding may be encountered.

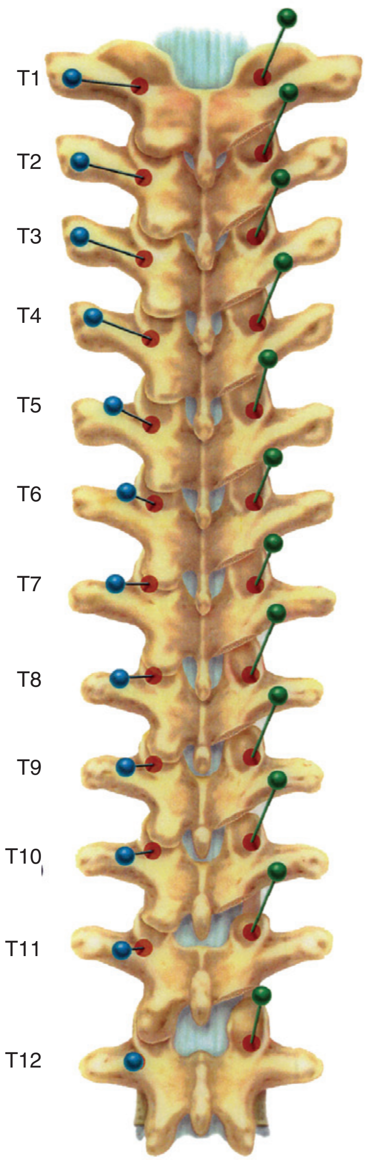
- Following dissection, all remaining soft tissues are removed using a large curette. The facet joint capsules are removed at each level using electrocautery. The wound is irrigated, and all loose soft tissues are removed. The spine should appear white and clean at this point.

OSTEOTOMIES

- Inferior facetectomies are performed at every level with a half-inch osteotome. In the thoracic spine, the first cut is along the medial aspect of the inferior facet going approximately 5 mm cranial. A small inflection point occurs at the junction of the medial facet and lamina; this guides the coronal cut. The second cut parallels the transverse process and completes the facetectomy. The facet joint is removed with a pituitary rongeur and is reserved for use as autograft (Fig. 61-11).
- A curette is used to remove the articular cartilage from the superior facet (now exposed). Hemostasis is achieved, a surgical sponge is packed into the facet joint, and the resection proceeds caudally.
- The spinous processes are removed and reserved for autograft.
- In cases of particularly stiff apical curves or hypokyphosis, we perform posterior column osteotomies (PCOs; Smith-Petersen or Ponté type) symmetrically about the apex.
- After resection of the inferior facet joint, the spinous process is removed with a large Leksell rongeur. This bone is reserved for autograft.
- The ligamentum flavum is removed using the Leksell rongeur. In the thoracic spine, the superior facet defines a "safe plane" for use of such a large instrument. We place one jaw of the Leksell on the superior facet and "bite" toward the joint until epidural fat is exposed.
- A Woodson elevator is used to define the plane between the epidural fat and the ligamentum flavum. Because the patient is prone, the spinal cord lies ventral to the area of resection. The Woodson is probed in a superolateral fashion toward the foramen.
- Using a Kerrison #3 rongeur, with the free hand braced on the patient, the ligamentum flavum and then the superior articular facet are removed, proceeding laterally and cranially from the midline.
- In cases of thick superior articular processes, we use a high-speed matchstick burr. The surgeon must undercut the overhanging inferior facet remnant and be sure to remove any residual superior facet fragment, because these may cause nerve root impingement following deformity correction.
- Hemostasis is achieved using collagen products and a cotton pad.

FREEHAND PEDICLE SCREW PLACEMENT

- We place thoracic and lumbar pedicle screws using a freehand technique.
- The previously performed facetectomies provide excellent visualization of the superior facet for placement of pedicle screws. This is essential for safe placement.
- We prefer to place pedicle screws at each level to maximize three-column control of the spine.
- The dorsal transverse process is removed in the thoracic spine, and the medial superior facet joint is removed in the lumbar spine. This accomplishes three goals:
  1. Harvest of more autograft
  2. Exposure of bleeding cancellous bone to facilitate fusion
  3. Entrance to the pedicle, especially if the pedicle "blush" is seen
- A starting point is created using a high-speed burr at the appropriate position at each level (Figs. 61-12 and 61-13).
- We start at the distal neutral vertebra.
- The start sites may be grouped together.
  1. T1, T2, T3, and T12 are located at the midpoint of the transverse process and 2 mm lateral to the midpoint of the superior facet.
  2. T4, T5, and T11 are located at the proximal one third of the transverse process 2 mm lateral to the midpoint of the superior facet.
  3. T6 and T10 are located at the confluence of the top of the transverse process and the lamina, again 2 mm lateral to the midpoint of the superior facet.
  4. T7, T8, and T9 are located at the confluence of the superior facet and lamina 2 mm lateral to the midpoint of the superior facet.
- We have dubbed the lateral start site the "Superior Facet Rule."
- A pedicle screw must never be started in the medial half of the superior facet joint, where the risk of a medial breach is high. All start sites should be placed in the lateral half of the superior facet joint.
- Using this start site, the ventral lamina can be used to guide the "gearshift" into the correct position.



Level	Cephalad-caudad starting point	Medial-lateral starting point
T1	Midpoint TP	Junction: TP-lamina
T2	Midpoint TP	Junction: TP-lamina
T3	Midpoint TP	Junction: TP-lamina
T4	Junction: proximal third-midpoint TP	Junction: TP-lamina
T5	Proximal third TP	Junction: TP-lamina
T6	Junction: proximal edge-proximal third TP	Junction: TP-lamina-facet
T7	Proximal TP	Midpoint facet
T8	Proximal TP	Midpoint facet
T9	Proximal TP	Midpoint facet
T10	Junction: proximal edge-proximal third TP	Junction: TP-lamina-facet
T11	Proximal third TP	Just medial to lateral parts
T12	Midpoint TP	At the level of lateral parts

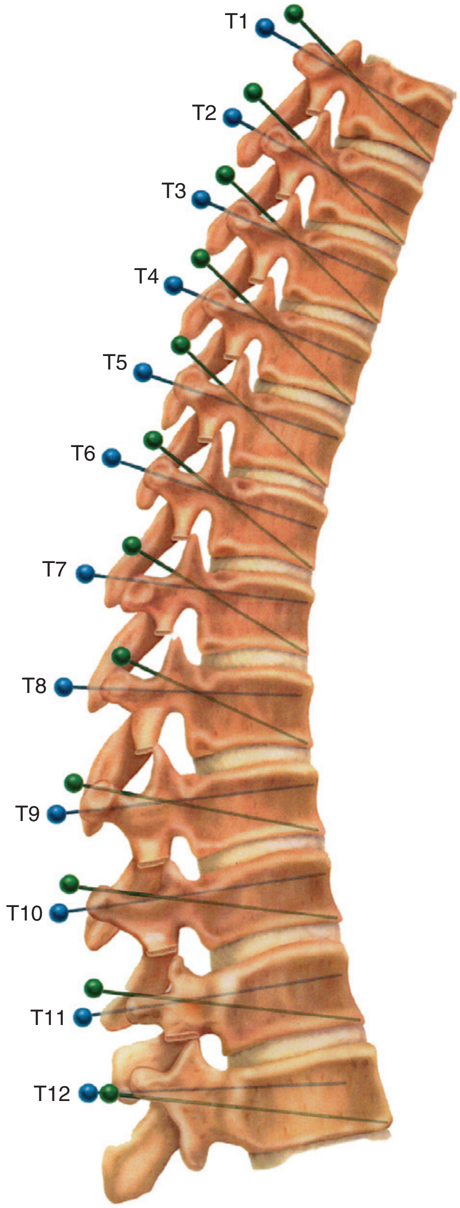


Figure 61-12 Anatomic and straight-ahead starting points for pedicle screw placement.

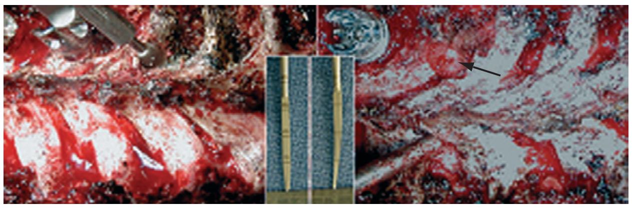


Figure 61-13 Creation of the starting point for curved pedicle-finder placement.

- At T1–T11, the medial wall of the pedicle is reliably formed by the ventral lamina and medial aspect of the superior facet. This dense bone can guide placement of the gearshift into the body of the vertebra.
- A curved pedicle probe is passed through the channel of the pedicle. The probe is turned facing lateral for the first 20 to 30 mm (Fig. 61-14). After passing this length, the probe is turned medially, and the probe is passed into the vertebral body (see Fig. 61-3). We prefer a straight-ahead pedicle screw placement, angling medially to maximize pullout strength, rather than attempting an anatomic placement, which is reserved for salvage situations.
- The path of the pedicle probe is checked with a ball-tip sounder (Fig. 61-15). Next, confirm a solid bottom, and then feel up the medial wall, checking for medial

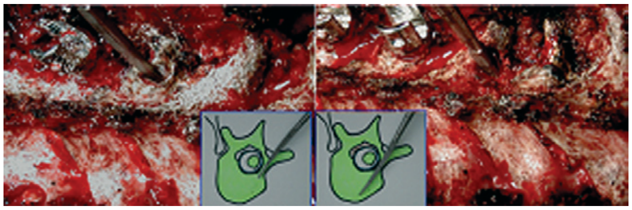


Figure 61-14 Passage of the curved pedicle finder into the pedicle tract. Note: begin facing laterally for 30 mm, then turn in a medial direction.

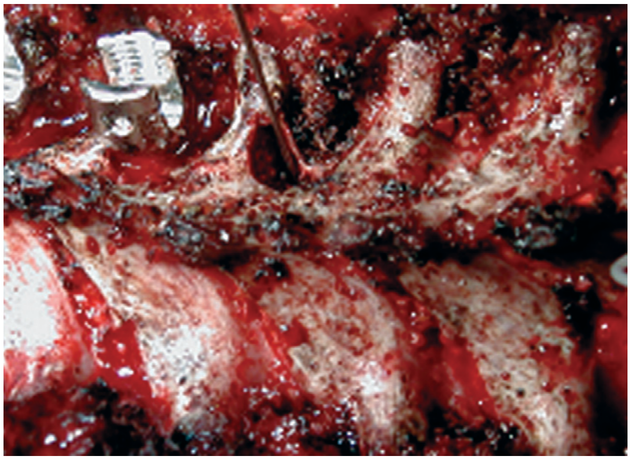


Figure 61-15 Palpate the walls of the pedicle tract with a ball-tipped sounder.

perforations. Do not check the medial wall with downward force, because the sounder may pass into the spinal canal and cause inadvertent damage.

- If a lateral breach is identified, redirect the tract using the pedicle probe. In such a case, it is necessary to confirm a solid, bony bottom at the new tract. We place a K-wire, over which a cannulated tap is used to ensure proper preparation of the screw tract.
- The length of the tract is measured using a clamp and the ball-tipped sounder (Fig. 61-16). We tape a ruler to the end of the surgical field, against which the length can be measured.
- We prefer to tap the course of the tract 1 mm undersized relative to the planned screw diameter.
- Before we place the screw, we check the tract one more time, confirming a solid bottom and medial wall. We check the length of the tract with a clamp and sounder against the length of the loaded pedicle screw.
- At the LIV, we will often place multiaxial reduction screws to facilitate rod reduction.
- We may place a multiaxial reduction screw at the apex of the concavity to assist in increasing thoracic kyphosis.
- If a derotation device is to be used, we place fixed-angle screws at the three vertebrae, along the apex of the convex deformity, to maximize the forces applied via the derotation device. At the apex of the concavity, we place a multiaxial reduction screw (Figs. 61-17 and 61-18).

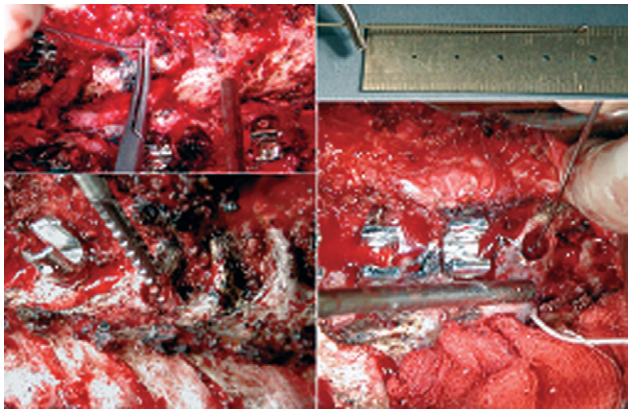


Figure 61-16 The ball-tipped sounder is used to check pedicle screw length before and after tapping the pedicle tract.

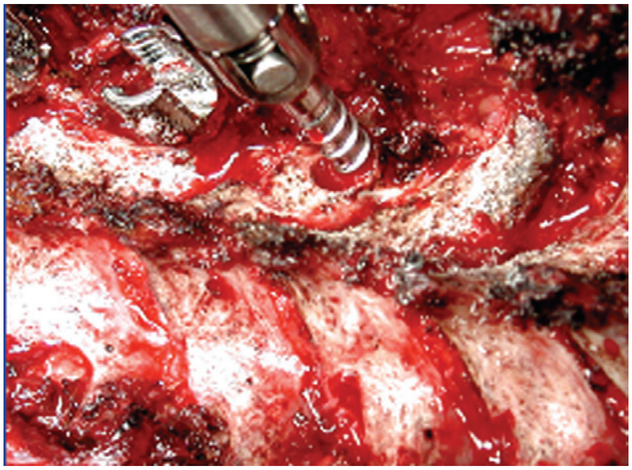


Figure 61-17 The pedicle screw is placed.

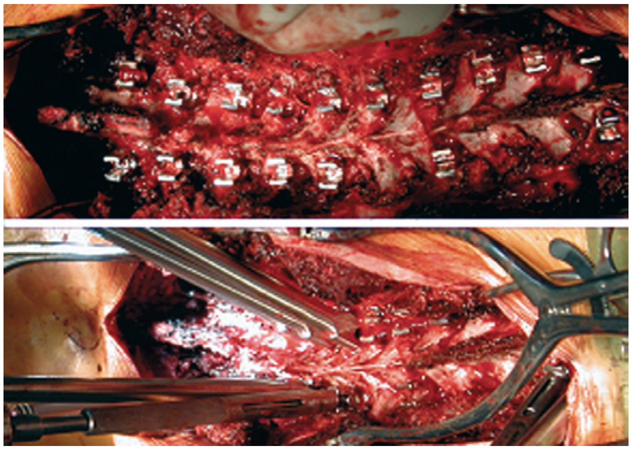


Figure 61-18 If necessary, vertebral column manipulation devices may be attached to the pedicle screw tulips.

- After all the screws are placed (Fig. 61-19), we stimulate the screws, checking for electromyographic (EMG) activity, up to the T6 level, with the abdominals corresponding to the thoracic screw stimulation.
- Intraoperative anteroposterior (AP) and lateral radiographs are obtained to evaluate screw positions (Fig. 61-20).

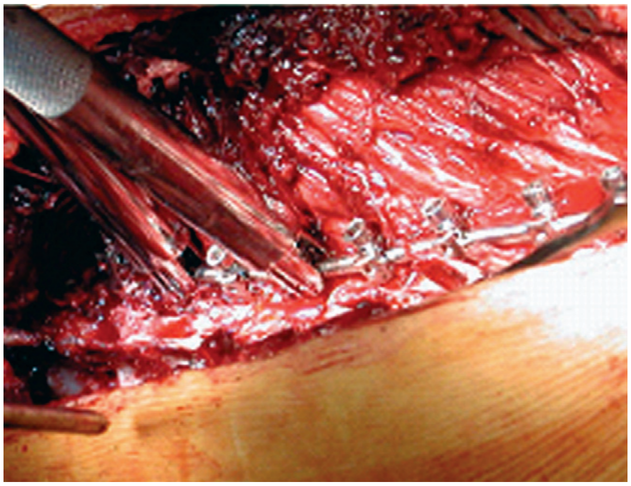


Figure 61-19 After all screws are placed, electromyelography (EMG) stimulation is performed from the lower instrumented vertebra (LIV) to T6.

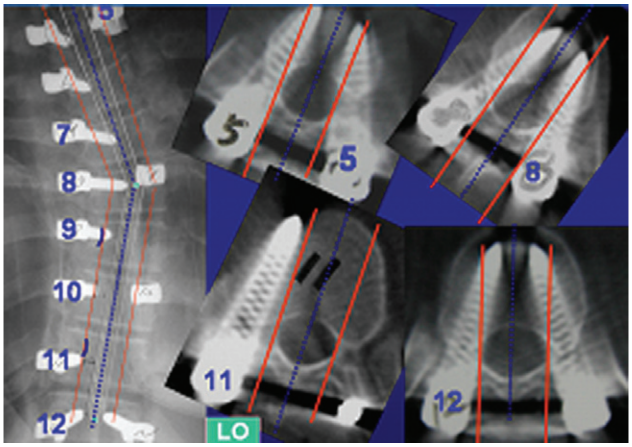


Figure 61-20 Intraoperative radiographs are obtained after screw placement. An intraoperative computed tomography (CT) scan may be obtained if CT is available.

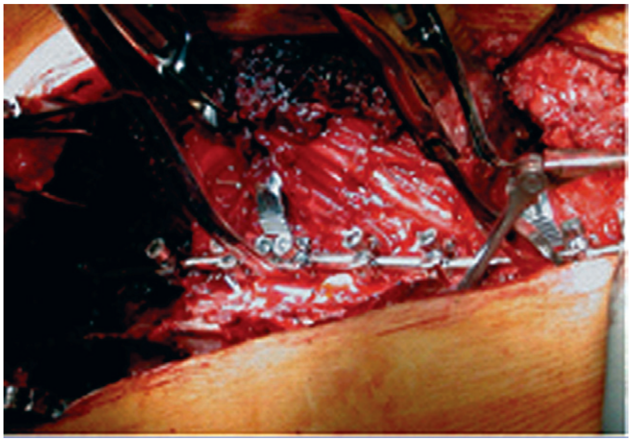


Figure 61-21 The contoured rod is placed into the tulip heads.

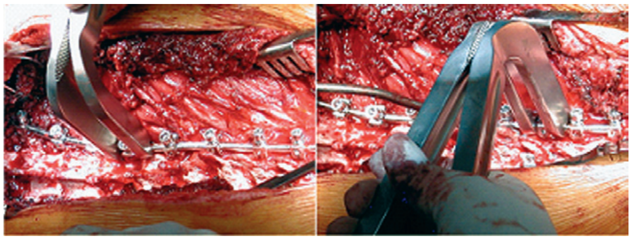


Figure 61-22 In situ contouring is performed with in situ benders.

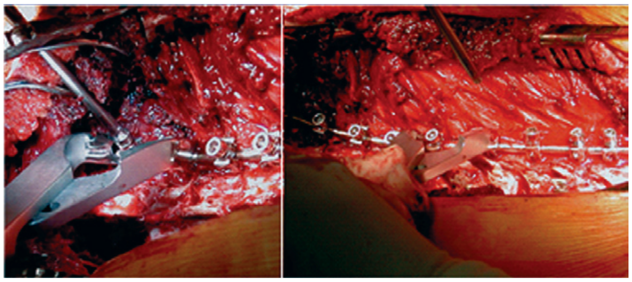


Figure 61-23 Compression and distraction is performed to obtain coronal and sagittal plane correction.

REDUCTION TECHNIQUES

- In many cases, the thoracic curve is hypokyphotic, in which case we will place the concave rod first.
- The rod is contoured to match the desired sagittal profile only.
- The rod is placed into the UIV and is gently rotated into the next several multiaxial screws, and it is provisionally fixed in place with set screws.
- The rod is then rotated into the multiaxial screws, including the periapical reduction screw and LIV reduction screw (Fig. 61-21).
- The rod is slowly reduced into the remainder of the screw heads, with care taken not to stress any single screw at one time. The goal is a slow reduction of the screws to the rod. All of the set screws are provisionally tightened.
- Using the in situ coronal rod benders, the rod is bent to correct the curve to the desired amount (Fig. 61-22). We begin in situ bending at the apex and move away, making small, successive movements and repeating the movements up and down the curve. In the case of a selective fusion, care must be taken not to correct the curve entirely, because this will result in a severely malaligned patient because of the residual noninstrumented curve.
- The convex rod is contoured to match the appropriate sagittal profile and is reduced to the screws.
- Gentle compression and distraction is performed to correct oblique vertebrae and in an effort to recreate thoracic kyphosis (distraction; Fig. 61-23).
- In the case of a kyphotic scoliosis, we place the convex rod first. With cantilever bending, we are able to reduce both the kyphosis and the scoliosis.
- In situ bending is performed in a manner similar to that for hypokyphotic scoliosis; the contralateral rod is placed, and distraction/compression is performed to achieve balance.

DEROTATION MANEUVER

- If a derotation device is to be used, we will place it at the three convex apical screws and at the screws one above and one below the concave apical reduction screw, which is a multiaxial reduction screw (Fig. 61-24).
- The arms are connected to create a single "frame," through which greater forces may be applied to the spinal column in a safe manner.
- The first maneuver is dorsal force applied to the concavity, the derotation maneuver.
- At the same time, a translatory force is applied to the apex.
- The concave rod—again, contoured to the desired sagittal profile—is reduced into the UIV and rotated to engage several proximal screws, followed by the distal screw heads. The reduction screw at the apex will facilitate capture there.
- By sequentially reducing the rod through the reduction screws and at the remainder of the fixation points, the rod is reduced to the concavity, and the correction is obtained.
- With in situ benders, we may obtain more correction of the deformity. When performing a selective thoracic fusion, the surgeon must be sure to match the residual thoracic curve to the lumbar curve.
- The downward translatory force is maintained, while the concave rod is placed and reduced.
- Distraction and compression is performed as needed to obtain both coronal and sagittal plane corrections. The surgeon must be mindful of the basic tenets of deformity correction when performing compression/distraction (lordosing/kyphosing) maneuvers.
- Intraoperative AP and lateral radiographs are obtained to evaluate for screw position and spinal column alignment.
- When the reduction is deemed adequate, the set screws are "final-tightened" using a torque/countertorque device (Fig. 61-25).

DECORTICATION/GRAFTING

- All cortical bone within the instrumented segments is removed using a high-speed matchstick burr. The facet joints are decorticated at each level.
- The transverse processes of the lumbar spine are decorticated, and autograft is placed within the posterolateral gutter.
- The remainder of the autograft is placed in the midline and in the facet joints at each level.
- Allograft is used to supplement the harvested autograft and is placed within the midline of the thoracic spine and in the midline and posterolateral gutter of the lumbar spine.

CLOSURE

- One gram of vancomycin powder is placed in the wound and along the wound edges.
- A deep drain is placed.
- The fascial layer is closed using braided, absorbable, interrupted suture.
- A suprafascial drain is placed.
- The subcutaneous layer is closed using braided, absorbable, interrupted suture.
- The skin is closed using a running, absorbable suture.
- Steri-Strips are placed over the wound, and a sterile dressing is placed.
- Neuromonitoring continues throughout wound closure to assess for any delayed onset of an identifiable neurologic deficit.
- The patient is turned supine onto the hospital bed. Before the contamination of any surgical instruments (all OR staff leave masks up and maintain sterility of instruments), a rehearsed wake-up test is performed to the satisfaction of the surgical team. A full-length AP radiograph is obtained.
- After the wake-up test is performed to satisfaction, and the radiograph has been reviewed, the patient is extubated, and masks may be removed.

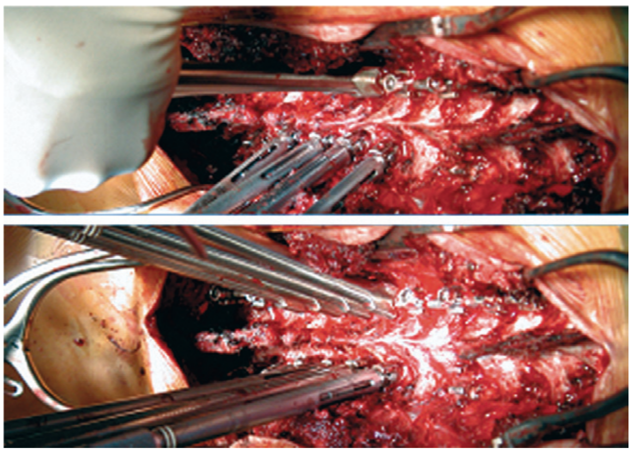


Figure 61-24 The derotation device is placed on periapical screws.

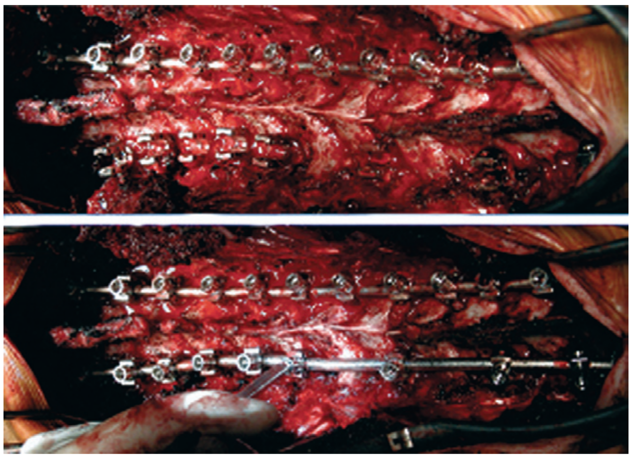


Figure 61-25 The last set screws are placed and are shorn off.

Postoperative Care

- Most patients receive a patient-controlled anesthesia (PCA) pump, and they are slowly weaned from the PCA to an oral pain-control program.
- Patients are made NPO (nothing by mouth), with the exception of ice chips, until bowel function has returned. Once bowel function has returned, as evidenced by flatus, the patient is transitioned to a clear diet and then to a regular diet.
- All patients are out of bed on postoperative day 1 (POD 1) and must participate with physical therapy. No bed rest is appropriate, and the patient should be upright to a chair on POD 1, at a minimum. We will assess shoulder balance at some point when standing. It must be noted, however, that small imperfections are not uncommon and will correct during follow-up.
- We prefer to leave the drains in until output is less than 30 mL over 8 hours. This often occurs around POD 3. The dressing is removed when the drains come out, and if the wound is clean and dry, we do not place another dressing cover. If Steri-Strips become loose, they are replaced.
- Full, standing AP and lateral radiographs are obtained prior to discharge.
- The patient is then seen at 6 weeks, 3 months, 6 months, and 1 year. Activity is restricted until at least 6 months, with no physical activity such as competitive sports allowed.
- Patients may complain of painful implants, but this is rare. We prefer to leave all implants in place and do not recommend removal, unless no other options exist, and the implant has been confirmed to be the inciting factor (through a lidocaine injection). If implants must be removed, only the offending implant should come out.

62 Surgical Treatment of Flat Back Deformity

RONALD LEHMAN

Overview

Flat back syndrome, otherwise known as *fixed sagittal imbalance,* describes a clinical entity that results in a symptomatic and fixed loss of physiologic lumbar lordosis, causing an overall spinal malalignment. Doherty[1] first described the condition in the early 1970s, after he observed a decrease of lumbar lordosis in a patient with scoliosis treated by posterior spinal fusion to the sacrum. Subsequent descriptions by Moe and Denis[2] and later Grobler and colleagues[3] introduced the term "flat back syndrome" as well as providing descriptions of surgical management and follow-up on the condition. Today, flat back syndrome has become a well-recognized condition, most commonly resulting from Harrington rod distraction and instrumentation for scoliosis into the lower lumbar spine and sacrum.[1-9] The terms *kyphotic decompensation syndrome* and *flat buttock syndrome* have since been introduced in patients with fixed sagittal imbalance who were treated for conditions other than scoliosis.[5] Clinically, radiographically, and prognostically, these terms are synonymous with *flat back syndrome* and differ only in etiology.

Fixed sagittal imbalance is generally classified into two broad categories: *type 1 imbalance* includes segmental hypolordosis or kyphosis across a fused section of vertebrae; in a *type 2 imbalance,* the C7 vertebrae remains centered over the sacrum, and the patient is able to compensate by hyperextension of the remaining mobile segments to maintain overall sagittal alignment of the spine. Type 2 imbalance describes the more classic "flat back," in which the hypolordotic malalignment is global and causes the cervical spine and thorax to be shifted anteriorly relative to the sacrum.[10-12]

Patients with flat back syndrome come to medical attention with a clinically evident decrease in normal lumbar lordosis that results in pain, fatigue, and difficulty standing upright with the knees fully extended. Although nonoperative treatment is the first line of defense, it is largely unsuccessful in moderate to severe malalignment cases; this leaves surgical correction as the only viable option for patients with significant symptoms.[5] Surgery involves corrective osteotomies, such as Smith-Peterson and pedicle subtraction osteotomies and combined anterior–posterior approaches used to restore normal lumbar lordosis and sagittal alignment.[4,5,10,13-16] Complication rates are high in surgically corrected flat back patients, and a large percentage experience residual pain.[4] However, the majority of patients report subjective improvement following surgery,[4,10,16] therefore strict adherence to surgical principles and proper planning are essential to maximizing patient outcomes with this challenging condition.

This chapter will highlight the etiologies and workup for patients with flat back syndrome. The surgical management of this disorder will be outlined to include the most commonly performed corrective surgeries: the *Smith-Peterson osteotomy* (SPO) and the *pedicle subtraction osteotomy* (PSO; Fig. 62-1).

Etiology

The etiology of flat back syndrome is often multifactorial.[13] However, by and large, the most common cause is posterior distraction of Harrington rod instrumentation into the lower lumbar spine and sacrum.[1-9] The majority of lordosis in the lumbar spine occurs within the two most caudal spinal segments,[17] and as a result, the loss of lordosis following posterior spinal fusion is directly related to how far caudally the fusion extends. Aaro and Ohen[6] found in their series that lumbar lordosis averaged 38 degrees when posterior fusion was stopped at T12; when stopped at L4, it averaged 21 degrees, and it averaged only 16 degrees when L5 was included in the fusion. This observation was later reinforced in Lagrone's series of flat back patients: no patient treated had a fusion cephalad to L3, and all patients in the cohort who underwent corrective surgery had fusions that extended into the lower lumbar spine and sacrum.[4]

In addition to the caudal extent of the fusion, flat back syndrome is further related to the type of instrumentation used for fusion. With straight Harrington rod instrumentation followed by a distractive corrective maneuver, the lumbar lordosis is forced straight and later reinforced and made rigid by successful fusion, thus leading to a flat back.[4,13] Prior to the use of Harrington rod distraction,[13,18] and today with modern segmental instrumentation technology, flat back syndrome following posterior spinal fusion for scoliosis is much less common (Fig. 62-2).

Several other causative factors have been identified as etiologies of flat back syndrome, and with an increasing number of lumbar fusions being performed for clinical conditions other than scoliosis—such as degenerative lumbar spondylosis, spondylolisthesis, posttraumatic kyphosis, and lumbar stenosis with instability—their prevalence as factors in the development of flat back syndrome is rising.[13,19,20] In the series by Lagrone, thoracolumbar kyphosis was identified as the second most common cause of symptomatic flat back, behind Harrington rod

Figure 62-1 Clinical photo of patient with flat back deformity.

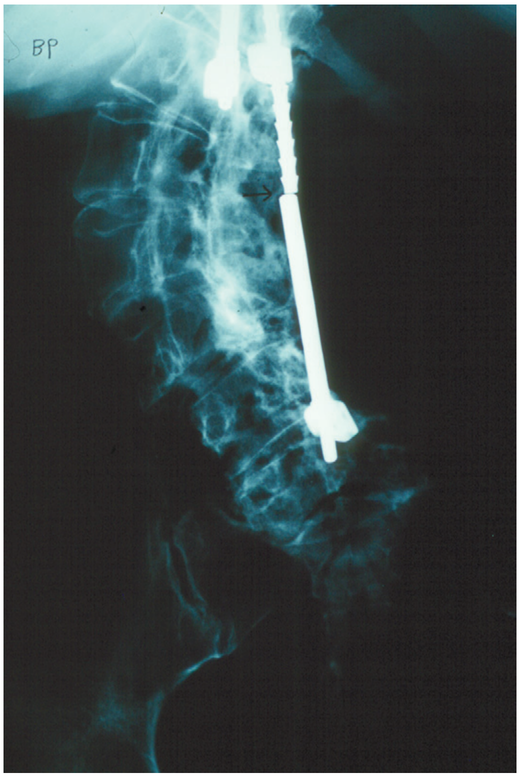


Figure 62-2 Harrington rod distraction instrumentation into the lower lumbar spine increases the risk of subsequent flat back deformity.

distraction and instrumentation.[4] Fusions with a cephalad extent at the thoracolumbar junction or an unrecognized preexisting kyphosis in the thoracolumbar junction and thoracic spine may contribute to flat back. Furthermore, to maintain sagittal balance, patients with thoracolumbar kyphosis compensate by increasing lumbar lordosis, thus even small decreases in lumbar lordosis may significantly alter overall sagittal alignment.[4,13,19,21] Pseudoarthrosis is another accepted cause and, at times, a complication of flat back syndrome.[4,10,13,15] After fusion into the lower lumbar spine, pseudarthrosis occurs at a higher rate secondary to the higher cantilever forces to which this region of the spine are subjected.[8,13,22] Pseudarthrosis results in eventual implant failure and progressive loss of sagittal alignment, therefore it plays a role in the pathogenesis of flat back syndrome, which was present in 20% of patients in the series by Lagrone.[4]

In addition to degeneration of cephalad and caudal intervertebral disks next to the fusion mass, fractures of vertebral bodies in the thoracolumbar spine are also recognized causes of flat back syndrome.[4,10,13,15,23] Both adjacent segment degeneration and vertebral body fractures result in loss of structural support and subsequent loss of height of the anterior column, leading to progressive kyphosis or straightening of the lumbar spine. If the rest of the spine is unable to compensate for the loss of lordosis, a flat back syndrome may occur. Finally, other less common causes include hip flexion contractures, ankylosing spondylosis, and anterior lumbar compression instrumentation.[13,15,23]

Clinical Presentation

The most common clinical presentation of patient with flat back syndrome is the inability to stand upright without flexing the knees and hips.[4,23] Patients often complain of frequent stumbling or difficulty walking on uneven ground. These symptoms, coupled with a history of multiple spine surgeries, should clue the clinician in to the diagnosis. In an attempt to maintain horizontal gaze and upright posture, the patient will flex the knees and hips and extend the thoracic and cervical spine through the remaining mobile spinal segments; maintaining this posture results in fatigue and pain.

Although pain is a common initial complaint, it is not a distinguishing symptom of flat back syndrome. Pain may be related to increased strain on the paraspinal muscles, adjacent disk degeneration, and possible pseudarthrosis.[10] The pain is poorly localized to the low and mid back and typically worsens with prolonged activity or standing. Radicular pain is rare, although the patient should be examined for the presence of true tension signs. Pain can occasionally extend into the thoracic and cervical spine, as these remaining mobile segments are hyperextended to preserve horizontal gaze. The fatigue caused by flat back syndrome is secondary to the increased strain on the paraspinal muscles from the straightening of the lumbar spine, and it is also the result of the increased amount of work required by these muscles, as the patient struggles to maintain an upright posture.[5,13]

Physical exam reveals an obvious loss of normal lordotic contour to the lumbar spine with forward tilting of the trunk. The loss of lordosis is typically rigid and therefore does not correct with bending or manipulation maneuvers. The patient should be evaluated for hip flexion contractures, because their presence may be a contributing factor of the flat back syndrome and must be taken into account during the preoperative planning and positioning process. Other joint contractures, pelvic obliquity, and the flexibility of the thoracic and cervical spine should be evaluated.

Radiographic Workup and Evaluation

Radiographic evaluation begins with standing anteroposterior (AP) and lateral 36-inch cassette plain films to assess the overall alignment of the spine. If needed, flexion and extension views or an extension prone view can be obtained to accurately define the rigidity of the deformity. Although difficult for some patients, effort must be made to ensure that the hips and knees are fully extended during standing radiographs. Flexion through these joints will mask potential sagittal imbalance and skew the overall measured alignment. Scoliotic deformity in the sagittal and coronal plane should be measured using the Cobb method. Although flat back syndrome is primarily a disorder of the sagittal plane, the spine surgeon must also evaluate for the presence of deformity in the coronal plane (Figs. 62-3 and 62-4).

If not accounted for, coronal plane deformities can be worsened during surgical correction designed for pure sagittal imbalance, as with the SPO.[10,12] The normal curvature of the spine varies among patients and is typically reported as a range of values. In general, normal ranges are 20 to 50 degrees for thoracic kyphosis and 20 to 65 degrees for normal lumbar lordosis; the thoracolumbar junction should be within a few degrees of straight.[17,24] As alluded to earlier, lumbar lordosis increases in more caudal levels of the lumbar spine. Approximately 67% of the lordosis in the lumbar spine occurs from L4 to the sacrum.[17,23,25] However, more important than the exact degree of deformity measured, and whether it falls within the accepted ranges, is the overall sagittal alignment of the spine; thus the diagnosis of a global flat back cannot be made based only on the degree of lordotic curve on a static plain film.

Determination of the sagittal balance of the spine is accomplished through the use of a *plumb line,* otherwise known as the *sagittal vertical axis.* This axis is a vertical line drawn from the center of the C7 body to the sacrum on the standing lateral film. In a spine with a normal sagittal alignment, the plumb line should cross the posterior superior end plate of S1.[13,23] Spines that have a negative sagittal balance will have a plumb line that falls posterior to S1, and spines with a positive balance, as in flat back syndrome, will have a plumb line anterior to S1. Normal spines have a plumb line that falls within 2 to 3 cm of the anterior aspect of the sacrum or 5 to 6 cm from the posterior superior aspect of S1.[26] Positive sagittal balance occurs when the plumb line falls more than 4 to 5 cm anterior to the sacrum promontory.[5,10,23] Patients with flat back syndrome have positive sagittal balances that range from 4.3 to 25 cm (Fig. 62-5).[5,10,13,14]

Advanced imaging, such as computed tomography (CT) and magnetic resonance imaging (MRI), can be helpful during the workup. CT is used to evaluate for the presence

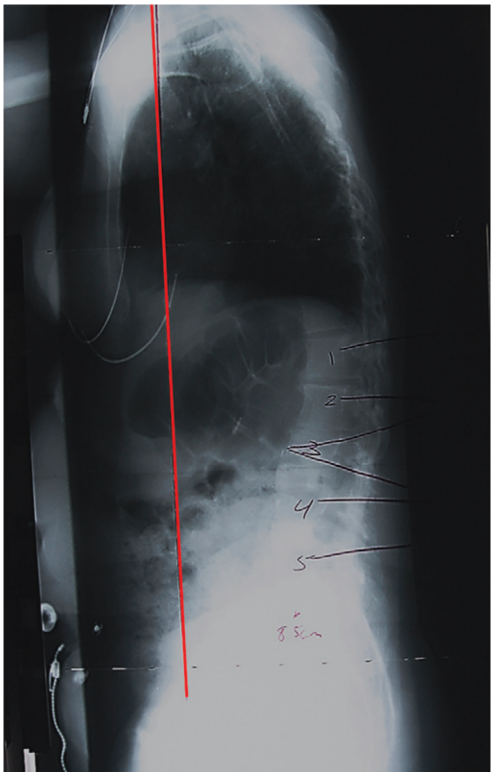


Figure 62-3 Standing lateral 36-inch film indicates positive sagittal balance as seen using the sagittal vertical axis (*red line*).

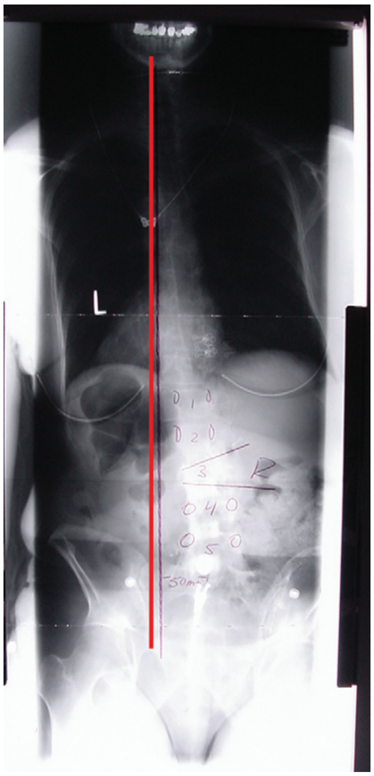


Figure 62-4 Standing anteroposterior 36-inch film depicts lumbar scoliosis and coronal imbalance.

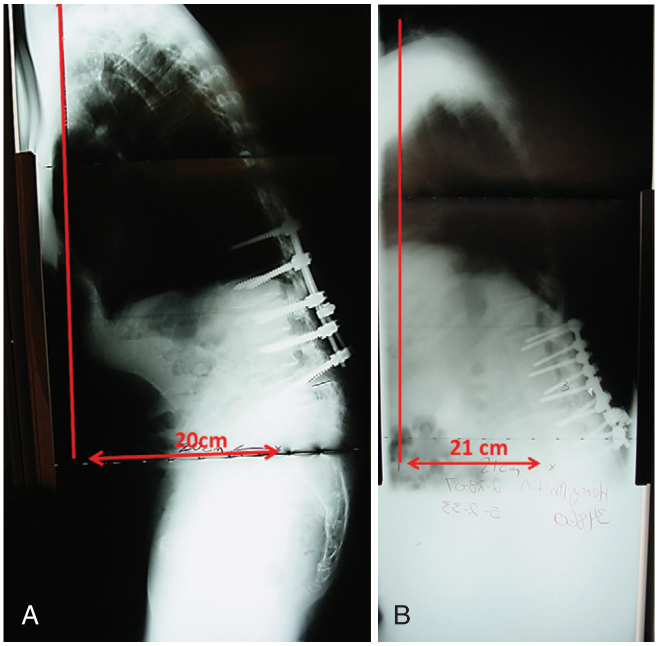


Figure 62-5 Severe positive sagittal imbalance measuring approximately 20 and 21 cm is revealed on 36-inch films.

of a potential pseudarthrosis and to better define bony anatomy. MRI is utilized in the occasional patient who does exhibit neurologic symptoms to assess for the presence of nerve root impingement or spinal stenosis.

Conservative Management

All patients with flat back syndrome warrant a trial of nonsurgical management, if for no other reason than to maximize aerobic fitness and flexibility prior to surgical correction. Enrollment in physical therapy and aerobic conditioning should be considered for patients who are able to tolerate such activities. Exercises that increase hip and back extension and focus on strengthening the core muscle groups are the first-line treatment. Bracing can be used temporarily, when it is found to be successful at providing symptomatic relief, but it should be avoided over the long term, because it will result in eventual weakening of the paraspinal muscle groups. If pain is located focally in one particular area of the spine, epidural and transforaminal injections can be used to provide short-term relief. Farcy and Schwab[5] reported a 27% success rate with conservative nonrealignment treatment in patients with a moderate positive sagittal imbalance of less than 4 cm. Patients with more than 4 cm of positive imbalance were unsuccessfully managed by conservative means alone and ultimately required realignment revision surgery. Therefore, conservative management can only be considered as definitive treatment in mild cases.

Operative Management

Once the decision is made to proceed with surgical correction of flat back syndrome, the spine surgeon must carefully define the surgical goals specific to the individual patient and that deformity. This begins with careful preoperative planning, including thorough assessment of the sagittal curve. In patients with type 1 segmental sagittal imbalance, the surgical objective is to increase the amount of lordosis through the affected spinal segments, while preserving the overall sagittal alignment of the spine.[10,23] In global type 2 deformity patients, the goal of surgery is to improve the overall sagittal balance of the spine. This is accomplished by increasing the lumbar lordosis, so that it is 10 to 30 degrees greater than the thoracic kyphosis, and maintaining a 2 : 1 ratio of lumbar–thoracic sagittal curvatures.[10,23] Unless necessary to avoid future curve progression or spinal instability, the fusion should not be carried caudal to L3.[6,8] Stopping the fusion at or above L3 decreases the risk of development of future sagittal imbalance, pseudarthrosis, retrolisthesis, and degeneration of spinal segments caudal to the fusion.[13,18,27,28] In the event that the fusion is extended to the lower lumbar spine, extreme care should be taken to not distract through these levels and thereby decrease lumbar lordosis.

Proper positioning of the patient on the operating table is key to successful correction. Patients are positioned prone on either a Jackson table or Wilson frame. Two pads are placed under the chest, and four are placed under the thighs; the goal is to extend the hips and the spine, because this will help maximize the amount of passive lumbar lordosis obtainable by the patient and will facilitate closure of the osteotomy later. If desired, the patient can be placed over a break in the table that allows gradual extension of the table to assist with osteotomy closure. Alternatively, additional pillows can be placed under the thighs after osteotomy to increase lumbar lordosis.

SMITH-PETERSON OSTEOTOMY

The SPO, originally described in 1945, depicts a V-shaped osteotomy that involves resection of the posterior column between the facet joints and extension anterior to the dura at a particular level.[29] This procedure was originally used in the treatment of ankylosing spondylitis and rheumatoid arthritis and has since been expanded for use in deformity correction of fixed sagittal imbalance.[30,31] Sagittal plane correction is accomplished by shortening the posterior column, hinging on the middle column through the posterior aspect of the intervertebral disk, and lengthening the anterior column. For successful anterior column lengthening, the intervertebral disk must be mobile; ideally, it should be greater than 5 mm in height.[32,33] Additionally, the anterior longitudinal ligament (ALL) should not be calcified or contracted.[32] When achieving length through the anterior column is a concern, anterior release or anterior column grafting has been advocated.[5,10,21,34,35]

A major downside of the SPO is the significant risk that distraction of the anterior column produces. This includes potentially fatal traction damage to great vessels and injury to neurologic structures.[12,36] Another drawback of lengthening the anterior column is that doing so may decrease the rate of successful fusion.[20] SPO is contraindicated in levels with foraminal stenosis, because the neural foramen is narrowed by osteotomy closure (Table 62-1).[13,23,32] As a general rule, one degree of correction is obtained for every millimeter of bone resected, and depending on the amount of bone removed, approximately 5 to 15 degrees of deformity correction can be achieved with a single SPO (Fig. 62-6).[4,5,13,15]

Correction of flat back syndrome typically requires SPOs at multiple spinal levels to achieve the aforementioned surgical goals.[20] For maximal correction, the osteotomies should be centered over the apex of the deformity when possible. Correction between 22 and 40 degrees can be expected after multiple osteotomies,[4,10,12] and the deformity ideal for correction via multiple SPOs is a back with a long, smooth, sweeping curve.[20,33] Patients with sharp, angular deformities and those with substantial positive imbalance of greater than 12 cm are best treated with a PSO.[12,20,33] Additionally, patients with a significant coronal plane deformity may have their condition worsened by an SPO through nonneutral vertebral segments, and therefore are better treated by PSO.[12,33]

Surgical Technique[23,32,37]

1. Position the patient prone on a Jackson table or Wilson frame. Pads should be placed under the chest and thighs to maximize lordosis through the lumbar spine.
2. A straight midline posterior approach, typically through a previous surgical incision, is followed down onto the fusion mass or posterior elements. In general at least two segments above and below the level of any planned osteotomy are exposed for instrumentation, and this is confirmed fluoroscopically.
3. Subperiosteal dissection is performed to expose the posterior elements or fusion mass.
4. Fixation points are identified and prepared, and pedicle screws are placed bilaterally two levels above and below any intended osteotomy site. Placement is confirmed fluoroscopically and with pedicle screw stimulation.
5. When a fusion mass is present, the mass is thinned down to its anterior cortex via a combination of osteotomes, rongeurs, and a burr. In a native spine, the overhang of the spinous processes above and below the intended osteotomy level are resected with a rongeur.
6. The superior and inferior articular processes are identified and resected with the use of a Leksell or other rongeur. Care is taken to ensure complete removal of the articular processes, because any bone remaining may prevent complete osteotomy closure. Once the osteotomy is done, it may close spontaneously; therefore a lamina spreader is used to prevent closure before the osteotomy can be carefully inspected to ensure it will not impinge any neurologic structures.
7. The spinal canal is entered centrally, and the ligamentum flavum is resected out laterally toward the facets.
8. Laminectomy of the inferior border of the lamina above and the superior border of the lamina below is performed from the midline bilaterally out laterally to the facets.
9. At this time, the neural foramina are inspected to ensure that there is room for the nerve roots after deformity correction. If the space is narrowed, resection of additional lamina or remaining articular processes is completed.

Table 62-1 Contraindications to Smith-Peterson Osteotomy[13]

Calcified great vessels
Contraction or calcification of the anterior longitudinal ligament
Anterior disk height less than 5 mm
Immobile anterior intervertebral disk
Significant coronal plane scoliosis
Foraminal stenosis

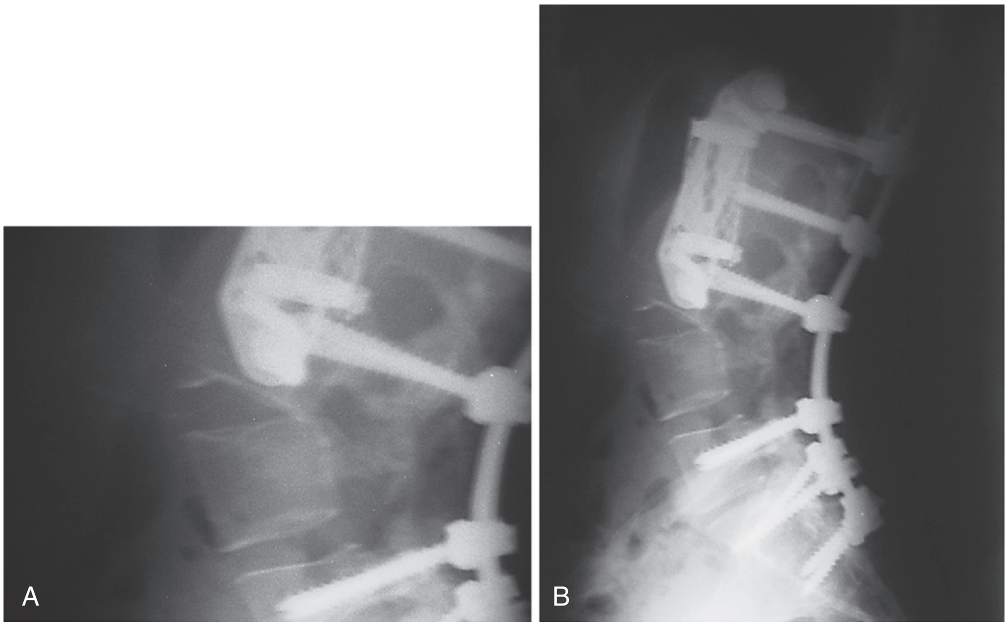


Figure 62-6 Smith-Peterson osteotomy. Note distraction of the anterior spinal column.

10. Hemostasis is achieved. The dura is visually inspected for damage and is examined via a Valsalva maneuver.
11. Contoured rods are seated within the pedicle screw heads, and gradual extension through the osteotomy site is performed via cantilever bending. Additional pads placed under the hips and/or extension through the surgical table may assist with osteotomy closure.
12. Deformity correction is assessed by visual inspection and intraoperative fluoroscopy.

PEDICLE SUBTRACTION OSTEOTOMY

In contrast to the SPO, the PSO corrects deformity though shortening of the middle and posterior columns while hinging on the anterior column. The anterior column is not lengthened during correction, therefore the risks of SPO associated with anterior column distraction are avoided. Otherwise known as the *transpedicular cortical decancellation procedure,* the osteotomy is performed via resection of a V-shaped wedge of vertebral body, partial resection and collapse of the lateral and posterior vertebral body walls, and removal of all posterior elements (Fig. 62-7).[14,16,38]

Approximately 30 to 35 degrees of correction are obtainable with each osteotomy.[11,16,39] Reported rates of maintained surgical correction following PSO range from 30 to 34 degrees at 1- to 2-year follow-up,[14,20,40] consistent with what can be achieved intraoperatively. Similar to SPO, the osteotomy is best performed at the apex of the deformity, and one degree of correction can be anticipated for every millimeter of bone resected. Ideally the osteotomy is performed at L2 or L3 to decrease the chance of injury to the spinal cord or conus medullaris, while allowing room for adequate instrumentation above and below.[13,16,20,32] Following completion, the exiting nerve root is included in the same, now expanded foramen as the superior nerve root. Care must be taken to observe the neurologic structures during osteotomy closure to ensure that impingement does not occur (Fig. 62-8).[32]

A clear advantage of the PSO is its ability to achieve significant correction through a single osteotomy without the risks associated with an SPO (Table 62-2). The PSO additionally offers the ability to correct coronal plane deformities via asymmetric resection of the body and posterior elements, therefore it is *not* contraindicated in patients with coronal scoliosis or rotated vertebrae.[12,16] Upon closure of

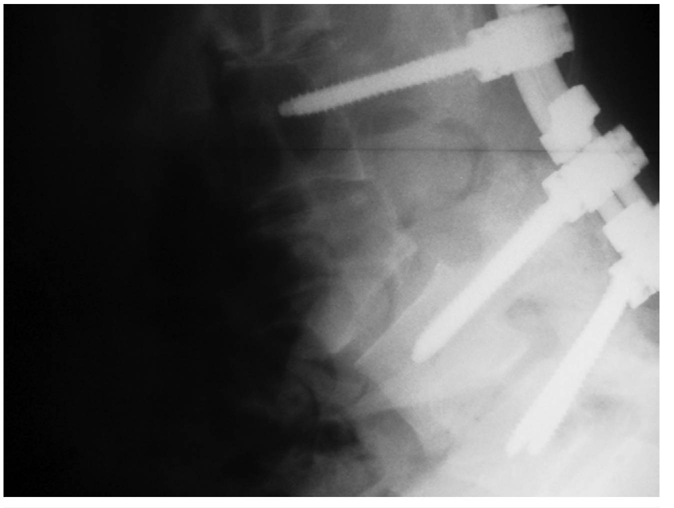


Figure 62-7 Pedicle subtraction osteotomy. Note that correction is achieved by shortening the posterior column without lengthening the anterior column.

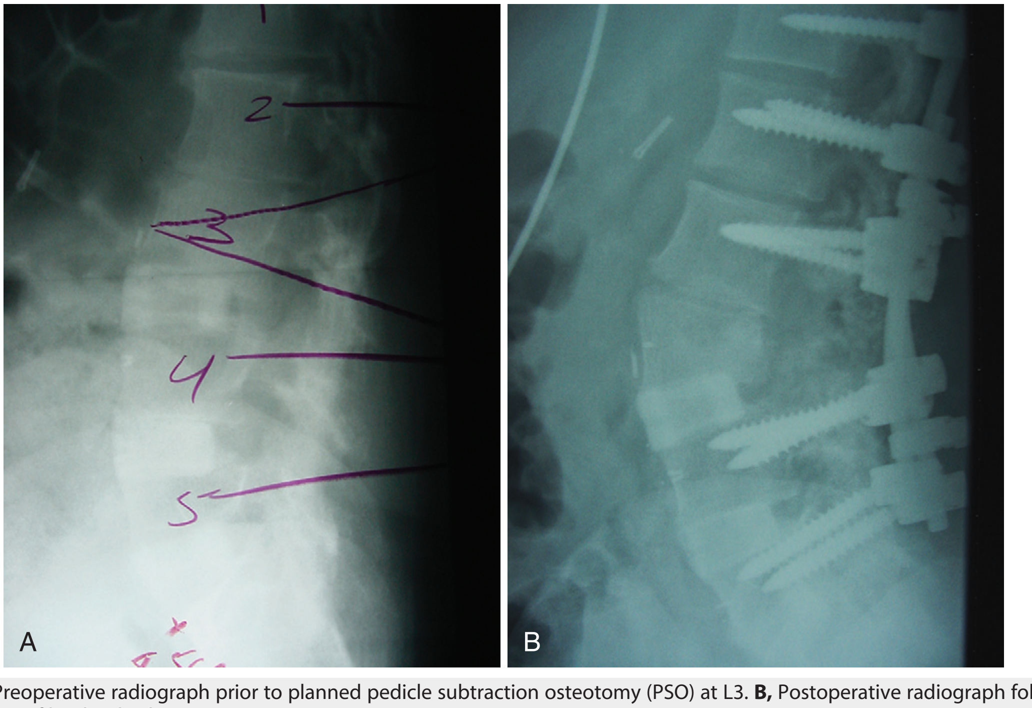


Figure 62-8 **A,** Preoperative radiograph prior to planned pedicle subtraction osteotomy (PSO) at L3. **B,** Postoperative radiograph following L3 PSO; note the restoration of lumbar lordosis.

Table 62-2 Comparison of Smith-Peterson Osteotomy (SPO) and Pedicle Subtraction Osteotomy (PSO)[12,41]

Criteria	Comparison
Technical Difficulty	PSO > SPO
Blood Loss	PSO > SPO
Degree of Correction	PSO > SPO
Supplemental Anterior Procedure	SPO > PSO
Pseudarthrosis	SPO > PSO
Vascular Injury	SPO > PSO
Overall Complications	SPO > PSO

the PSO, large surfaces of bone are approximated, thus creating a more robust area for successful fusion compared with the SPO. The deformity best suited for PSO is a sharp, angular deformity or one with significant positive sagittal imbalance (> 12 cm).[33] Although clear advantages are evident, the procedure is lengthy and technically demanding, and it is associated with significant blood loss. Anterior subluxation of the vertebrae is possible during closure of the osteotomy and requires careful monitoring during final deformity correction.[33] The PSO should also be avoided when an anterior pseudarthrosis or preexisting anterior instrumentation is present.[13]

Surgical Technique[23,32,39]

1. Patient positioning and surgical approach is identical to that of an SPO.
2. Two levels above and below the intended osteotomy site are exposed. However, in patients with poor bone stock, or if a level cannot be instrumented with pedicle screws, additional levels may require exposure.
3. Subperiosteal dissection is used to expose all of the posterior elements or fusion mass at the intended osteotomy site. The correct level should be confirmed fluoroscopically prior to bone resection.
4. Aside from the osteotomy site, the exposed levels are then prepared and instrumented bilaterally with pedicle screws. Correct placement is confirmed using intraoperative fluoroscopy and pedicle screw stimulation.
5. The spinous processes at the osteotomy level and the process on the level above are resected with a rongeur.
6. Wide laminectomy is next performed from the midline out laterally to the facets. The ligamentum flavum is also resected laterally, toward the facet joints. If a fusion mass is present, it is thinned with a burr or a combination of curettes and rongeurs and is carefully resected away from the midline to expose the spinal canal.
7. The epidural space is now accessible, nerve roots are identified, and the epidural space is decompressed centrally.
8. All posterior elements are then resected to completely isolate the pedicles at the osteotomy level.
9. The lateral aspect of the pedicle is removed along with the transverse processes. Care must be taken to avoid the segmental artery and exiting nerve root.
10. The pedicle bases are curetted into the main vertebral body, and care is taken not to disrupt the medial pedicle wall, which protects the neural elements and dura.
11. Increasingly larger curved and angled curettes and various rongeurs are used to enter the vertebral body, through the base of the right and left pedicles, and carve out a hollow space within the vertebral body. The cavity is made progressively larger, until the anterior vertebral body wall is reached, and the left and right sides communicate. Alternatively, bone removal is stopped at the anterior one third of the body, and the remaining bone is fractured upon closure of the osteotomy. Attention must be paid to ensure the anterior vertebral body cortex is not violated in order for it to act as a hinge and prevent anterior translation. The cavity is tapered into a wedge-shaped “V” in the sagittal plane with the apex toward the anterior vertebral body.
12. Significant bleeding may occur at this stage secondary to the raw cancellous bone surfaces. Hemostasis is achieved using a combination thrombin-soaked Gelfoam, FloSeal, and packing.
13. The posterior vertebral wall, now a thin cortical shell, is resected next, along with the medial pedicle bases with reverse-angled curettes and rongeurs. A dural retractor is used to medially retract the thecal sac. Straight osteotomes are used, directed anteriorly along the cranial and caudal margins of the posterior wall osteotomy, to ensure the osteotomy margins are parallel to each other. Enough wall must be resected to allow for effective closure of the osteotomy.
14. The lateral body walls are next carefully dissected free of soft tissue using a small Cobb elevator. The lateral walls are then resected with a pituitary rongeur, and care is taken to ensure that resection is equal on both sides to allow symmetric osteotomy closure. The depth of lateral wall resection can be monitored using fluoroscopy.
15. Once it has been determined that an adequate amount of bone has been removed, osteotomy closure proceeds after placement of contoured rods via symmetric compression and cantilever bending of the cranial and caudal pedicle screws and gradual extension of the hips. The dura and exiting nerve roots must be closely monitored to ensure they are not impinged during closure.
16. Deformity correction is assessed by visual inspection and intraoperative fluoroscopy.[12,41]

ANTERIOR SURGERY

Frequently, posterior vertebral osteotomy is insufficient in isolation to correct flat back deformity and maintain the reduction. In these scenarios, anterior releases and/or fusion and strut grafting supplement posterior procedures. Situations in which anterior procedures are needed include, but are not limited to, cases with multiple anterior pseudarthroses, circumferential fusions along several segments, and cases with scarring of the ALL or anterior disk that prevents complete closure of an SPO.[13,33] In 2005, Cho and colleagues[12] published a series in which 39% of patients who underwent a PSO had additional anterior surgery, and 87% of patients undergoing an SPO had a concomitant anterior procedure. Furthermore, Kostuik and colleagues[21] presented their series, in which 86% of patients had decreased pain; in addition, a 29% improvement of lumbar lordosis was appreciated in patients treated with combined anterior and posterior osteotomies.

As an alternative to an SPO or PSO, some surgeons have advocated for anterior deformity correction combined with removal of any posterior spinal implants. Jang and colleagues[19] reported on a series of patients treated using a posterior-anterior-posterior technique that consisted of removal of posterior hardware, followed by anterior strut grafting and deformity correction, and finalized with posterior compression instrumentation. Results showed sustained improvement in lumbar lordosis and sagittal vertical axis, and they revealed subjective improvements in function and pain at final follow-up. Anterior surgery plays a significant role in the treatment of flat back syndrome, although posterior extension-type osteotomies are the most widely used procedures, alternatives are available, and anterior body work is frequently needed for adequate correction.

Patient Outcomes

Complication rates are high following surgical correction of flat back syndrome. Rates in the literature range from 25% to 60%.[4,5,10,12] Early postoperative complications include neurologic injury, dural tears, postoperative myocardial infarction, massive transfusion requirements, wound infection, and deep venous thrombosis. The most common late complications are pseudarthrosis, hardware failure, and degeneration of adjacent spinal segments.[4,5,10,12]

Despite the high rate of complications, patients do report subjective improvement postoperatively. In Lagrone's[4] series that reported a 60% complication rate and a 36% rate of significant residual pain, 95% of patients reported benefit from the procedure in terms of pain relief and posture correction. More recent series have reported lower overall complication rates and have continued to echo subjective improvement in a large percentage of patients in regard to pain, function, and overall self-image.[20,21] Bridwell's[16] series reported statistically significant improvement in postoperative pain and Owestry scores, and 88% of patients stated that they would undergo the procedure again.

Clearly, surgical correction is beneficial for patients with flat back syndrome; however, patients should be counseled preoperatively about high rates of potential complications and residual pain. Patient expectations should be focused on improvements in function and pain relief, but they must be apprised that a complete resolution of symptoms is unlikely.[4,5,11,12,14,16,19,21]

Summary

Flat back deformity most often results from postsurgical fusion and distraction into the lower lumbar spine. Patients come to medical attention complaining of pain and fatigue and are unable to stand erect without bending their legs, and a loss of the normal lumbar lordosis with a fixed positive sagittal imbalance of the spine is appreciable on radiography. All but the mildest symptomatic cases are best treated with surgical deformity correction; the most common surgical procedures are the SPO and PSO, with or without a supplemental anterior procedure. The goal of these corrective surgeries is to increase lumbar lordosis and ultimately restore neutral spinal alignment as measured by the plumb line, or sagittal vertical axis. These osteotomies are technically challenging and lengthy, and they carry the potential for a high rate of morbidity. Despite the surgical risks and persistence of symptoms in a large portion of treated patients, with careful preoperative planning and close attention to surgical detail, a high percentage of patients will achieve overall improvement following surgical correction.

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63 Surgical Management of Degenerative Lumbar Scoliosis

REX A.W. MARCO and ROBERT J. WOODRUFF

Overview

Adult degenerative scoliosis remains a challenging problem for patients and spine surgeons. Treatment decisions can be complicated by social, psychologic, and medical factors. Patient outcomes can be optimized by understanding the natural history of degenerative scoliosis as well as the various nonoperative and operative treatment options.

Adult degenerative scoliosis can develop de novo as a result of asymmetric disk and facet degeneration in a spine with relatively normal alignment, or it can occur as a result of asymmetric disk and facet degeneration associated with adolescent idiopathic scoliosis (AIS). The natural progression of adult scoliosis varies from individual to individual. Glassman and colleagues[1] showed that patients with degenerative scoliosis have significantly lower SF-36 scores in 7 of 8 categories than age-matched controls. These patients also scored lower in 7 of 8 categories compared with patients who had back pain, sciatica, and hypertension. The decision to continue with nonoperative treatment or to pursue operative intervention remains complex and difficult, despite the fact that these patients have lower health-related quality of life scores.[1] These patients must balance issues of progressive deformity, pain, cosmesis, overall medical condition, and the extent of potential intervention in their decision making.

Natural History

The true natural history of degenerative scoliosis, either from previously existing AIS or de novo scoliosis, is not fully understood. The recommendation for fusion of AIS curves during adolescence comes in large part from the hope that the surgery will prevent curve progression. Forty-year follow-up data out of Iowa suggest that thoracic curves measuring more than 50 degrees and lumbar curves measuring more than 30 degrees will progress at a rate of approximately 1 degree per year.[2,3] However, these data represent an average of all subjects, thus not every patient will demonstrate curve progression. In fact, many patients' curves remain stable throughout their entire life. Scoliosis has been associated with psychosocial consequences, slightly higher rates of back pain, and decreased cardiac and pulmonary function in curves measuring over 100 degrees. In adults with de novo scoliosis, the natural history is even more poorly understood. The constellation of symptoms varies greatly among patients and cannot be determined based on the size of the curve. However, with aging, the natural tendency is for progressive loss of disk height through dessication, decreased lumbar lordosis, increased sagittal imbalance, and decreased motion. This process is further complicated with coronal and sagittal changes related to osteoarthritis and osteoporosis, which lead to compression fractures and hypertrophy of the facet joints and ligamentum flavum in some patients. The combination of facet and ligamentum flavum hypertrophy, coupled with disk protrusions commonly seen anteriorly, can lead to central and lateral recess stenosis with resultant radiculopathy. However, even with these changes, some patients remain remarkably asymptomatic, whereas others with seemingly mild radiologic changes may complain of debilitating pain. Regardless of the patient's symptoms, frank paralysis from compression and worsening alignment is rare, therefore surgical treatment of the disorder is almost never an emergency. It is thus prudent to spend adequate time on the patient's workup to fully understand the source of the complaints, to exhaust nonoperative measures prior to pursuing surgery, and to have an extensive preoperative discussion to fully address the risks and benefits of proceeding with any sort of operative correction.

History and Physical Examination

The assessment of these patients begins with a detailed history and physical exam. Clarification of the patient's primary complaint should be elucidated, and it should be determined whether these symptoms are worsening.[4] Patients who come to medical attention with worsening, intractable pain or neurogenic claudication may require different intervention than someone concerned with cosmesis alone. A history of vascular claudication can mimic neurogenic claudication; however, patients with vascular claudication often have improvement of their symptoms while standing still or sitting, whereas patients with neurogenic claudication show improvement while leaning forward.

Patients with adult scoliosis can come to medical attention with multiple medical problems. A patient with a history of cardiopulmonary disease may not tolerate a prolonged operation and anesthesia, similarly, diabetes will adversely affect the cardiovascular system and wound healing, which in turn can increase the incidence of postoperative complications such as infection, deep venous thrombosis (DVT) and/or pulmonary embolism (PE), and pneumonia. Similarly, a history of smoking should be addressed, and every attempt should be made to institute a smoking cessation program at least 1 month prior to surgery that continues 6 months after surgery, because tobacco use correlates with a higher risk of pseudarthrosis and pulmonary complications, poor wound healing, slower rate of recovery, and overall poorer outcome of the procedure.[5-7] A personal or family history of bleeding problems or blood clots is extremely important and may warrant a preoperative hematologic evaluation. A history of susceptibility to infection should also be obtained to determine whether the patient may be more prone to developing perioperative wound complications. Rheumatologic disorders are not uncommon in this population, and the current disease-modifying antirheumatic drugs (DMARDs) need to be altered if any surgery is being planned. Medications that inhibit coagulation, such as nonsteroidal antiinflammatory drugs (NSAIDs), acetylsalicylic acid, clopidogrel, anticoagulants, vitamin E, and fish oil should be stopped prior to surgery to decrease intraoperative bleeding and decrease the likelihood of developing postoperative wound and epidural hematomas.

Assessing patients' social support structure is invaluable in determining their ability to tolerate the postoperative demands during recovery. Patients without an extensive family support system may not be ideal surgical candidates. Elicit any history of previous treatments, such as physical therapy and injections; although these may have been previously tried, patient compliance and the quality of the injections vary greatly, so a history of either does not automatically mean that nonoperative treatment has failed.

The physical exam begins with observation of the patient. Facial expressions are noted, because patients may occasionally grimace and appear uncomfortable while sitting, standing, or walking. Standing coronal and sagittal alignment, shoulder height, waist asymmetry, and pelvic obliquity are evaluated. Paraspinous rib and lumbar humps are evaluated with the Adam's forward bend test. Significant loss of lumbar lordosis may present with a forward pitch of the trunk, which impairs forward gaze of the eyes, and patients compensate by flexing the hips and knees to maintain forward gaze. Asking the patient to stand sideways with straight legs further accentuates the severity of the sagittal imbalance. Observation of the gait is used to identify any limitations and signs of weakness or myelopathy. A thorough neurologic exam is necessary, including an assessment of strength, sensation, and the reflexes. Assessment of the distal pulses evaluates for evidence of vascular insufficiency, and examination of the hips and knees can assess for signs of symptomatic osteoarthritis, which can alter treatment recommendations.

Radiologic Evaluation

The radiologic evaluation begins with full-length 36-inch anteroposterior (AP) and lateral scoliosis films. The patient's position during these films must be standardized to negate any compensatory positioning. Patients should stand with their feet together and their hips and knees fully straightened; arms should be in 30 to 45 degrees of forward flexion with elbows flexed and hands resting on the clavicles. Standardizing this positioning prevents inaccurate representation of the sagittal vertical axis.[8]

In the AP projection, the coronal curves are measured using the Cobb technique, and the coronal alignment is measured using the C7 plumb line. Any deviation of the C7 plumb line from the central sacral vertical line (CSVL) suggests coronal imbalance. Shoulder asymmetry, waist asymmetry, pelvic obliquity, and vertebral body lateral listhesis may also be present. The appearance of an outlet view of the pelvis suggests that the patient has decreased lumbar lordosis and retroversion of the pelvis.

In the lateral view, the overall sagittal alignment is examined by drawing the C7 plumb line and then determining the distance from this line to the lateral sacral vertical line (LSVL), a vertical line drawn from the posterosuperior corner of S1. This line ideally overlaps the C7 plumb line and transects the T12–L1 disk space as well as the C7–T1 disk space.

The regional sagittal alignment of the thoracic, thoracolumbar, and lumbar spine is also measured. An oversimplified method to remember the normal sagittal alignment of these regions is the 0/30/60 rule, which states that the thoracolumbar alignment should be around 0 degrees, the thoracic kyphosis should be around 30 degrees, and the lumbar lordosis should be around 60 degrees. The pelvic incidence (PI) and pelvic tilt (PT) are also measured (Fig. 63-1). The PI is an angle made by the intersection between a line drawn perpendicular to the S1 end plate at its midpoint and a line from this point to the center point of a line drawn between the centers of the femoral heads.

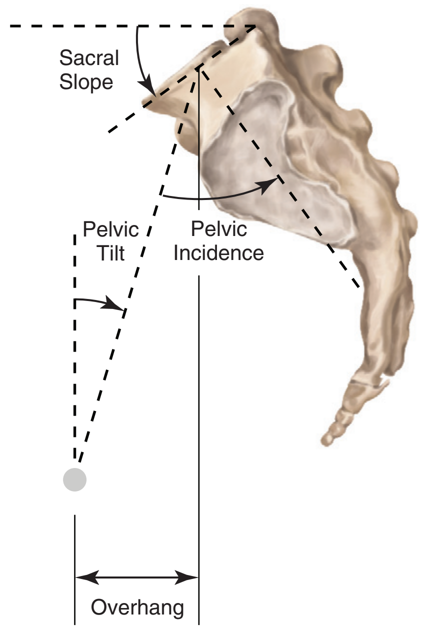

Figure 63-1 Pelvic parameters measured on lateral radiograph. *Sacral slope* (SS) is the angle from horizontal made by the superior end plate of S1. *Pelvic tilt* (PT) is defined as the angle formed by a line drawn vertically from the center of the femoral head and one drawn from this point to the center of the S1 end plate; PT is a measure of the relative amount of pelvic retroversion. *Pelvic incidence* is the angle formed by drawing a line perpendicular to the S1 end plate at its center and one from that point to the center of the femoral heads. In most cases, the femoral heads do not perfectly overlap. In that case, find the center of each femoral head, draw a line between these points, and measure to the midpoint of this line.

Schwab and Lafage[9] discussed the importance of the relationship between PI and the ideal degree of lumbar lordosis (LL; Fig. 63-2). They suggested that the ideal LL can be estimated with the following formula:

$$LL = PI + 9\ \text{degrees}\ (\pm 9)$$

Whereas PI remains fairly constant as pelvic retroversion increases, PT increases (Fig. 63-3). PT is an angle formed by the intersection of a vertical line drawn from the center point of a line drawn between the centers of the femoral heads and the line drawn from the midpoint of the S1 end plate to the center point of the line between the centers of the femoral heads (see Figs. 63-1 and 63-2). Lafage and Schwab[10] showed that with increasing PT, pain and disability increase as measured by the Oswestry Disability Index, Short-Form 12 questionnaire, and Scoliosis Research Society 22 questionnaire scores. Similarly, Schwab and colleagues[11] showed the disability caused by adult scoliosis in general. If surgery is planned, full-length supine AP bending and supine lateral radiographs can help assess curve flexibility in the coronal and sagittal planes.

Patients with degenerative scoliosis can come to medical attention with symptoms suggestive of spinal stenosis and radiculopathy. Other pathologies, such as tumor and infection, may also be affecting the alignment of the spine; therefore further imaging may be indicated. Magnetic resonance imaging (MRI) can be useful in assessing the degree of spinal stenosis, disk desiccation and protrusion, ligamentum flavum hypertrophy, and facet pathology, and it may help identify signs of osteomyelitis, diskitis, and neoplasm. The MRI should be performed with gadolinium in patients who have had previous surgery to help differentiate scar tissue from disk material. However, MRI can be difficult to interpret in patients with a coronal deformity greater than 40 degrees or retained metallic implants. In these cases, a CT myelogram may be more useful. Both of these studies can be used for more advanced preoperative planning, such as vascular mapping, bone quality assessment, planning of screw lengths and trajectory, and identification of levels for decompression.

Nonoperative Management

In the absence of progressive neurologic deficit, nonoperative measures should be pursued first. This treatment consists of NSAIDs, physical therapy for strengthening and stretching exercises, cardiovascular conditioning, avoidance of painful activities, corticosteroid injections, and modalities such as heat and ice for symptom relief. Bracing

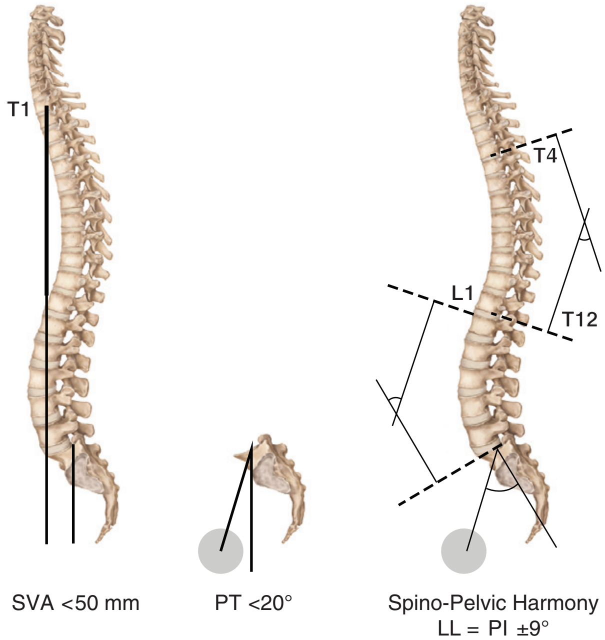

Figure 63-2 Ideal measurements for various pelvic parameters.

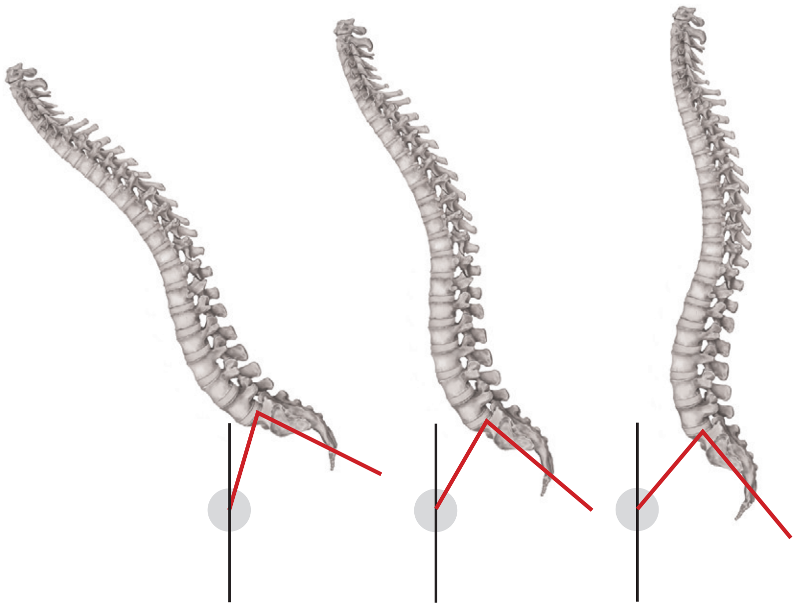

Figure 63-3 As pelvic retroversion increases to compensate for sagittal imbalance from no retroversion (**A**) to moderate retroversion (**B**) to severe retroversion (**C**), the pelvic tilt (*grey lines*) also increases; however, pelvic incidence (*red lines*) remains fairly constant regardless of compensatory retroversion.

is poorly tolerated in the degenerative population and can lead to unnecessary expenses. Therapy should focus on strengthening the abdominal and paraspinal musculature, increasing hip and knee range of motion, and improving cardiovascular endurance. The patient must be diligent about doing exercises at least once per day 5 to 7 days per week. In addition, patients should increase their activity level and endurance, with the goal of walking a mile each day, even if it has to be broken up into several smaller sessions. Even if the patient fails to improve with nonoperative therapy, the increased activity will hopefully allow them to better tolerate the demands of postoperative therapy. Patients are also encouraged to pursue alternative measures that have helped them in the past, such as chiropractic care, acupuncture, and Eastern medicine.

Developing a professional relationship with a rehabilitation physician and pain medicine specialist will allow the surgeon to develop a thorough rehabilitation protocol for their patients. It also ensures that the patient is receiving the most effective and comprehensive nonoperative therapy program. Epidural and selective nerve root injections can provide symptomatic relief for many patients. Serum 25-hydroxy vitamin D levels are checked, and supplementation with vitamin D3 is prescribed for patients with low vitamin D3 levels. Bone mineral density studies are ordered, and appropriate treatment with bisphosphonates or teriparatide is administered whenever indicated.

In patients with neurologic symptoms, such as radiculopathy and claudication, gabapentin and pregabalin can be helpful. The use of antidepressant medications has also been described. Long-term narcotic pain medications and muscle relaxants should be prescribed by the pain management specialist.

A rigorous nonoperative protocol that has been carefully coordinated with a rehabilitation physician and pain management specialist can benefit the majority of patients. These patients usually demonstrate enough improvement that they do not pursue operative intervention. However, some patients do not benefit as much as others from nonoperative treatment, and these patients may be more appropriate surgical candidates.

Operative Care

Similarly, proper selection of a procedure is crucial, both to address the patient's symptoms and to maximize outcome and minimize complications.[12] Transfeldt and colleagues[13] pointed out that complications are inherent in all varieties of surgery for degenerative lumbar scoliosis, so proper selection is important. A patient's overall medical condition may affect their fitness for a large surgery. Outcomes may also vary depending on the age of a patient,[14] therefore it is critical to be familiar with and to recognize the indications, management options, risks, and outcomes of surgery for adult scoliosis to correctly inform your patients about the proposed surgical procedure.[15]

RISKS

Before pursuing surgery, a long conversation regarding the risks and benefits of surgery is necessary with all patients. Each patient is different and has different medical and spinal pathology, so each conversation is individualized. According to the Scoliosis Research Society[16] data published in 2011, 10.5% of patients will experience complications. Dural tear occurred in 2.9%, superficial infection in 0.9%, deep infection in 1.5%, implant complications in 1.6%, acute neurologic deficits in 1%, delayed deficits in 0.5%, epidural hematoma in 0.2%, wound hematoma in 0.4%, PE in 0.2%, and DVT in 0.2%. Death occurred in 0.3% of patients. These findings did not differ significantly between adult idiopathic scoliosis and de novo scoliosis; however, complications were higher in patients who underwent osteotomies, revision surgery, and combined anterior-posterior surgery. This data may also be somewhat underreported, and it is important for patients to know the risks of surgery, so that they can make informed decisions. Lapp and colleagues[17] reported high complication rates in both revision and primary surgical patients. They noted 23% and 22% minor complications and 12% and 22% major complications in each group, respectively. They also reported a higher pseudarthrosis rate for the primary group (22% vs. 4%).

Considering this relatively high complication rate for adult scoliosis surgery, it is important to remember that this is an elective procedure in most cases, and the patient has to make the decision to proceed based on an objective presentation of the risks and benefits of the surgery. Even in the presence of progressive neurologic deficit, the patient may elect for nonoperative care, if the risks of surgery and anesthesia are unacceptable to them. Therefore it is critical to make the patient an active participant in the decision to pursue surgery.

Once the decision is made to proceed with surgical intervention, preoperative clearance and medical optimization is critical. Patients must see their internist and any specialty physicians necessary for clearance. Preoperative consultation with the anesthesiologist is useful to prevent any delays on the day of surgery and to maximize operative and postoperative planning. Finally, a bone density scan may be useful. For those patients with poor bone quality, administration of teriparatide preoperatively may be of great benefit. This anabolic medication helps restore bone quality and has the potential to improve outcomes by increasing stability at the bone–implant interface.

PREOPERATIVE PLANNING

Patients who have failed nonoperative management of their symptoms and those who develop progressive deformity are considered for surgical intervention. The difficulty of treating adult degenerative scoliosis lies in the selection of the correct procedure. Whether the symptoms are best treated with a limited decompression, a limited decompression and fusion, isolated lumbar fusion, or fusion to the upper thoracic spine in conjunction with multiple osteotomies to correct coronal and sagittal imbalance remains controversial. Based on the patient's symptoms, the entire curve may not need to be corrected. Patients who are seen with neurogenic claudication symptoms may be adequately treated with a decompressive laminectomy and foraminotomy. If iatrogenic or preexisting instability at the operative level is evident, a limited fusion may be appropriate.

Transfeldt and colleagues[13] evaluated a group of patients with degenerative scoliosis and radiculopathy who underwent a decompression alone, decompression and limited fusion, or decompression and full-curve fusion. These authors found that the complication rate was highest (56%) in the full-fusion group; it was 40% in the limited fusion group and 10% in the decompression-alone group. The SF-36 analysis of all groups combined showed significant improvement in bodily pain, social function, role emotional, mental health, and mental composite domains. Oswestry Disability Indexes improved significantly in the decompression-alone and limited-fusion groups, but not in the full-fusion group. However, the satisfaction questionnaire showed the highest success to be in the full-curve fusion group: 77% of patients claimed that they would have the same surgery again, compared with 55% of patients in the decompression group.[13]

Silva and Lenke[18] developed a methodical classification system from which treatment decisions can be made. Six distinct levels of operative treatment are available for adult degenerative scoliosis: level I is decompression alone; level II is decompression and limited, instrumented posterior spinal fusion; level III is decompression and lumbar curve instrumented fusion; level IV is decompression with anterior and posterior spinal instrumented fusion; level V is thoracic instrumentation and fusion extension; and level VI includes osteotomies for specific deformities.

If no significant stenotic, radicular, and/or back pain symptoms are present, including curves less than 30 degrees with less than 2 mm of subluxation with anterior osteophytes, nonoperative management is started. According to Silva and Lenke's system, patients who have a complaint mainly of buttock and leg pain with less than 2 mm of listhesis at the stenotic levels, curves less than 30 degrees, a relatively well-balanced alignment, and no thoracic hyperkyphosis may be better treated with a smaller surgery. Patients whose curves progress more than 10 degrees and those who have an increase in subluxation greater than 3 mm with increasing clinical symptomatology are offered surgical options. Level III treatment of the entire lumbar curve in addition to the necessary decompressions is included in the instrumented fusion when symptoms of primary back pain are associated with the spinal deformity. Here, the clinical correlation of pain with the location of the curve becomes very important in terms of further selecting the appropriate operative treatment. Typically, these curves are greater than 45 degrees, have more than 2 mm of subluxation, and lack anterior osteophytes in the operative region, although coronal and sagittal balance is reasonably good (Fig. 63-4).

Anterior spinal fusion via a thoracolumbar interbody fusion (TLIF) approach can be an important adjunct at the lower ends of the construct when fusing to the lumbosacral junction. If debilitating back pain is the main symptom, and deformity and imbalance are greater, more extensive surgery is indicated. The system used by Silva and Lenke, and also other classification systems, can be used to help guide treatment decisions and formulate a base on which each surgeon can develop their own thought processes about the treatment of degenerative scoliosis.

Figure 63-4 Anteroposterior (**A**) and lateral (**B**) standing radiographs of a patient with severe sagittal and coronal imbalance.

As stated earlier, preoperative planning must be methodical and thorough. Full-length radiographs are used to select the operative levels and plan the osteotomies. The bending x-rays, as in AIS surgery, help to determine the flexibility of the structural and compensatory curves and help to guide levels of fusion. Coronal plane alignment is best addressed by ensuring that the upper and lower instrumented vertebrae are ideally stable (bisected by the center sacral vertical line). Instrumentation should not end at a level of instability (lateral, anterior, or posterior listhesis) or kyphosis. The proximal extent of the fusion should be proximal to T5 or distal to T9 to avoid stopping the instrumentation within the kyphotic region of the thoracic spine.

Kim and colleagues[19] reported nonsignificant differences in the incidence of proximal junctional kyphosis and revision rates when they compared stopping the fusion at L1–L2 versus at T11–T12 versus at T9–T10. Nevertheless, they reported a 36% to 55% incidence of kyphosis and a 24% to 26% incidence of revision across all groups. Fusion and instrumentation to T2 to T4 is warranted for patients who require correction of sagittal imbalance or hyperkyphosis of the thoracic or thoracolumbar alignment. However, compared with instrumentation to the lower thoracic spine, instrumentation to the upper thoracic spine is associated with an increased incidence of perioperative complications (30.0% vs. 15.8%), pseudarthrosis (20.0% vs. 5.3%), and revision surgery (20.0% vs. 10.5%).[20] In contrast, instrumentation to the lower thoracic vertebrae appears to have a higher incidence of proximal junctional kyphosis compared with that of the upper thoracic vertebra (18.4% vs. 10.0%).

The distal vertebra of the fusion should be neutral and stable as defined by the CSVL. If the patient has minimal to moderate degeneration at the lower lumbar segments, and curve correction can be achieved by stopping short of L5, these motion segments can be preserved. However, patients should be instructed that they may develop adjacent segment degeneration at these levels and may need a revision surgery to extend the fusion to the sacrum or pelvis. Some patients with adult scoliosis are candidates for a selective thoracic fusion. These patients are usually younger than 50 years old and have a history of Lenke 1A or 1B adolescent idiopathic scoliosis. The majority of patients with symptomatic adult scoliosis have a thoracolumbar or lumbar curve. It is reasonable to stop at L5 if the patient has a level, hydrated L5–S1 disk with maintained disk height, restored coronal and sagittal balance, normal L5–S1 facets, and normal bone mineral density. However, the majority of patients with a thoracolumbar or lumbar curve are fused to the sacrum, especially if the patient has a fixed L4–L5 tilt or has had previous surgery, or if spondylolisthesis, stenosis, or disk degeneration is present at L5–S1.[21]

When the decision is made to recommend long fixation from above L2 to the sacrum, the patient should be made aware of how the changes will effect in their flexibility and ease of performing activities of daily living (ADLs). Moreover, sacral stress fractures below the S1 screws can occur in patients with osteoporotic bone, thus fusing to the pelvis is recommended for most patients undergoing long fusions to the sacrum. Fusion to the pelvis usually produces more functional limitation than fusion to the sacrum, because flexion can only occur at the hips after this procedure. Patients should be informed that long fusion to the pelvis may alter their gait and can decrease sexual satisfaction for women, because they can no longer tilt the pelvis. Moreover, patients fused from above L2 down to the pelvis may have difficulty with personal hygiene, because flexion of the thoracolumbar, lumbar, and lumbosacral spine is no longer possible, thus limiting their reach. Cleaning aids that extend the patient's reach and bidet toilets can help patients who may have difficulty with personal hygiene.

When fusing to the pelvis, several technique considerations should be addressed. Some surgeons have reported implant prominence necessitating implant removal in up to 50% of patients with iliac bolts.[22,23] Emami and colleagues[24] reported a pseudarthrosis rate of 14% in patients undergoing pelvic fixation compared with 8.5% for patients undergoing sacral fixation alone, even with the use of interbody grafts. Nevertheless, placing lordotic interbody grafts at L4–L5 and L5–S1 decreases strain on the posterior instrumentation, improves sagittal alignment, and promotes fusion at these levels. Using bolts with slotted connectors, rather than polyaxial screws with side connectors, may provide improved control of the pelvis; it is also less likely to fail in flexion as a result, compared with top-loading polyaxial screws. The bolts should be inserted past the center of rotation of the pelvis, with lengths typically measuring 85 mm to 105 mm. Finally, removing a U-shaped section of bone inferior to the posterior superior iliac spine allows placement of the implant below the highest point of the posterior superior iliac spine, which decreases the likelihood of prominent, symptomatic iliac screws.

SAGITTAL ALIGNMENT

Sagittal balance is of the utmost importance, because it has been shown to correlate with adverse health status outcomes and increased pain and disability.[25-27] Silva and Lenke[18] eloquently outline their approach to ensure that sagittal balance is restored or maintained. Our recommendation centers around measuring the lumbar, thoracolumbar, and thoracic alignment on the lateral full-length radiograph. The degree of correction required at each region can then be calculated using the 0/30/60 degree rule in combination with the PI to help determine the type and number of osteotomies or corpectomies required to correct or prevent sagittal imbalance. For example, if the patient has a lumbar lordosis of 40 degrees, thoracolumbar kyphosis of 10 degrees, thoracic kyphosis of 40 degrees, and a PI of 60 degrees, we can calculate that the patient requires 20 degrees of additional lumbar lordosis to reach 60 degrees of lordosis, 10 degrees of lordotic correction in the thoracolumbar spine to reach 0 degrees, and 10 degrees correction of kyphosis in the thoracic spine to correct 40 degrees of kyphosis to 30 degrees of kyphosis. The PI is measured to ensure that the lumbar lordosis is neither overcorrected or undercorrected. Thus if the PI measures 50 to 70 degrees, correcting the lumbar lordosis to 60 degrees (LL = PI ± 9 degrees) should result in a balanced sagittal alignment, as long as the thoracolumbar and lumbar corrections are made. However, if the PI measured 35 degrees, the LL should not be corrected beyond 45 degrees. In general, increasing the lumbar lordosis by the value of the PI minus the LL provides satisfactory correction of the kyphotic deformity in the lumbar spine. The thoracolumbar alignment should be corrected to 0 degrees and the thoracic spine should be corrected to 30 degrees.

The number and types of osteotomies are then planned once the degree of correction within the thoracic, thoracolumbar, and lumbar spine has been calculated. In our experience, wide posterior releases with aggressive lumbar facetectomies (Ponte or Smith-Peterson osteotomies) can provide 3 to 5 degrees of lordosis if the patient has unfused disks.[28] Resection of the superior and inferior articular facets bilaterally, the inferior portion of the cephalad spinous process, and a portion of the inferior lamina of the cephalad vertebra and the superior lamina of the caudal vertebra, and the superior aspect of the caudal spinous process increases mobilization of the motion segment. The amount of correction obtained is approximately 1 degree per millimeter of bony resection. Correction relies on a mobile intervertebral disk, which may no longer be present if enough deformity and degeneration has occurred.

A greater degree of correction can be achieved if lordotic interbody grafting is placed anteriorly or posteriorly. Aggressive lumbar posterior releases combined with lordotic anterior interbody cages or grafts can reliably provide 10 to 15 degrees of correction per motion segment. Transforaminal and posterior lumbar interbody fusions with lordotic interbody cages or grafts can also improve the amount of lordosis obtained, compared with aggressive posterior releases alone. However, these constructs do not appear to reliably create as much lordosis as placement of anterior lordotic grafts combined with aggressive posterior osteotomies. Anterior and posterior lordosis correction is ideally performed at the

L4–L5 and L5–S1 level, because two thirds of the lordosis (~40 degrees) within the lumbar spine arises from L4–S1. The primary emphasis on correction is placed at the L5–S1 level, because two thirds of the lordosis between L4 and S1 (~25 degrees) normally originates from the L5–S1 level. Transverse osteotomies at the thoracolumbar junction reliably provide 1 to 3 degrees of correction of sagittal malalignment. The addition of lordotic interbody cages placed through less invasive lateral approaches in combination with transverse osteotomies can reliably provide 5 to 7 degrees of sagittal correction per level. Transverse osteotomies in the thoracic spine provide 1 to 2 degrees of correction. If transverse osteotomies will not properly correct the regional alignment, with or without interbody reconstruction, more aggressive osteotomies—pedicle subtraction osteotomies (PSOs), corpectomies, decancellation, or posterior vertebral column resection—may be required. PSOs can provide 20 to 30 degrees of correction and are ideally used for patients with previous anterior and posterior spinal fusions. Patients with posterior-only fusions can also benefit from a standard PSO or a one that involves removal of the adjacent disk. Removal of the pedicle and adjacent disk reliably provides 30 degrees of correction. PSOs through unfused segments should be combined with interbody fusion above and below the osteotomy to decrease the likelihood of pseudarthrosis. Bridwell and colleagues[29] and Berven and colleagues[30] obtained an average correction of 34.5 and 29.9 degrees in lordosis, respectively, after performing PSOs. Bridwell noted a 13.5 cm improvement in the C7 plumb line, and Berven reported a 9.1 cm improvement at final follow-up. Although a large degree of correction is obtainable with a PSO, the correction is quite abrupt and angular, which does not provide the ideal sagittal contour to the spine. Additionally, performing a PSO devascularizes the lateral aspect of the vertebral body and requires complete removal of the posterior elements, which in turn probably increases the likelihood of pseudarthrosis compared with multilevel anterior interbody fusion combined with aggressive posterior releases.

Corpectomy and decancellation procedures combined with aggressive posterior releases are used for patients who require over 40 degrees of correction.[31] Thorough diskectomies above and below the vertebral body that include removal of the anterior longitudinal ligament are performed. The lateral aspect of the vertebral body is then removed, maintaining a shell of bone anteriorly, laterally, and posteriorly. A strut graft, cage, or morcellized bone is then placed within this shell of bone. Posterior instrumentation, wide laminectomies, and transverse osteotomies are performed in conjunction with the corpectomy or decancellation to further mobilize the spinal column. Posterior vertebral column resections can also provide over 40 degrees of correction, but this technique is reserved for patients with acute angular deformities, because this procedure necessitates complete removal of the posterior elements and predisposes patients to pseudarthrosis. Vertebral column reconstruction has proven to be a powerful correction tool, especially for patients with rigid deformities.[32-34]

The amount of sagittal correction achievable can be estimated by obtaining intraoperative lateral radiographs of the lumbar spine to visualize the lateral sagittal vertical line (LSVL) drawn from the posterior aspect of the S1 body. This line ideally bisects the T12–L1 disk. If the LSVL remains posterior to the midpoint of the T12–L1 disk, more lordosis may be required to ensure proper correction of the sagittal alignment.

Figures 63-4 through 63-8 illustrate the measurements, preoperative planning, and surgical correction obtained when following these principles.

STAGING

Performing the procedure under one anesthesia has been shown to result in less expense, shorter hospital stays, less nutritional depletion, and a lower infection rate.[35] However, this often necessitates a very long operative procedure, which may be poorly tolerated by the patient. The procedure should be staged if prolonged surgery is anticipated, and each stage should be kept as short as possible. Parenteral nutritional supplementation can be used between stages, and Lapp and colleagues[36] suggest that this strategy helped patients achieve normal levels of nutritional markers, including pre-albumin, albumin, absolute lymphocyte count, transferrin, and total protein in patients undergoing staged surgery, which theoretically facilitates healing following the second stage of the surgery.

With staged procedures, a period of relative immobility ensues, and with it comes the risk of development of DVT

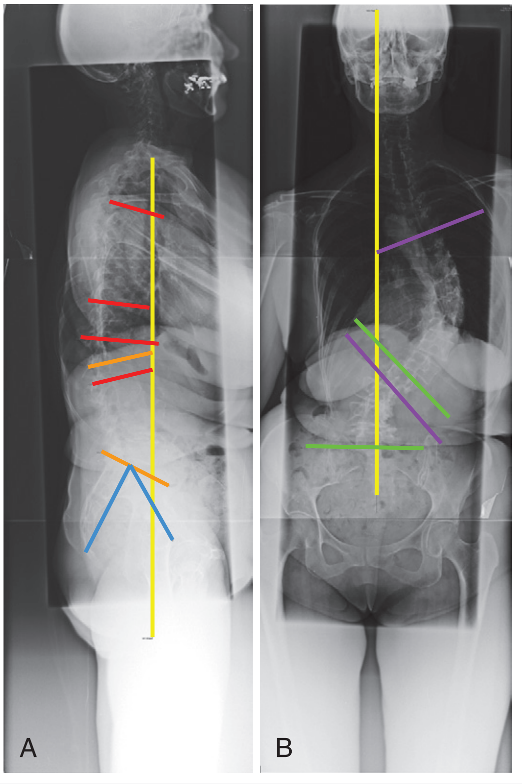

Figure 63-5 Preoperative standing anteroposterior (**A**) and lateral (**B**) radiographs demonstrate a lumbar lordosis (LL) measuring 38 degrees (*orange*), which is less than the pelvic incidence (PI) of 57 degrees (*blue*). Ideally, these should be between 66 ± 9 degrees (LL = PI + 9 ± 9 degrees). A 20 degree thoracolumbar kyphosis (*maroon*) is also present, and the patient is hypokyphotic at 11 degrees (*red*). She is coronally imbalanced by approximately 2.5 cm and has a right-sided thoracic scoliosis measuring 73 degrees (*purple*) and a lumbar scoliosis measuring 46 degrees (*green*).

Figure 63-6 Standing lateral radiograph after stage 1 involving an anterior lumbar interbody fusion at L5–S1 and lateral interbodies at L3–L4 and L4–L5. Lumbar lordosis improved by 17 degrees.

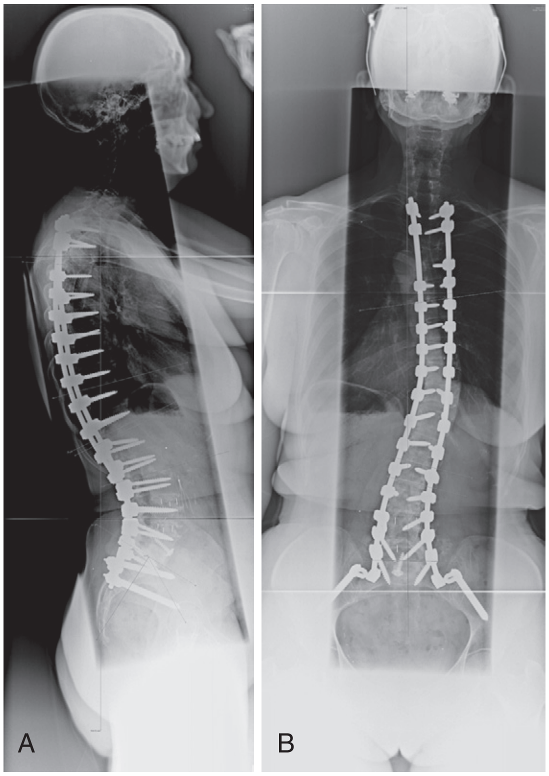

Figure 63-7 Postoperative standing lateral (**A**) and anteroposterior (**B**) radiographs. The second-stage procedure consisted of a posterior instrumentation and fusion from T2 to the pelvis with multiple Smith-Peterson osteotomies.

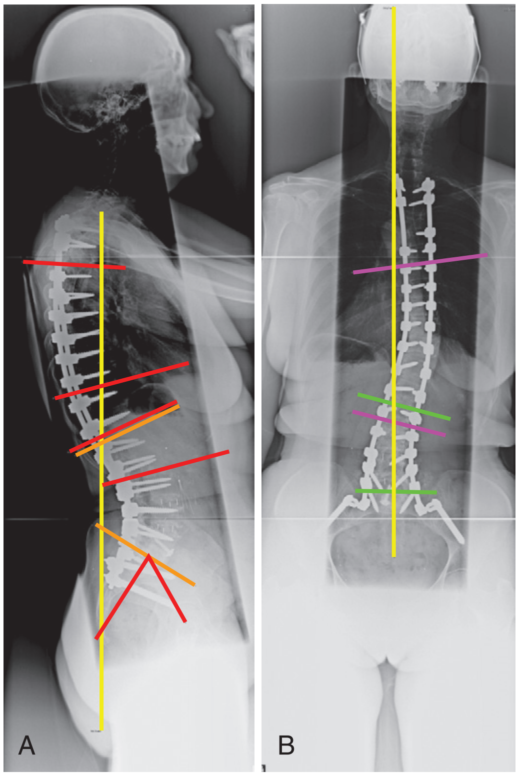

Figure 63-8 Postoperative lateral (**A**) and anteroposterior (**B**) radiographs show improvement in balance and sagittal parameters. The C7 plumb line now falls posteriorly to the posterosuperior end plate of S1. The thoracolumbar kyphosis has been corrected to 1 degree (*maroon*), the thoracic kyphosis now measures 28 degrees (*red*), and the lumbar lordosis equals the lumbar lordosis at 57 degrees (*orange*), almost perfectly matching the 0/30/60 rule. The thoracic scoliosis has been corrected to 22 degrees (*purple*), and the lumbar scoliosis now measures approximately 13 degrees (*green*). Coronal imbalance is now less than 2 cm.

or PE. The long-standing protocol for spine surgery has been mechanical prophylaxis with sequential compression devices during and after surgery with early patient ambulation. However, a recent increase in interest has erupted regarding the use of chemoprophylaxis. Schizas and colleagues[37] reported on the use of low–molecular-weight heparin (LMWH) given to patients 8 hours after surgery until their discharge. They found a 2.5% incidence of PE in patients undergoing fusion operations, the same as reported in a study by Dearborn in which patients using only compression stockings and sequential compression devices (SCDs) were monitored for PE without the use of chemical prophylaxis. However, they had two patients who required emergent evacuation of postoperative hematomas. Glotzbecker and colleagues[38] performed a systematic review of DVT prevalence in the elective spine surgery population and found that the use of compression stockings and SCDs had an incidence of 1.3%, whereas chemoprophylaxis was reported at 0.6%. The same authors also reported on rates of epidural hematoma following spinal surgery, with and without chemoprophylaxis. They found the reported rates to be up to 1% in both groups. Ideally, the risk/benefit ratio of chemoprophylaxis is discussed with each patient to enhance informed decision making by the patient.

OUR PREFERENCES

Most of our patients with adult scoliosis are treated with an aggressive nonoperative treatment program. If this fails to control their symptoms, we prefer staged anterior interbody reconstructions with anterior lumbar interbody fusion (ALIFs) at L5–S1 and L4–L5 with the occasional use of lateral interbody cages at levels above L4–L5. If an ALIF at L5–S1 is not required, a transpsoas lateral interbody cage reconstruction can be attempted at L4–L5. However, up to 20% of the time, the overlying lumbar plexus impedes the ability to safely place the cage at this level. Placing multilevel interbody implants releases the annulus and allows greater correction posteriorly. When coupled with multilevel transverse osteotomies, approximately 40 degrees of harmonious correction can be appreciated. A corpectomy or decancellation procedure is utilized if more than 40 degrees of correction is required. PSOs are used for patients with previous anterior and posterior fusions, and vertebral column resections are used for patients with acute angular deformities.

Aggressive posterior releases with facetectomies are performed during the posterior part of the procedure. The rods are contoured to fit the ideal sagittal contour based on our preoperative measurements, ensuring that the thoracolumbar junction (T10–L2) is straight whenever possible. After correction of the curve, decortication with removal of the spinous processes with a Leksell rongeur followed by removal of the outer cortex of the lamina with a curved half-inch osteotome is performed. A burr is used to decorticate the facets at each level, as well as the transverse processes and sacral ala if fusing the lumbar and sacral spine. Placing bone graft across the transverse processes and sacral ala prior to placing the instrumentation may increase the likelihood of fusion. Local bone graft mixed with cancellous allograft granules is placed over the decorticated posterior elements.

The procedures are staged if the total anesthesia time is expected to be longer than 6 hours and an anterior or lateral procedure is needed in conjunction with the posterior surgery. If a corpectomy is planned, the posterior instrumentation and posterior osteotomies can be performed on the first day, followed by a staged corpectomy with simultaneous or sequential posterior spinal fusion and instrumentation. If the placement of multiple anterior or lateral interbody devices are planned, these procedures can be done on the first day followed by a staged posterior fusion and instrumentation. The patients are kept on mechanical DVT prophylaxis and are instructed on in-bed exercises. Lower extremity duplex ultrasounds can be obtained prior to returning to the operating room (OR). If DVT is evident, a vena cava filter is placed. However, even with negative ultrasound screening, intrapelvic DVT may be present, so a high index of suspicion should be maintained.[39]

The second stage of the procedure is performed four to seven days after the first stage. For long cases with extensive blood loss and fluid resuscitation, hemodynamic instability and airway problems can easily occur, so close observation by a critical care team should be considered.

The patient is mobilized on the first postoperative day with the help of physical therapists. Patients should be repositioned every 2 hours to prevent breakdown of the skin, both over the wound and over bony prominences. Avoidance of supine positioning decreases direct pressure on the wound, but prolonged sitting is discouraged for patients fused at the sacrum and pelvis to minimize stress placed on the instrumentation. A brace is not needed in most cases; they are bulky and restrictive and may actually slow down a patient's rehabilitation, although patients with poor bone quality or suboptimal fixation are occasionally placed in braces. If the patient has severe osteoporosis despite preoperative bisphosphonate or Forteo use, a prolonged period of bed rest until the fusion has begun to heal may prevent instrumentation failures. Marco and colleagues[40] recently reported on a series of patients with suboptimal fixation as a result of either poor bone quality or lack of segmental fixation who were treated with prolonged bed rest following reconstructive spine surgery with instrumentation. These authors found acceptably low complication rates with no need for revision surgery.

Afterward, patients are followed at 2 weeks, 6 weeks, 3 months, 6 months, 1 year, and 2 years with repeat x-rays. They should progress with their exercising and should be able to walk at least a mile each day by 6 weeks. Bending, lifting over 10 pounds, and twisting are discouraged for 3 months. Figures 63-9 through 63-12 present a patient treated using the principles outlined above.

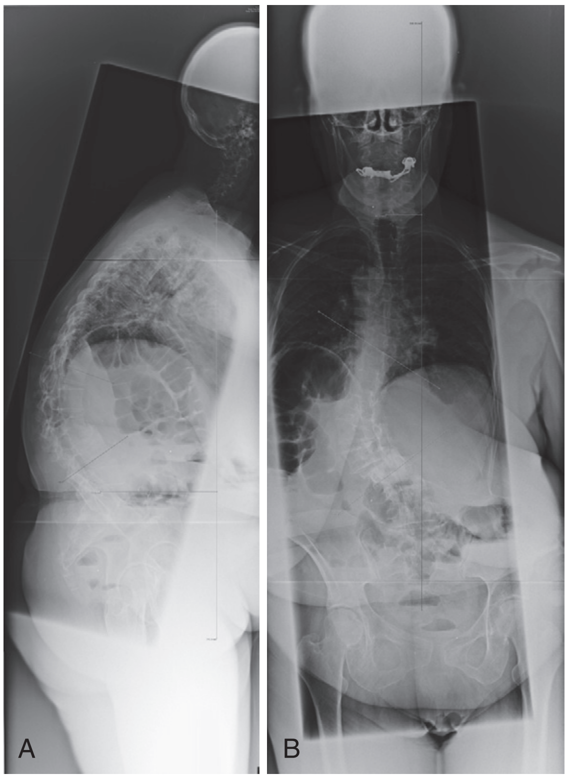

Figure 63-9 Preoperative standing lateral (**A**) and anteroposterior (**B**) radiographs show significant sagittal and coronal imbalance.

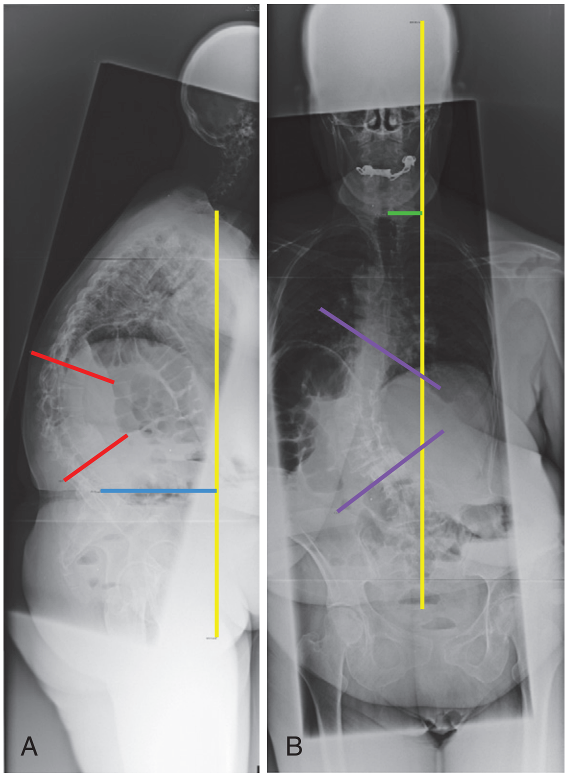

Figure 63-10 Preoperative standing lateral (**A**) and anteroposterior (**B**) radiographs show a marked thoracolumbar kyphosis of 55 degrees (*maroon*) and severe positive sagittal imbalance measuring approximately 16 cm (*blue*). Patient has a 70 degree left thoracolumbar degenerative scoliosis (*purple*) with several levels of lateral listhesis with an approximate 4.7 cm shift to the left (*green*).

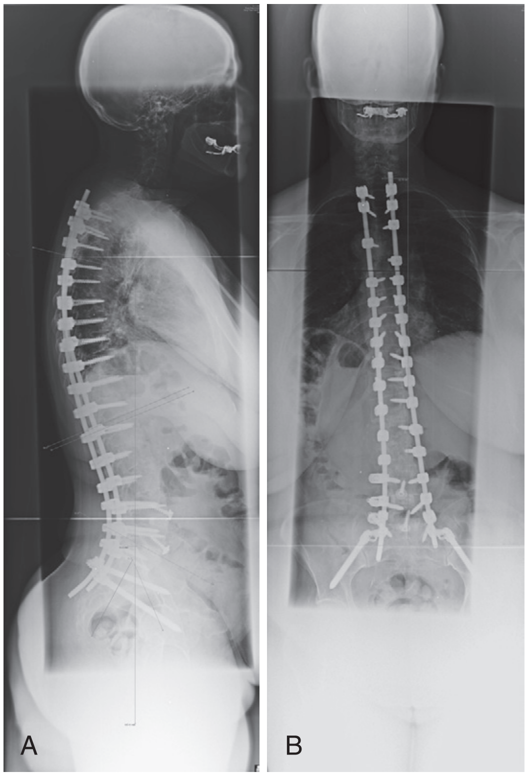

Figure 63-11 **A** and **B**, Postoperative standing radiographs demonstrate improved balance.

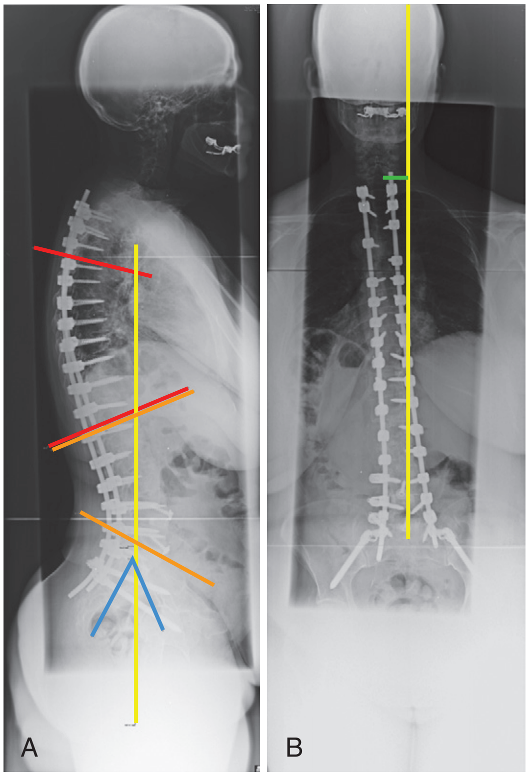

Figure 63-12 **A** and **B**, Postoperative standing lateral and anteroposterior (AP) radiographs following a two-stage operation that involved decancellation procedures at L2 and L3, lateral interbody placement at L2–L3, and ALIFs at L4–L5 and L5–S1 followed by a thoracic 2 to the pelvis posterior spinal fusion and instrumentations with multiple Smith-Peterson osteotomies. Patient had dramatic improvement of the sagittal contour of her spine and now is sagittally positive by only 1 cm (*blue*). Her thoracolumbar junction is now neutral, lumbar lordosis measures 51 degrees (*orange*), the pelvic incidence measures 52 degrees (*blue*), and thoracic kyphosis is 36 degrees (*red*). Patient fits into the 0/30/60 rule, and her lumbar lordosis now equals her pelvic incidence.

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SECTION G

Spinal Tumors and Vascular Lesions

64 Primary Malignant and Benign Tumors of the Spine

RIPUL R. PANCHAL, ERIC O. KLINEBERG, and KEE D. KIM

Overview

Spinal tumors are generally categorized by location, and they fall into three anatomic groups: 1) extradural, 2) intradural-extramedullary, and 3) intramedullary.[1,2] Primary malignant and benign tumors are typically extradural lesions. Compared with metastatic lesions of the spine, these tumors are rare and comprise less than 10% of spinal column tumors (Table 64-1).[3-7] These tumors may be found in both pediatric patients and adults. The initial age at presentation correlates to the aggressiveness of the tumor: the older the patient, the more likely the lesion is to be malignant (mean age at diagnosis is 21 years for a benign lesion and 49 years for a malignant lesion).[8,9] In patients older than 21 years who are diagnosed with primary spinal tumors, 70% of the lesions are identified as malignant.[8] Therefore primary tumors diagnosed in patients over the age of 30 should be considered malignant until proven otherwise.[10,11]

Presentation

Primary tumors of the spine often have a variety of subtle and nonspecific symptoms because of to the insidious nature of the disease.[3] However, pain is present in nearly 85% of patients on initial evaluation.[9] The hallmarks of destructive lesions of the vertebral column, both primary and secondary metastatic lesions, are nocturnal pain and pain related to recumbency.[7] A high index of suspicion must be maintained for patients with non–weight-dependent pain. Pain, as well as neurologic symptoms that include weakness and bowel and/or bladder dysfunction, may result from pathologic fracture, tumor vascular engorgement, or periosteal stretching leading to neural compromise. Rarely, patients present with point tenderness over a particular dermatomal segment that can aid in diagnosis. On physical exam, 55% of the patients with malignancy and 35% with benign primary spinal lesions will have neurologic deficits.[7] Occasionally, a palpable mass or spinal deformity may be identified.

Evaluation

Clinicians should have a higher suspicion for neoplastic etiology when patients come to medical attention with nocturnal pain, pain at rest that has persisted for more than 3 months, or progressive neurologic deficits; any of these should prompt an initial radiographic evaluation. Plain radiographs of the appropriate location, both anteroposterior (AP) and lateral views, can help identify the spinal lesion. However, 30% to 50% of the vertebral trabeculated bone must be resorbed before a lytic lesion can be detected.[12] Computed tomography (CT) and magnetic resonance imaging (MRI), both with and without contrast, can be used to help identify the exact location, characteristics, and extension of the lesion. CT reveals the extent of the bony destruction, and MRI identifies the soft tissue and neural involvement. Other imaging techniques—such as arteriography, bone scan, CT myelography, and positron emission tomography (PET)—may help better characterize the tumor and distant metastatic lesions. Laboratory studies should include complete blood count, comprehensive metabolic panel, and urinalysis.

To rule out more common metastatic pathology, initial evaluation should consist of a CT scan of the chest, abdomen, and pelvis with and without contrast; nuclear scans; and MRI of the neural axis (brain through sacrum). Laboratory tests should include serum calcium levels, prostate-specific antigen, alkaline phosphatase, carcinoembryonic antigen, and serum and urine protein electrophoresis.

Management

The presenting neurologic deficits and the nature of the lesion as revealed by imaging studies play an integral role in determining the management of the spinal tumor.[3] A biopsy of the lesion must be performed prior to attempting resection (Fig. 64-1). When a lesion is found posteriorly, excisional biopsy may be considered, but the default should be an incisional or needle biopsy for presurgical diagnosis.[13] For the thoracic or lumbar spine, a transpedicular needle biopsy with fluoroscopy or CT provides accuracy over 95% and has a complication rate of 0.2% to 0.7%.[14,15]

An interdisciplinary approach should be adopted and must include the oncologist, radiation specialist, interventional radiologist, pathologist, and spinal surgeon for the appropriate management of these tumors.[3] The location, histology, and presenting clinical features of the lesion determine the surgical and other nonsurgical modalities used for treatment.[3,6] More importantly, the wishes of patients and their families should also be respected, and their expectations should coincide with those of the physician.

With progressive neurologic deficits, early surgical intervention should be considered, and the need for

Table 64-1 Common Primary Malignant and Benign Spinal Tumors Organized in Order of Incidence[5-7]

PRIMARY MALIGNANT TUMORS
Multiple myeloma/plasmacytoma (most common)
Ewing sarcoma (most common in pediatrics)
Chondrosarcoma
Osteosarcoma
Chordoma*
PRIMARY BENIGN TUMORS
Hemangioma (most common)
Osteoid osteoma/osteoblastoma
Giant cell tumor*
Chondroma/enchondroma/osteochondroma
Aneurysmal bone cyst

*Locally aggressive

Figure 64-1 Percutaneous biopsy of chordoma guided by computed tomography.

instrumentation should be anticipated if there is significant bony destruction, or if significant bone resection is required that may lead to iatrogenic instability. The goal of surgery varies with the specifics of the tumor pathology and the stage of the lesion (e.g., metastatic lesions).[3] Preoperative endovascular embolization of the lesion may assist with the resection by limiting blood loss, especially in highly vascular lesions, such as renal cell carcinoma. Radiotherapy and chemotherapy may also play a role in both preoperative and postoperative management.

To develop the optimal treatment regimen for a particular lesion, the understanding of the anatomic and cytologic characteristics and subtleties of these tumors is necessary.[5] Numbers of scoring systems have been developed to assist with surgical decision making and related prognosis and complications. These include Harrington classification,[16] Modified Bauer score,[17] Tomita scoring system,[18] modified Tokuhashi scoring system,[19] Van der Linden score,[20] Spine Instability Neoplastic Scoring (SINS) system,[21] and the "LMNOP" system (see Chapter 65, Tables 65-2 to 65-5, for modified Tokuhashi, Tomita, SINS, and LMNOP systems).[22] Sioutos et al identified the preoperative neurological status, anatomic site for primary carcinoma, and number of vertebral bodies involved as poor prognostic indicators, and radical resection is not recommended for patients with spinal metastases and cord compression if two or more of these factors are present.

To anticipate the utility of an en bloc resection of spinal lesions, many surgeons describe the tumor using the Weinstein-Boriani-Biagini (WBB) staging system (Fig. 64-2).[23] Prior to WBB surgical staging, the final tumor diagnosis must be known. The WWB system divides the vertebrae and adjacent soft tissue into twelve zones and five concentric layers. This allows the surgeon to determine the approach or combination of approaches for the en bloc resection: vertebrectomy comprises zones 4 through 8 and 5 through 9; sagittal resection, zones 3 through 5 and 8 through 10; or resection of the posterior arch based on the

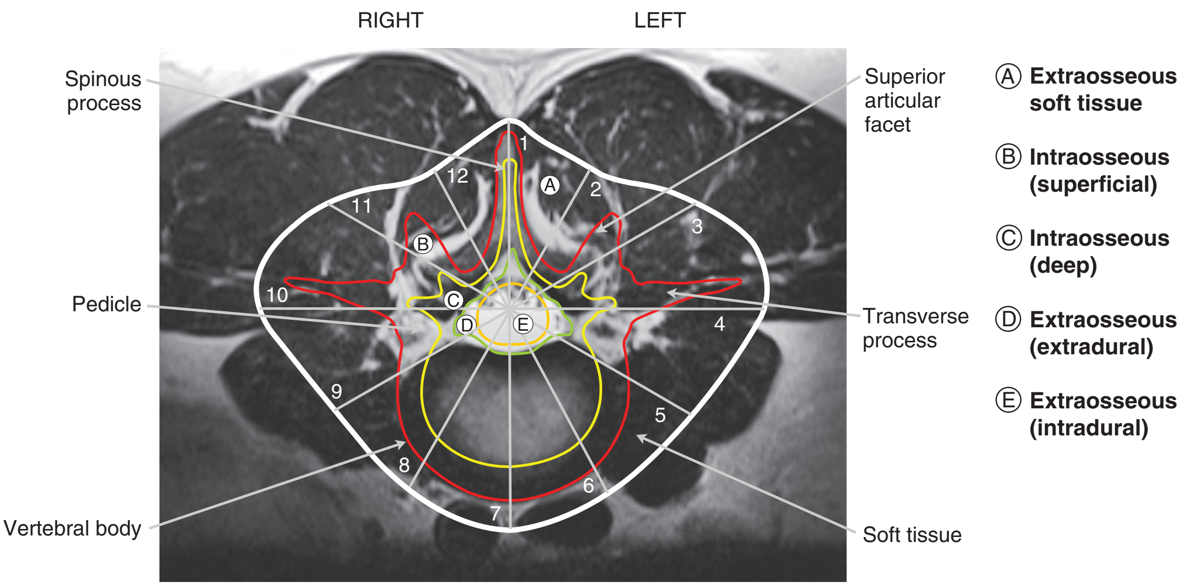

Figure 64-2 Weinstein-Boriani-Biagini system[23] for spinal tumor surgical staging for en bloc resection planning. (Illustrated by Avani R. Pavasia.)

zones, specifically, zones 3 through 10, counterclockwise. This also allows the surgeon to anticipate which lesions may not be amenable to complete en bloc resection. Weinstein and colleagues believe that determination of the tumor location in the wedge sectors helps preserve vital structures and maximize the tumor resection with appropriate margins.

Malignant Tumors

MULTIPLE MYELOMA AND PLASMACYTOMA

Plasmacytoma and multiple myeloma are the most common primary malignant tumors of the vertebral column. Kelley and colleagues[24] reported a 42-year survey from a tumor registry that noted that 26% of primary vertebral tumors were plasmacytoma or multiple myeloma. Plasmacytoma is a solitary lesion limited to one or two foci, whereas multiple myeloma is a more systemic disease.[25,26] Both are B-cell lymphoproliferative diseases with a male/female 2 : 1 predominance and a peak age of 55 years old.[27] These lesions have a propensity for the posterior elements of the vertebral body and are most commonly found in the thoracic spine.[28-30]

Initial evaluation should include diagnostic radiography, CT, and MRI of the spinal axis. Plain radiographs illustrate the degree of osteolysis or "punched out" radiolucent areas.[26] CT and MRI will help determine bony destruction and soft-tissue compression of the neural elements, respectively (Fig. 64-3). Serum and urine immunoelectrophoresis may show abnormal Bence-Jones proteins, which will aid in the diagnosis of the disease.[5]

When neural compromise or spinal instability is evident, surgical intervention may include decompression and/or instrumentation. Vertebroplasty and kyphoplasty are reserved for pathologic compression fractures with intractable pain, without neurologic compression, and with competence of the posterior vertebral body, to prevent cement extravasation. However, radiation and medication are the initial treatment of choice.[31] In myeloma patients, increased osteoclastic activity and inhibition of osteoblasts results in increased bone resorption and decreased bone formation. Bisphosphonates, such as pamidronate or zoledronic acid, are currently the standard of care to inhibit bone resorption.[32,33] However, bone anabolic agents such as bortezomib may be used as therapeutic agents to target osteoblasts, reduce tumor burden, and improve bone health. Chemotherapy and bone marrow transplantation are used for more systemic disease.

Solitary plasmacytoma has a 5-year disease-free survival of approximately 60% with radiation treatment with or without surgical resection.[34] However, these lesions will progress to multiple myeloma in 55% to 60% within 5 years, and untreated multiple myeloma has median survival of only 6 months.[35]

EWING SARCOMA

Ewing sarcoma was first described in 1921 by Sir James Ewing. It is the most common malignant primary spinal tumor of childhood[36] and has a male predominance with peak incidence in the second decade.[37] The most common site of occurrence is the sacrum.[38]

Laboratory studies include alkaline phosphatase and lactic dehydrogenase levels. On imaging studies, an eroded vertebral body or "moth-eaten" lesion with a large, pathognomonic paraspinal soft-tissue mass is typically seen. Neurologic compromise will be evident in 58% to 64% of patients.[39-41] MRI of these tumors tends to enhance with contrast because of the vascularity of the lesion. Additional

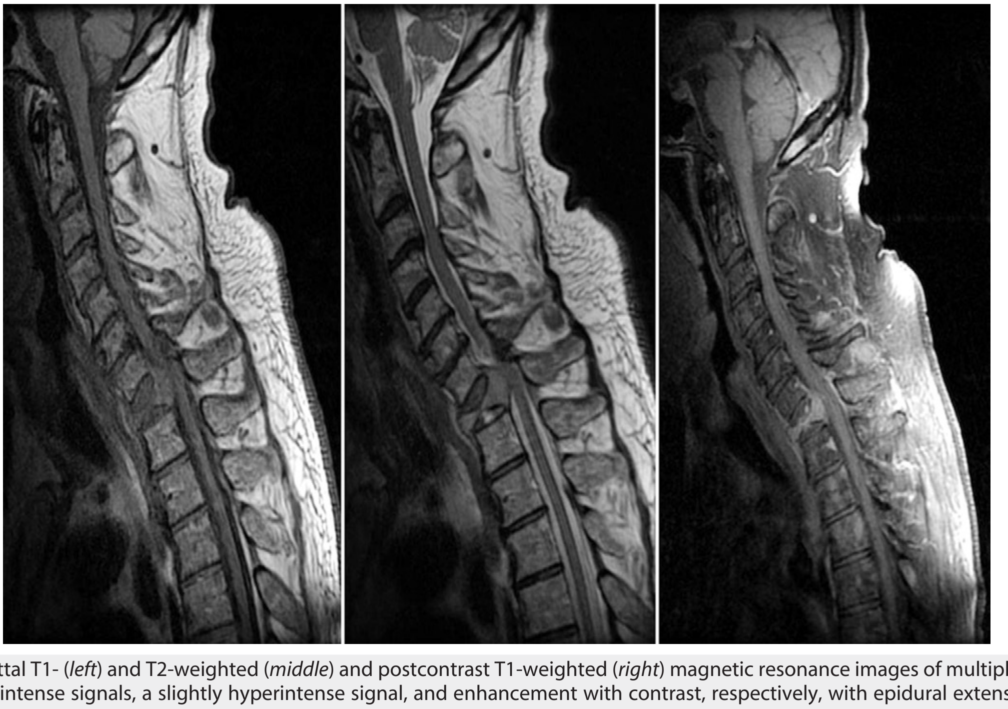

Figure 64-3 Sagittal T1- (*left*) and T2-weighted (*middle*) and postcontrast T1-weighted (*right*) magnetic resonance images of multiple myeloma show hypointense to isointense signals, a slightly hyperintense signal, and enhancement with contrast, respectively, with epidural extension compressing the spinal cord.

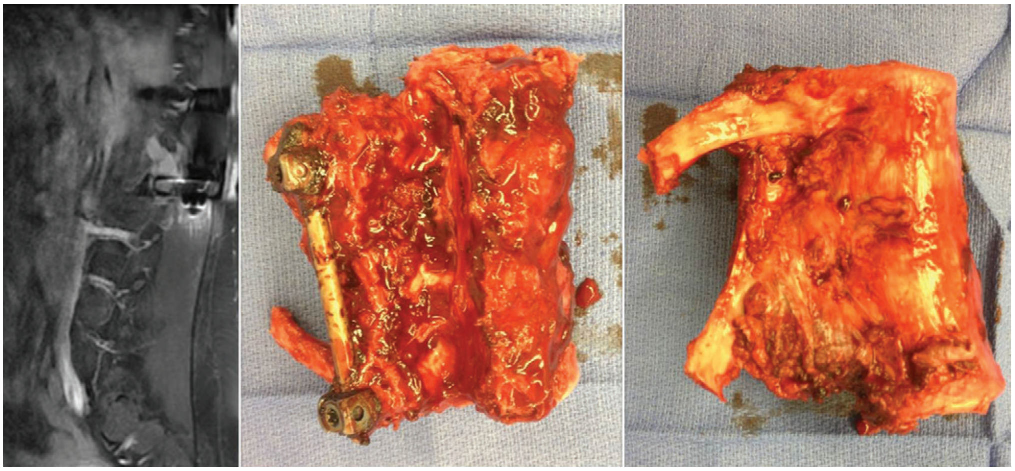

Figure 64-4 Sagittal MRI with contrast of recurrent Ewing sarcoma at T11–L1 (*left*) and en bloc resection of the tumor (*middle* and *right*).

studies should include technetium bone scan, full-body CT, or positron emission tomography (PET) scan to evaluate for metastatic lesions.

Neoadjuvant chemotherapy is as critical as the tumor's response to the therapy.[36,42] Surgical excision should be considered, followed by chemotherapy and potentially radiation therapy in certain cases.[40] A recent study by Boriani and colleagues concluded that wide en bloc resection leads to better local control and longer survival (Fig. 64-4).[43] With a combination of aggressive chemotherapy and surgical resection, the 5 year survival rate approaches 60%.[44]

CHONDROSARCOMA

Chondrosarcomas arise from mesenchymal cells as primary malignant tumors or as a secondary transformation from osteochondromas.[7] They are the second most common primary vertebral column tumor of the non-myeloproliferative tumors, and they originate in the spine in about 12% of cases.[45] Middle-aged men in their fifth or sixth decades are affected twice as often as women and have a propensity for lesions in the thoracic spine.[46]

Radiographically, chondrosarcomas are expansive osteolytic lesions with diffuse, mottled "ring and arc" calcifications and associated soft-tissue mass as a result of the mix of chondroid (cartilage) and osteoid (bone).[26,47] Similar to chordomas, chondrosarcomas are both hypointense and hyperintense on T1- and T2-weighted MR images, respectively, but do not usually arise in midline locations.[26,45]

CT-guided biopsy will help determine the aggressiveness of the tumor, which is graded from 1 to 4 (most malignant).[48] Complete en bloc surgical resection offers the best survival; however, survival is primarily determined by tumor grade. The 5 year survivals for low- and high-grade chondrosarcoma are 65% to 85% and 15%, respectively.[48] Radiation therapy and chemotherapy are ineffective treatments.

OSTEOSARCOMA

Osteosarcoma originates from primitive bone-forming mesenchymal cells. It is the third most common primary spinal tumor and the most common primary bony tumor in young patients (first to third decade).[24,49] They may occur with increased frequency in patients with a history of Paget disease, trauma, or irradiated bone.[50,51]

On presentation, a palpable mass is often identified, and neurologic deficits are present in 70% to 80%.[26] In contrast to some of the other lesions, this tumor demonstrates osteoblastic changes, and primitive osteoid is seen on pathology. MR images display hypointensity and hyperintensity on T1- and T2-weighted images (Fig. 64-5).[52]

Historically, prognosis for osteosarcoma was poor, and the treatment of choice was wide en bloc resection. However, with advancements in adjuvant therapies and aggressive resection combined with neoadjuvant chemotherapy and radiation therapy, the prognosis has improved over the years (68% 5 year survival).[49]

CHORDOMA

Chordomas arise from the remnants of the notochord and are a locally aggressive but exceedingly rare tumor.[53] They constitute only 2% to 4% all primary malignant tumors and are more common in men; they typically occur in the fifth or sixth decade of life.[26] The most common tumor sites include the cranium, sacrum, and the rest of the spine, equally distributed in the Surveillance Epidemiology and End-Results (SEER) study.[53] Initial symptoms may include sensation of rectal fullness with large sacrococcygeal lesions in addition to spinal pain and potential for neurologic deficits from neural element compression.

Grossly this tumor is appears as a lobulated, gelatinous mass; on radiographs, it appears as a midline, destructive lytic lesion (Fig. 64-6).[52] A CT-guided biopsy should be performed for diagnosis (see Fig. 64-1). Under the microscope, these tumor cells have characteristic "soap bubble" or physaliphorous cells because of the vacuolated cytoplasm.[54] On MRI, the lesion usually has a low intensity on T1-weighted images, and it is hyperintense on T2-weighted images because of its high water content.[45] The contrast enhancement of this lesion varies (Fig. 64-7).

The ideal treatment for this tumor is en bloc excision without spillage of the tumor cells. Chordoma can metastasize in approximately 40% of patients,[55,56] and neoadjuvant radiation treatment is used for recurrence or

Figure 64-5 Sagittal T1- (*left*) and T2-weighted (*middle*) and postcontrast T1-weighted (*right*) magnetic resonance images of osteosarcoma with low intensity, hyperintensity, and enhancement of the tumor, respectively.

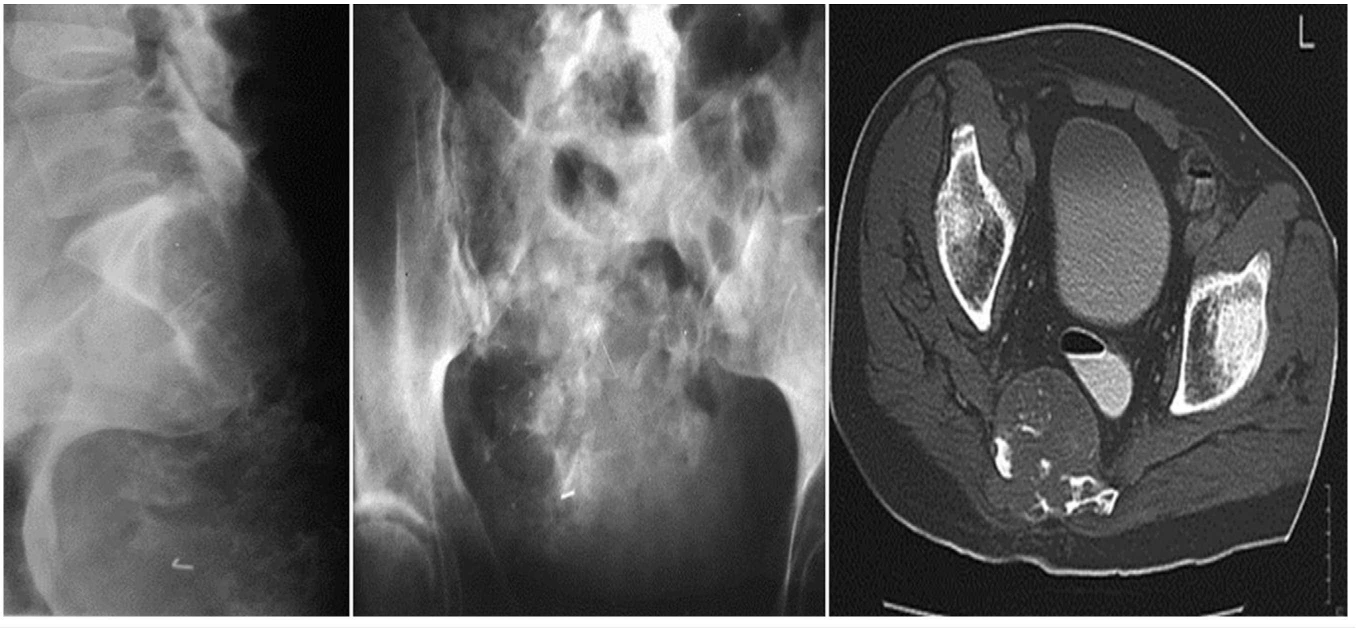

Figure 64-6 Lateral (*left*) and anterior-posterior radiographs (*middle*) and axial computed tomographic (*right*) illustrate a chordoma, a midline expansile lytic lesion with irregular borders. (Courtesy John C. Hunter, MD, University of California–Davis Medical Center, Sacramento.)

residual tumor.[29,30] The 5 and 10 year survival rates are 67.6% and 39.9%, respectively.[53]

Benign Tumors

HEMANGIOMA

Vertebral hemangiomas are the most common primary benign spinal tumors, and they affect approximately 10% to 12% of the population, as revealed in autopsy studies.[57] The incidence of these tumors increases with age, and they are more common in females.[58,59] Only 0.9% to 1.2% of these lesions are found to be symptomatic.[35]

Usually, hemangiomas are incidentally identified in the vertebral body on thoracolumbar imaging studies.[6] They originate from mature capillaries, cavernous veins, or veins that replace the normal bone marrow and create bony trabeculations.[60] Therefore, on plain radiographs, they have a honeycomb appearance, and on axial CT, they have a "polka dot" appearance.[52,61,62] Hyperintense signal is seen in both T1- and T2-weighted MR images (Fig. 64-8).

Asymptomatic hemangiomas should be observed,[6] although they can be treated with vertebroplasty, kyphoplasty, radiation therapy, or embolization when present

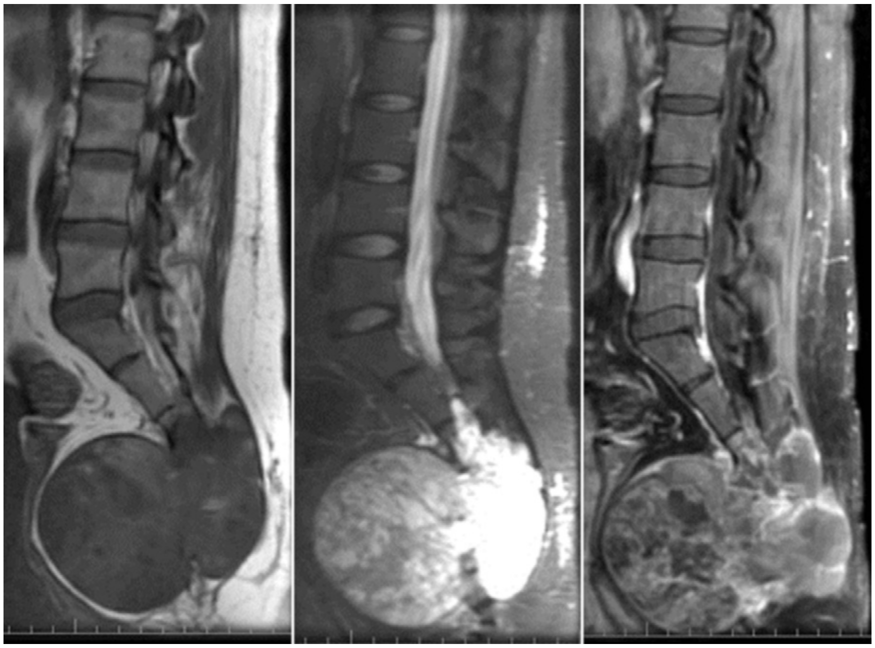

Figure 64-7 Sagittal T1- (*left*) and T2-weighted (*middle*) and postcontrast T1-weighted (*right*) magnetic resonance images of chordoma with low intensity, hyperintensity, and variable enhancement of the lesion, respectively. (Courtesy of John C. Hunter, MD, University of California–Davis Medical Center, Sacramento.)

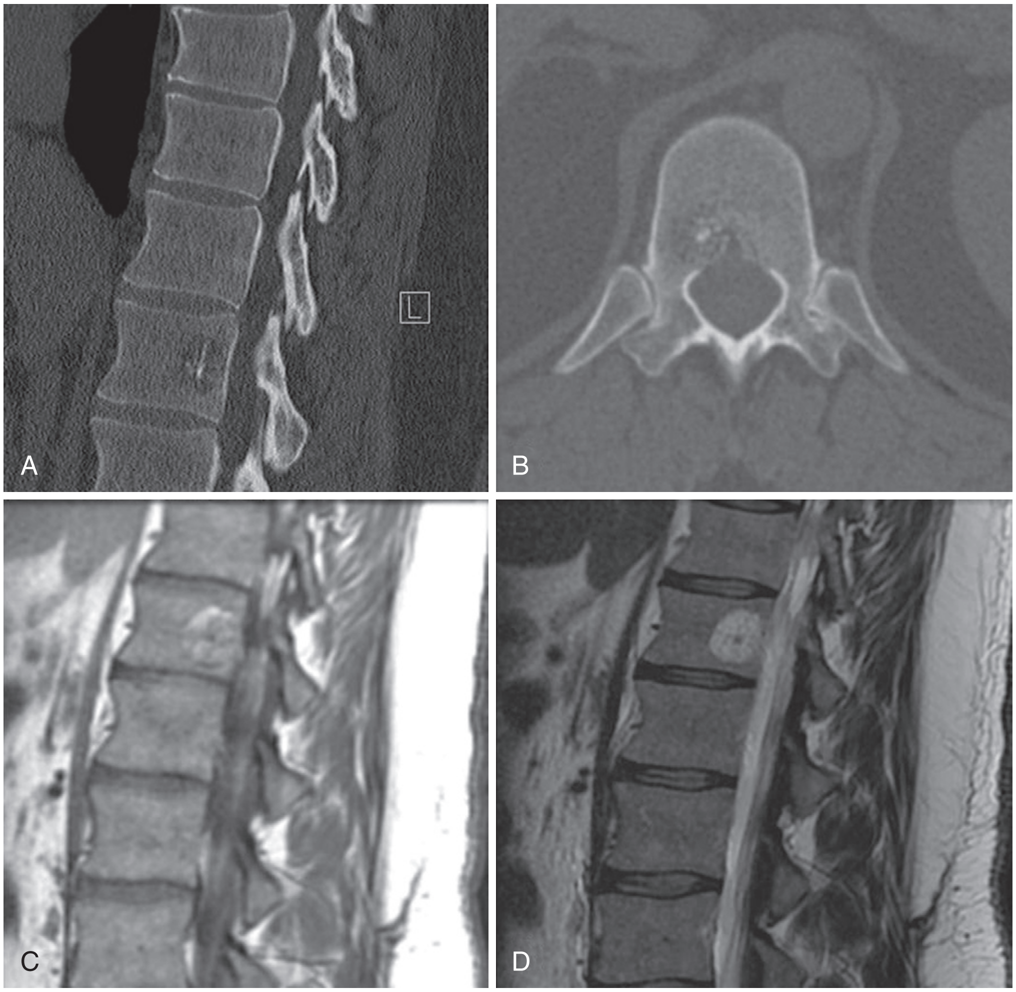

Figure 64-8 Sagittal (**A**) and axial (**B**) computed tomography scan of thoracic spine demonstrates bony trabeculations and "polka dot" sign of a hemangioma, respectively. Hyperintense signal in both T1- (**C**) and T2-weighted (**D**) sagittal MRIs of a hemangioma.

with pathologic fracture or pain (Fig. 64-9).[59,63,64] Surgical intervention that involves decompression with possible resection is advocated only for neural compression. Preoperative embolization and postoperative radiation therapy may prevent significant blood loss and recurrence.[65] Subtotal resection followed by radiation therapy has decreased the recurrence rate to 13% to 23%.[35] No known malignant transformation of hemangiomas has been reported.

OSTEOID OSTEOMA AND OSTEOBLASTOMA

Benign osteoblastic lesions of the bone are known as either *osteoid osteoma* or *osteoblastoma,* depending upon their size. Tumors less than 2 cm are referred to as *osteoid osteoma,* and lesions greater than 2 cm are called *osteoblastoma.* Histologically, these are similar lesions that arise from cancellous bone.[66] Osteoid osteoma is typically found in the long bones of children and adolescents, with less than 20% diagnosed as a spinal lesion, whereas osteoblastomas present in the second or third decade of life.[26,63] Osteoid osteoma is four times more common than osteoblastoma, and both are found to be more prevalent in males (2 to 3:1).[58,64]

Patients report nocturnal worsening of spinal pain, and neurologic deficits are usually worse in patients with osteoblastoma because of the size of the tumor causing neural compression. In contrast to many other tumors, osteoid osteomas have a propensity for the posterior elements and may present as pathologic scoliosis because of muscle spasm and pain.[67] CT, MRI, and technetium bone scan are useful to identify these lesions; bone scan is the most sensitive modality (Fig. 64-10).[68]

Osteoid osteoma may be a self-limiting lesion, and it can be initially treated with nonsteroidal antiinflammatory drugs (NSAIDs).[64,69,70] Other treatments include surgical curettage and radio frequency ablation (RFA).[71,72] CT-guided RFA of the tumor has been found to be a safe and effective treatment, and it is reported to provide pain relief in 78% to 97% of cases.[73,74] Patients with neural compression from osteoid osteoma or osteoblastoma should undergo surgical excision. Although an osteoid osteoma cure is possible with complete excision, osteoblastoma has a local recurrence rate of 10%.[63,75,76] Osteoblastomas may also undergo malignant transformation.[7] The role of radiation therapy for treatment of these lesions is controversial.[77]

GIANT CELL TUMORS

Giant cell tumors (GCTs), or osteo*clastomas*, are osteoclastic expansile lesions that arise from giant and spindle cells.[26]

Figure 64-9 Hemangioma treated with vertebroplasty.

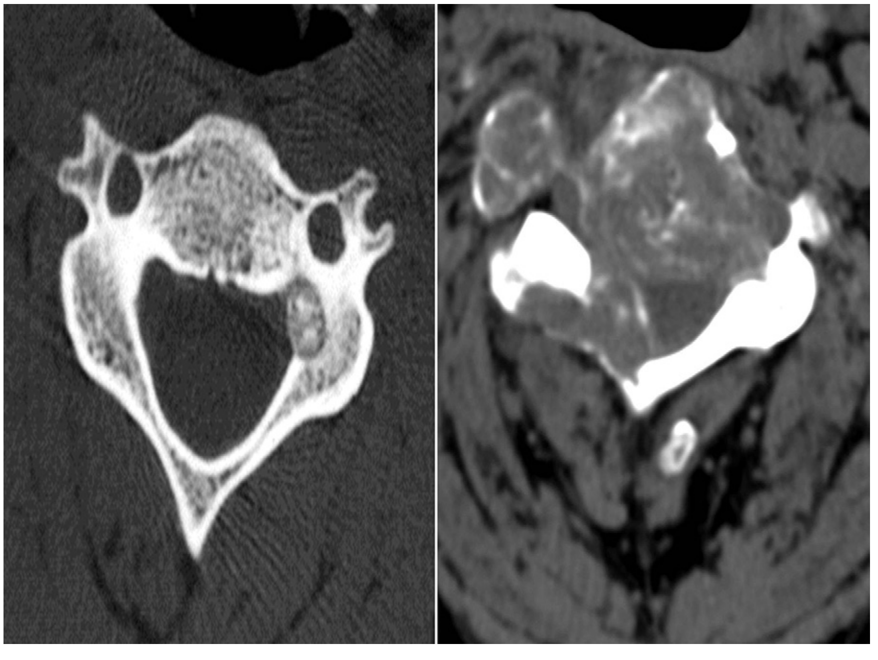

Figure 64-10 Axial cervical computed tomography (CT) (*left*) of osteoid osteoma, a lesion sharply demarcated from surrounding bone with a central nidus of thickened bone. Axial cervical CT (*right*) of osteoblastoma, an expansile lobulated lytic lesion. (Courtesy John C. Hunter, MD, University of California–Davis Medical Center, Sacramento.)

They are classified as benign lesions but are locally aggressive tumors,[26] and about 2.6% to 5% of these tumors metastasize, mostly to the lungs.[78,79] After chordomas, GCTs are the second most common spine tumor of the sacrum, but they account for less than 10% of primary spinal tumors.[5,45,80] More common in females than males, GCTs are typically found in young adults 20 to 40 years of age, after skeletal maturation.[81,82]

On CT imaging these tumors are characterized as "soap bubble" expansive osteolytic lesions with internal septations.[83] Their hypointense signal on T2-weighted MR images distinguish them from other primary sacral tumors.[81] Workup for these tumors should include a chest CT to evaluate for metastatic disease.

The treatment of GCT is aggressive resection of the lesion and, when possible, wide en bloc resection. The recurrence rates range from 46% to 48% for these tumors after subtotal resection, with or without radiation therapy.[84] Due to its hypervascularity, secondary aneurysmal bone cyst formation,[60] preoperative embolization is strongly recommended; and given the aggressive nature of GCTs, patients should be closely monitored with frequent imaging for local or distant metastasis.

CHONDROMA, ENCHONDROMA, AND OSTEOCHONDROMA

Chondromas are benign cartilaginous tumors that arise from failed migration of chondrocytes. Although they are common, benign, appendicular skeletal tumors, they are extremely rare as spinal lesions (<5%). Chondromas are made up of hyaline cartilage, and when they originate from the medullary cavity and form expansile bony lesions, they are referred to as *enchondromas*.[6] These tumors usually peak

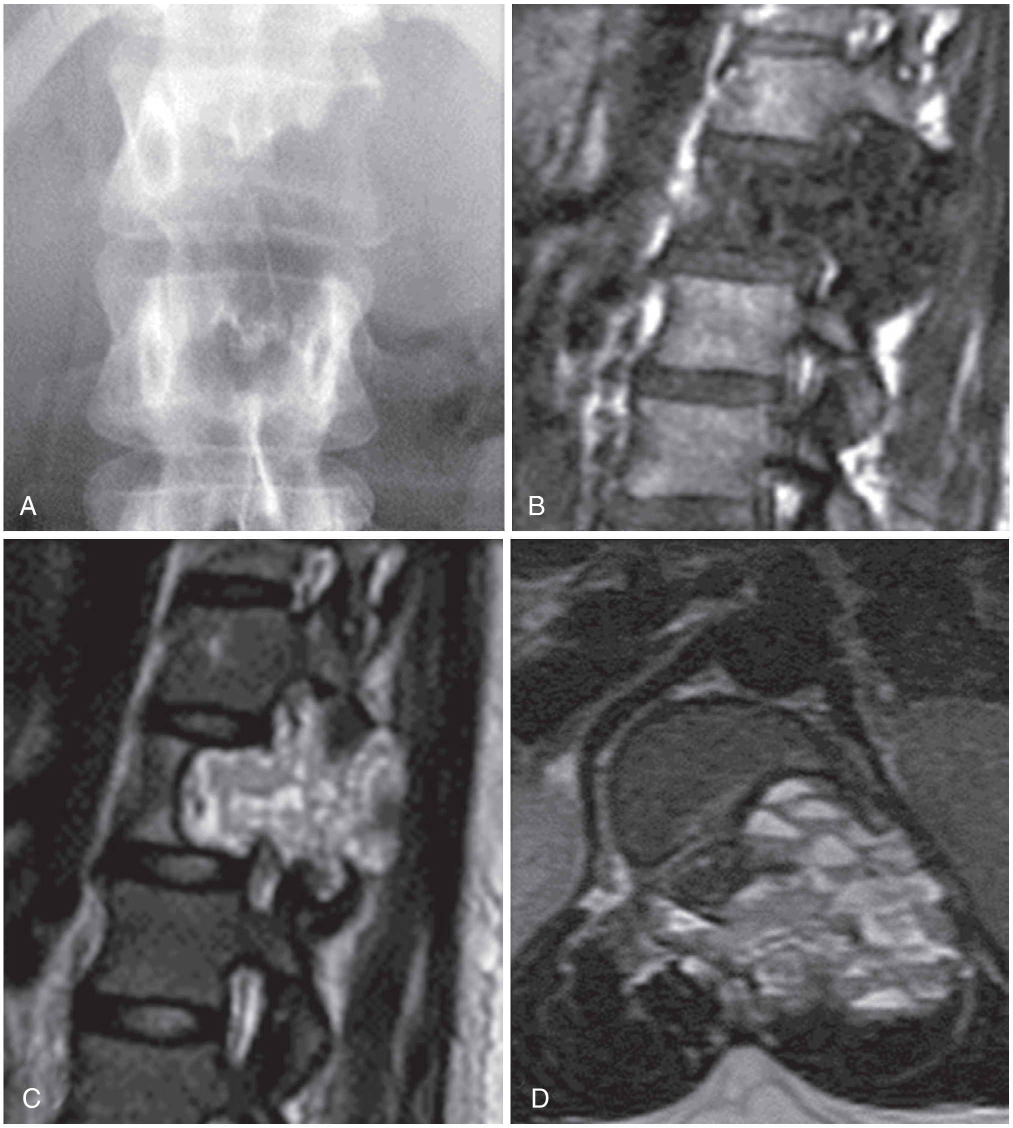

Figure 64-11 Anteroposterior radiograph (**A**) and sagittal T1- (**B**) and T2-weighted (**C**) and axial T2-weighted (**D**) magnetic resonance images of an aneurysmal bone cyst, an osteolytic lesion that demonstrates a cortical eggshell appearance, with fluid-filled levels and loss of pedicle apparent on plain film; multiseptated cysts with fluid-filled levels extend into the posterior elements and compress the spinal cord. (Courtesy John C. Hunter, MD, University of California–Davis Medical Center, Sacramento.)

in their incidence during the second and third decades of life. Because they are generally surrounded by a thin layer of bone, they are well-circumscribed osteolytic lesions on imaging studies.[26] Surgical excision is the treatment of choice after biopsy.[85]

When multiple enchondromas are identified, clinical syndromes such as Ollier syndrome or Maffucci syndrome (with hemangioma) should be suspected; these lesions also carry the additional risk of malignant transformation,[86-88] although solitary lesions rarely undergo malignant transformation.[7]

Spinal osteochondroma may occur in association with hereditary multiple exostoses.[89] Osteochondroma is derived from aberrant cartilaginous epiphyseal growth plate tissue, and malignant transformation may occur in rare cases.

ANEURYSMAL BONE CYST

Aneurysmal bone cysts (ABCs), or "blood-filled sponges," are rare lesions known to be cystic and vascularly expansile in nature.[90] The incidence of these tumors is reported to be 1 in 700,000.[91] They have predilection for young patients (<30 years) and are more common in females. ABCs tend to involve the posterior elements and the pedicles and are most frequently located in the thoracic spine.[92,93] These tumors may occur in association with other spinal tumors, such as GCTs, hemangioma, osteoblastoma, and chondroblastoma.[94]

Plain film radiographs and CT scans demonstrate the osteolytic lesions as cortical eggshells with fluid-filled levels (Fig. 64-11). On MRI, these cysts are visualized as heterogeneous lesions that contain blood degradation products.[95] Because of the vascular nature of ABCs, embolization should be used as first-line treatment or, at a minimum, as preoperative treatment to minimize blood loss.[96] Curretage or surgical resection of the lesion is the treatment of choice. However, even with complete surgical excision, recurrences may still occur; the 10 year recurrence rate is about 10%.[92] Although ABCs are radiosensitive benign tumors, the use of radiation therapy in young patients increases the risk for developing a secondary malignancy.[97]

Conclusion

Primary tumors that involve the spine are rare. Clinicians who treat patients who come to them with nocturnal pain, pain at rest that has persisted for more than 3 months, or progressive neurologic deficits must consider a neoplastic etiology in their differential diagnoses. Initial evaluation should include radiographs of the region of concern, a thorough history, and neurologic exam. Once a diagnosis is suspected or confirmed, additional studies and tests can be coordinated. The management of primary spinal tumors requires a multispecialty and multimodality approach to develop a treatment plan individualized to the tumor pathology and the patient.

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65 Secondary Metastatic Tumors of the Spine

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Overview

The American Cancer Society estimated that in 2011 alone, about 1.6 million new cases of cancer would be diagnosed, and about one third of that number are expected to die from cancer that same year.[1] Metastatic disease is identified in about 70% of patients at the time of death, and metastasis to the spine is the most common osseous location (50% to 75%).[2-4] Of those, 5% to 10% will have symptomatic spinal metastases.[5-7] The most common primary cancers are breast, prostate, and lung, and of those, 16.5%, 15.6%, and 9.2%, respectively, are found to have symptomatic spinal metastases.[8] A majority of the spinal metastases are located in the thoracic and lumbar regions (90%).[3,9-12] Primary tumors may metastasize via direct extension or invasion, seeding into the cerebrospinal fluid, or hematogenously disseminating through the arterial, venous, or Betson's plexus.[13]

Clinical Presentation

The most common initial symptom is pain, which may be biologic and/or mechanical.[14] *Biologic pain* is tumor-related and is characteristically a dull, constant ache with nocturnal exacerbation as a result of venous engorgement; a change in position or activity does not generally affect the pain intensity. *Mechanical pain* originates from structural abnormality in the spine with resultant increase in pain with motion. Standing, coughing, or any activity leads to increased pain. Frequently, patients are able to point to the spinal level involved during the evaluation.

Neurologic symptoms manifest when neural compression is present. Depending on the extent of the disease, patients may present with radiculopathy and/or myelopathy (weakness, sensory deficits, autonomic dysfunction).

Evaluation

Complete evaluation should include a thorough patient history, clinical exam, and appropriate laboratory work. Different systems have been developed to categorize neurologic status: the Frankel grade, American Spinal Injury Association (ASIA) impairment scale, and Eastern Cooperative Oncology Group (ECOG) performance status grade.[15-17] These scales allow for ease of communication among medical personnel, and they help clinicians follow the patient's clinical status (Table 65-1).

Imaging studies should include radiographs with flexion and extension views, computed tomography (CT), and magnetic resonance imaging (MRI) of the spine. Plain radiographs provide evidence of bony destruction and alignment of the spinal column, and they also localize the lesion. Approximately 30% to 60% of the bone loss, however, occurs before it may be visible on plain radiographs.[18] Flexion and extension views are helpful in detecting any abnormal motion that may be present. CT will further evaluate the integrity of the vertebrae and osseous extension of the lesion (Fig. 65-1), and MRI will determine the soft tissue extension of the lesion and will show any neural compression (Fig. 65-2). Additionally, positron emission tomography (PET) and technetium bone scans may help determine whether the lesion is neoplastic or nonneoplastic and will identify other areas of metastasis.[19] When a vascular lesion is suspected, angiography may be used for better characterization of the lesion and for possible preoperative embolization. For patients with prior spinal instrumentation, or when MRI is contraindicated, CT myelogram is very useful to assess the degree of neural compression. When a biopsy is performed as part of the initial evaluation, and tumor control is a goal of the surgery, the tract should be excised at the surgical intervention.

Management

The management of secondary metastatic spinal tumors requires the participation of medical and radiation oncologists and a spine surgeon, radiologist, rehabilitation medicine specialist, and the patient and family members.[20] Treatment options include chemotherapy, radiation therapy, surgery, or a combination of these treatments.[21] Patchell and colleagues[22] reported that direct decompressive surgery plus postoperative radiotherapy is better than radiotherapy alone for patients with metastatic disease with spinal cord compression. A total of 101 patients were randomized into two groups that either received surgery plus radiation or radiation alone. Those who received surgery and radiation not only regained their ability to ambulate (62% surgery plus radiation vs. 19% radiation alone, $P = .01$), they were also able to do so for longer periods of time (median, 122 days vs. 13 days; $P = .03$). Radiation therapy should not be started within 3 weeks after surgery to allow ample time for wound healing and to delay the adverse effect of radiation on fusion.[3,9,10]

For most spinal metastatic disease, the goal is palliative care of pain relief, preservation of neurologic function, and mechanical stabilization.[23] In patients with progressive neurologic deficits, neural elements should be decompressed as soon as possible. The patient's life expectancy must be at least 3 to 6 months when considering more extensive surgical intervention.[23,24]

Table 65-1 Frankel Grading System,[17] American Spinal Injury Association (ASIA) Impairment Scale,[15] and Eastern Cooperative Oncology Group (ECOG) Performance Score System[16]

Grade	Description
FRANKEL GRADE	
A	No motor or sensory function
B	No motor function, sensory function preserved
C	Nonambulatory
D	Ambulatory with neurologic symptoms
E	Normal motor and sensory function
ASIA IMPAIRMENT SCALE	
A	No motor or sensory function
B	No motor function, sensory function preserved BNL
C	Motor muscle grade <3 in majority of muscles BNL
D	Motor muscle grade 3 in majority of muscles BNL
E	Normal motor and sensory function
ECOG PERFORMANCE STATUS GRADE	
0	Fully active
1	Restricted in physically strenuous activity
2	Ambulatory, self-care, bed-ridden <50% of the day
3	Limited self-care, bed-ridden >50% of the day
4	Completely disabled, no self-care
5	Dead

BNL, below the neurologic level.

Different scoring systems have been developed to assist with surgical decision making that take prognosis into account. These include the Harrington classification,[25] Modified Bauer score,[26] Tomita scoring system,[27] modified Tokuhashi scoring system,[28] Sioutos,[29] Van der Linden score,[29] and the "LMNOP" system.[30] The Tokuhashi[28] and Tomita[27] scoring systems are most commonly used in our institution.

The Tokuhashi system is a preoperative prognostic scoring system divided into six prognostic factors: 1) general medical condition, 2) number of extraspinal osseous metastases, 3) number of vertebral metastases, 4) metastases to the major internal organs, 5) primary cancer site, and 6) neurologic deficits (Table 65-2).[28] For each factor, the score ranges from 0 to 2. The estimated life expectancy correlates to the score: for a total score of 0 to 8, life expectancy is less than 6 months; for a score of 9 to 11, it is 6 months or more; when it is 12 to 15, life expectancy is a year or more. Management of patients is recommended based on the scoring system: 0 to 8, conservative treatment (radiation therapy alone); 9 to 11, palliative surgery (decompression with or without instrumentation); and 12 to 15, excisional surgery with stabilization (Fig. 65-3 and Fig. 65-4).

Tomita and associates developed a scoring system based on the grade of the primary tumor and related metastases, both visceral and bone (Table 65-3).[27] In contrast to the Tokuhashi system, the lower the score, more aggressive the recommended treatment: 2 to 3, long-term goal with wide or marginal excision; 4 to 5, middle-term goal with marginal or intralesional excision; 6 to 7, short-term goal with palliative surgery; and 8 to 10, terminal and supportive care. In the 67 patients treated accordingly, they observed the mean survival time to be 38.2, 21.5, 10.1, and 5.3 months, respectively.

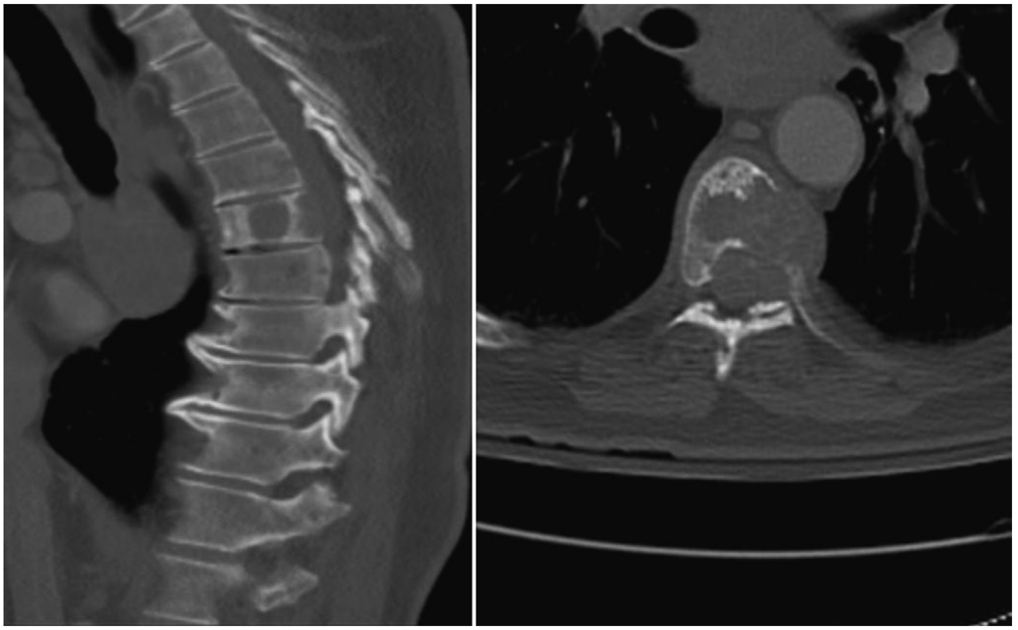

Figure 65-1 Lateral (*left*) and axial (*right*) computed tomographic scan of thoracic spine demonstrates an osteolytic lesion of the T7 vertebra (adenocarcinoma) involving the vertebral body and the posterior elements.

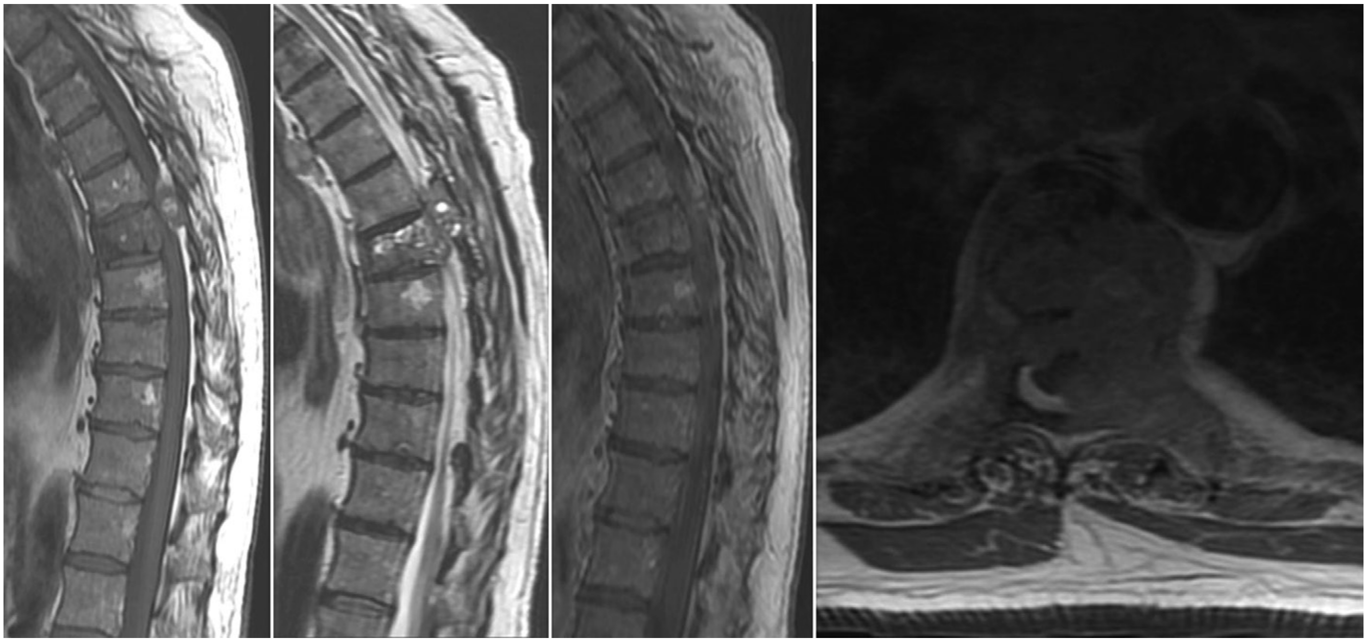

Figure 65-2 Sagittal T1-weighted magnetic resonance image (MRI), sagittal T-1 and T2-weighted MRIs with contrast, and axial T1-weighted MRI with contrast showing soft-tissue extension of the T7 lesion shown in Figure 65-1 causing spinal cord compression.

Table 65-2 Revised Tokuhashi Scoring System for Prognosis of Metastatic Spine Tumors

Characteristic	Score
GENERAL CONDITION (KARNOFSKY SCORE, PERFORMANCE STATUS)	
Poor (10% to 40%)	0
Moderate (50% to 70%)	1
Good (80% to 100%)	2
NUMBER OF EXTRASPINAL BONE METASTASES FOCI (BONE SCAN)	
≥3	0
1 to 2	1
0	2
NUMBER OF METASTASES IN THE VERTEBRAL BODY	
≥3	0
1 to 2	1
0	2
METASTASES TO THE MAJOR INTERNAL ORGANS	
Unremovable	0
Removable	1
No metastases	2
PRIMARY SITE OF CANCER	
Lung, osteosarcoma, stomach, bladder, esophagus, pancreas	0
Liver, gallbladder, unidentified	1
Others	2
Kidney, uterus	3
Rectum	4
Thyroid, breast, prostate, carcinoid tumor	5
PALSY (FRANKEL GRADE)	
Complete (A, B)	0
Incomplete (C, D)	1
None (E)	2

From Tokuhashi Y, Matsuzaki H, Oda H, et al: A revised scoring system for preoperative evaluation of metastatic spine tumor prognosis. *Spine (Phila Pa 1976)* 30:2186–2191, 2005.

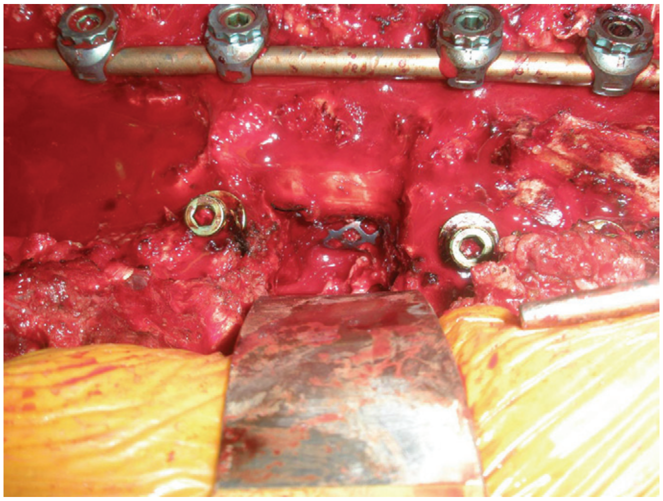

Figure 65-3 Posterior approach for T7 excision of tumor and placement of cage and posterior instrumentation for Tokuhashi score above 13. (Courtesy Eric Klineberg, MD.)

All these scoring systems, however, have limitations. They do not give much direction regarding the type of surgical treatment. Fisher and colleagues[31] developed the Spine Instability Neoplastic Score (SINS), which helps surgeons determine spinal mechanical instability (Table 65-4), and they recommend that this system be taken into consideration with other elements such as neurologic symptoms, extent of disease, prognosis, patient health factors, oncologic subtype, and radiosensitivity of the tumor. Paton and associates[30] proposed the "LMNOP" system to guide decision making on a case-by-case basis. This mnemonic refers to a modification of the system originally described by Bilsky and Smith[32] in 2006. The LMNOP system (Table

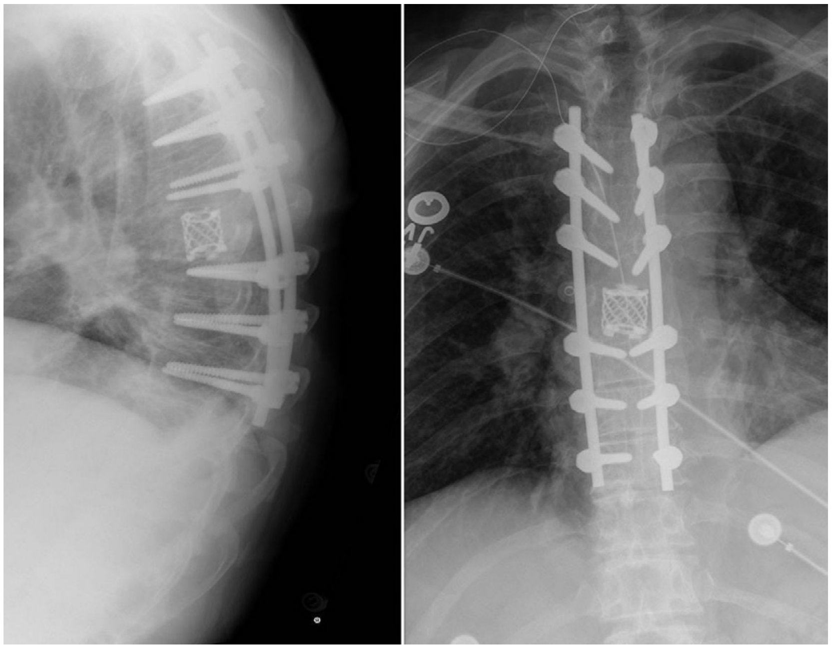

Figure 65-4 Lateral (*left*) and anteroposterior (*right*) radiographs illustrate T7 corpectomy and instrumented stabilization of thoracic spine.

Table 65-3 Tomita Scoring System

Characteristics	Score
PRIMARY TUMOR	
Slow growth	1
Moderate growth	2
Rapid growth	4
VISCERAL METASTASES	
Treatable	2
Untreatable	4
RAPID GROWTH	
Solitary/isolated	1
Multiple	2

Tomita K, Kawahara N, Kobayashi T, et al: Surgical strategy for spinal metastases. *Spine (Phila Pa 1976)* 26:298–306, 2001.

Table 65-4 Spine Instability Neoplastic Scoring (SINS) System[31]

Characteristics	Score
LOCATION	
Rigid (S2–S5)	0
Semirigid (T3–T10)	1
Mobile spine (C3–C6, L2–L4)	2
Junctional (occiput–C2, C7–T2, T11–L1, L5–S1)	3
PAIN WITH LOADING OF SPINE?	
Yes	0
No/occasional	1
Pain free	3
BONE LESION	
Blastic	0
Mixed	1
Lytic	2
RADIOGRAPHIC SPINAL ALIGNMENT	
Normal	0
De novo deformity	2
Subluxation/translation	4
VERTEBRAL BODY COLLAPSE	
None	0
None with >50% body involved	1
<50% collapse	2
>50% collapse	3
POSTERIOR ELEMENT INVOLVEMENT	
None	0
Unilateral	1
Bilateral	3

Fisher CG, DiPaola CP, Ryken TC, et al: A novel classification system for spinal instability in neoplastic disease: an evidence-based approach and expert consensus from the Spine Oncology Study Group. *Spine (Phila Pa 1976)* 35:E1221–E1229, 2010.

65-5) includes more factors to consider in the management of metastatic disease to the spine: location and number of levels involved (*L*); mechanical instability (*M*); neurology (*N*); oncology (*O*); and patient fitness, prognosis, and prior therapy (*P*). This system is not a treatment algorithm, but it is a good reminder for surgeons of the various issues to consider before recommending surgical treatment for metastatic tumor of the spine. Specific surgical approaches are covered in other chapters.

Surgical Management "Pearls"

- Identify the goal of surgery (e.g., improve quality of life).
  - Resection (all tumors need not be aggressively resected)
  - Pain relief
  - Decompression
  - Stabilization

Table 65-5 "LMNOP" System[30]

Location/ **L**evels	Extent of the disease (anterior/posterior elements) Solitary or multilevel
Mechanical Instability	Stable (SINS = 0 to 6) Potentially unstable (SINS = 7 to 12) Unstable (SINS = 13 to 18)
Neurology	Symptoms from cord compression
Oncology	Radiosensitive/radioresistant
Patient fitness/ **P**rognosis/ **P**rior therapy	Medically fit for surgery History of radiation at the level(s) Failed multiple systemic treatments

Paton GR, Frangou E, Fourney DR: Contemporary treatment strategy for spinal metastasis: the "LMNOP" system. *Can J Neurol Sci* 38:396–403, 2011.

- Patient's and family's expectations and the surgeon's goals for the surgery coincide.
- Location of tumor determines the approach (described elsewhere in this text).
  - Need for multiple approaches should be considered.
  - Need for staged procedures should be assessed.
  - Weinstein-Boriani-Biagini (WBB) system[33] for spinal tumor surgical staging for en bloc resection (see Fig. 64-2) may be helpful.
- Biopsy: percutaneous or open
  - Seeding or recurrence along the biopsy needle tract may occur.
  - A spine surgeon should be involved to plan the biopsy procedure so that the tract can be resected when the tumor is approached.
- Angiogram/preoperative embolization
- Ventral approaches
  - Transthoracic: endoscope assisted, manubriotomy/manubriectomy, sternotomy, thoracotomy
  - Retroperitoneal: anterior, anterolateral, direct lateral, minimally invasive
  - Good for lesions that involve anterior elements
- Dorsal approaches
  - Kyphoplasty/vertebroplasty—for pain relief
  - Decompressive laminectomy—for posterior decompression
  - Transpedicular—for posterior and anterolateral decompression
  - Constotransversectomy—for posterior and anterolateral decompression and instrumented stabilization
  - Lateral extracavitary—allows circumferential decompression and reconstruction of both anterior and posterior columns
- Anatomic considerations
  - Cervical region
    - With multilevel corpectomies, consider posterior instrumentation
  - Thoracic region
    - T2–T3—innominate vein
    - T4–T5—scapula
    - T12–L1—diaphragm
    - Rib resection is usually one or two levels above the involved vertebral level.
    - Ligate the nerve roots on the side of the patient's radicular pain when possible.
  - Lumbosacral
    - Retroperitoneal approach—left more often than right, avoids having liver obstructing the surgical field.
    - Ligate segmental vessel at midvertebral body to avoid possible ischemia.

Conclusion

The evaluation and management of metastatic tumors of the spine require a thoughtful decision-making process that involves the patient, family members, and multiple specialties. Even with use of the many systems described in the literature to help in that process, the spine surgeon needs to be flexible. With advancement in technology and increased surgeon experience, surgical treatment is always possible. However, the wishes of the patient should never be disregarded, and the goal should always include improving the patient's quality of life.

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66 Surgical Technique for Resection of Intradural Tumors

RIPUL R. PANCHAL, EDWARD E. KERR, and KEE D. KIM

Overview

Primary tumors of the spinal cord are relatively rare, comprising 2% to 4% of all primary central nervous system tumors.[1] Spinal tumors are generally identified by location and can be put into three groups: *extradural, intradural-extramedullary,* and *intramedullary*.[2,3] The surgical approach to intradural neoplasms depends primarily on two factors: location of the mass and whether the mass is intramedullary or extramedullary. An overview of the most common adult intramedullary and extramedullary tumors is provided in Table 66-1 and Table 66-2, respectively.[1]

Spinal magnetic resonance imaging (MRI) and computed tomographic (CT) myelogram are helpful to distinguish between intramedullary and extramedullary tumors (Fig. 66-1). Intramedullary lesions typically can be resected with posterior or posterolateral approaches, whereas intradural-extramedullary tumors may require anterior, anterolateral, lateral, posterolateral, or posterior approaches.

In this chapter, we will discuss the common open approach for intradural-extramedullary and intramedullary tumor resection. In the recent literature, different authors describe minimally invasive surgical (MIS) approaches to access these types of tumors.[4-7] However, unless the surgeon is very familiar and comfortable with these approaches, we recommend the more traditional open approach.

Indications and Contraindications

INDICATIONS

- Neurologic deficit
- Histologic diagnosis of lesion
- Recurrence of lesion

RELATIVE CONTRAINDICATIONS

- No neurologic deficit
- Blood dyscrasias
- Multiple comorbidities
- Poor prognosis (life expectancy <3 to 6 months)

Surgical Technique

EQUIPMENT

- Mayfield calvarial fixation for posterior approaches (cervical or upper thoracic)
- Radiolucent operating table
- Fluoroscopy
- High-magnification and high-illumination microscope
- Self-retaining retractor system (cerebellar retractor, modular retractor, or tubular dilator retractor for MIS approach)
- Electrocautery (monopolar and bipolar)
- Hemostatic agents (bone wax, Gelfoam, Surgifoam, and/or FloSeal)
- Various sizes of Kerrison and pituitary rongeurs and microcurettes
- High-speed drill with matchstick or diamond burr
- Various sizes of sutures
- Neurophysiologic monitoring (somatosensory-evoked and motor-evoked potentials [SSEPs and MEPs], electromyelogram [EMG], and anal sphincter monitoring)
- High-dose steroids at start of case or preoperatively
- Prophylactic antibiotics

PATIENT POSITIONING

- Prone for posterior or posterolateral approaches with the patient taped down to prevent movement with operating bed rotation
- Lateral for lateral or anterolateral approaches
- Supine for anterior approach
- Adequate padding of all bony prominences and pressure points

EXPOSURE

- Use a localizing imaging study (fluoroscopy or portable x-ray) to mark the site of incision.
- The incision should be extended slightly at both ends of the localized lesion to allow ample exposure and watertight dural closure.
- For open prone approaches, subperiosteal dissection should be performed with either monopolar electrocautery

Table 66-1 Primary Intramedullary Tumors

Tumor	Prevalence*	Location	Treatment	Notes
Ependymoma	~50% to 60%	Cervical > thoracic > lumbosacral (except myxopapillary subtype)	Gross total resection if possible; radiation and/or chemotherapy if unresectable	Myxopapillary subtype typically arises in the conus or filum and is extramedullary.
Astrocytoma	~25% to 35%	Cervical > thoracic	Gross total resection rarely possible; biopsy to guide treatment and for prognosis; chemotherapy and/or radiation	World Health Organization grade is most important prognosticator.
Hemangioblastoma	Rare	Cervical > thoracic	Gross total resection if possible; radiation and/or chemotherapy if unresectable	10% to 30% of patients with spinal hemangioblastoma have von Hippel-Lindau syndrome.
Ganglioglioma	Rare	Cervical > thoracic	Gross total resection if possible; radiation and chemotherapy data lacking	Prognosis is excellent if gross total resection is achieved.
Primary CNS lymphoma	Rare	Typically diffuse disease	Biopsy only; surgical debulking not indicated; chemotherapy mainstay of treatment	Prognosis is poor.
Germinoma	Rare	Insufficient data	Biopsy only; typically sensitive to chemotherapy and radiation	Image entire neuroaxis to rule out disease elsewhere.
Melanoma	Rare	Insufficient data	Gross total resection if possible (rare); radiation and/or chemotherapy if unresectable	Prognosis is poor.

*Percent of intramedullary tumors.
CNS, central nervous system.
From Chamberlain MC, Tredway TL: Adult primary intradural spinal cord tumors: a review. *Curr Neurol Neurosci Rep* 11:320–328, 2011.

Table 66-2 Primary Intradural, Extramedullary Tumors

Tumor	Prevalence*	Location	Treatment	Notes
Meningioma	~50%	Thoracic (~80%) ≫ cervical > lumbosacral	Surgical if symptomatic; may be observed with serial imaging; radiotherapy an option for incomplete resection or recurrence	Gross total excision may be curative; 80% occur in females
Schwannoma	~25%	Cervical > cauda equina > thoracic > conus	Surgical if symptomatic; may be observed with serial imaging	Increased incidence in NF2; almost uniformly histologically benign
Neurofibroma	~25%		Surgical if symptomatic; usually observed with serial imaging	Increased incidence in NF1; plexiform subtype carries poor prognosis (may progress to MPNST), but otherwise benign
MPNST	Rare		Gross total resection if possible (rare); radiation and/or chemotherapy if unresectable	Associated with NF1 and poor prognosis

*Percent of intradural-extramedullary tumors.
MPNST, malignant peripheral nerve sheath tumor; NF1, neurofibromatosis type 1; NF2, neurofibromatosis type 2.
From Chamberlain MC, Tredway TL: Adult primary intradural spinal cord tumors: a review. *Curr Neurol Neurosci Rep* 11:320–328, 2011.

or a Cobb dissector with gauze to minimize tissue injury and bleeding (Fig. 66-2).

- If unfamiliar with anterolateral or anterior approaches, have an access surgeon, either a general surgeon or a cardiothoracic surgeon, provide the exposure.
- Wide osseous removal is the goal, although laminectomies, vertebrectomies, and rib resections should be performed without destabilizing the spinal column when possible.
- Because of cord traction with change in position, thoracolumbar intramedullary tumors are generally localized approximately 1 cm more rostral when the patient is prone than when supine; radiographic study is commonly done supine.[8]

DURAL OPENING

If not already present, the operative microscope is brought into the field for this portion of the procedure. Hemostasis is ensured before incising the dura to minimize the morbidity caused by spinal subarachnoid blood and to avoid obscuring the operative field. Intraoperative ultrasound may help precisely localize the tumor in real time.[9]

After the tumor is localized, and good hemostasis is achieved, moistened cotton pledgets are placed on either side of the planned dural opening to prevent blood from entering the subarachnoid space (Fig. 66-3). The anesthesiologist is made aware of imminent dural opening and possible rapid loss of a substantial quantity of cerebrospinal

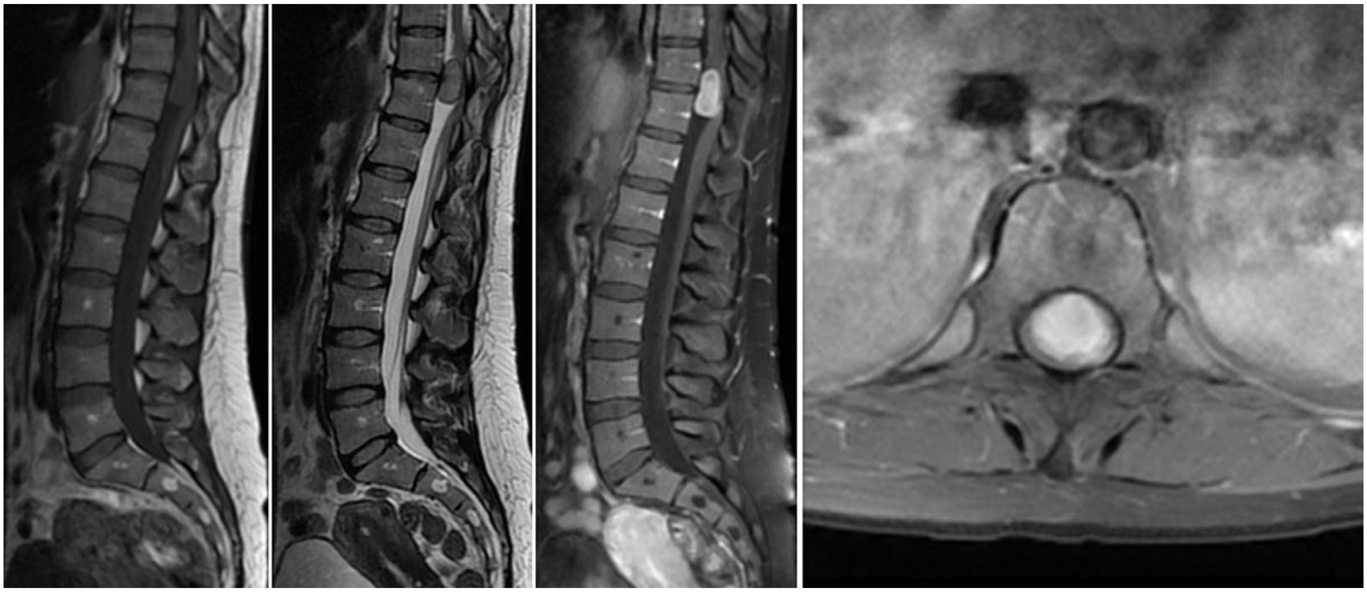

Figure 66-1 Magnetic resonance imaging (MRI) shows an intradural-extramedullary homogeneously enhancing lesion consistent with a schwannoma (*left to right,* Sagittal T1-, T2-, and T1- weighted MRI with contrast and axial T1-weighted MRI with contrast).

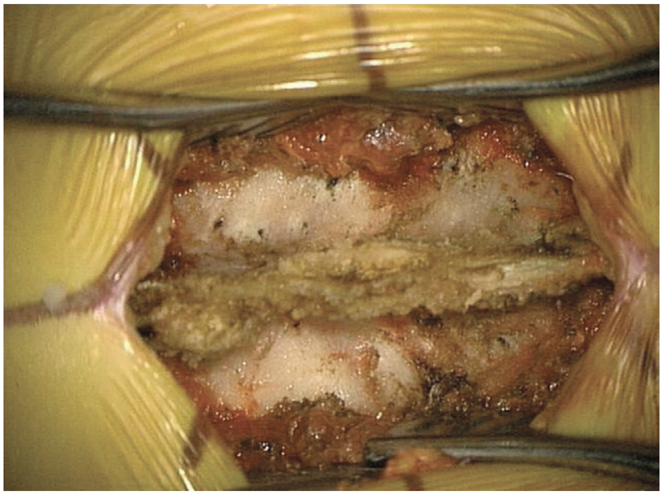

Figure 66-2 Posterior approach to T10–T11 schwannoma, subperiosteal dissection.

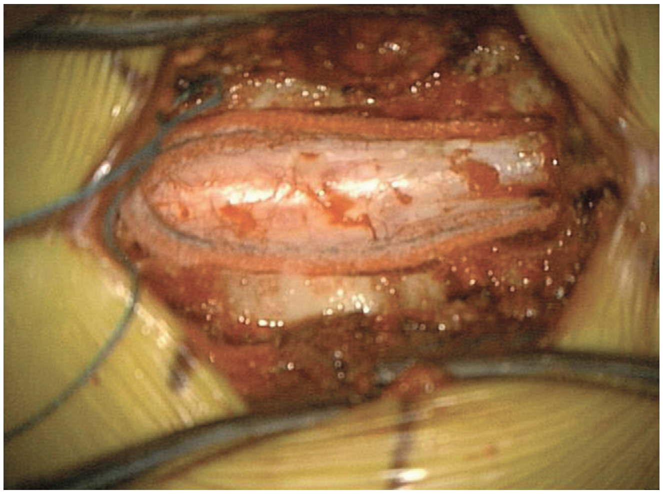

Figure 66-3 Posterior approach to T10–T11 schwannoma, dural exposure.

fluid (CSF). Using the microforceps to hold the dura, a No. 15 scalpel blade is used to incise the dura in the midline without opening the arachnoid layer.

Next, a Woodson dissector is placed between the dural opening and the arachnoid layer. The dura is opened further with the scalpel to provide adequate visualization of the region of interest; if more lateral visualization is desired, the dura may be incised laterally in a "T" shape toward the nerve root. Also, the operating table may be rotated as needed to facilitate an ergonomically sound approach for the neurosurgeon. We use 4-0 braided nylon sutures placed in the dural edges for lateral retraction to keep the operative field exposed and to prevent blood from bone edges and retracted muscle from entering the subarachnoid space (Fig. 66-4). Intradural exposure is maintained by tying the sutures to the paraspinal musculature or surgical drape or by clamping a hemostat to the two free ends of the suture and allowing the hemostat to hang over the side of the patient. Finally, if still intact, the arachnoid layer is opened sharply. Electrophysiologic monitoring may both facilitate identification of neural element function and provide medicolegal documentation of spinal cord function during the operation.[10]

APPROACH TO INTRADURAL-EXTRAMEDULLARY TUMOR

The borders of the intradural-extramedullary tumor are defined using microinstruments, such as from a Rhoton tray, to minimize direct pressure or manipulation of the spinal cord. Caudal to the conus medullaris, the nerve roots may be gently retracted either medially or laterally

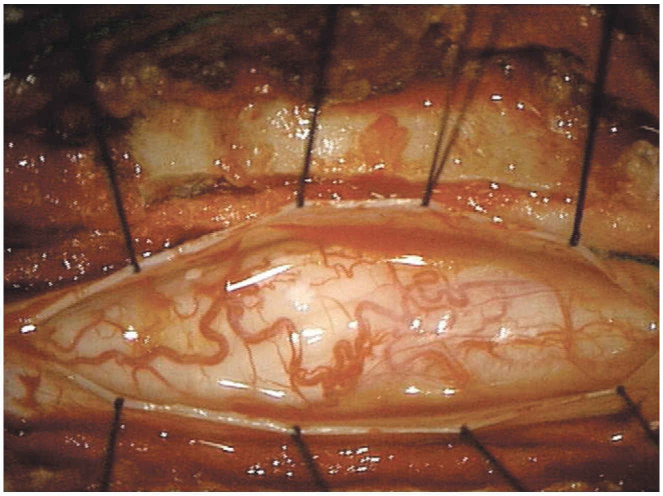

Figure 66-4 Posterior approach to T10–T11 schwannoma. Dural opening reveals bulging spinal cord with underlying ventral mass.

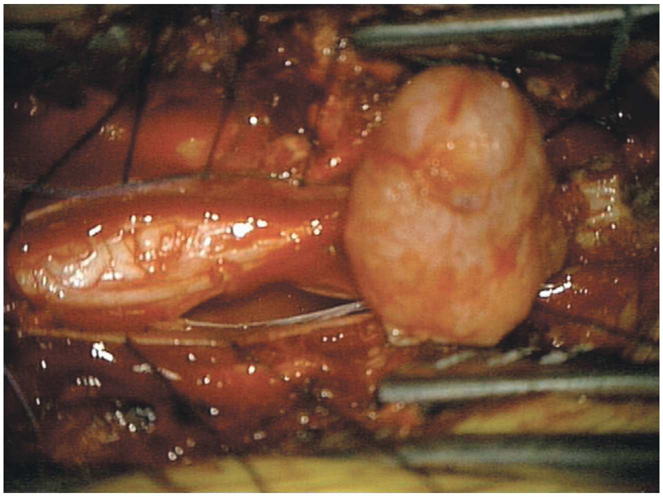

Figure 66-6 Posterior approach to T10–T11 schwannoma internally debulked with the Cavitron ultrasonic surgical aspirator (ValleyLab, Boulder, CO) and teased out of the canal with minimal retraction on the spinal cord.

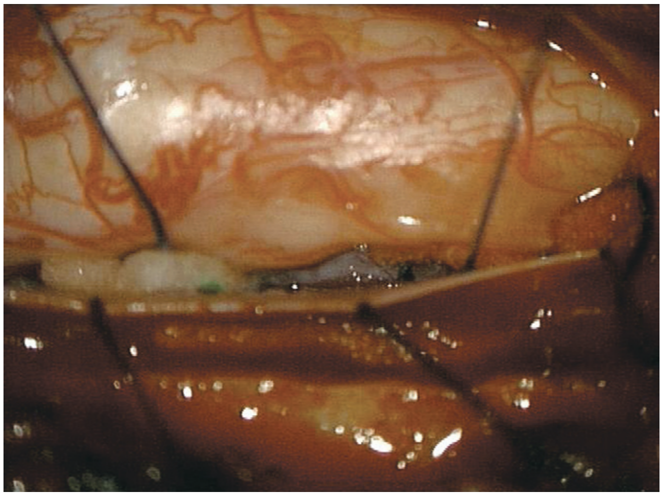

Figure 66-5 Posterior approach to T10–T11 schwannoma. Moistened cotton pledgets are used to expose and demarcate the dissection plane between the tumor and the spinal cord.

to facilitate visualization of the mass. Moistened cotton pledgets are used to demarcate the tumor border and separate it from the spinal cord (Fig. 66-5). A biopsy may be taken for intraoperative frozen pathologic analysis. For a neurofibroma or schwannoma, the involved nerve root is stimulated to determine what portion of the mass is safely resectable.

While resecting a tumor, any damage to neural structures that produces reproducible extremity or anal motor function on intraoprative stimulation should be avoided. In such cases, gross total resection may not be possible. For lesions caudal to the conus medullaris and attached to filum terminale, the proximal cut should be made first to prevent retraction of the lesion cranially. If the attachment is identified and can be easily separated, the tumor can be removed in a piecemeal fashion with biopsy forceps or as one piece. Because of the small working corridor, piecemeal resection is preferred to avoid applying undue pressure on the cord. A Cavitron ultrasonic surgical aspirator (CUSA) may also be used to resect the tumor in a piecemeal fashion and debulk the lesion internally (Fig. 66-6). Bipolar electrocautery should be used at a very low current setting and should be limited to avoid thermal injury to the cord.

In the case of meningioma, all involved dura mater is exposed to facilitate gross total resection. Gross total resection of meningioma is important for the long-term prognosis in World Health Organization (WHO) grade 2 or higher meningiomas. However, achieving gross total resection may not be as important with WHO grade 1 meningiomas, because their recurrence rate is low.[11]

APPROACH TO INTRAMEDULLARY TUMOR

Intradural tumors are almost exclusively approached posteriorly. The initial approach is exactly as described previously in this chapter for intradural-extramedullary tumors. Under microscopic magnification, the dura is incised in the midline over the entire length of the lesion. If a biopsy alone is planned, the exposure may be very limited to avoid the morbidity of a larger exposure. The lesion may not be apparent at the pial surface, so the approach must be planned based on the preoperative imaging. Ultrasound may be useful in locating the lesion intraoperatively to plan the myelotomy.[9] Lesions situated centrally are approached via a midline myelotomy; lesions situated more laterally are approached via the dorsal root entry zone or midline myelotomy. Keep in mind that the posterior median sulcus may be difficult to identify for the midline myelotomy because of edema. In such cases, the superficial vessels also may not serve as reliable markers to identify the midpoint between the bilateral dorsal root entry zones.

The myelotomy may be made with either a No. 11 blade knife or a carbon dioxide laser (Fig. 66-7). At this point there may be a loss of SSEPs. The remainder of the surgery depends on the surgical goal, whether it is to merely obtain a biopsy, to debulk, or to achieve a gross total excision. In general, a diffusely infiltrative mass, such as an astrocytoma, cannot be safely excised; a more discrete mass, such as an ependymoma, may allow for a gross total resection.

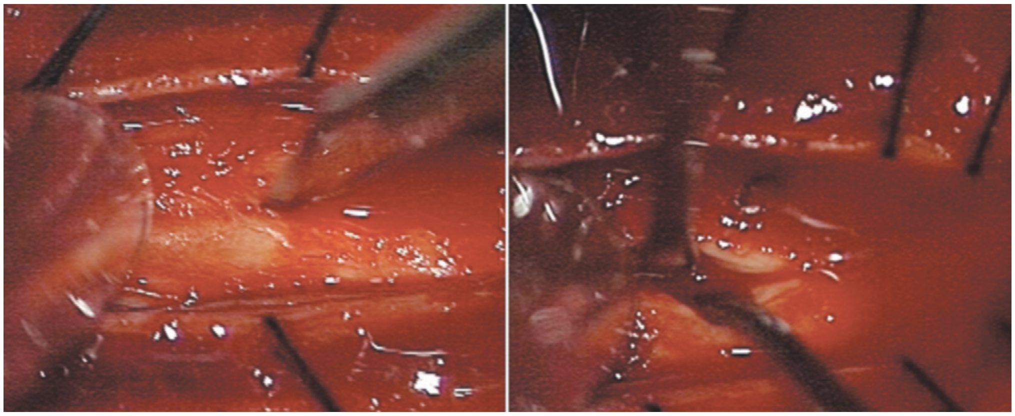

Figure 66-7 Posterior approach to C3 ependymoma. Midline myelotomy with a No. 11 blade scalpel (*left*) and separation of the edges using Rhoton dissectors (*right*).

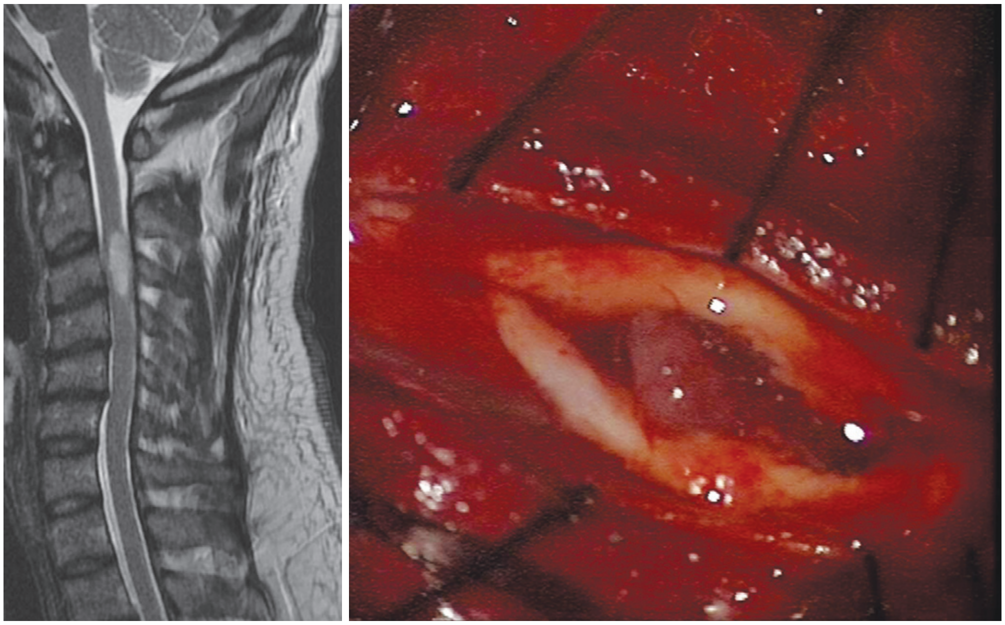

Figure 66-8 Posterior approach to C3 ependymoma. Sagittal T2-weighted magnetic resonance imaging shows a hyperintense lesion (*left*); midline myelotomy reveals an encapsulated intramedullary tumor with a reddish to purplish appearance (*right*).

Before attempting this, the mass should be internally debulked to create a safe working space. This is achieved using microdissectors, bipolar electrocautery, and/or the CUSA. We do not recommend the use of electrocautery because of the potential for neural damage from dissipating current.

The key to safely excising an intradural tumor is to identify the plane of dissection between the mass and the normal surrounding neural tissue. This plane is carefully developed using gentle retraction with microdissectors and microforceps (Fig. 66-8). If this plane is apparent, but the tumor is adherent to normal-appearing neural tissue, centrifugal resection should be performed with the goal of maximum subtotal resection. Care must be taken at all times not to apply direct or indirect traction to the spinal cord, and care must be taken not to pull on the tumor adherent to the spinal cord. When the surgical goal has been met, the pia mater may be closed with interrupted 8-0 nonabsorbable monofilament or equivalent sutures.

HEMOSTASIS

When operating in the intradural space, hemostasis is achieved in multiple ways. A moistened cotton pledget or Surgifoam may be placed on bleeding neural tissue and left in place for a few seconds or minutes, and bleeding often stops with this alone. Absorbable gelatin sponges either soaked in saline or in recombinant human thrombin may also be placed on top of bleeding neural tissue to achieve hemostasis. Only when nondestructive measures have failed to stop bleeding should the neurosurgeon resort to electrocautery, which damages intervening neural tissue. We do not recommend monopolar electrocautery; bipolar electrocautery minimizes the current spread and the consequent unnecessary neural injury. Saline irrigation should be used with bipolar cautery to limit the heat transference.

CLOSURE

Once the lesion is excised, the area should be inspected for any residual lesion and active bleeding (Fig. 66-9). Blood products should be evacuated with copious warm irrigation to minimize the risk of postoperative chemical meningitis. Ultrasound can be used to assess the extent of resection of the tumor.

The lateral traction sutures are removed from the dural edges, and the dura is closed using either interrupted or running suture. This may either be braided (4-0 nylon) or monofilament (5-0 or 6-0 nylon or Gore-Tex) suture (Fig. 66-10). For minimally invasive approaches, nitinol U-clips (Medtronic, Minneapolis, MN) can be used for dural closure.[12] In the case of meningioma, a dural substitute must be used to repair the defect caused by excision of the mass. Many products are commercially available. Alternatively, autologous fascia lata may be harvested and used as a patch graft. The dural closure should be watertight to prevent the development of a pseudomeningocele, and this is tested by having the anesthesiologist hold a positive pressure of 30 to 40 mm H_2O in the patient's lungs while inspecting the dural suture line for leaks. Leaks may be addressed by primary repair with the aforementioned suture or by patch grafting with the materials discussed here or with locally harvested muscle. If the dura mater cannot be closed in a watertight fashion, a lumbar drain should be placed, and CSF should be drained postoperatively to reduce intrathecal pressure at the dural repair. Placement of an overlying collagen matrix could also be considered in this case to reduce the risk of pseudomeningocele (Fig. 66-11). Alternatively, a sealant approved by the Food and Drug Administration (FDA), such as DuraSeal spine sealant, can be used to reinforce watertight closure of the dura. This may be supplemented with a back brace to increase intraabdominal pressure to counteract the CSF leak.[13]

Finally, the wound is closed in multiple layers. The overlying muscle is loosely approximated with size 0 absorbable suture. The muscle fascia is tightly closed with either interrupted or running size 0 absorbable suture. Finally, the dermis and epidermis are closed according to surgeon preference.

Postoperative Care

- The extent of resection should be confirmed with contrast MRI (Fig. 66-12).
- Oral opiates or intravenous patient-controlled analgesics should be considered for postoperative pain control.

Figure 66-10 Posterior approach to T10–T11 schwannoma. Primary closure with 6-0 Gore-Tex suture in running locking fashion.

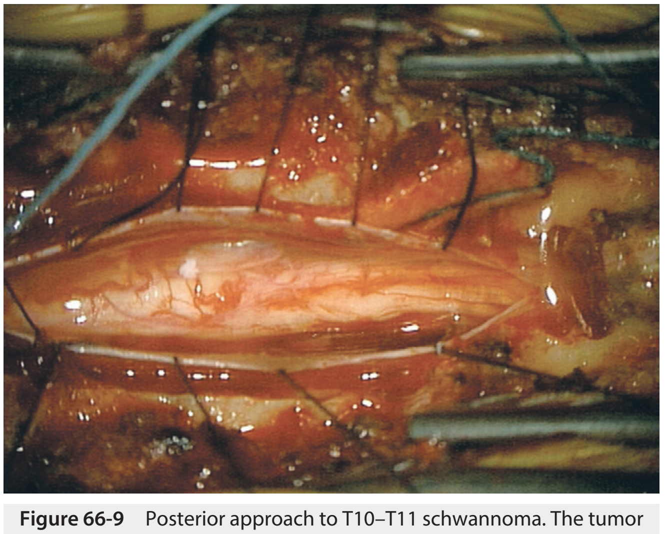

Figure 66-9 Posterior approach to T10–T11 schwannoma. The tumor is excised, and hemostasis is achieved. No gross injury to the cord is observed.

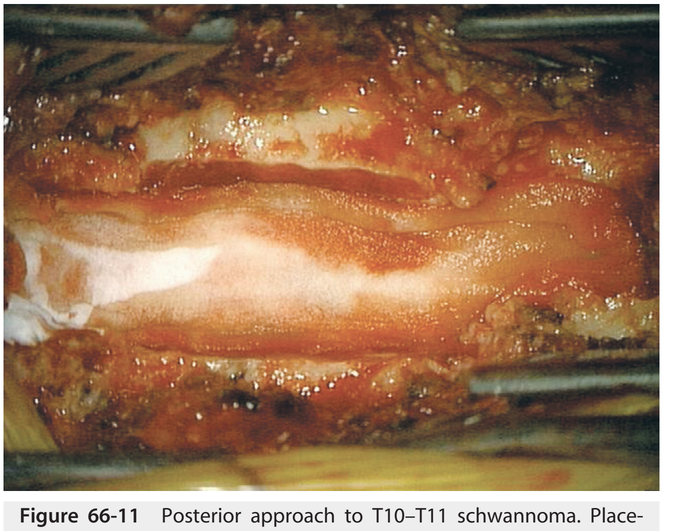

Figure 66-11 Posterior approach to T10–T11 schwannoma. Placement of an overlying collagen matrix over the primary dural closure can reduce the possibility of delayed pseudomeningocele.

Figure 66-12 Magnetic resonance imaging (MRI) after posterior approach for resection of schwannoma shows no evidence of residual lesion (*left to right,* sagittal T1-, T2-, and T1-weighted MRI with contrast and axial T1-weighted MRI with contrast).

- Early mobilization, physical therapy, and rehabilitation are recommended.
- Follow-up should include x-rays; spinal instability or delayed deformity may occur after laminectomy that involves the lower cervical or cervicothoracic region, especially in younger patients.

Complications

- Common transitory postoperative symptoms: spinal headache, motor changes, and/or sensory changes, especially when myelotomy is performed
- Permanent neurologic deficits
- Epidural hematomas
- Pseudomeningocele/CSF leak, wound infection, meningitis, or postlaminectomy spinal deformity

Conclusion

Most common approaches used for the majority of intradural-extramedullary or intramedullary tumors are described here. With posterior exposures with varying degrees of lateral bone resection, dentate ligament division and gentle cord rotation may allow for safe removal of a majority of lesions irrespective of their location in reference to the cord.[14] However, an anterior approach may be necessary for some ventral tumors. Use of spinal instrumentation should be considered preoperatively if the exposure or the resection could lead to instability of the spine.

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67 Vascular Lesions of the Spinal Cord

NIKOLAY L. MARTIROSYAN, SERGEY NECKRYSH, FADY T. CHARBEL, NICHOLAS THEODORE, and G. MICHAEL LEMOLE JR

Overview

Four topics will be addressed in this chapter: 1) normal vascular anatomy of the spinal cord; 2) vascular neoplastic lesions, represented by hemangioblastomas and cavernous malformations; 3) arteriovenous malformations (AVMs) and arteriovenous fistulas; and 4) spinal cord aneurysms.

Normal Vascular Anatomy of the Spinal Cord

The vascular anatomy of the spinal cord is divided into extrinsic and intrinsic spinal arteries and veins.[1] The intrinsic arteries are further divided into central and peripheral arterial systems, which are supplied by central arteries anteriorly, and the pial network.[1,2] More specifically, the central system supplies the anterior two thirds of the spinal cord through the anterior spinal artery (ASA).[2] The posterior spinal artery (PSA) consists of the peripheral system and supplies the posterior component of the spinal cord.[3] Overlaps between these two systems are found only in the terminal branches, which are not true anastomoses; in the inner white matter; and at the periphery of the gray matter.[4] The extrinsic arteries are metameric in nature, integrating tissues with one source of supply.[1]

ANTERIOR SPINAL ARTERY

The ASA supplies the anterior two thirds of the spinal cord.[5] Rostrally it originates from the vertebral arteries, before they join to form the basilar artery.[4] The ASA travels through the anterior median fissure,[3] and its diameter decreases as it proceeds rostrally.[2,3] The diameter of the ASA becomes consistent once it reaches the thoracic region. The size variation is anatomically explicit: the ASA gets progressively smaller until it joins with the artery of Adamkiewicz, at which point it becomes very prominent. Lastly, the terminal branches of the ASA allow it to form several anastomoses (Fig. 67-1).[6]

POSTERIOR SPINAL ARTERY

The vertebral artery gives off the paired posterior spinal arteries (PSA); however, the PSA sometimes originates from a posterior radicular artery. The arteries proceed rostrally and travel posterolaterally; they terminate near the end of the spinal cord after providing several branches to posterior rootlets of the cauda equina.[2,3] The PSA is fed by the 10 to 20 ipsilateral posterior radiculomedullary arteries.[6,7] Nevertheless, in a few instances, a single radiculomedullary artery does supply both posterior spinal arteries.[7,8] Anatomically, the PSA has a characteristic single-vessel appearance; however, it can form several anastomosing channels. The PSA has a plexiform design, and it can become so small that it is difficult to see (Fig. 67-2; see also Fig. 67-1).[9]

PIAL ARTERIAL PLEXUS

The pial arterial plexus is formed by the surface anastomoses of the ASA and the PSA systems, and it is responsible for blood supply of the spinal cord surface.[6] It supplies the peripheral sections of the spinal cord and includes the posterior horns and substantia gelatinosa.[4] The pial arterial plexus branches infiltrate the dorsal midline of the spinal cord and then proceed inward in a perpendicular fashion.[10] The plexus is fed on the lateral surfaces by the posterior radicular arteries, which are also responsible for supplying the dura mater, spinal ganglia, PSA, and the nerve roots (see Fig. 67-1).[7]

RADICULAR ARTERIES

Radicular arteries originate from segmental vessels that arise from such larger tributaries as the aorta or the subclavian artery. The 31 pairs of radicular arteries are responsible for supplying numerous structures that include the dura mater, spinal ganglia, PSA, and ASA.[11] Radicular arteries are classified into those that divide into 1) arteries that do not reach the dura of the spinal cord; 2) arteries that penetrate the dura but end early; and 3) radiculomedullary arteries that actually vascularize the spinal cord.[11] It is important to make a note about the artery of Adamkiewicz, also known as the *arteria radicularis magna* or the *great radicular artery*, which is the largest radiculomedullary artery, with a diameter of 1.0 to 1.3 mm.[7] Nearly 80% of the time, it is present on the left side, anastomoses with the ASA, and then divides into small ascending and large descending branches (see Fig. 67-1).[3,12]

CENTRAL ARTERIES

The central arteries arise from the ASA and pierce the anterior median fissure to enter the spinal cord. The 210 central arteries form a centrifugal system that supplies the middle of the spinal cord, the central sulcus, anterior and posterior gray horns, and periphery of the white matter.[11,13,14] Once

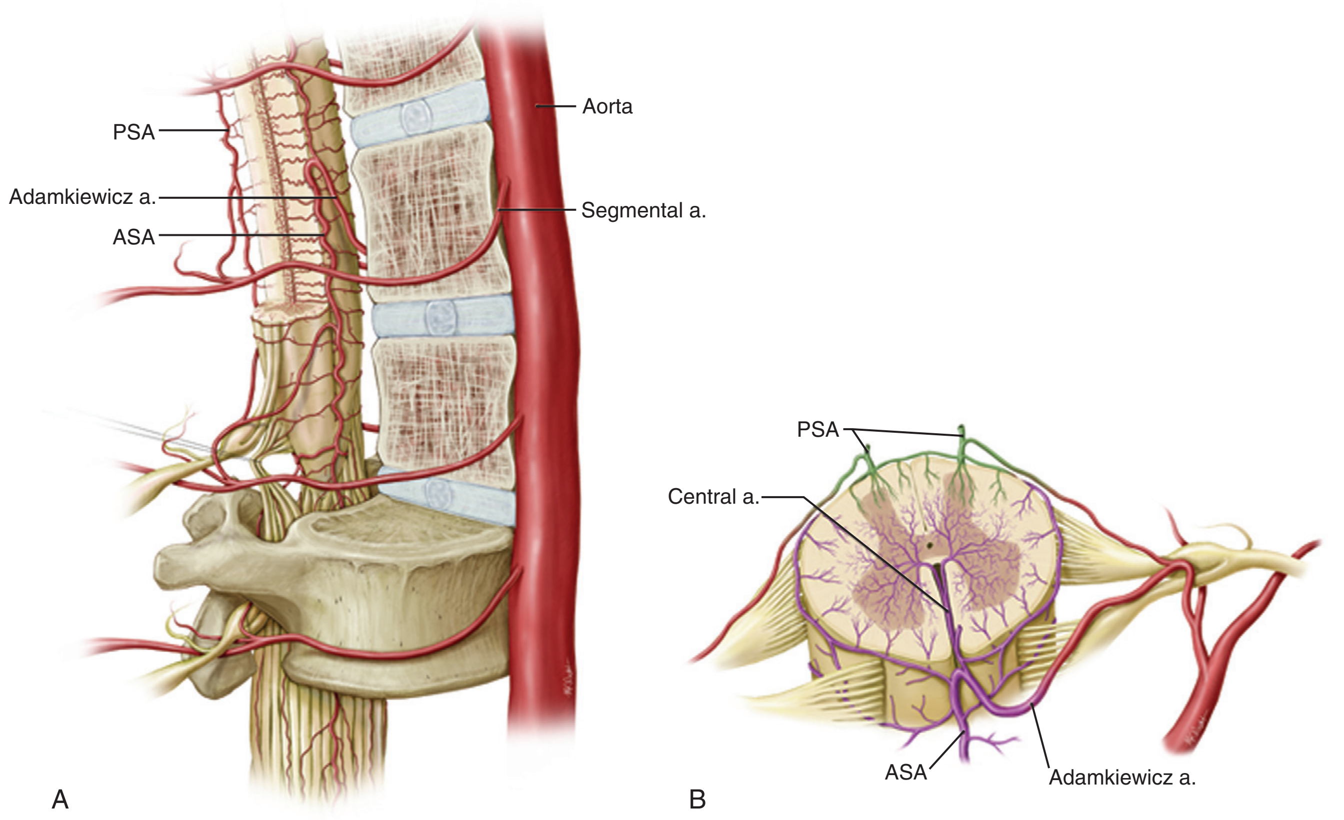

Figure 67-1 **A,** Anterolateral view of lumbar spinal cord. **B,** Vascularization of lumbar spinal cord. Contribution of the anterior spinal artery and posterior spinal artery in supplying the blood to the spinal cord. (Courtesy Nicholas Theodore, MD.)

it reaches the anterior gray matter, it divides into short ascending and descending branches that supply the edges of the gray matter.[2] The number of central arteries present at specific segments of the spinal cord also differs.[15] The central arteries are most numerous in the cervical and lumbosacral region and are least numerous in the thoracic region. Lastly, the acute angle formed by these arteries in the lumbosacral region permits for a wider perfusion of the spinal cord.[13,16]

VEINS OF THE SPINAL CORD

The veins of the spinal cord follow a pattern similar to the arteries of the spinal cord. The intrinsic spinal cord veins are formed by two groups. First is the longitudinal anteromedian group, which collects into the central veins. The second group is collected through radial veins to coronal veins.[17,18] Three anterior and posterior spinal veins drain the spinal cord and are in turn drained by the anterior and posterior radicular veins. The internal vertebral venous plexus integrates the venous drainage in the epidural space; this plexus communicates with the dural sinuses and external vertebral venous plexus.[19]

The spinous Batson venous plexus is valveless, which allows blood to pass into the systemic venous system. This network provides an easy route of dissemination for metastases.[20] This can be quite significant in cases of prostate cancer, in which increased intraabdominal pressure facilitates spread of metastatic tumor in the vertebrae, brain, or skull through this venous plexus.[21]

CAPILLARIES OF THE SPINAL CORD

The capillaries of the spinal cord differ according to location. The capillary bed is at least five times denser in the gray matter of the spinal cord than in the white matter, because other arterial structures provide the white matter. It is greatest near the site of cell bodies, which reflects their increased metabolic requirements. The capillary beds of the white matter are robust, as are the nerve fiber routes. When the capillary density of the white matter alone is compared with the transition zone of the gray and the white matter, the latter has been shown to have a higher density.[16]

Hemangioblastoma

GENETICS

Hemangioblastoma is sporadic in nature or is inherited in an autosomal dominant fashion with von Hippel–Landau (VHL) syndrome.[22] The VHL gene is located at the locus of 3p25-p26.[23-27] Mutations such as point and frameshift mutations and large deletions have been identified within the VHL gene. A mutation within codon 238 is specifically implicated in retinal and CNS hemangioblastoma.[27] A loss of function mechanism of a single tumor suppressor gene has also been attributed in development of hemangioblastoma pathology, and several molecular factors have been associated with hemangioblastoma. Increased hypoxia-induced factor (HIF) and vascular endothelial growth factor (VEGF) transcripts have been found in ocular hemangioblastoma.[28-30] Increased expression of VEGF in part is responsible for tumor growth through abundant neovascularization. Other HIF-induced molecules—including transforming growth factor (TGF), platelet-derived growth factor (PDGF), fibroblast growth factor (FGF), and epidermal growth factor (EGF)—are increased in hemangioblastoma and are all factors associated with angiogenesis.[29] Presence of erythropoietin (Epo) and Epo receptor (EpoR) also alludes to the presence of involvement of progenitor cells in VHL-associated lesions.[29,31,32]

The origin of the stromal, neoplastic component of hemangioblastoma[33] continues to elude researchers; however, immunohistochemical studies have consistently identified the following epitopes: neuron-specific enolase,[22,34] neural cell adhesion molecule (CD56),[35,36] and vimentin.[35-38] The vascular endothelial cells in hemangioblastoma are also characterized by expression of von Willebrand factor, platelet–endothelial cell adhesion molecules, and Weibel–Palade bodies.[27,39-41]

EPIDEMIOLOGY

Spinal cord hemangioblastomas (Fig. 67-3; see also Fig. 67-2) are rare lesions that represent 1% to 3% of all intramedullary spinal cord tumors, and men are affected twice as often as women. Central nervous system (CNS) hemangioblastomas are present in 21% to 72% of patients with VHL disease, and approximately 40% are located in the spinal cord. Multiple lesions may be present in 25% to 33% of patients with CNS hemangioblastomas,[42] although this figure may underestimate the actual incidence, because not all patients undergo a full workup for VHL disease. Spinal hemangioblastomas are intramedullary (75%) or have extramedullary or intradural extension (10% to 15%). Approximately 96% of spinal hemangioblastomas are located posterior to the dentate ligament.[43] Extradural hemangioblastomas are rare and may arise from the vertebral bodies. By location, 50% of spinal hemangioblastomas occur in the thoracic cord, 40% are in the cervical cord, and 6% are in the lumbar region. Hemangioblastomas have also been rarely reported in the conus medullaris,[44] filum terminale,[45] nerve roots, and peripheral nerves.[46] Typical age at presentation is between 40 and 50 years in patients with sporadic hemangioblastomas (lesions are more often intracranial); patients with VHL disease are usually seen in their late twenties to early thirties.

Hemangioblastomas usually present with nonspecific signs of intramedullary mass and syrinx, and syrinx is seen in approximately 50% to 70% of patients. Initial symptoms can be divided into three major groups: 1) sensory changes, which occur in 38.9% of patients, mostly as numbness and involvement of posterior columns; 2) weakness in 27.8%; and 3) pain in 33% (in these cases the tumor frequently extends into or originates from the dorsal root entry zone).[47] Patients may also come to medical attention with signs of myelopathy and urinary incontinence. Surprisingly, spontaneous hemorrhage from spinal hemangioblastomas is quite rare; although the majority of patients had subarachnoid hemorrhage (SAH), intramedullary hemorrhage was less common.[48]

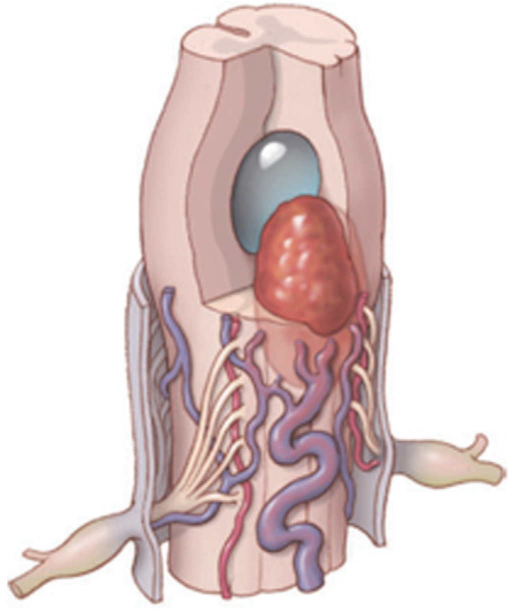

Figure 67-2 Hemangioblastoma.

PATHOLOGY

The typical spinal cord hemangioblastoma usually enlarges the cord, is well demarcated, and consists of a highly vascular nodule with an associated cyst; leptomeningeal vessels are prominent. Histologically, these tumors are composed of an intricate vascular network of irregular and often dilated capillaries with intervening stromal cells. These stromal cells can produce erythropoietin, resulting in erythrocytosis. Immunostaining for epithelial markers is negative for hemangioblastoma; these markers are important when differentiating between hemangioblastoma and metastatic renal cell carcinoma, which may also develop in patients with VHL syndrome.[49,50] A recent study showed high Ki67 activity in intramedullary–extramedullary hemangioblastomas, whereas the Ki67 activity was less than 1% in intramedullary lesions.[51]

IMAGING

Dilated, tortuous feeding arteries and draining pial veins can be seen on a myelogram in approximately 50% of cases. Angiography demonstrates a highly vascular mass with dense vascular blush and draining vessels, which can mimic an AVM. Preoperative embolization is a valid option. Magnetic resonance imaging (MRI) findings are consistent with diffuse cord expansion with high signal intensity on T2-weighted imaging with prominent foci of high-velocity signal loss. Cyst formation and syrinx are seen in 50% to 70% of cases.[42,43] The tumor nodule is strongly enhanced with contrast administration, and intraoperative use of

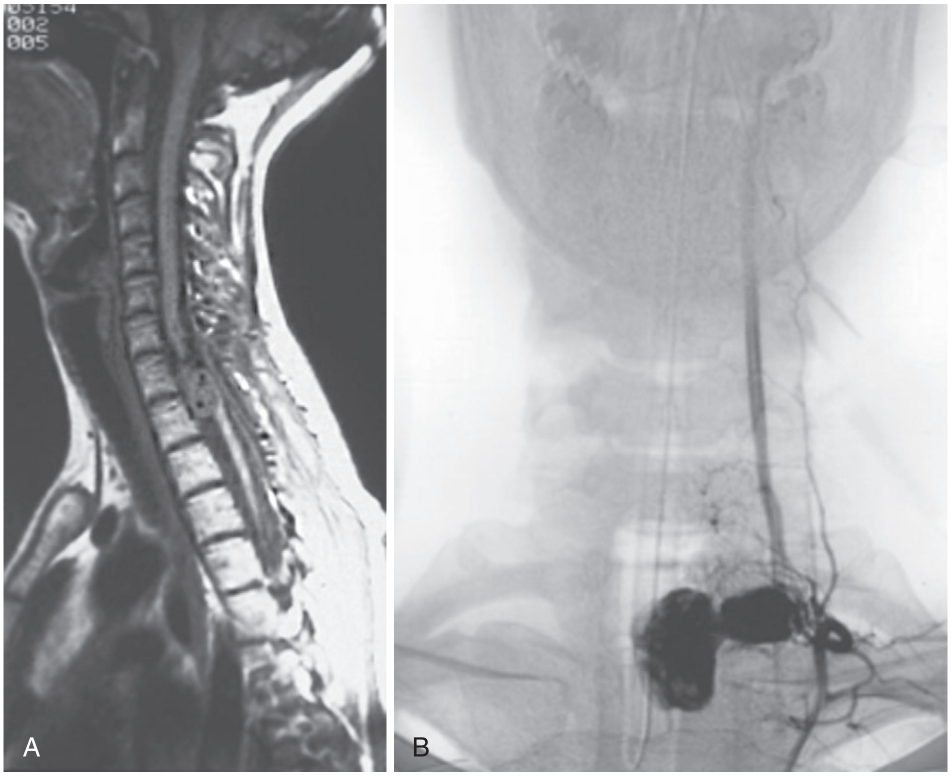

Figure 67-3 Spinal hemangioblastoma. **A,** T1-weighted sagittal magnetic resonance image demonstrates hemangioblastoma in the ventral portion of the spinal cord at the T1–T2 level. Flow voids from the dilated venous plexus of the spinal cord surrounding the lesion at the corresponding levels. **B,** Selective spinal angiogram of the same patient demonstrates a lobulated, highly vascular lesion that was found to be hemangioblastoma on pathologic examination after surgical resection.

indocyanine green angiography facilitates lesion delineation to ensure completeness of resection.[52]

SURGICAL CONSIDERATIONS

Progressive neurologic deterioration caused by mass effect of the tumor and enlarging syrinx and acute neurologic deficit caused by hemorrhage are indications to surgically intervene. In patients with VHL disease, lesions may be multiple, and it is very important to pinpoint the deficit to the particular symptomatic location. Ultimately, multiple surgical interventions may be needed in these patients to treat the disease over their lifetime. Hemangioblastomas are considered in the discussion of vascular spinal cord malformations, because they often behave like AVMs during surgical resection. Presurgical embolization can be implemented to reduce the risk of intraoperative bleeding.[53]

SURGICAL TECHNIQUE

- The patient is positioned depending on the location of hemangioblastoma, and the appropriate approach is performed to extend one level above and one level below the margins of the tumor. Bone removal (laminectomy, laminoplasty, or corpectomy) must be adequate to allow exposure of tumor margins along with associated feeding and draining vessels.
- The dura mater is incised in the midline, elevated, and retracted the entire length of the exposure with preservation of the arachnoid membrane. Sharp or blunt "tearing" techniques can be used to extend the dural opening. Cotton pads or balls are sometimes used to protect the underlying spinal cord during dural opening; recall that spinal dura has only one layer, unlike cranial dura. Cottonoid strips can be packed into the lateral paraspinal gutters to maintain a bloodless operative field, and dural leaflets are tacked up to adjacent muscles or drapes with 4-0 braided nylon suture.
- The microscope is brought into the operative field, and the arachnoid is sharply dissected from the surface of the hemangioblastoma and associated vessels. In general, the tumor is approached in much the same manner as an AVM, and special attention is paid to feeding and draining vessels.
- Pial vessels that cross the margin of the tumor at its junction with the pia mater are coagulated using bipolar cautery at a low setting and are sharply divided to clearly expose the margin of the tumor at the pial surface. Sensory rootlets embedded into the tumor may be dissected free or interrupted if the tumor is to be completely resected.
- The plane of dissection is developed in a circumferential manner using bipolar cautery, microscissors, and small cottonoid strips. The tumor capsule is normally prominent. It is important that dissection be performed in a completely bloodless field, so that each feeding and draining vessel can be distinguished from en passant vessels and interrupted as it reaches the surface of tumor capsule. Again, surgical technique mirrors that used for AVM resection.

- Traction on the spinal cord, including "tenting," should be avoided while reflecting the poles of the tumor.
- Bipolar electrocautery must be used judiciously and at low voltage to avoid thermal injury to adjacent neural tissue. If bleeding occurs from the tumor capsule, coagulation often makes it worse. Hemostasis can be obtained by application of a variety of hemostatic agents, such as Gelfoam soaked in thrombin.
- Piecemeal resection of the tumor often causes vigorous bleeding; thus it should not be attempted unless the tumor is large and cannot otherwise be safely removed. In this scenario, meticulous coagulation and hemostasis are imperative. A portion of the tumor can be removed to afford additional exposure.
- The operative bed is directly inspected to make certain no tumor remains and that hemostasis is complete.
- Dural closure is performed in a watertight manner with monofilament 4-0 or 5-0 suture on a tapered needle. Some surgeons apply fibrin glue over the suture line.
- Multiple-layer closure of the wound is performed in a standard fashion.

OUTCOMES

Hemangioblastomas can be safely removed without significant new postoperative deficit. Approximately 96% of patients will remain unchanged or will improve neurologically, and 4% will worsen. A recent National Institutes of Health (NIH) study published on surgical outcomes after hemangioblastoma resection demonstrated the following[54,55]:

- Location of the tumor anterior to the dentate ligament carries a higher risk of new postoperative neurologic deficit.
- Likelihood of new permanent postoperative neurologic deficit increases with lesions larger than 500 mm.[3]
- Cysts associated with hemangioblastoma diminish or resolve in almost all patients. Presence of a cyst preoperatively does not alter the surgical outcome, and further surgical manipulations on the tumor cyst during resection are not needed.[54]

Spinal Cord Cavernous Malformations

GENETICS

Cavernous malformations have a strong genetic predisposition, and some familial and sporadic forms have incomplete penetrance and variable expressivity.[56,57] Nearly 150 types of mutations are reported, and frameshift and nonsense mutations are the most prominent. Sporadic cases account for 80% of the cavernous malformations, with an incidence of 1 in 200, and these cases demonstrate great locus and allelic heterogeneity.[58] Several rare causes have also been reported, such as a balanced translocation between chromosomes 3 and X in a female with skewed X inactivation.[59]

EPIDEMIOLOGY

Cavernous malformations (Fig. 67-4) can be considered neoplastic lesions based on their features and growth pattern. These lesions can occur sporadically or in a familial pattern and have an identifiable genetic abnormality with an autosomal dominant pattern of inheritance and incomplete penetrance. Spinal cord cavernous malformations represent 5% to 12% of all spinal cord vascular malformations and 3% to 15% of all cavernous malformations that occur in the CNS. There is slight female predominance, and symptomatic presentation and diagnosis usually occur in the fourth decade of life. The thoracic cord is affected more often than the cervical, and lesions in the conus medullaris and cauda equina are rare.

CLINICAL PRESENTATION AND NATURAL HISTORY

The clinical course of spinal cord cavernous malformations is variable. Patients can develop acute symptoms attributed to hemorrhage, or they may come to medical attention with stepwise deterioration, which can mimic demyelinating disorders. Acute presentation is characterized by pain that corresponds to the level of the cavernous malformation and neurologic deterioration that can occur over several days. This is different from the typical hemorrhage caused by an AVM of the spinal cord, which is typically more acute, and neurologic deficit is concomitant with the onset of pain. Initial hemorrhage from a cavernous malformation can cause paraplegia or quadriplegia, although incomplete neurologic deficit followed by some degree of recovery, which is rarely complete, is more common. In untreated lesions, repeated hemorrhages may occur months to years after the initial hemorrhage. A more subtle presentation can occur when the lesion is primarily localized on the

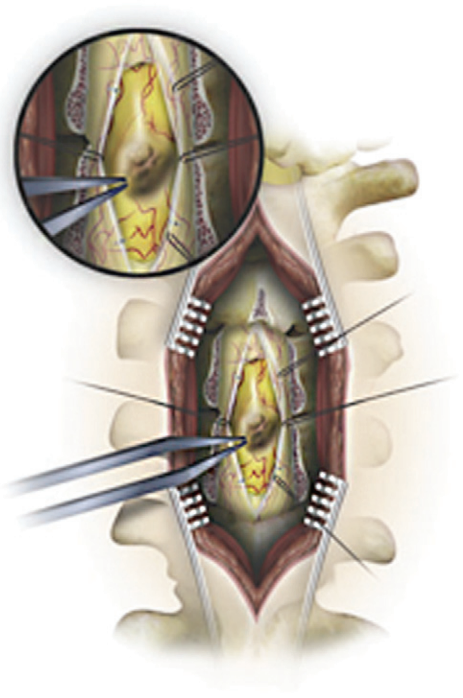

Figure 67-4 Spinal cavernous malformation.

dorsal aspect of the spinal cord, and patients initially complain of intermittent paresthesias. Radiculopathy is more common with lesions in the dorsal root entry zone. With the widespread use of MRI, cavernous malformations are often discovered at an early symptomatic stage or even while asymptomatic.

PATHOLOGY

Spinal cord cavernous malformations are identical in appearance and histopathology to intracranial cavernous malformations, and grossly they may be described as soft and spongy with a dark blue to red-brown hue. Cavernous malformations are usually well circumscribed, and hemosiderin staining of the surrounding tissues as a result of repeat bleeding can clearly define the plane of dissection. This discoloration is sometimes the only visual clue that a cavernous malformation may be located under the pial surface. Microscopically, cavernous malformations consist of endothelium-lined channels filled with blood with no intervening brain tissue. Vessel walls lack elastic and muscular layers, and calcifications are rare. A gliotic, often hemosiderin-laden plane usually is evident around the malformation. Tonguelike extensions of the cavernous malformation can extend into the surrounding gliotic plane, and this should be kept in mind during resection to achieve complete excision.

IMAGING

Findings on MRI include signs of hemorrhage in different stages of blood product degradation with a mixture of high- and low-intensity signals. The typical appearance of a cavernous malformation is an inhomogeneous high-intensity signal on both T1- and T2-weighted images with a surrounding dark ring of hemosiderin and appearing hypointense on T1- and T2-weighted images. Enhancement is not typical for cavernous malformations. Unlike their intracranial counterparts, the diagnosis of spinal cord cavernous malformations with MRI is not always straightforward, especially with small lesions. The classic "popcorn" appearance is not always seen in spinal cord cavernous malformations. In some cases, spinal MRI, particularly T2-weighted images, can be misleading for surgical planning when trying to estimate where the malformation comes closest to the pial surface. Malformations that appear to be located superficially on MRI may be found to lie deeper in the spinal cord during surgical exploration. Nevertheless, MRI represents an invaluable imaging technique, compared with more traditional imaging modalities, and with emergence of more powerful MR scanners, the quality of spinal cord imaging is rapidly improving.

Angiography has very little value in diagnosing these angiographically occult lesions. The angiogram may demonstrate a venous anomaly associated with a cavernous malformation; the cavernous malformation, not the venous anomaly, is felt to be the source of recurrent hemorrhage. The venous anomaly represents an anatomic variant that should be preserved during surgical resection, because it provides venous drainage to the surrounding normal tissues. Preoperative embolization is not an option with cavernous malformations.

SURGICAL CONSIDERATIONS

The increasing experience with surgical excision of intramedullary spinal cord cavernous malformations and the high probability of neurologic deterioration if these are left untreated have expanded the role for surgical treatment. Studies clearly demonstrate that progression of neurologic symptoms in patients with spinal cord cavernous malformations is the rule rather than the exception. Neurologic outcome is most dependent on the preoperative neurologic status of the patient, and best outcomes are achieved in patients with good neurologic status preoperatively.

Given its small cross-sectional area and high eloquence, the spinal cord is unlikely to tolerate even minor expansions from hemorrhage or from growth of the malformation, and this is an important consideration. Modern microsurgical technique can provide good outcomes with an acceptable level of postoperative morbidity in patients with spinal cord cavernous malformations. A recent study showed the effectiveness of a carbon dioxide laser in spinal cord cavernous malformation resection; the laser allows the surgeon to perform delicate myelotomies safely and to shrink cavernous malformations away from eloquent spinal cord tissue.[60] Surgery may be recommended for appropriate candidates with symptomatic lesions, especially when the cavernous malformation extends to the pial surface. However, this decision is significantly more difficult in patients with asymptomatic or minimally symptomatic lesions and in patients with deep-seated lesions. In these cases, recommendations for radical surgical resection should be tailored to each individual case. Young patients and patients with large lesions are the most appropriate candidates in this group, because they are most likely to experience long-term benefit from early surgical intervention.

SURGICAL TECHNIQUE

Dorsally Located Lesions (Fig. 67-5)

- Preoperative localization is an important part of surgical planning and can be done using techniques such as external skin marking or image guidance with fiducial application.
- Most cavernous malformations can be exposed and resected via a posterior approach. Laminectomy or laminoplasty should provide adequate exposure for dorsally located lesions. Laminoplasty has been recommended for cervical or upper thoracic lesions to prevent postsurgical kyphotic deformity.
- Laminoplasty in patients without significant degenerative disease or spinal cord expansion can be performed with a pneumatic drill and a footplate attachment with laminar cuts on both sides. Ligamentous structures are sharply divided, and the laminae and spinous processes are removed en bloc over the levels of interest. Absolute hemostasis should be obtained before opening the dura.
- The intraoperative microscope is brought into the operative field, and the dura mater is incised in the midline with preservation of the underlying arachnoid layer as described in previous sections. The dural edges are tacked up to the drapes or paraspinous muscles using 4-0 braided nylon sutures.

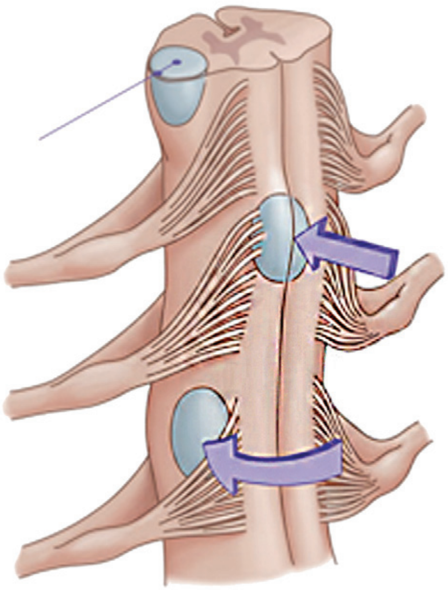

Figure 67-5 Surgical corridors to the lesions in the spinal cord. *Straight arrow:* Certain lesions in the spinal cord located posteriorly and extending to the pial surface in the midline could be approached safely by performing an incision through the dorsal median septum of the spinal cord. *Curved arrow:* Lesions located paramedially and extending to the pial surface of the spinal cord at the dorsal root entry zone could be approached via the dorsolateral sulcus of the spinal cord. *Dotted line:* The two-point method is used to design a surgical approach to lesions of the spinal cord located laterally, when anatomic sulci of the spinal cord cannot be used. The first point is placed in the center of the lesion; the second point is placed where the lesion comes closest to the pial surface. The line connecting the two points indicates the shortest trajectory to the lesion.

- The arachnoid is opened sharply in the midline, and the edges are secured to the ipsilateral dural leaflet.
- The spinal cord is examined under high magnification; malformations that extend toward the pial surface may be visible at the surface, and in other cases, blue or red-brown discoloration of the spinal cord caused by hemosiderin deposits will be visible and will point to the location of the malformation. Image guidance or intraoperative ultrasound could be used to localize those lesions that leave no clues as to their location.
- A two-point method is used to determine the optimal entry point and trajectory through the spinal cord to the cavernous malformation: a line is drawn through the center of the lesion to the point where it comes closest to the surface. For deeper lesions, this technique is modified in the spinal cord to avoid eloquent tracts and to take advantage of better tolerated avenues of approach (see Fig. 67-5).
- For deep-seated lesions, myelotomy is performed under high magnification, either through the dorsal median sulcus or along the dorsal root entry zone, whichever offers a better trajectory to the malformation.
- Care must be taken to avoid damaging the adjacent normal spinal cord parenchyma, and sharp dissection with judicious use of bipolar electrocautery is the standard of care. Myelotomies should be parallel to fiber tracts on the long axis of the spinal cord to minimize damage.
- Resection of the lesion is performed using microcurettes and gentle suction aspiration. Handheld suction devices with thumb apertures offer controlled suction strength, which is critical to avoid injury to surrounding tissues. Typically, lesions will be removed in a piecemeal fashion, although some can be resected en bloc. Although not truly encapsulated, cavernous malformations have a well-defined gliotic plane that separates them from the surrounding spinal cord.
- Bleeding is seldom a problem with cavernous malformations because of their low-flow nature, and hemostasis should be accomplished using hemostatic agents and gentle compression. Bipolar cautery use should be avoided unless absolutely necessary, and when used at all, it should be set to a low power. Venous draining anomalies are often associated with cavernous malformations and should be preserved, because they may provide venous drainage for adjacent eloquent tissues.
- After hemostasis is obtained, careful inspection of the resection bed under high magnification is imperative to identify and further resect small "tongues" of the cavernous malformation that may extend into the adjacent tissue. Incompletely resected lesions can recur and hemorrhage; therefore every attempt should be made to resect these lesions fully during the first surgery.
- Dura is closed in a watertight fashion as described in previous sections. A multilayer wound closure is performed using standard techniques.

Ventrally Located Lesions

Lesions involving the anterior and lateral aspect of the spinal cord are much more difficult to approach (Fig. 67-6); however, if the lesion is symptomatic and reaches the anterior or lateral pial surface, surgery can be attempted. In these cases surgical morbidity is generally higher owing to the increased spinal cord eloquence and difficulty of the surgical approaches. Generally, only lesions that reach the pial surface are approached anteriorly; approaches through the dorsal median sulcus and dorsal root entry zone are better tolerated with deep lesions. Lesions located anteriorly in the cervical spinal cord can be approached via cervical corpectomy, which requires anterior interbody arthrodesis and instrumentation at the conclusion of the surgical procedure.

The depth and narrowness of the surgical field in this approach is a challenge. Principles of dural opening, lesion localization and removal, and closure are similar to those of the posterior technique. In the thoracic region, access to the anterior spinal cord can be obtained via thoracotomy with a corpectomy. Although this approach allows adequate visualization of the anterolateral aspect of the spinal cord, the working angle and field depth make surgical conditions less ideal. Watertight dural closure is even more crucial in this location because of the potential to develop a cerebrospinal fluid leak into the pleural cavity. The posterolateral transpedicular approach described by Martin and colleagues[11] can also be used to access lesions in the anterolateral thoracic spinal cord. Details of this approach are summarized here.

- Combined posterior midline and transverse incisions are performed over the appropriate levels, and the thoracic laminae are exposed on the side of the approach.
- Bony elements of the posterolateral thoracic spine are removed using rongeurs and a high-speed drill.

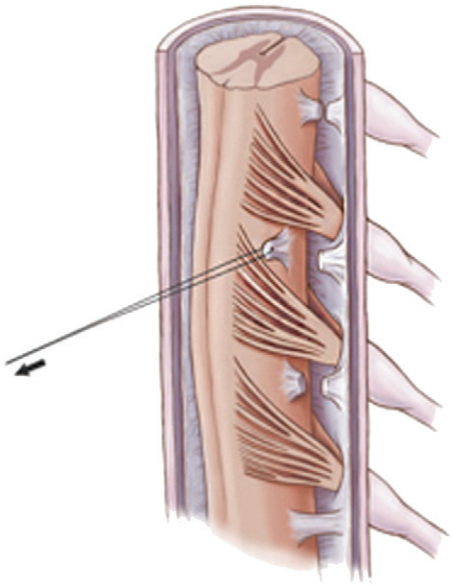

Figure 67-6 Approach to spinal cord lesions located ventrally. Lesions extending to or located on the anterior surface of the spinal cord represent the most challenging surgical approach. They could be accessed via vertebral corpectomy, or they could be exposed from a posterior approach. Dentate ligament closest to the lesion is cut, and 4-0 braided nylon suture is passed through the stump of the ligament. Suture is used to gently rotate the spinal cord to expose the anteriorly located lesion.

- The ipsilateral pedicles at the corresponding levels are removed down to their insertion with the vertebral bodies to expose the lateral aspect of thoracic dura.
- Dural opening is performed along the lateral thecal sac in a fashion similar to the one described for the posterior approach.
- The critical part of the approach is to identify and section the dentate ligament several levels above and below the cavernous malformation. Stitches are placed in the proximal portion of the ligament to facilitate gentle rotation of the spinal cord and expose the ipsilateral ventral portion of the cord and the cavernous malformation, which extends to the pia. Resection of the malformation is then carried out as described in previous sections.
- Limitations of this approach include inadequate visualization of anterior cord surface beyond the anterior midline and ASA. Bilateral posterolateral transpedicular approaches may be performed to expose a lesion that crosses the midline, although such aggressive bony resection will likely require stabilization with instrumentation and fusion at the completion of the procedure.

OUTCOMES

Cavernous malformations of the spinal cord can be resected using contemporary microsurgical techniques with overall improvement in patient condition and natural history. Morbidity and recovery after surgical resection usually mimics a bleeding episode and can be justified if the risk of future bleeding is eliminated. If surgical intervention is attempted, every possible effort should be made to resect the lesion fully to prevent lesion recurrence, regrowth, and rehemorrhage. MRI immediately after surgery can be ambiguous if blood in the operative bed obscures the presence of residual cavernous malformation. This is particularly the case with T2-weighted imaging. Patients should undergo MRI surveillance 6 to 12 months after the initial surgery and 2 to 3 years thereafter. If recurrence is suspected clinically and radiographically, reoperation can be considered. A recently published large case series analysis showed that 11% of patients worsen, 83% remain unchanged, and 6% improve after surgery.[61]

Spinal Cord Arteriovenous Malformations

GENETICS

Several contributing factors to AVM pathology have been isolated, yet the exact mechanisms still bewilder researchers and physicians. Repression of VEGF and angiopoeitin 1 and 2 and their receptor Tie2 have been shown to result in AVM pathology through downstream effects on tumor growth factor β (TGF-β) and vascular instability.[62] Moreover, mutation or deletion of integrin-β8 has an effect on the proper signaling pathway of TGF-β, which causes AVM.[63] The downregulation of endothelin-1 (ET-1) mRNA has also been shown to be involved in the pathophysiology of AVM through anomalous vascular remodeling and dysautoregulation of vessel injury.[64-68] Another molecular factor involved in AVM is endoglin (Eng), which has several roles in vascular physiology, including remodeling of capillary plexi and proliferation of endothelial cells. Patients with type 1 hereditary hemorrhagic telangiectasia also have an *Eng* mutation and subsequently develop AVM pathology, which provides further evidence for its role in AVM.[69] Furthermore, stromal cell–derived factor 1 (SDF-1), a chemokine, is found in the AVM-affected vessels and causes increases in the migration and deposition of endothelial cell progenitors in the involved vessels.[70]

CLASSIFICATION

Historic classification schemes for rare spinal cord AVMs were often confusing, but as case numbers and surgical experience grew, more coherent systems of thought were devised. The classification proposed by Rosenblum and colleagues[71] in 1987 defined four major types of spinal AVMs based on angiographic findings and hemodynamic features (Table 67-1). With later modifications, this system became the most widely accepted system in use. Recent attempts to simplify and offer a more-inclusive system of thought for all AVMs that affect the spinal cord led to a new classification by Spetzler and colleagues,[72] and this system is used for the discussion that follows here.

EPIDEMIOLOGY AND NATURAL HISTORY

Extradural Arteriovenous Fistulas

Extradural-arteriovenous fistulas (Fig. 67-7) are rare lesions. A direct connection between an extradural artery and vein results in venous hypertension, enlargement of the epidural venous complex, mass effect on the spinal cord, and impaired venous outflow. Sometimes these lesions

Table 67-1 Classification Systems for Spinal Arteriovenous Malformations (AVMs)

Traditional Classification*	Spetzler† and Traditional Classifications* of Extradural Arteriovenous (AV) Fistulas
I. AV fistulas located in the dura of the nerve root	1. Extradural AV fistulas, an AVM subtype
	2. Intradural dorsal AV fistulas Single feeders (subtype A) Multiple feeders (subtype B)
IV. Intradural AV fistulas with medullary artery on the pial surface, communicating directly with the pial vein without intervening nidus	3. Intradural ventral AV fistulas Type A (small shunt, low flow) Type B (medium shunt, higher flow) Type C (large shunt, highest flow)
III. Juvenile AVM with abnormal tangle of blood vessels filling the spinal cord at the involved levels and containing neural parenchyma within the nidus of the AVM	4. Extradural-intradural AVM
II. Glomus AVM with localized and tightly coiled intraparenchymal nidus supplied by medullary artery and drained via normal venous routes	5. Intramedullary AVM
	6. Conus AVM

*Rosenblum B, Oldfield EH, Doppman JL, et al: Spinal arteriovenous malformations: a comparison of dural arteriovenous fistulas and intradural AVMs in 81 patients. *J Neurosurg* 67(6):795–802, 1987.
†Spetzler RF, Detwiler PW, Riina HA, et al: Modified classification of spinal cord vascular lesions. *J Neurosurg Spine* 96(2):145–156, 2002.

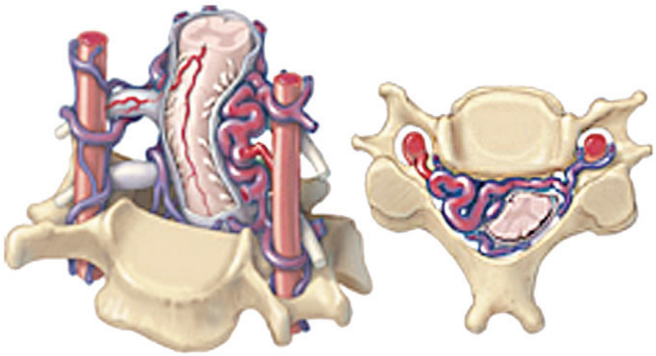

Figure 67-7 Extradural arteriovenous fistulas. (From Spetzler RF, Meyer FB, editors: *Youman's neurological surgery, vol 2,* ed 5, St Louis, 2004, Elsevier.)

present with acute epidural hemorrhage, which requires urgent surgical intervention.[73] When treated promptly, these patients generally have a good prognosis.

Intradural Dorsal Arteriovenous Fistulas

Intradural arteriovenous fistula (Fig. 67-8) is the most common type of spinal vascular malformation, responsible for approximately 30% to 80% of spinal vascular malformations. Men are affected approximately three to five times more often than women.[74] These lesions predominantly

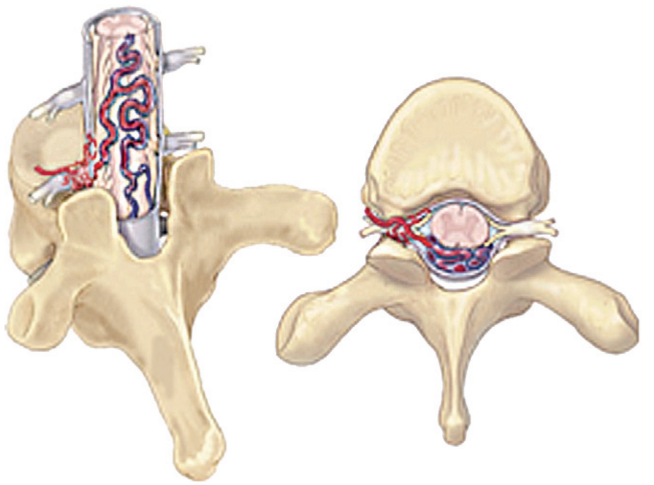

Figure 67-8 Intradural dorsal arteriovenous fistulas. (From Spetzler RF, Meyer FB, editors: *Youman's neurological surgery, vol 2,* ed 5, St Louis, 2004, Elsevier.)

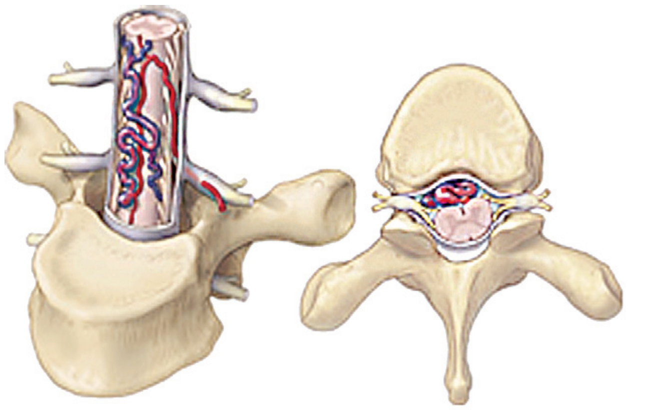

Figure 67-9 Intradural ventral arteriovenous fistulas. (From Spetzler RF, Meyer FB, editors: *Youman's neurological surgery, vol 2,* ed 5, St Louis, 2004, Elsevier.)

occur in the lower thoracic spinal cord and conus medullaris and usually consist of a plexiform low-flow shunt from intervertebral (radicular) arterial feeders or, less frequently, from sacral and hypogastric arteries. The connection to the medullary venous system is within the dural leaflet of the nerve root or immediately adjacent to it; there is no intervening nidus.[73] The shunt produces venous hypertension in the medullary veins, which constitute the sole venous outflow from the coronal venous plexus of the spinal cord. Symptoms are nonspecific and include back pain, weakness, sensory symptoms, and bowel or bladder dysfunction. Hemorrhage is rare, and patients rarely come to medical attention with acute symptoms. Once patients become symptomatic, 90% will become disabled within 5 years if treatment is not initiated.

Intradural Ventral Arteriovenous Fistulas

Intradural ventral arteriovenous fistulas (Figs. 67-9 and 67-10) account for 15% to 30% of spinal vascular malformations and occur in both men and women with equal

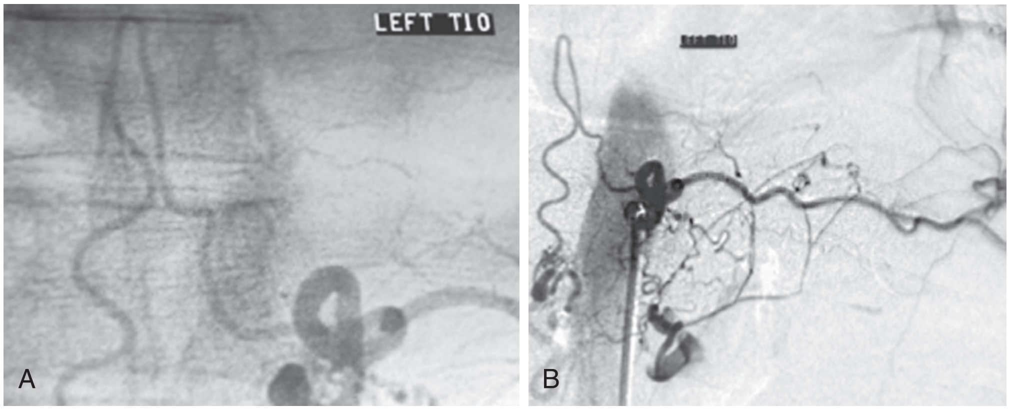

Figure 67-10 Ventral arteriovenous fistula supplied by Adamkiewicz artery. **A,** Non–digital subtraction angiography (DSA) superselective image of the artery forming an arteriovenous fistula. **B,** DSA image of the same patient demonstrates dilated coronal venous plexus of the spinal cord with engorgement of the draining veins.

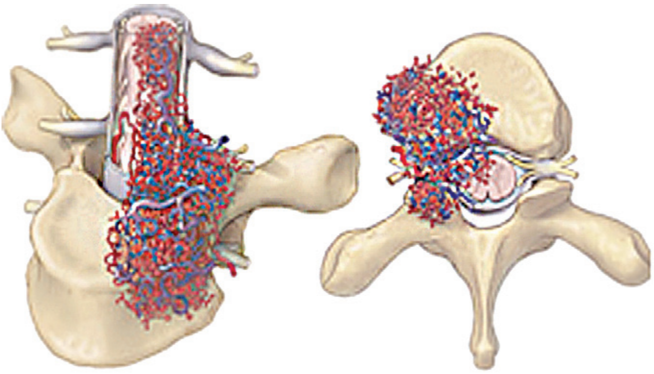

Figure 67-11 Extradural-intradural arteriovenous malformations. (From Spetzler RF, Meyer FB, editors: *Youman's neurological surgery, vol 2,* ed 5, St Louis, 2004, Elsevier.)

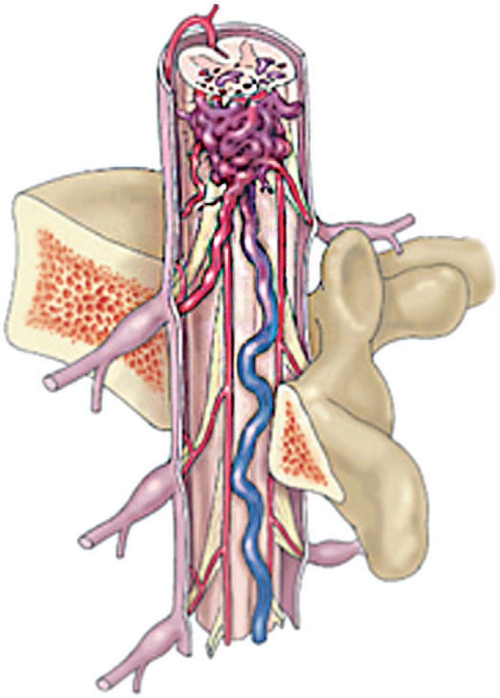

Figure 67-12 Intramedullary arteriovenous malformations. (From Spetzler RF, Meyer FB, editors: *Youman's neurological surgery, vol 2,* ed 5, St Louis, 2004, Elsevier.)

frequency. Mean age at presentation is 45 years; The most typical location is in the thoracolumbar spinal cord and conus medullaris, but these fistulas may be found anywhere; midline lesions derive their blood supply from the ASA or, less frequently, from the PSA with a fistulous component into the superficial venous system of the spinal cord.[75] Patients present with myelopathy, weakness, sensory deficits, pain, or sphincter problems. The incidence of hemorrhage is 10% to 20%, and a progressive course is more typical than an acute presentation.

Extradural-Intradural Arteriovenous Malformations

Extradural-intradural AVMs (Fig. 67-11) are large but rare. Also known as *juvenile AVMs,* they are typically found in the cervical spinal cord in adolescents and young adults. The vascular supply may arise from anterior and posterior spinal arteries and from arteries that feed extradural tissues. These lesions present with hemorrhage, pain, and rapidly progressive neurologic deficit; they may occupy the entire lumen of the spinal canal, and they may extend into the surrounding tissues and bone.[76] It is theorized that these AVMs arise embryologically from a single metamere. They can have an aggressive clinical course, are difficult to treat, and are often considered inoperable. Despite multimodal intervention, prognosis is poor, and as one researcher put it, "their rarity is perhaps the only favorable aspect."[74]

Intramedullary Arteriovenous Malformations

Intramedullary AVMs (Figs. 67-12 and 67-13) are a true AVM but with a nidal component located within the parenchyma of the spinal cord; this type accounts for 15% to 20% of all spinal cord vascular malformations. No gender predilection is apparent, and lesions may be located anywhere in the spinal cord; occasionally, they will extend to a pial surface. The main presenting symptom is acute or progressive myelopathy with or without radiculopathy. These high-flow and high-pressure lesions may harbor aneurysms in approximately 20% to 50% of cases. This leads to a higher

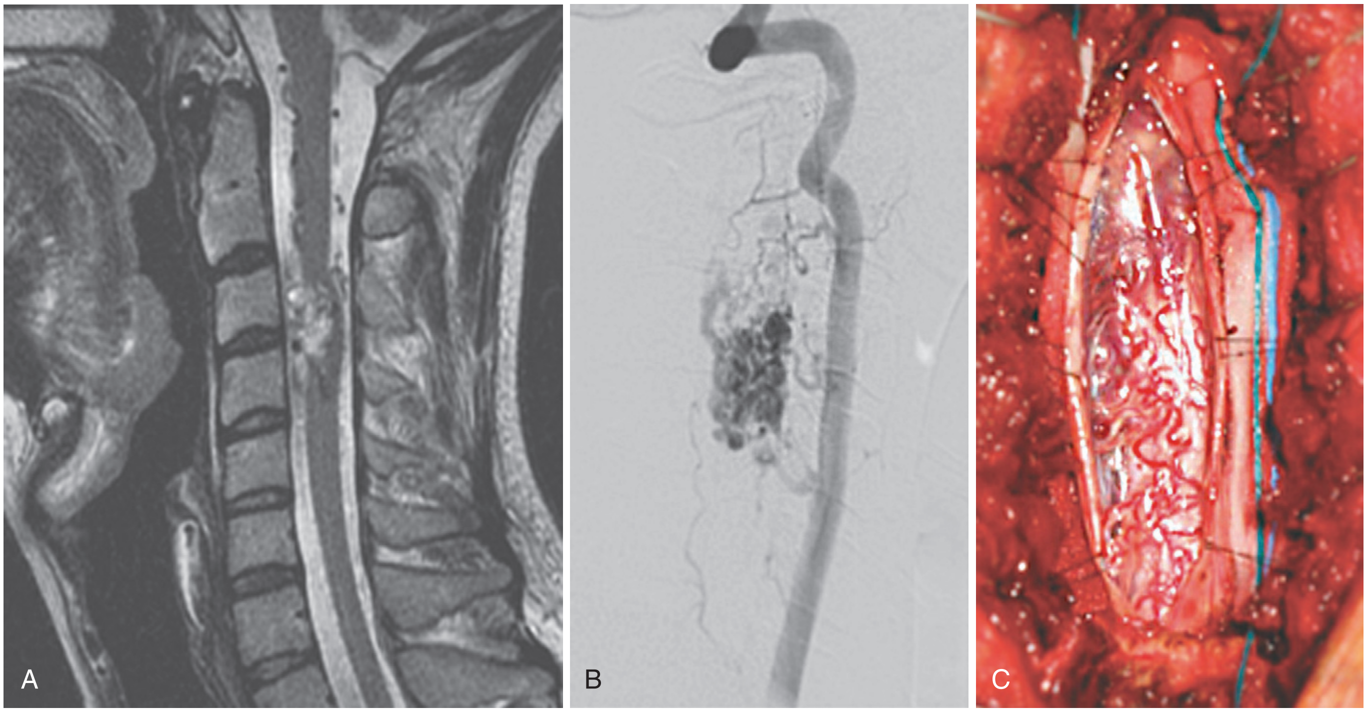

Figure 67-13 Intramedullary arteriovenous malformations (AVMs). **A,** T2-weighted sagittal magnetic resonance imaging demonstrates intramedullary AVM at C3–C4 levels with associated hematoma and flow voids from arterialized coronal venous plexus of the spinal cord. **B,** Selective spinal angiogram of the same patient demonstrates intramedullary AVM supplied mainly by the feeders arising from the left vertebral artery. **C,** Intraoperative image of the same patient. The spinal cord at C3–C4 levels was exposed via laminectomy. Note arterialized venous plexus of the spinal cord.

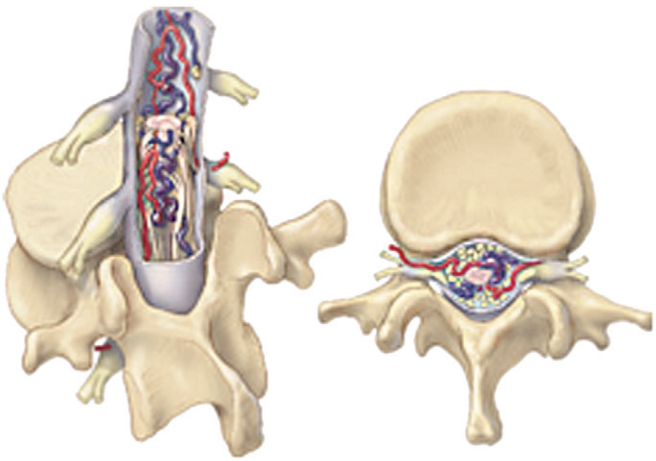

Figure 67-14 Conus arteriovenous malformation. (From Spetzler RF, Meyer FB, editors: *Youman's neurological surgery, vol 2,* ed 5, St Louis, 2004, Elsevier.)

incidence of acute presentation as a result of subarachnoid or intraparenchymal hemorrhage.

Conus Arteriovenous Malformations

Conus AVMs (Fig. 67-14) are location-specific lesions that are rare and complex; they involve the conus medullaris or cauda equina and consist of multiple feeders and multiple nidi with complex venous drainage. The arterial supply arises from the ASA or branches of the PSA.[72] Presentation is nonspecific, and myeloradiculopathy is attributed to mass effect, hemorrhage, or venous hypertension.

PATHOPHYSIOLOGY

By definition, shunting of arterial blood flow into a venous bed without an intervening capillary network is the main feature of any AVM. Histopathologic analysis of a recovered specimen will demonstrate vascular tissue with varying degrees of vessel wall breakdown, particularly in the venous elastic lamina. Shunting of arterial flow results in the cascade of pathophysiologic mechanisms that are responsible for neurologic symptoms. These mechanisms include subarachnoid and intraparenchymal hemorrhage, venous hypertension, vascular steal, arachnoiditis, and mass effect with compression of the spinal cord or nerve roots Depending on the type of vascular malformation, its location, and the nature of the arterial feeders and venous outflow, one or several of these mechanisms may be present. A detailed discussion of AVM pathophysiology is beyond the scope of this chapter.

IMAGING

Although conventional myelography and computed tomographic (CT) myelography have been described as an imaging modality of some value in the past, today the patient is most likely to get an MRI of the spine and spinal cord as an initial imaging step. MRI can demonstrate a dilated, tortuous venous system with flow void signals, enlargement of the cord at the level of the nidus, products of blood degradation in cases of prior hemorrhage, and changes in the cord attributed to venous hypertension, vascular steal, and prior hemorrhage. Current MRI resolution usually does not demonstrate the nidus or fistula, nor can it clearly delineate the feeding and outflow vascular anatomy precisely; thus selective and superselective angiography remain the gold standards for evaluation of spinal cord vascular malformations. Endovascular treatment has a role in management of spinal vascular malformations and sometimes is the only treatment option.

SURGICAL CONSIDERATIONS

It is crucial that the vascular anatomy and flow characteristics of these lesions be understood exquisitely before attempting to treat them surgically. Angiography allows precise localization of the nidus or fistula and allows identification of the vascular supply and venous drainage patterns. It is useful to perform angiography using external markers that will later serve as a reference for the surgical approach. Intraoperative monitoring of somatosensory-evoked potentials (SSEPs) has been demonstrated to improve outcomes after endovascular and surgical stages of treatment. The surgical approach is selected based on the location of the lesion: dorsally located lesions are approached via laminotomy, laminectomy, or hemilaminectomy with facetectomy; intraoperative angiography can be extremely useful, both to locate a lesion and to demonstrate its obliteration.

Before patient positioning, the femoral sheath for angiography is usually placed and secured. The patient is generally positioned prone on chest rolls or a frame, and careful positioning will avoid abdominal compression, which can increase venous pressure in the venous plexus of the spinal cord; venous hypertension can make hemostasis problematic. Alternative positions, such as sitting and lateral positions, can be considered for appropriate lesions.

The skin incision is planned two levels above and below the level of interest. Laminae are exposed using standard techniques, and skin edges and paraspinous musculature are retracted using self-retaining retractors. Alternatively, fishhooks can be used by securing them to Leila bars on either side of the incision; this will depress the edges of the incision, offer a shallower surgical field, and facilitate surgical technique under the microscope. Laminotomy is performed en bloc using a high-speed pneumatic drill with a pediatric footplate tip. Laminae can be reimplanted at closure and secured with either plates or sutures. The dural opening is performed without violation of the arachnoid membrane, and the dural edges are secured to the drapes or paraspinous tissues with 4-0 Neurolon sutures. The microscope is usually brought into the field at this point, although microscopic technique may also facilitate dural opening.

Occasionally, a hemilaminectomy with unilateral facetectomy can be used to gain adequate exposure to dorsolateral lesions, such as intradural dorsal arteriovenous fistulas. Stability is usually not an issue after unilateral facetectomy, but a stabilization procedure can be performed at the time of initial surgery, or as a second stage, after assessment of stability in the postoperative period. The surgical approach to the ventrally located lesions is more difficult. Corpectomy is generally used to gain exposure to the ventral dura. The approach for anterior cervical lesions is similar to that used for anterior cervical corpectomies. Thoracic lesions can be approached via thoracotomy, and a retroperitoneal approach is used for lumbar lesions. Approaches to ventrally located lesions require a surgical stabilization procedure at the completion of the operation.

SURGICAL TECHNIQUE

Extradural Arteriovenous Fistulas

Surgical treatment of extradural arteriovenous fistulas is focused on interrupting the shunt into the venous plexus of the cord. The lesion is exposed posteriorly using one of the approaches previously described. The feeding vessel is identified and sacrificed using electrocautery and is interrupted with microscissors.

Intradural Dorsal Arteriovenous Fistulas

- The goal of surgical treatment is to eliminate venous hypertension by interrupting communication between the fistula and venous plexus of the spinal cord.
- Rarely, these lesions may be considered for endovascular obliteration, but in general, they are considered surgical cases.
- After the dura is opened, the operative microscope is brought into the surgical field.
- The arachnoid is opened with microscissors, and the edges are secured to the dura using small hemoclips or sutures. The underlying veins of the coronal venous plexus can be quite dilated, and caution should be exercised while opening the arachnoid over them.
- Vascular anatomy should be explored to differentiate the efferent vein from the fistula, which is generally located in the dural leaflet along the nerve root sleeve. Temporary interruption of the fistula can be accomplished using temporary aneurysm clips.
- The coronal venous plexus is observed for decreased venous distension as a result of interruption of the shunt. If this phenomenon does not occur, it means additional vascular contribution to the coronal venous plexus may exist, and intraoperative angiography can be used to identify it.
- Once the fistula site is confirmed, the fistula itself is cauterized using bipolar cautery, and it is sharply sectioned. Temporary clips are removed, and the venous plexus is inspected for resumption of normal venous color and distension.
- The dura is closed in a standard watertight fashion, followed by standard multilayer soft tissue and skin closure.
- General anesthesia is reversed at the end of the case, and the patient's neurologic function is assessed in the operating room.
- Patients should undergo an intraoperative or postoperative angiogram on the first postoperative day to evaluate the completeness of the surgical intervention. If the fistula is not completely obliterated, serious consideration must be given to reexploration.

Intradural Ventral Arteriovenous Fistulas

- The goal of surgery is to interrupt the communication between the arterial feeder—or, rarely, *feeders*—that arise most often from the ASA and draining veins on the pial surface. These lesions do not have a formal nidus and are superficial.

- Many surgeons agree that type A and some type B lesions should be approached surgically, not endovascularly, because the fistula is very small, and attempting embolization can result in occlusion of the ASA with devastating neurologic sequelae.
- Anterior approaches to the spinal cord are described in preceding sections. The dura and arachnoid are opened in the usual manner.
- The ventral surface of the spinal cord is explored using the operative microscope, and the location of the fistulous connection is established. Feeders that arise from the posterior spinal arteries must also be interrupted. The veins on the pial surface drain normal tissue and should be preserved during dissection.
- Whenever possible, the fistula should be interrupted using clip ligation, rather than bipolar electrocautery, because of possible current spread and coagulation of the ASA with devastating neurologic consequences.
- Veins in the ventral surface of the cord are observed for color change and collapse after fistula obliteration. If the veins remain arterialized, additional feeders must be located and ligated.
- Dural closure is performed in a standard watertight fashion, and soft tissues and skin are closed in a multilayer fashion.

Extradural-Intradural Arteriovenous Malformations

- Surgical experience with extradural-intradural AVMs is limited owing to their rarity. Only a few cases of successful treatment of extradural-intradural AVMs appear in the literature.
- Many surgeons accept these lesions as inoperable, and endovascular treatment predominates in their management. Surgical or endovascular treatment is often palliative in nature and aimed at reducing shunt flow to ameliorate neurologic symptoms from venous hypertension or mass effect.
- When surgery is an option, it is performed in a staged fashion in combination with preoperative embolization. The surgical techniques used are described in the sections of this chapter for the other types of vascular malformations.

Intramedullary Arteriovenous Malformations

- A combined endovascular and surgical approach is considered to be most effective for the management of intramedullary AVMs.
- Laminectomy and dural and arachnoid openings are performed as described earlier.
- Sharp arachnoid opening and dissection are performed, because use of bipolar electrocautery may result in current spread to the adjacent dilated veins that drain the normal spinal cord.
- Arachnoid dissection should be performed carefully to avoid damage to the underlying distended veins. Because these AVMs are high-flow and high-pressure lesions, hemostasis can be very problematic, and all attempts should be made to avoid violating the integrity of the distended venous vasculature.
- No vessel should be coagulated and interrupted until it has been clearly determined to supply the nidus of the AVM. This can be best ascertained by intraoperative exploration or angiography. As with cerebral AVMs, arterial feeders must be sacrificed before the venous outflow is disconnected; otherwise, a devastating rupture of the nidus could ensue.
- Midline or paramedian myelotomy is performed if nidus of the AVM is deep and does not reach the pial surface. The paramedian myelotomy can be considered if the patient already has fixed sensory deficit.
- A very thin gliotic plane often surrounds the nidus of the AVM. Resection of the nidus is undertaken using bipolar electrocautery within this plane by interruption of the small penetrating vessels. Penetrating vessels should be cauterized and cut with microscissors as close to the nidus as possible, because proximal portions of the vessel tend to retract into the cord parenchyma and continue bleeding. Chasing these vessel stumps with electrocautery risks damaging the adjacent spinal cord tissue.
- Many AVMs harbor aneurysms, which can be obliterated using bipolar electrocautery during the early stages of nidus resection. This maneuver gains additional working space for nidus dissection.
- When contribution from the ASA is significant, hemostasis may become an issue, because these feeders may be deep to the nidus. Early identification and interruption of these feeders may decrease the amount of intraoperative bleeding and volume of the nidus. Extreme caution must be used when working near the ASA.
- Very meticulous hemostasis and minimal cord manipulation is imperative for successful resection with minimal neurologic deficit.
- Closure is performed in the standard fashion.

Conus Arteriovenous Malformations

Because of their complexity, conus AVMs often require a staged, combined endovascular and neurosurgical approach. Embolization could be used as either a definitive treatment or as an adjunct to surgical resection. Operative technique incorporates approaches and surgical techniques described earlier for intramedullary malformations and intradural fistulas.

Spinal Cord Aneurysms

Spinal cord aneurysms are extremely rare, and only sporadic cases are described in the literature. Spinal cord aneurysms can be classified into two basic groups: those that arise within the abnormal vasculature of preexisting vascular malformations and isolated aneurysms that form without any associated vascular anomalies.

Aneurysms are also rooted in other pathologies, such as Marfan syndrome, and they represent the major cause of mortality in Marfan syndrome. Ehlers-Danlos syndrome pathology is strongly associated with cerebrovascular complications, namely aneurysms,[77] although intracranial aneurysms are the prevalent form of aneurysm in patients with Ehlers-Danlos syndrome type IV.[77,78]

Patients with spinal cord aneurysms usually come to medical attention with subarachnoid or intraparenchymal hemorrhage. Treatment of the aneurysms within the nidus of an AVM was described earlier. Isolated aneurysms can be clipped or treated using endovascular techniques. Surgical approaches to specific spinal regions are described in previous sections.

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SECTION H

Inflammatory Disease

68 Ankylosing Spondylitis: Posterior Approaches (Osteotomy) to the Cervical and Lumbar Spine in the Management of a Fixed Sagittal Plane Deformity

ALAN HILIBRAND, MAURICE GOINS, and CHRISTOPHER KEPLER

Overview

Ankylosing spondylitis (AS) is a chronic inflammatory disease of unknown etiology that affects approximately 197 people per 100,000 per year in the United States with a male-to-female predominance of approximately 3 : 1. An idiopathic seronegative spondyloarthropathy, AS is strongly associated with the class I antigen HLA-B27. The sacroiliac joints and the axial skeleton are most commonly affected by AS, but clinically significant peripheral joint involvement may also occur. The chronic inflammatory nature of the condition causes stiffness and loss of lordosis or increased kyphosis of the spine through destruction and autofusion of the vertebral motion segments. This can ultimately lead to a dramatic imbalance of sagittal alignment, causing severe deformities throughout the cervical, thoracic, and lumbosacral spine (Fig. 68-1).

Osteotomy for Correction of Kyphotic Deformity of Ankylosing Spondylitis

INDICATIONS

Involvement of the cervical spine in patients with AS is often overlooked, because lumbar spine and appendicular sequelae may be more obvious. Cervical kyphosis may slowly progress in an insidious fashion, resulting in the development of a chin-on-chest deformity. When cervical kyphosis progresses to the point of causing difficulty with function and hygiene, a corrective cervical osteotomy is indicated. Functional difficulty may present as dysphagia or inability to lift the head to allow forward gaze. Inability to achieve forward gaze inhibits activities of daily living, such as forward ambulation and ascending and descending stairs. Also, difficulty swallowing solids may cause malnourishment. In addition to the cervical spine, the thoracic and lumbar spine may contribute to the kyphotic deformity.

Kyphosis of the ankylosed thoracic spine usually does not progress sufficiently to require surgical intervention. When it occurs in AS, increased thoracic kyphosis often goes unnoticed owing to the naturally occurring thoracic kyphosis. The combination of this natural kyphosis and the relatively small thoracic spinal canal places the thoracic spinal cord at higher risk of traction and ischemic injury with osteotomy.

In the lumbar spine, AS presents as low back pain for more than 3 months duration, stiffness, diminished range of motion, and hypolordosis. Osteotomy is the procedure of choice to address severe, fixed kyphotic deformities in the lumbar spine that result from AS. The midportion of the lumbar spine is the safest area for correction, below the termination of the spinal cord (i.e., the conus medullaris at the L1–L2 level). Correction of kyphotic deformity of the lumbar spine via osteotomy may be safer than in the cervical spine because of the potential to perform the correction below the level of the spinal cord. In cases of coexisting deformities of the cervical and lumbar spine, osteotomy of the lumbar spine is generally preferred for this reason, and also because it can simultaneously correct the forward gaze and lumbar kyphosis. Patients with preexisting cervical kyphosis who come to medical attention with acute cervical spine fractures that require surgical stabilization may occasionally be treated with osteotomy to simultaneously stabilize the acute fracture and correct the functionally limiting deformity.

CONTRAINDICATIONS

Extraarticular manifestations of AS include aortic incompetence, cardiac conduction defects, fibrotic lung disease, and renal amyloidosis. These extraskeletal expressions of AS can present a significant risk for serious perioperative complications, including cardiopulmonary compromise and renal insufficiency. In some instances, the severity of these concomitant medical conditions may result in an

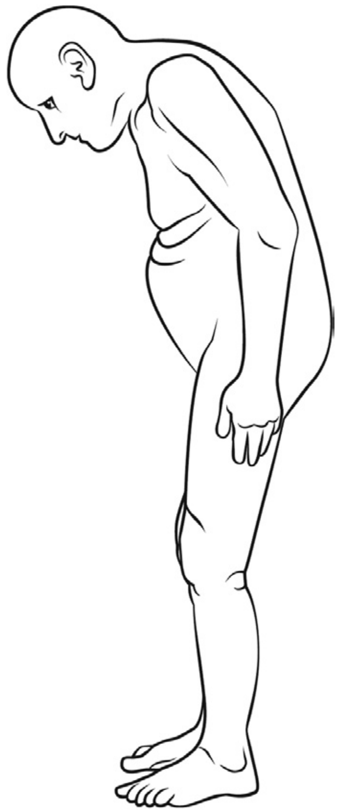

Figure 68-1 A patient with ankylosing spondylitis.

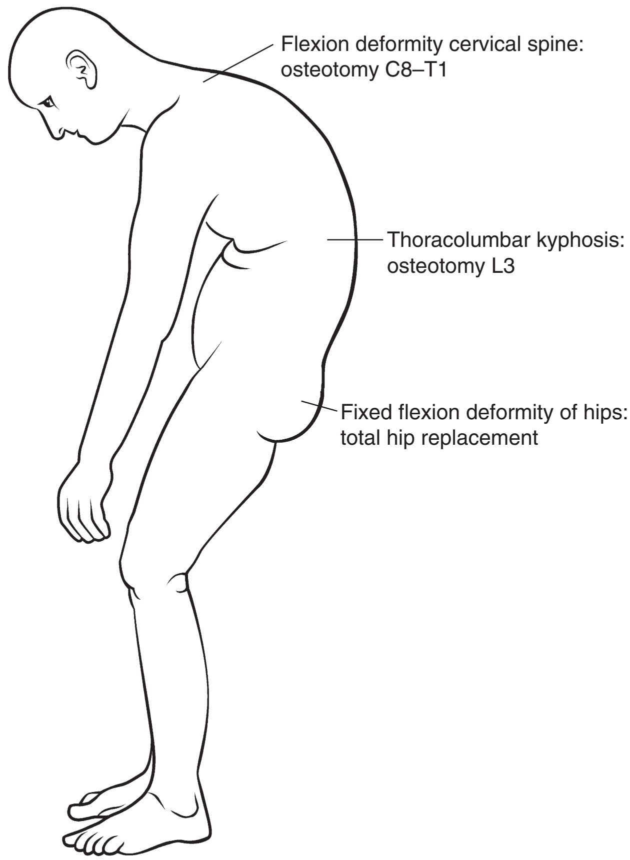

Figure 68-2 Anatomic sites of deformity in ankylosing spondylitis and their surgical correction.

unacceptably high level of morbidity for the patient to tolerate surgery, and careful preoperative evaluation is warranted.

Appendicular skeletal manifestations of AS, such as hip-flexion contractures and osteoarthritis, may exaggerate a kyphotic spinal deformity by tipping the patient forward, thereby worsening effective sagittal balance. Correction of hip pathology in AS is safe and efficacious and should be addressed before spinal management.

POSTERIOR CERVICAL OSTEOTOMY FOR CORRECTION OF KYPHOTIC DEFORMITY OF ANKYLOSING SPONDYLITIS

Advantages

- High degree of correction
- Single-level surgery for correction
- Availability of segmental internal fixation for precise control and maintenance of osteotomy correction

Disadvantages

- Risk of neurologic injury (infrequent)
- Risk of vascular injury
- Technically demanding
- Inability to correct concomitant lumbar deformities

Preoperative Evaluation

Preoperative evaluation begins with a thorough history and physical evaluation. The medical history should focus on premorbid conditions that may compromise surgical treatment and recovery. In addition to evaluating the entire spinal column, the musculoskeletal examination should also evaluate the hip joints, which are often affected by osteoarthritis in AS. As a result, loss of the normal chin-brow vertical angle either occurs as a result of flexion deformity throughout the spine or through fixed hip-flexion contractures (Fig. 68-2). Surgical correction should be planned for the area of the major deformity after conducting a thorough medical evaluation.

Measurement of the chin-brow and sagittal vertical angles is necessary for preoperative planning of the degree of correction needed from the osteotomy (Fig. 68-3). In addition, the inion-wall angle can also be helpful in preoperative planning; it is measured by standing the patient against the wall and measuring the distance between the wall and the inion at the base of the skull. This provides another useful tool for monitoring the progression and subsequent correction of cervical kyphosis.

Once the chin-brow angle has been determined, the angle necessary to bring the face to within 10 degrees of horizontal gaze can be calculated. The goal is to provide a reasonably safe correction to improve the patient's ability to perform the activities of daily living that rely on forward gaze, such as grooming, eating, reading, and ambulation. Correction beyond neutral (overcorrection) is not recommended, because a fixed gaze above the horizon creates significant difficulty for the patient during straightforward ambulation and stair descent.

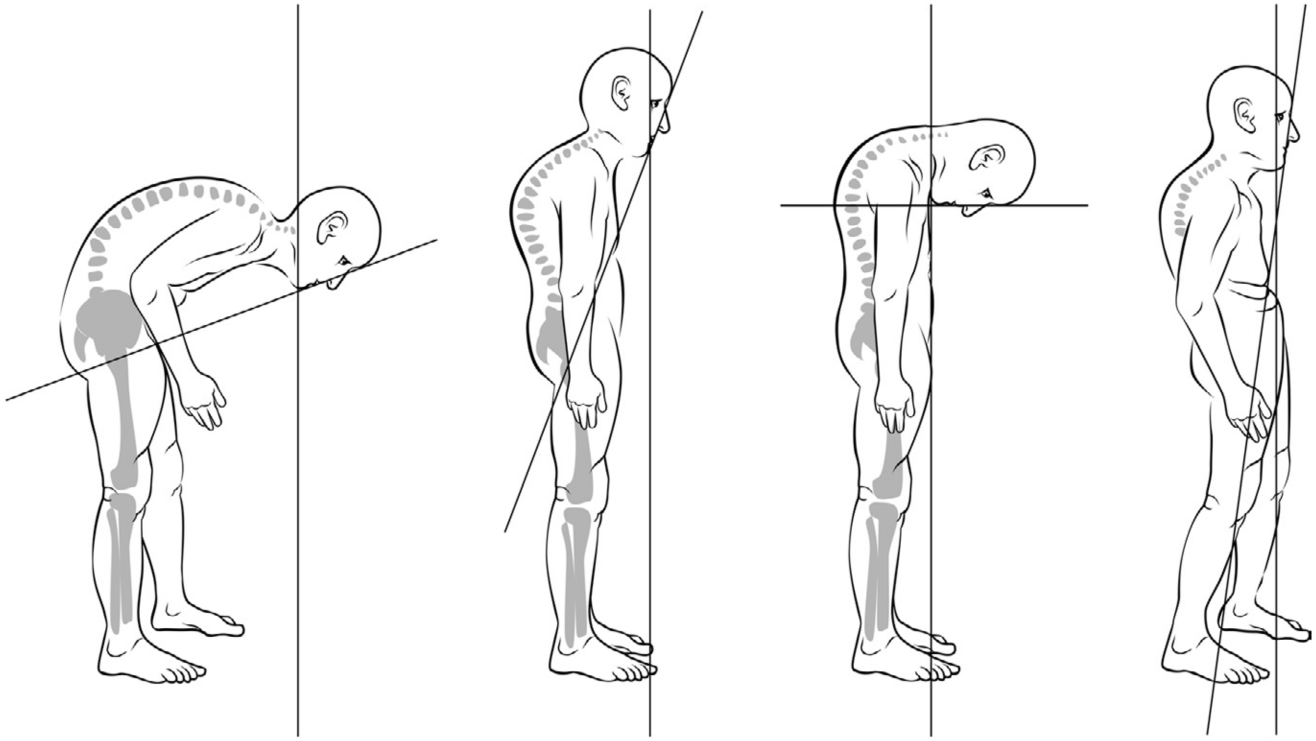

Figure 68-3 Measurement of sagittal-vertical and chin-brow angles in preparation for ankylosing spondylitis deformity correction surgery.

To view the entire spine and assist with determining the level for corrective osteotomy, lateral radiographs of the entire cervical, thoracic, and lumbar spine on a 36-inch cassette are necessary. A sketch of the spinal osteotomy can be drawn on tracing paper, which can also be used to outline the surgical algorithm. Alternatively, the osteotomy and operative plan can be written on radiographs with a wax pen (Fig. 68-4).

One day before surgery, the patient should be admitted to the hospital. This allows for the application of a halo cast with a contoured plaster jacket. After the halo cast is applied, the patient is placed in a seated position to evaluate for potential areas of undue pressure that will be placed on the patient intraoperatively. If necessary, areas of the cast that could contact pressure points are trimmed, and these are well padded.

The restrictive nature of a kyphotic posture causes many patients with AS to have a protuberant abdomen, which affects their breathing (Fig. 68-5); therefore the abdominal portion of the contoured body cast must avoid compression that might inhibit respiratory function. The cast is also modified posteriorly to allow access to the cervical and upper thoracic spine. Preadmission also allows for the establishment of central venous access, which is necessary for intraoperative hemodynamic monitoring by the anesthesiologist. Completing these procedures before surgery maximizes patient safety and surgical efficiency when the patient arrives in the operating room.

Intraoperative Technique

1. After awake fiberoptic intubation and induction of anesthesia, the patient should be placed in a beach chair position.
2. It is imperative to have the appropriate neurophysiologic monitoring available throughout the entire procedure; if available, this should include transcranial-evoked motor potentials, somatosensory-evoked potentials, and C8 dermatomal-evoked potentials.
3. If neurophysiologic monitoring is unavailable, the procedure should be performed under local anesthesia.
4. The patient is positioned on the operating table in the seated position, and the halo cast is secured to the table. Cervical traction is then applied to the halo to stabilize the head and cervical spine (Fig. 68-6). The posterior support bars of the halo may be removed if they hinder the approach to the cervical spine.
5. Following the induction of general anesthesia, transesophageal echocardiographic monitoring should be established to assist with detection of a possible air embolus, which may occur secondary to the patient's upright position. Air can be removed via the central venous pressure line if necessary.
6. The posterior cervical spine is approached through a standard midline incision, and Gelpi retractors are used to provide exposure. Meticulous hemostasis is essential. Subperiosteal dissection should widely expose the laminae, facet joints, and transverse processes.
7. The C7–T1 interval is identified with intraoperative radiographs. Performing the osteotomy at the cervicothoracic junction minimizes the risk of injury to the vertebral artery, which enters the transverse foramina at the C6 level in the majority of patients (Fig. 68-7).
8. The incision should be long enough to allow placement of fixation in four spinal segments proximally and distally from the osteotomy level.

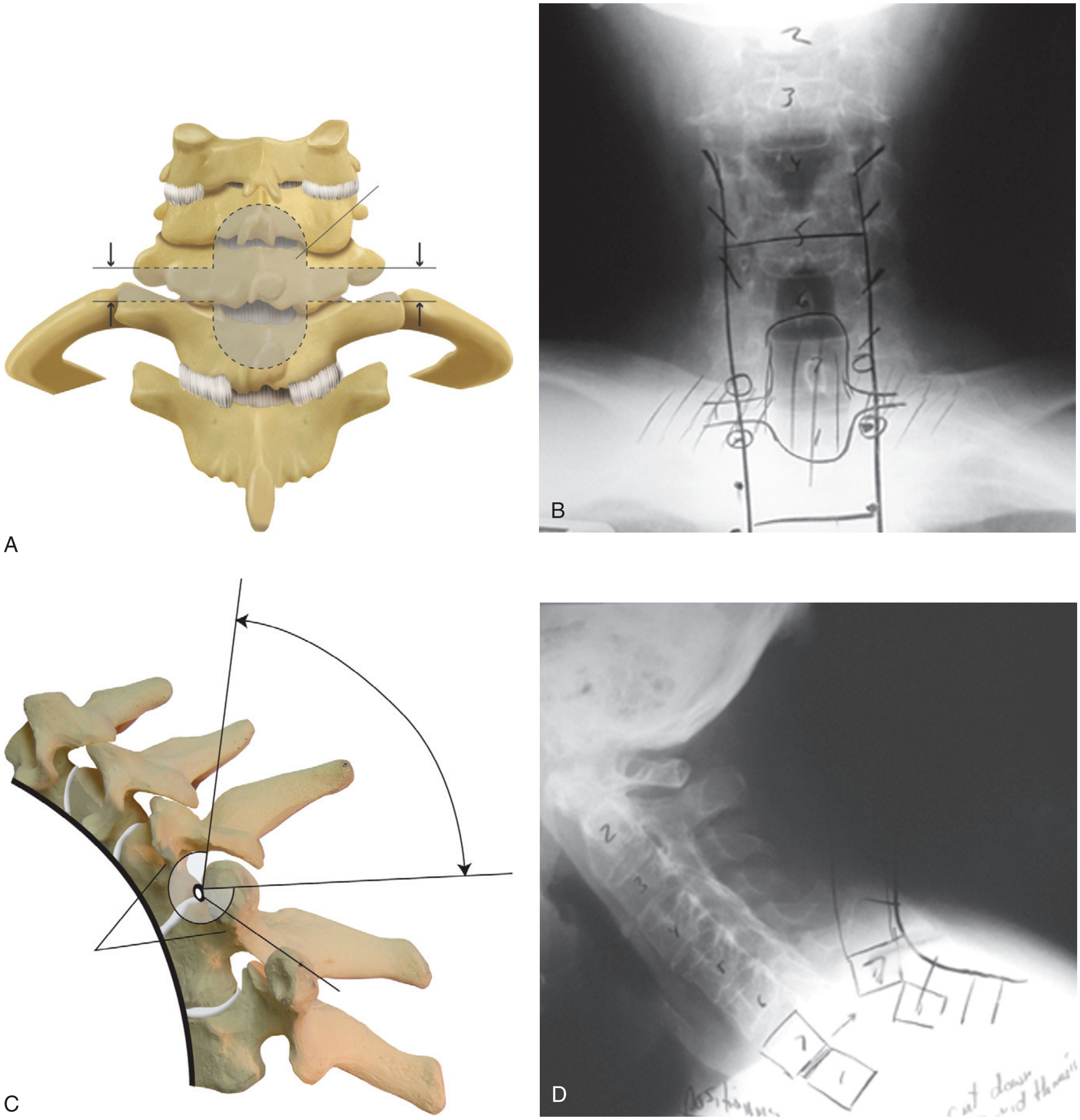

Figure 68-4 **A,** Anteroposterior (AP) schematic of preoperative planning for posterior cervical osteotomy. **B,** AP radiograph shows preoperative planning for posterior cervical osteotomy. **C,** Lateral schematic of preoperative planning for posterior cervical osteotomy. **D,** Lateral radiograph shows preoperative planning for posterior cervical osteotomy.

9. To minimize the amount of time the osteotomy will be vulnerable to displacement, internal fixation points should be established before resection of bony elements and osteotomy. Segmental instrumentation is usually placed to before lateral mass screw fixation at C3, C4, and C5 and pedicle screw fixation distal to the osteotomy site, typically at T2 to T4.
10. A wide laminectomy of C7 and a partial laminectomy of C6 and T1 should be performed. This will prevent cord compression that can occur after closing the osteotomy because of impingement by the laminae of adjacent levels (Fig. 68-8).
11. After performing the laminectomy, remove the C7 pedicles using a rongeur and motorized burr. This should be done very carefully to avoid iatrogenic nerve injury to C8 or C7.
12. Next, any remaining soft tissue or bone that contacts the C7 and C8 nerve roots should be resected (Fig. 68-9).
13. Osteoclasis is now performed with extreme caution by gradually extending the patient's cervical spine from its

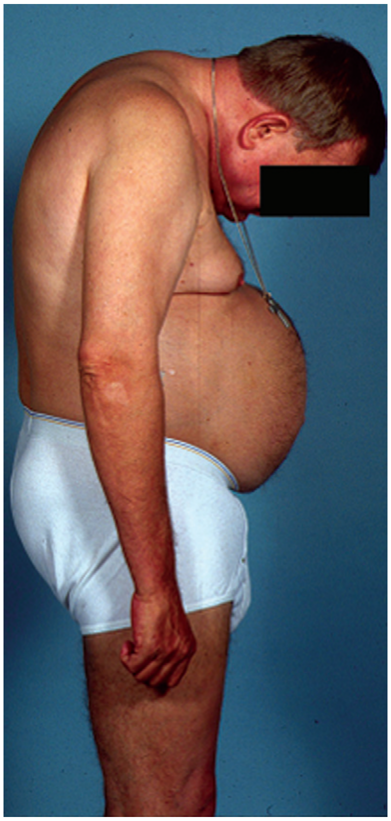

Figure 68-5 Patient with ankylosing spondylitis with protuberant abdomen secondary to pulmonary restriction.

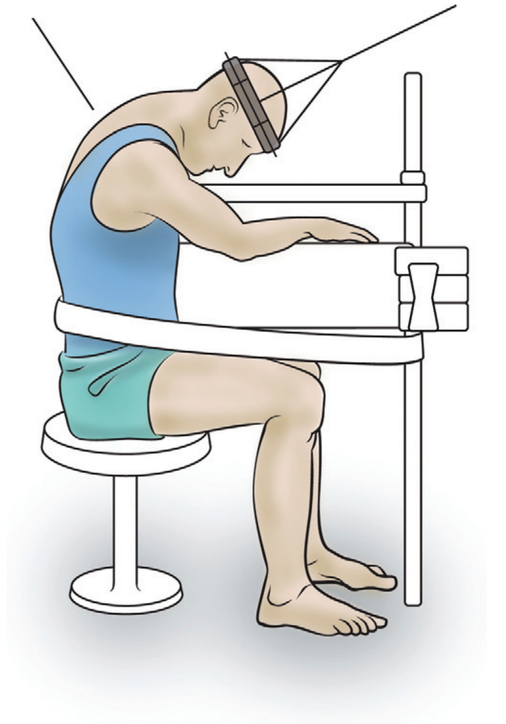

Figure 68-6 Patient with ankylosing spondylitis in upright position and cervical traction in preparation for posterior cervical osteotomy.

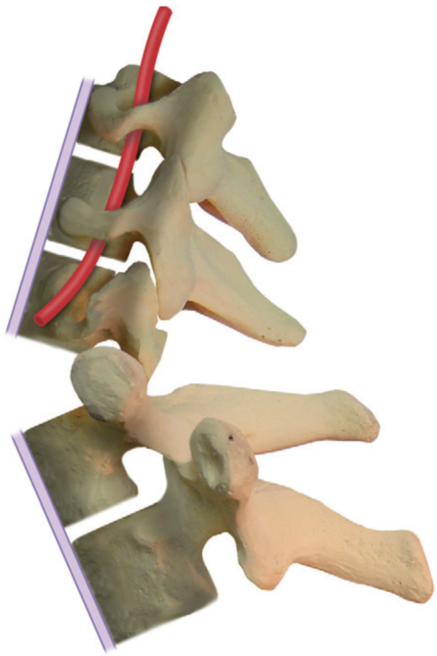

Figure 68-7 Schematics show the location of the prominent vasculature in the cervical spine relative to the posterior cervical osteotomy site.

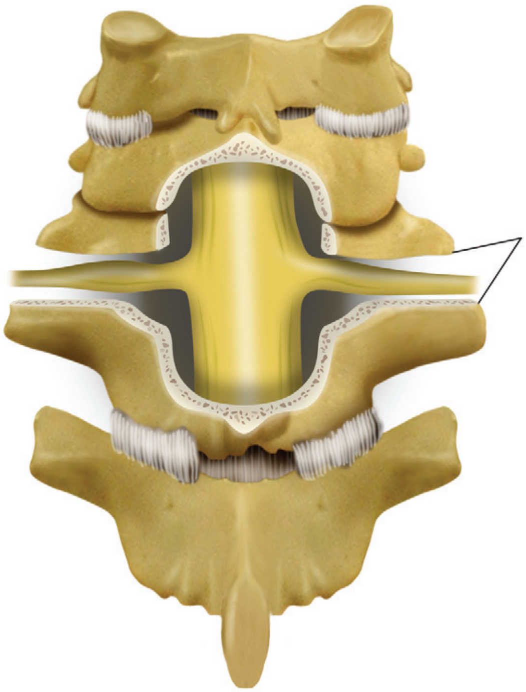

Figure 68-8 Posterior cervical osteotomy with wide laminectomy of C7 and partial laminectomy of C6 and T1.

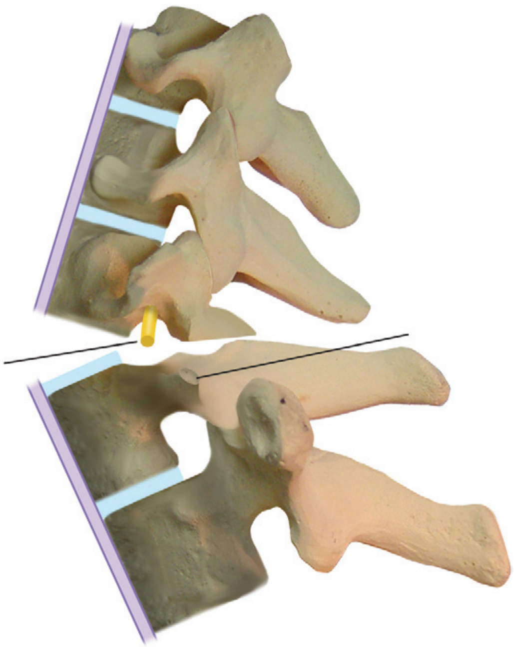

Figure 68-9 Lateral cervical schematic following removal of tethering bone and soft tissue near C8 nerve root following osteotomy and osteoclasis.

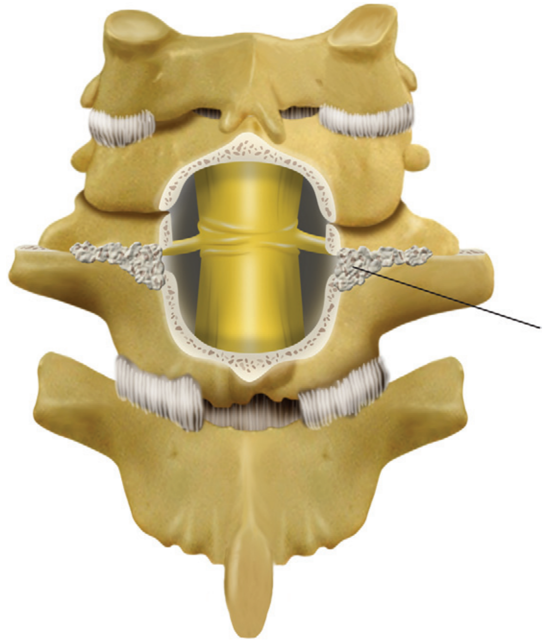

Figure 68-10 Closed posterior osteotomy with local bone graft supplementation.

kyphotic position. It is imperative that neurophysiologic monitoring be performed before, during, and after osteoclasis. Special attention must be paid to avoiding anterior or posterior translation of C7 onto T1, which may lead to spinal cord compression.

14. The head should be positioned such that the gaze will be directed approximately 10 degrees downward from standing horizontal gaze after the correction is secured. This will minimize the risk of overcorrection. Having the patient seated in an upright position allows easy visual assessment of the patient's horizontal gaze.
15. As the desired amount of correction is approached, the spinous processes of C6 and T1 should approximate each other, yielding adequate bony apposition of the remaining transverse processes of C7 and T1 to promote fusion. At this time, readjust and secure the halo in position to stabilize the cervical spine.
16. Internal fixation points should now be connected via longitudinal rods.
17. After closing the osteotomy and securing it in position with instrumentation, autologous bone graft from the resected posterior elements may be used to supplement the arthrodesis (Fig. 68-10).
18. Closure of the wounds is often difficult. We recommend fascial closure and meticulous skin closure using interrupted vertical mattress sutures. Retention sutures may also be needed to assist with approximation of wound edges.
19. The posterior aspect of the halo–vest may be replaced to provide further mechanical support.

Postoperative Management

The sudden change in cervical positioning may cause formation of a retropharyngeal hematoma, which can potentially lead to airway compromise. Dramatic fluid shifts also occur postoperatively as patients go from an upright operative position to a supine postoperative position. In addition, many patients have underlying pulmonary compromise as a result of restrictive lung disease, and large fluid shifts in these patients create an environment in which congestive heart failure can develop. As a result, we recommend that patients with restrictive lung disease remain intubated in an intensive care unit until airway and cardiopulmonary function have stabilized.

Because the fulcrum of rotation for the osteotomy is along the posterior vertebral cortex, the anterior column of the spine is lengthened. Structures anterior to the spine, therefore, are very vulnerable to stretch and traction injuries, including the esophagus. This often leads to postoperative dysphagia that may necessitate a period of parenteral nutrition. For prolonged dysphagia, we recommend placement of a feeding tube. In addition, we also recommend that the surgical team keep a cast saw at the patient's bedside in the event that rapid removal of the halo-vest is required. Postoperative immobilization in a halo-vest is mandatory for 6 to 12 weeks. After this, the patient is placed in a standard Philadelphia collar for another 6 to 8 weeks. Radiographs are taken at 1-, 3-, and 6-month intervals to evaluate fusion and graft incorporation.

Complications

Significant neurovascular complications may occur following cervical osteotomies, including spinal cord compression or traction that causes paraparesis or paraplegia, vascular injury to the spinal cord that causes anterior spinal cord ischemic injury, and nerve-root impingement that results in radiculopathy. Performing the operative procedure in the seated position also brings the additional risk of air entering the low-pressure venous system and causing an air embolus.

If this occurs, the wound should be immediately filled with irrigant and moist sponges to prevent air from entering the low-pressure venous system. Additional complications such as infection, nonunion, malunion, dysphagia, halo-pin loosening, and loss of fixation with recurrence of kyphotic deformity may potentially occur in the postoperative period.

PEDICLE SUBTRACTION OSTEOTOMY FOR KYPHOTIC DEFORMITY OF THE THORACOLUMBAR SPINE

Advantages

- Achieves posterior correction via a single osteotomy
- Avoids anterior approach
- Avoids anterior gap that may occur after Smith-Peterson technique
- Eliminates need for multiple osteotomies
- Reduces distraction/stretch of abdominal structures
- May improve forward gaze and avoid or delay the need for correction of cervical kyphosis in patients with deformities of both regions

Disadvantages

- Potential for excessive blood loss
- Potential for neurologic injury

Preoperative Evaluation

Localize any levels of deformity: cervical, thoracic, or lumbar.

- Full-length radiographs to review spinal alignment
- Specialized views to assess for correction
  - Traction
  - Hyperextension
- Radiographic assessment
  - Sagittal vertical axis
  - Regional assessment of lordosis and kyphosis
  - Chin–brow angle
  - Trace deformity and plan corrective osteotomy site
  - Plan hardware insertion

Location of Osteotomy

Osteotomies performed in the lumbar spine in patients with AS often provide sufficient correction such that additional osteotomies in the cervical or thoracic spine are usually unnecessary. Ideally, lumbar osteotomy is performed at or below L2. This places the osteotomy below the level of the conus medullaris and the rib cage and above the level of the aortic bifurcation, thus minimizing surgical complications.

Operative Technique

Equipment

- Fluoroscopy- and radiography-compatible table
- Fluoroscopy
- Straight and angled curettes
- Kerrison punches
- Rongeurs
- Stille-Horsley bone-cutting forceps
- Impactor
- Bechman-Adson retractor
- Adson cerebellar retractor
- Gelpi retractors
- Osteotomes
- Scoville nerve root retractor
- Pedicle screw fixation system
- Red blood cell recovery system
- Neurophysiologic monitoring

Patient Positioning. Once intubation, general anesthesia induction, and placement of appropriate hemodynamic and neurophysiologic monitors are complete, the patient is carefully turned onto the operating table into the prone position. Proper surgical positioning for a patient with a severe kyphotic deformity is challenging but not impossible. We recommend using a radiolucent table that flexes to accommodate the patient's posture. Extension of the table will assist with reduction after completion of the osteotomy (Fig. 68-11). It is critical to meticulously pad all bony prominences and ensure that no undue pressure is exerted on the ocular region. In addition to evaluating these areas at regular intervals, they must also be evaluated after a change in table position from a flexed to an extended posture.

Alternatively, to accommodate the kyphotic posture, the patient's trunk could be placed on a four-poster frame, omitting the thigh supports (Fig. 68-12). This will assist with positioning by allowing the hips to flex and the knees to touch the table at the level of the kidney rest. Elevation of the kidney rest later in the procedure will assist with reduction of the patient's deformity. Pillows should also be used to maintain knee flexion; this will decrease the amount of tension placed on the sciatic nerve when the reduction maneuver is eventually performed.

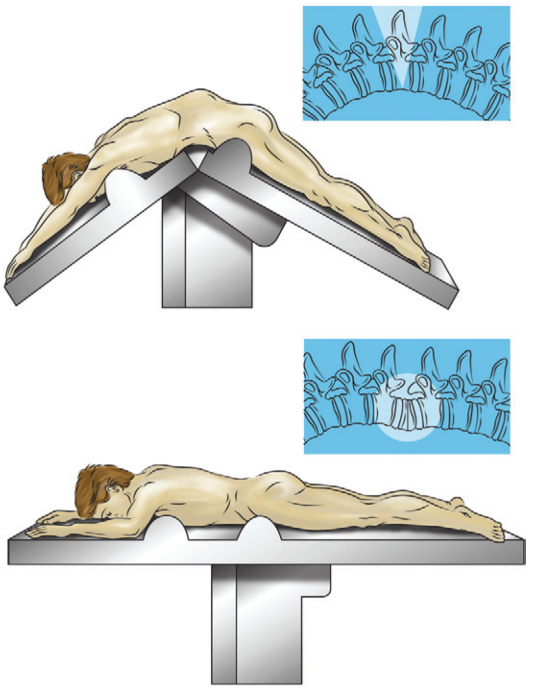

Figure 68-11 Patient positioning for lumbar pedicle subtraction osteotomy shows table extension to close the osteotomy site.

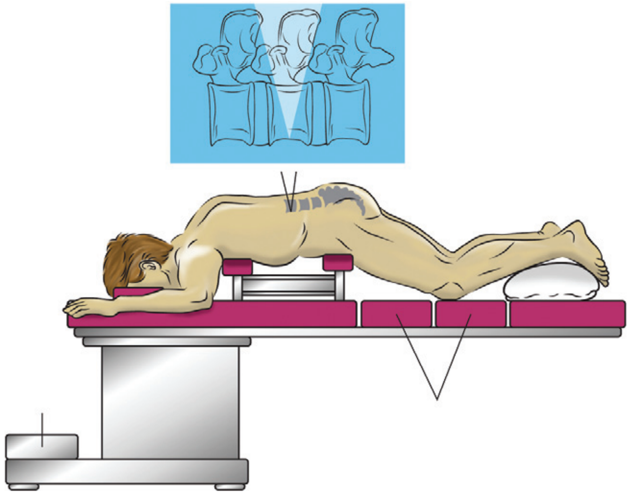

Figure 68-12 Alternative patient positioning for lumbar pedicle subtraction osteotomy to accommodate kyphotic posture with hip flexion and kidney rest supports.

Another option is to perform the procedure on a Jackson lordosing table. The head may be suspended with cranial tongs to prevent undue pressure on the face. On this table, the patient's pelvis and iliac crests may be suspended above the bed but will be reduced down toward the hip bolsters once the correction is performed. The lordotic nature of the frame will provide the reduction force to reduce the osteotomy.

Location of Incision. The spine should be exposed through a midline posterior approach, centering over the level of the osteotomy; this is usually done at the center of the lumbar lordosis (L3–L4), although recent study has shown that the level of osteotomy has little effect on the degree of correction achieved. The skin incision is marked in a longitudinal fashion to allow exposure from T12 to the sacrum.

Intraoperative Technique. After the skin incision is marked, the surgical area is cleaned and draped in the usual sterile fashion. The area is widely prepped to include the iliac crest, in case autograft bone harvesting is necessary because of insufficient local bone graft.

1. Incision is made, and soft-tissue dissection is performed.
2. The lumbar spine is exposed through a standard posterior midline approach.
3. The incision is taken down through the subcutaneous tissues to the fascia, which is incised over the spinous processes.
4. The paraspinal muscles are dissected off the spinous processes and laminae subperiosteally with a combination of Bovie cautery and a Cobb periosteal elevator.
5. Sponges are packed into the wound to assist with dissection of soft tissue and also to provide hemostasis.
6. Elevation of the paraspinal muscles and soft tissue should continue laterally over the facets and out to the tips of the transverse processes.
7. If needed, large Gelpi retractors can replace cerebellar retractors to provide a wider, deeper exposure.
8. Intraoperative radiographs or fluoroscopy is used to ensure that the osteotomy will be performed at the correct level.
9. Pedicle screws should be placed before the bony resection and osteotomy. If the procedure is performed on a Jackson table, a provisional rod should be placed as lateral as possible to connect fixation points above and below the osteotomy at this time.
10. For an L3 osteotomy, a complete resection of the posterior elements of L3 along with the caudal half of the lamina of L2 and the cephalad half of the lamina of L4 will be necessary. It is imperative that portions of L2 and L4 be resected to prevent a pincer effect, in which the correction maneuver causes the laminae of L2 and L4 to compress the thecal sac.
11. A Horsley bone rongeur is used to remove the spinous processes from L2 through L4, and a Leksell rongeur is used to thin the laminae.
12. A large curette may be used to resect the ligamentum flavum from the laminae, allowing entrance into the spinal canal.
13. Kerrison punches are used to perform a wide laminectomy of L3 out to the pedicles. Caution should be used when resecting the laminae in fixed kyphotic deformities, because the dura may be adherent to the lamina. A Penfield elevator is useful to free the dura from the lamina.
14. Using a combination of Leksell rongeurs and Kerrison punches, resection of the posterior elements proceeds to include the pars interarticularis, superior and inferior facets, and the transverse processes of L3. At this point the pedicles are the only remaining posterior elements of the L3 vertebra.
15. The inferior facets of L2 and the superior facets of L4 must also be resected.
16. Curettes are used to remove the cancellous bone from within the pedicles and to begin decancellation of the L3 vertebral body.
17. The lateral aspect of the pedicle can be removed with Kerrison punches and rongeurs so that curettes can be placed into the posterior portion of the vertebral body to remove cancellous bone.
18. The posterior vertebral cortex is left in place, while the cancellous bone is removed. Leaving the posterior vertebral wall intact provides a bony barrier that protects the thecal sac, which lies immediately adjacent to the posterior vertebral wall.
19. Once the cancellous bone has been removed from the posterior two thirds of the vertebral body, the thecal sac is retracted, along with the nerve root, toward the contralateral side. This will allow access to the posterior wall of the vertebra, which is now cut using a quarter-inch osteotome.
20. Bone tamps are used to implode the posterior wall into the defect within the vertebral body created by previously removing cancellous bone (Fig. 68-13).
21. The displaced posterior cortical wall is removed with pituitary rongeurs and Kerrison punches.
22. The bony resection creates a large surface area of exposed cancellous bone that may bleed tremendously. Hemostatic agents such as Gelfoam and FloSeal should be readily available to place onto bleeding surfaces.

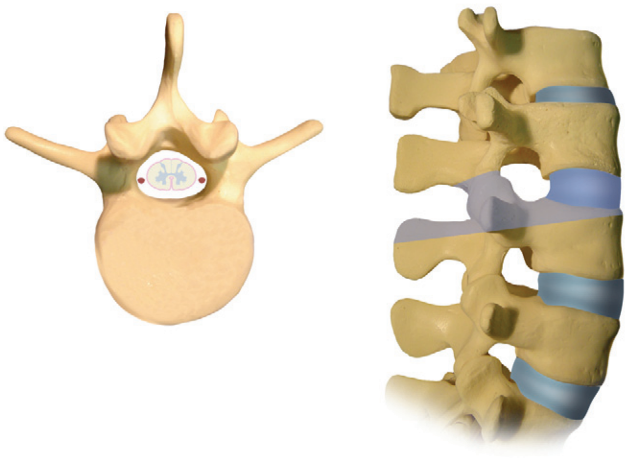

Figure 68-13 "Eggshell" procedure for removal of lumbar vertebral body in closing wedge osteotomy.

23. Once the bleeding is controlled, excess hemostatic agent should be removed because it may be extruded into the canal during osteotomy reduction, which can cause neurologic compression.
24. The previously flexed table is now gradually brought into extension, thereby closing the osteotomy. If a Jackson table is used, the provisional rod is loosened, and the connecting fixation points are allowed to approach one another to close down the posterior bony resection.
25. Rods are contoured and placed into the previously placed pedicle screws to secure the reduction of the osteotomy.
26. The osteotomy edges are brought into close contact by compressing across the pedicle screws. Careful neurologic monitoring should be performed while closing the osteotomy site. If there are any changes in neurologic monitoring, the site should be reopened.
27. The canal should be inspected carefully for sites of impingement by extruded bony fragments or hemostatic agents. After inspection, the osteotomy site should be closed and secured into position using the previously placed fixation construct.
28. The bony surfaces are decorticated, and local bone graft is placed. The wound is then closed in layers over a drain.

Postoperative Care

Postoperatively, the patient is placed in a custom thoracolumbosacral orthosis until the osteotomy site is healed, which typically occurs after approximately 3 months. Radiographs are taken at monthly intervals to evaluate fusion healing.

Complications

As noted earlier, the complications of thoracolumbar pedicle subtraction osteotomy are principally neurologic and vascular. Translation across the osteotomy site may cause severe compression of the cauda equina, resulting in paraparesis and bowel and bladder dysfunction. Another possible cause of postoperative paresis may be due to decreased blood flow to the thoracic spinal cord itself as a result of hemodynamic instability, an event that can cause an anterior spinal cord injury because of ischemia. Blood loss during this procedure can be quite high, typically over 2 liters, and anesthesia personnel must be prepared to rapidly infuse blood products and crystalloid to maintain spinal cord perfusion pressures. In addition, patients may also require concomitant replacement of clotting factors because of heavy bleeding and dilution effects.

Although the risks of abdominal stretch and the potential for superior mesenteric artery syndrome are lower with this procedure than with the traditional Smith-Peterson osteotomy, the patient's abdomen must be carefully evaluated for signs of an extended postoperative ileus. Large fluid shifts may occur in the first 3 days after surgery such that the patient's hemodynamic status must be carefully monitored. Other postoperative complications may include nonunion, loss of correction, and wound infection.

Conclusion

Patients who have kyphotic deformities as a result of AS are often extremely disabled. They have difficulty with activities of daily living because of an inability to sustain a forward gaze to view the horizon. This poses a unique challenge for the patient and also for the treating spine surgeon. Fixed kyphosis of the cervical spine is often further complicated by profound osteopenia. Serious complications or unsatisfactory results have often caused patients and doctors alike to be hesitant in choosing surgery for treatment of AS. Although the techniques for correction of fixed flexion deformity remain demanding, advancements in surgical techniques, instrumentation, neurophysiologic monitoring, and medical management have minimized the risk of intraoperative complications and have made surgical treatment of kyphotic deformities of the ankylotic spine a safer option. In all such patients, the goals of surgical management remain the correction of forward gaze to the horizon and improvement of gait and ambulation by restoring the C7 plumb line over the sacrum.

SECTION I

Spinal Infection

69 Bacterial, Fungal, and Tuberculosis Diskitis and Osteomyelitis of the Cervical, Thoracic, and Lumbar Spine

MICHAEL J. VIVES and AMIT SOOD

Overview

The management of spinal infections involves several general considerations. The ultimate goals in management are eradication of the infection, preservation of neurologic function, and prevention of sequelae such as progressive deformity and chronic pain. A systematic approach is used in the diagnosis and treatment of spinal infections; early diagnosis is of the utmost importance, before the onset of neurologic sequelae or spinal instability. These infections are evaluated according to the location, pathogen (bacterial vs. fungal), route of infection (direct inoculation, contiguous spread from an adjacent infection, or hematogenous seeding), age of the patient, and immune status of the host. In the setting of diskitis or spinal osteomyelitis (Fig. 69-1), these goals can often be achieved without operative intervention. A presumptive diagnosis is established by the combination of suggestive laboratory findings, which include elevated erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP), along with plain radiographs and advanced imaging studies such as computed tomography (CT) and magnetic resonance imaging (MRI). A definitive tissue diagnosis of the offending pathogen can often be made using percutaneous CT-guided biopsy.

After determination of the organism's sensitivity profile, a 6-week course of the appropriate intravenous (IV) antibiotics is usually sufficient. Bracing is often prescribed as adjuvant treatment to optimize the environment for eradication of the infection as well as for structural stability. Often patients are immunocompromised and/or malnourished; thus a multidisciplinary approach toward treatment with infectious disease and nutritional services is important.

Indications and Contraindications for Surgical Management of Spinal Infection

INDICATIONS

- Neurologic deficit from spinal cord injury or progressive root-level deficit
- Significant deformity, instability, or bone destruction/pathologic fracture
- Persistent sepsis or abscess formation
- Inability to identify the offending pathogen by closed methods
- Inability to eradicate the infection by medical management alone
- Intractable pain localized to the involved area of the spine

CONTRAINDICATIONS

- Medical comorbidities that make operative intervention prohibitive
- Uncorrected coagulopathies
- Medically stable, immunocompetent patients with early involvement, none of the above indications, and diagnosis made by biopsy

Operative Technique

GENERAL CONSIDERATIONS

When surgical treatment is deemed necessary, several concepts appear to be generally accepted:

- Thorough débridement, decompression (if necessary), and establishment or maintenance of spinal stability are critical steps in treatment.
- In most cases, if the microbiologic diagnosis has not been established, preoperative antibiotics should be held until adequate tissue is obtained.
- The location of the lesion is usually anterior; therefore anterior procedures are usually preferred with the exception of selective lower lumbar lesions, in which the neural elements can be safely manipulated to permit anterior débridement and reconstruction.
- Systemic illness and malnutrition are often present and must be addressed concurrently.

Conversely, several issues in the surgical management of spinal infections remain controversial.

- *Choice of structural graft.* Owing to the attendant morbidity of harvesting large structural autografts (tricortical iliac crest, fibula, and vascularized rib), alternative methods of reconstructing the weight-bearing anterior

Figure 69-1 In the setting of diskitis or spinal osteomyelitis, treatment goals can often be achieved without operative intervention.

column are increasingly used. Despite concerns about the risk of sequestration and delayed healing, recent studies have demonstrated good outcomes, and without the aforementioned complications, using both allograft and titanium cages for spinal reconstruction after débridement of active infection.

- *Use of recombinant human bone morphogenetic protein (rhBMP).* Over the past several years, use of rhBMP has increased in a variety of orthopedic procedures to enhance bone formation. Specifically, it is being used with increased frequency for spinal fusion procedures given its potent osteoinductive properties. Studies thus far have not demonstrated an increase in morbidity or mortality associated with the use of rhBMP in the setting of local infection[1-5]; however, such application is off label.
- *The use of instrumentation in the infected spine.* Concerns have led to the common and effective practice of performing the anterior reconstruction with a strut graft and instrumenting the spine through a separate, posterior approach. Recent studies, however, have demonstrated successful management of pyogenic and granulomatous infections using anterior instrumentation.
- *Same-day anterior–posterior versus staged procedures.* Some have advocated staging the posterior placement of hardware to prevent "seeding" of the hardware by bacteremia produced by the anterior débridement. Although this advice is well reasoned, it is unclear whether it is necessary. The authors feel that the decision should be made on a case-by-case basis, predicated primarily on the patient's overall physiologic condition on completion of the anterior procedure.

The techniques for treatment of diskitis and osteomyelitis of the cervical, thoracic, and lumbar spine are generally similar to those used for the anterior treatment of degenerative and traumatic conditions. Because these methods have been described in separate, detailed sections, this chapter will review each technique more generally, and it will highlight important considerations for applying these methods to the management of spinal infections.

CERVICAL DISKITIS AND OSTEOMYELITIS

Positioning

- The patient is positioned supine with a bump under the buttocks if autograft harvesting is planned.
- A roll placed between the shoulder blades may facilitate visualization of the lower cervical spine.
- Gardner-Wells tongs may be applied for distraction once the patient has been appropriately positioned. Taping the shoulders with judicious caudal distraction may improve radiographic visualization and increase working space.
- Somatosensory-evoked and transcranial motor-evoked potentials are used when patients' neurologic function is preserved.
- If the offending organism has not been previously identified, clear instructions to hold preoperative antibiotics are given to the anesthesia team.

Approach

- A left-sided approach is favored by many, although studies have failed to firmly establish an association between the side of approach and the incidence of recurrent laryngeal nerve symptoms.[6,7]
- Transverse skin incisions are preferred if three or fewer vertebral bodies must be visualized. For more extensive procedures, an oblique incision just anterior to the anterior border of the sternocleidomastoid muscle is used.
- A standard anterolateral approach to the subaxial cervical spine is performed (Fig. 69-2).
- Location with fluoroscopy should be performed to clearly identify the levels of interest.
- A self-retaining retractor is used with blades placed beneath the elevated medial borders of the longus colli muscle.

Débridement and Decompression

- Great care should be taken to maintain orientation with respect to the midline, because the anatomy in the region of the active infection may be distorted. Exposure of an uninvolved level above and below may be helpful.
- Much of the initial débridement can be performed piecemeal using pituitary rongeurs and curettes. Generous sampling of pathologic material should be sent for Gram stain; culture for aerobic, anaerobic, acid-fast, and fungal organisms; and histologic evaluation.
- The remainder of the decompression is accomplished in standard fashion, with a high-speed burr used to sequentially thin the bone from anterior to posterior. The thin remaining shell of bone is then removed with microcurettes (Fig. 69-3).

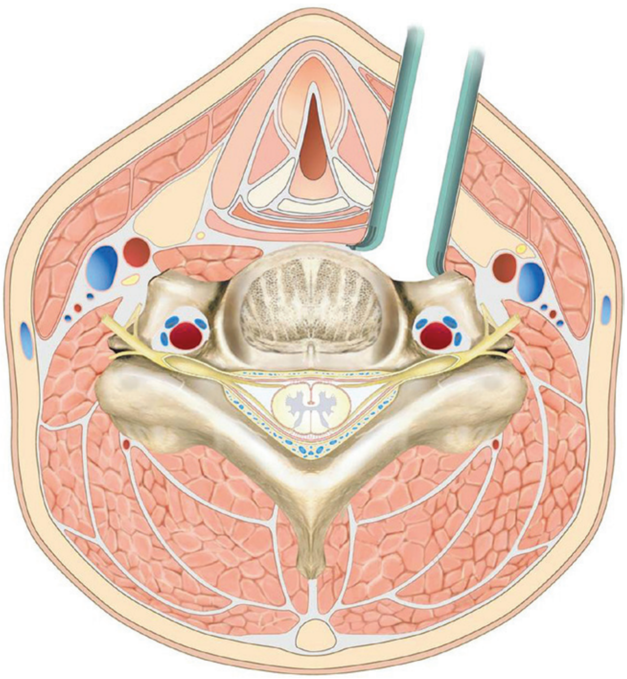

Figure 69-2 A standard anterolateral approach to the subaxial cervical spine.

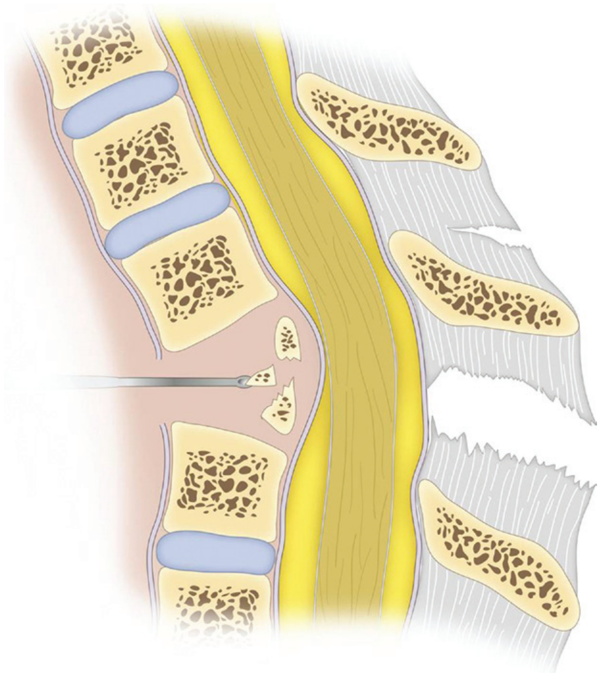

Figure 69-3 The thin remaining shell of bone is removed with microcurettes.

Reconstruction

Strut Graft Without Anterior Instrumentation

- To prevent dislodgment, the graft is countersunk into the vertebral bodies above and below.
- A high-speed burr is used to create slots in the bone above and below. The graft is placed in the slot in the superior vertebra first.

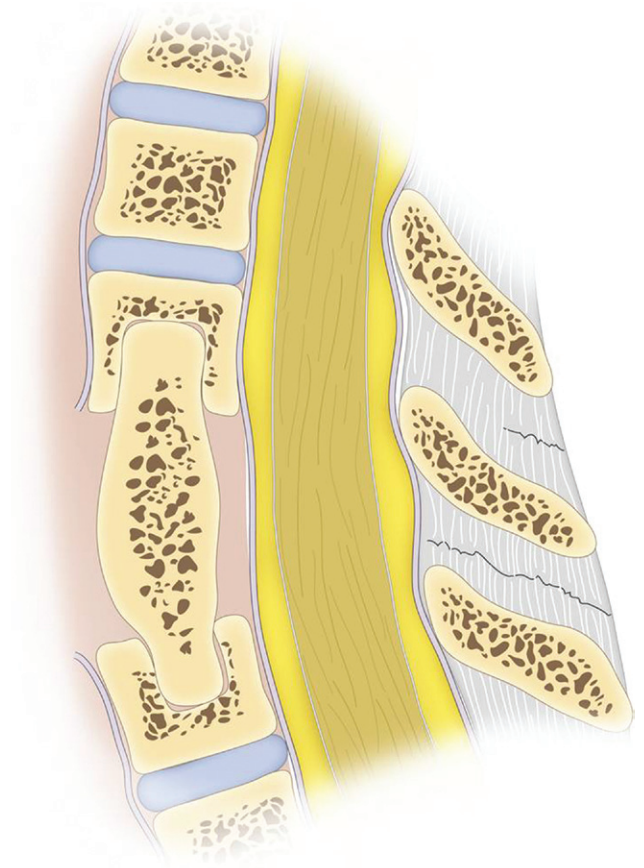

Figure 69-4 With distraction applied, the graft is rotated and tamped into the slot in the inferior vertebra.

- Distraction across the defect using the Caspar distractor alone or in addition to Gardner-Wells tongs is helpful for seating the graft.
- With distraction applied, the graft is rotated and tamped into the slot in the inferior vertebra (Fig. 69-4).

Strut Graft with Anterior Instrumentation. If this technique is selected, grafting is done in the manner previously described for cervical corpectomy. Specifics for applying this technique in the infected spine include the following:

- Preservation of end plate integrity is achieved by gentle preparation with a high-speed burr or rasps and curettes.
- Screws are inserted into uninvolved bone by correlating preoperative imaging with intraoperative findings. Reliance of screw purchase in pathologic bone is not recommended. A preoperative CT scan may be helpful to evaluate bone quality at the levels considered for screw fixation.
- The anterior vertebral body surfaces often undulate with convexities in the peridisk areas. Flattening any anterior prominences with a high-speed burr will allow the plate to sit flush against the bone and decrease the overall profile.

Posterior Instrumentation

- If noninstrumented strut grafting was performed anteriorly, we favor the addition of posterior instrumentation to increase stability of the construct and decrease postoperative immobilization requirements. Posterior instrumentation is also used in most cases of three-level corpectomy owing to concerns of inadequate stability with anterior plating.
- Posterior instrumentation is done using standard techniques described elsewhere in this book. Lateral mass screws are generally used from C3 to C6, and pedicle screws are used caudally at C7 at the end of long constructs, as anatomy permits. Some favor extension of long posterior constructs to the upper thoracic spine.
- If the posterior procedure is performed under the same anesthesia, a separate set-up table of instruments to be used for the posterior procedure is requested in advance and kept separate from instruments used during the anterior stage.

Illustrative Case

- Lateral cervical radiograph of cervical diskitis/osteomyelitis in a middle-aged man with insulin-dependent diabetes (Fig. 69-5)
- T2-weighted sagittal MRI (Fig. 69-6)
- Postoperative lateral radiograph after anterior débridement and decompression, allograft fibula strut grafting with anterior plating, and posterior lateral mass fixation (Fig. 69-7)
- Postoperative anterior–posterior (AP) radiograph of the same patient (Fig. 69-8)

Figure 69-5 Lateral cervical radiograph of a middle-aged man with insulin-dependent diabetes and cervical diskitis/osteomyelitis.

Figure 69-6 T2-weighted sagittal magnetic resonance imaging.

Figure 69-7 Postoperative lateral radiograph after anterior debridement and decompression, allograft fibula strut grafting with anterior plating, and posterior lateral mass fixation.

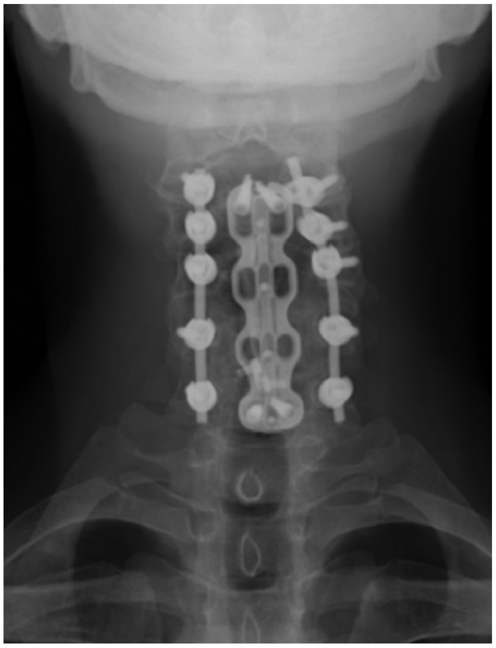

Figure 69-8 Postoperative anteroposterior radiograph.

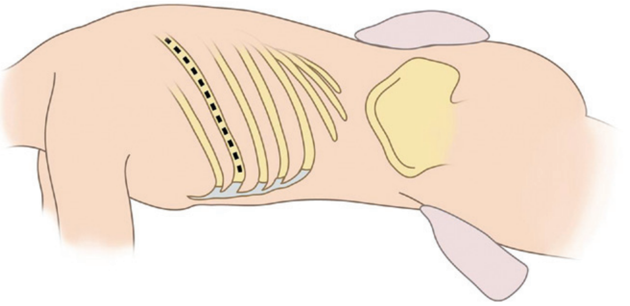

Figure 69-9 Care is taken to stabilize the patient at an angle perpendicular to the floor, using padded attachments to the table or a beanbag and tape.

THORACIC DISKITIS AND OSTEOMYELITIS

Anesthesia

- The thoracolumbar junction can be approached using standard, two-lung ventilation; higher transthoracic approaches may be facilitated by selected intubation and one-lung ventilation with a double-lumen endotracheal tube.
- An arterial line, central venous line, and Foley catheter are typically placed for continuous blood pressure and fluid status monitoring.
- Somatosensory and transcranial motor-evoked potentials are used when patients have preservation of neurologic function.
- Antibiotics are withheld until specimens are obtained to establish the microbiologic diagnosis.

Patient Positioning

- For anatomic reasons, a left-sided approach is favored by many. The thick-walled aorta can be manipulated with less risk than the thin-walled vena cava. In addition, because of the right-sided location of the liver, less caudal access is available to the thoracolumbar junction without a transdiaphragmatic approach. Midthoracic levels can be adequately approached from either side.
- For anterior approaches to the upper thoracic spine, the patient is positioned supine as described earlier.
- For access to the middle and lower thoracic spine, the patient is positioned in a true lateral decubitus position. Care is taken to stabilize the patient at an angle perpendicular to the floor, using padded attachments to the table or a beanbag and tape (Fig. 69-9).
- An axillary roll is placed just below the dependent axilla to protect the neurovascular supply to the arm.

Localization

- If the patient is supine, localization with fluoroscopy is performed to identify the levels of interest.
- If the patient is to be placed in the lateral decubitus position, a high-quality plain radiograph is obtained before positioning to correlate the rib with the vertebral body of interest. The ribs are then manually palpated and counted. The incision is based over the rib, one or two levels above the vertebrae to be resected, to permit adequate direct access to the cephalad vertebrae if instrumentation is planned.

Surgical Approach

- For access to T1 through T4, posterior and posterolateral approaches are typically used. However, anterior decompression requires a low anterior cervical approach combined with either a sternotomy or partial clavicle resection, which is associated with significant perioperative morbidity. For access to the upper thoracic spine, another technique has been described, a modified low anterior cervical dissection combined with a partial manubriotomy; this spares the sternoclavicular joints and the sternum, decreasing the morbidity from these additional procedures.[8,9]
- For access to T4 through T10, a transthoracic-transpleural approach is typically performed through the bed of the resected rib (Fig. 69-10).
- For exposure of the thoracolumbar junction, a transpleural-retroperitoneal thoracoabdominal approach, with detachment of the diaphragm, is commonly used. The thoracolumbar junction can also be exposed through an extrapleural-retroperitoneal approach, which avoids incision of the diaphragm and may be associated with less pulmonary morbidity.
- In selected cases of thoracic level osteomyelitis, costotransversectomy and lateral extracavitary approaches may be options; these are described elsewhere. Whereas such approaches are effective for decompression and bony débridement, debulking and débridement of anterior paraspinal collections may be incomplete. This may result in a higher load of pathogens in the vicinity of cages used for anterior column reconstruction.

Decompression and Reconstruction

Supine Position

- After the initial exposure, either a manubriotomy or resection of the sternum or distal clavicle is performed. After lateral reflection of the thymus, the tracheoesophageal bundle is retracted medially, and the brachiocephalic trunk is retracted laterally. The prevertebral fascia may then be divided.

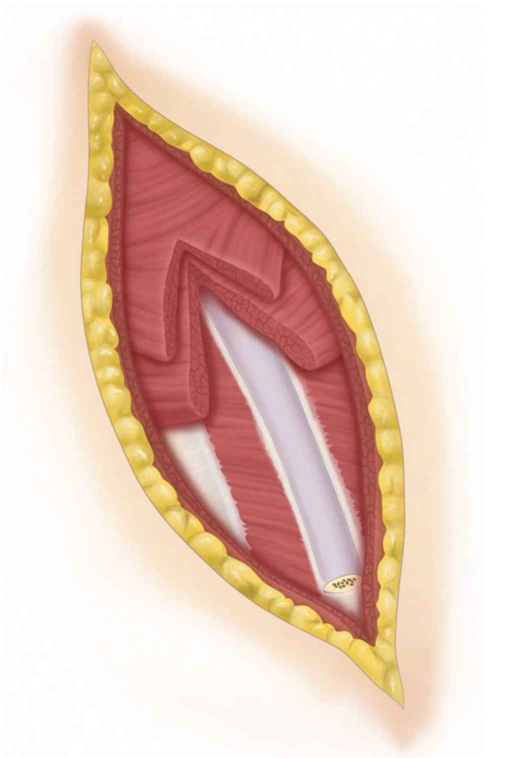

Figure 69-10 For access to T4 through T10, a transthoracic-transpleural approach is typically performed through the bed of the resected rib.

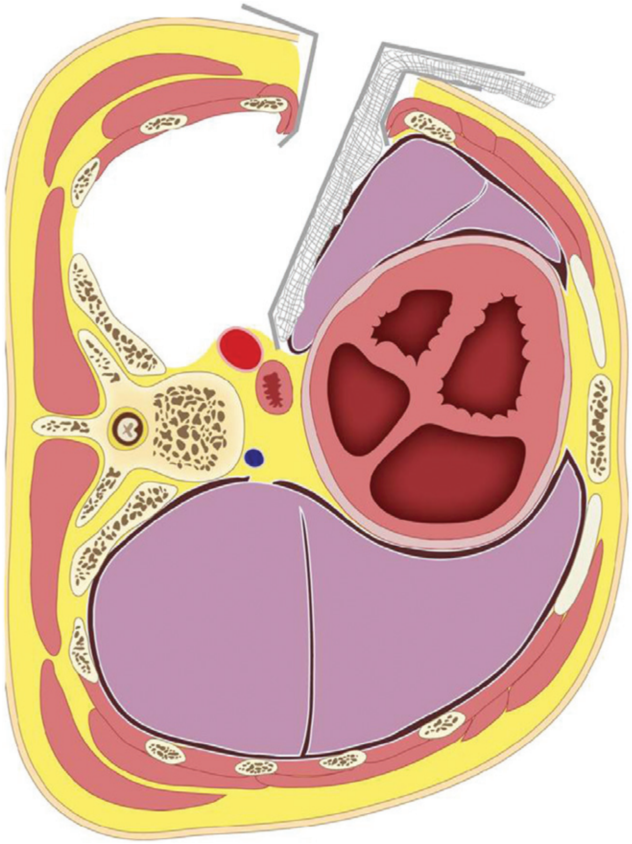

Figure 69-11 After the initial exposure, the lung is gently retracted superomedially, away from the spine.

- An operating microscope may be used for optimal visualization.
- Corpectomy of the pathologic vertebrae is then performed, as described in earlier sections, using a combination of osteotomes, rongeurs, punches, and a high-speed burr. Infected and necrotic bone and disk material may be easily removed with rongeurs and curettes and sent for microbiologic analysis.

Lateral Decubitus

- After the initial exposure, the lung is gently retracted superomedially, away from the spine (Fig. 69-11).
- Confirmation of the involved level is performed by intraoperative imaging. The anatomy of the involved segments may be severely distorted, so careful correlation to the localizing film and preoperative imaging studies is necessary.
- Ligation of the segmental vessels overlying the vertebral bodies to be instrumented, as well as those at the corpectomy level, is generally required (Fig. 69-12). The parietal pleura is typically thickened and inflamed, making vessel identification difficult.
- Corpectomy of the pathologic vertebrae may then be performed as described above. Removal of the involved disks can provide orientation before the bloodier portion of the corpectomy proper.
- If formal neurologic decompression is required, removal of retropulsed tissue should continue across the spinal canal until the contralateral pedicle is identified. Based on preoperative imaging, the posterior longitudinal ligament may require opening to débride epidural components of infection.

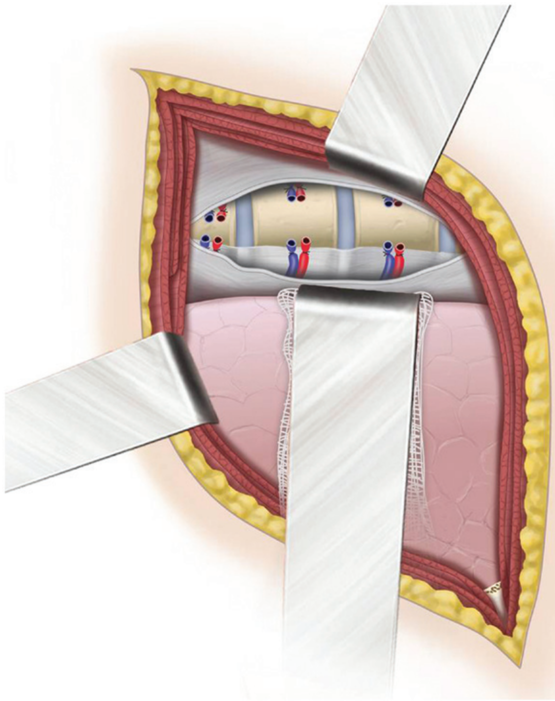

Figure 69-12 Ligation of the segmental vessels overlying the vertebral bodies to be instrumented, as well as those at the corpectomy level, is generally required.

- Reconstruction of the anterior weight-bearing column can be performed with structural autograft, typically the iliac crest; structural allograft; or cages packed with morcellized autograft, allograft, or a combination of both (Fig. 69-13).
- If anterior strut grafting without anterior instrumentation is preferred, the graft should be countersunk into the vertebral bodies above and below (Fig. 69-14). If anterior instrumentation is to be used, the graft should be fit to span from the inferior end plate of the proximal vertebra to the superior end plate of the inferior vertebra; this will facilitate screw placement into the adjacent vertebral bodies.

Anterior Instrumentation

- If anterior instrumentation is to be used, standard techniques for plate or screw-rod devices can be applied. This should be performed after thorough débridement and irrigation of the field.
- Reliance of screw purchase in pathologic bone is not recommended. Where possible, bicortical purchase of normal, uninvolved segments is preferable (Fig. 69-15).

Illustrative Case

- A 50-year-old man with a history of IV drug use came to medical attention with thoracic back pain and rapidly progressive cord-level neurologic deficit.
- T2-weighted sagittal MRI demonstrates T6–T7 diskitis/osteomyelitis with pathologic fracture, epidural extension, and spinal cord compression (Fig. 69-16).
- Postoperative AP radiograph is taken after anterior débridement and decompression involving T6 and T7 corpectomies with instrumentation at T5 through T8 (Fig. 69-17).

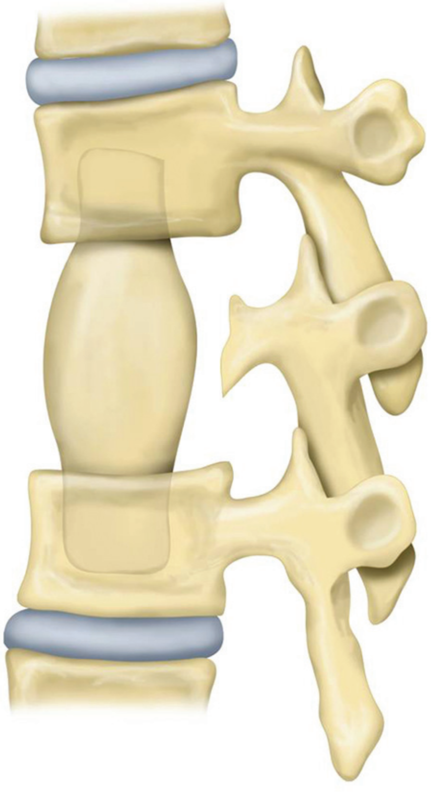

Figure 69-14 If anterior strut grafting without anterior instrumentation is preferred, the graft should be countersunk into the vertebral bodies above and below.

Figure 69-13 Reconstruction of the anterior weight-bearing column can be performed with structural autograft, typically iliac crest; structural allograft; or cages packed with morcellized autograft, allograft, or combinations of both.

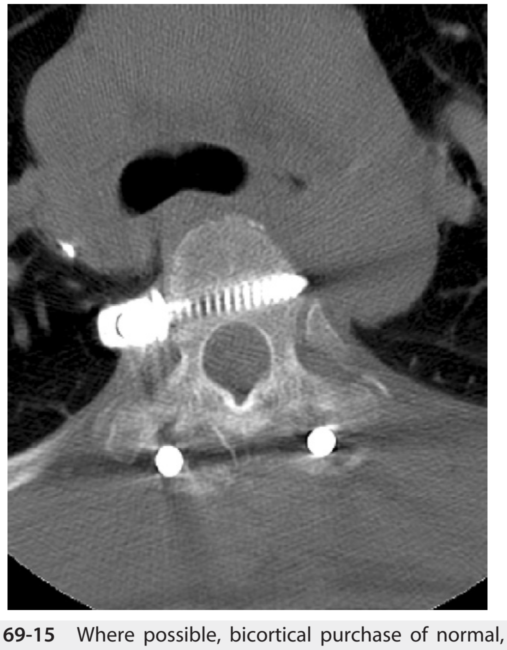

Figure 69-15 Where possible, bicortical purchase of normal, uninvolved segments is preferable.

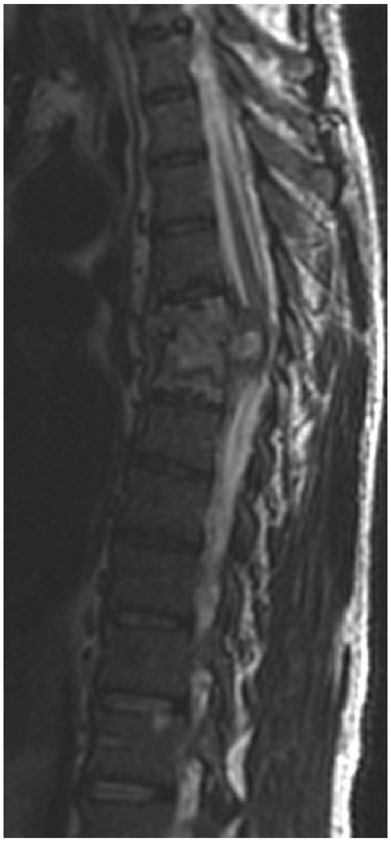

Figure 69-16 T2-weighted sagittal magnetic resonance imaging demonstrates T6–T7 diskitis/osteomyelitis with pathologic fracture, epidural extension, and spinal cord compression.

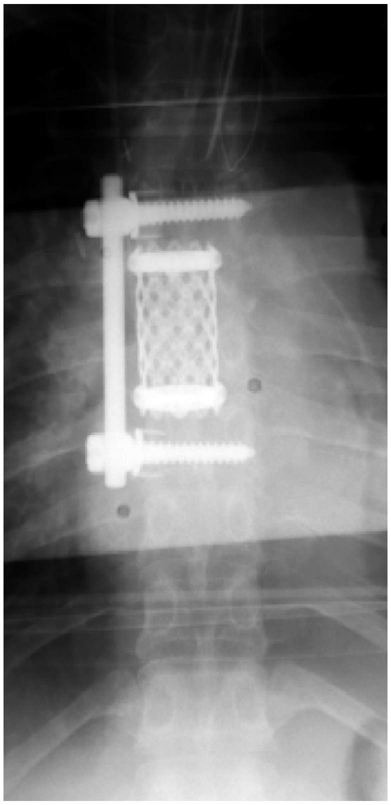

Figure 69-17 Postoperative anteroposterolateral radiograph after anterior débridement and decompression involving T6 and T7 corpectomies with instrumentation at T5 through T8.

Posterior Instrumentation

- Posterior stabilization is generally recommended after noninstrumented anterior strut grafting. Standard techniques described in earlier sections are applicable. We favor segmental fixation with hook or pedicle screw constructs.
- In selected cases involving multilevel anterior corpectomies, the addition of posterior instrumentation is utilized to achieve greater initial stability, increase the fusion rate, and decrease postoperative bracing requirements. In most cases, more limited posterior constructs appear sufficient when combined with anterior plate or screw-rod devices.

Illustrative Case

- Postoperative lateral radiograph after addition of posterior instrumentation to the patient presented in Figures 69-16 through 69-18
- Axial CT scan that demonstrates appropriate position of the pedicle screws selected for the posterior construct (Fig. 69-19)

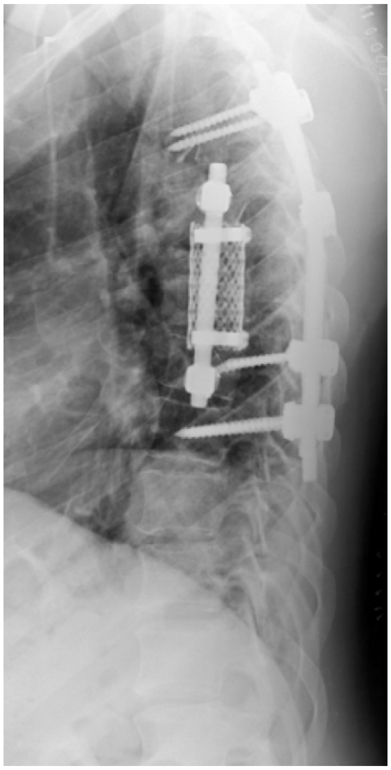

Figure 69-18 Postoperative lateral radiograph after addition of posterior instrumentation to the patient presented in Figures 69-16 and 69-17.

Figure 69-19 Axial computed tomography scan demonstrates the appropriate position of the pedicle screws selected for the posterior construct.

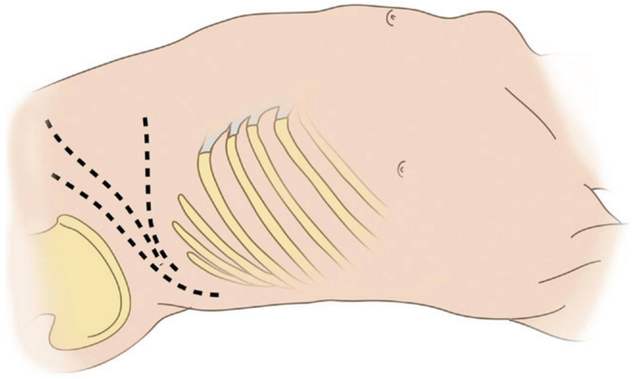

Figure 69-20 The patient is placed in a lazy, right lateral decubitus position with a bump under the left side.

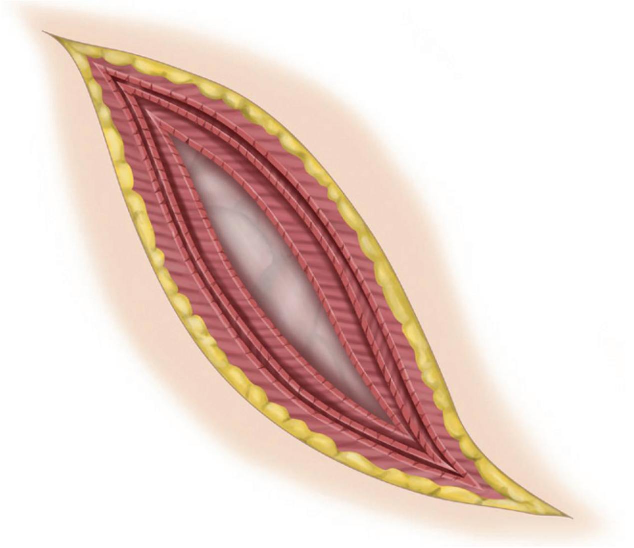

Figure 69-21 The flank approach involves division of the external oblique, internal oblique, and transversus abdominis muscles.

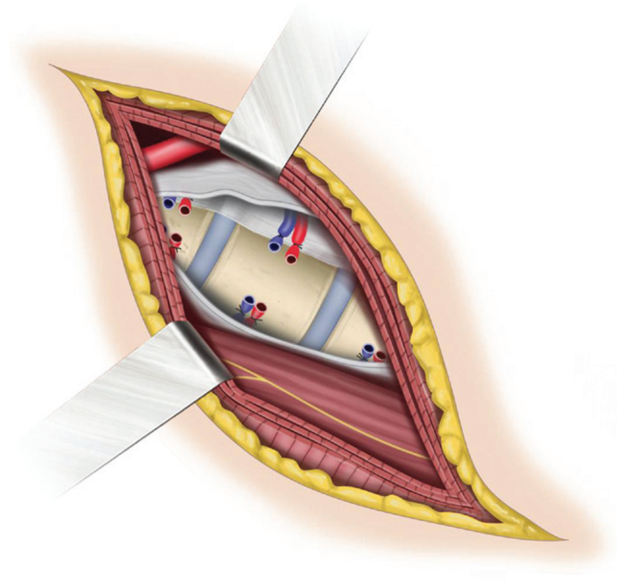

Figure 69-22 After ligation and division of the segmentals, the great vessels can be gently retracted toward the right with the psoas mobilized toward the left to expose the spine.

LUMBAR DISKITIS AND OSTEOMYELITIS

Positioning and Anesthesia

- For approaches that involve levels proximal to L4, a retroperitoneal flank approach is utilized. The patient is placed in a lazy, right lateral decubitus position with a bump under the left side (Fig. 69-20).
- To approach the lumbosacral junction, the patient is positioned supine, and a retroperitoneal approach is performed through a midline vertical incision. A roll may be placed beneath the lumbar spine to maintain lordosis, and the legs are slightly flexed and abducted to relax the iliopsoas.
- Transpsoas approaches have also been described but may be best suited for cases where only limited anterior débridement and no formal anterior decompression are required.[10]
- If the organism has not been identified, antibiotics are withheld until specimens are obtained.

Exposure

- A standard retroperitoneal approach to the lumbar spine is performed. The flank approach involves division of the external oblique, internal oblique, and transversus abdominis muscles (Fig. 69-21). The vertical midline approach involves splitting the rectus abdominis muscle in the midline linea alba.
- The retroperitoneal space is entered laterally by identification of the retroperitoneal fat. Blunt finger dissection along the anterior surface of the left psoas muscle should lead to the great vessels.
- At L4 and higher, ligation and division of the segmentals allow the great vessels to be gently retracted toward the right, with the psoas mobilized toward the left to expose the spine (Fig. 69-22). The local anatomy may be distorted by the infection, and the vessels may be difficult to mobilize secondary to inflammation. Blunt dissection

with firm, controlled pressure on the surface of the disks is most effective.

- The L5–S1 level is exposed through the bifurcation of the great vessels after ligation and division of the middle sacral vessels. The L4–L5 disk can be exposed by two techniques: both the left iliac artery and vein can be carefully retracted from left to right, or the disk can be approached between the left iliac artery and vein; with this latter method, the left iliac artery is mobilized to the left, and the iliac vein is retracted across the midline toward the right after careful ligation and division of the ascending lumbar segmental vein.
- A spinal needle is inserted into the appropriate disk, and an intraoperative image is obtained to verify the local anatomy.

Débridement and Decompression

- Removal of severely affected bone and disk is readily performed using rongeurs and curettes.
- To increase yield, generous amounts of tissue should be sent for analysis. After adequate specimens have been obtained, empiric antibiotic coverage should be started.
- The remainder of the decompression is performed in routine fashion as described in previous sections. All gross purulence and necrotic bone should be removed back to a margin of healthy, bleeding tissue.
- If an epidural abscess is present anterior to the dural sac, a formal decompression is performed from pedicle to pedicle. The abscess can be gently débrided with a Penfield dissector, and careful suction and irrigation are performed.

Anterior Reconstruction

- The orientation of the great vessels in the lower lumbar spine should be evaluated if stabilizing anterior plates or screw-rod constructs are being considered.
- Strut grafting to achieve stability after corpectomy can be performed using iliac crest autograft (Fig. 69-23) or allograft. If anterior stabilizing implants are not being used, the graft should be countersunk in the upper end plate above and in the lower end plate below.

Illustrative Case

- A 68-year-old man developed severe, unrelenting back pain several months after experiencing bacteremia from a chronic lower extremity infection.
- Sagittal T1-weighted MRI demonstrated diskitis and osteomyelitis involving L4–L5 (Fig. 69-24). Sagittal T2-weighted MRI demonstrated bony involvement with pathologic fracture of L4 (Fig. 69-25).
- The patient was treated with IV antibiotics after CT-guided biopsy but experienced increasing pain and evidence of further bone loss.
- Sagittal reconstruction of CT scan was performed after anterior débridement, decompression, and reconstruction with an iliac crest strut graft. Posterior stabilization was performed under a separate anesthesia (Fig. 69-26).

Figure 69-23 Strut grafting to achieve stability after corpectomy can be performed using iliac crest autograft or allograft.

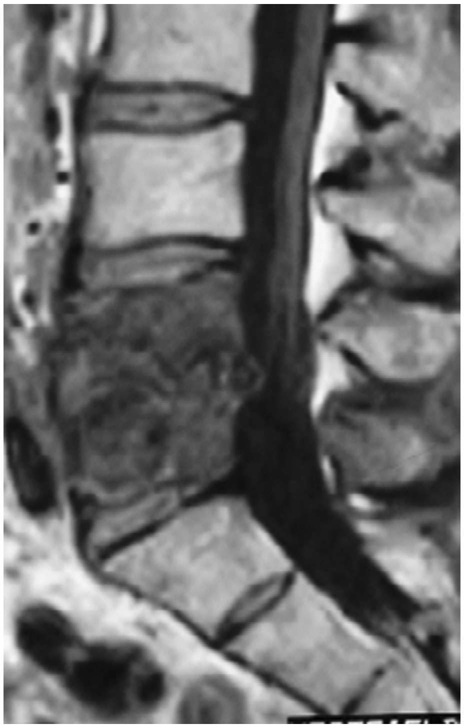

Figure 69-24 A 68-year-old man developed severe, unrelenting back pain several months after experiencing bacteremia from a chronic lower extremity infection. Sagittal T1-weighted magnetic resonance imaging demonstrates diskitis and osteomyelitis involving L4–L5.

Figure 69-25 Sagittal T2-weighted MRI demonstrates bony involvement with pathologic fracture of L4.

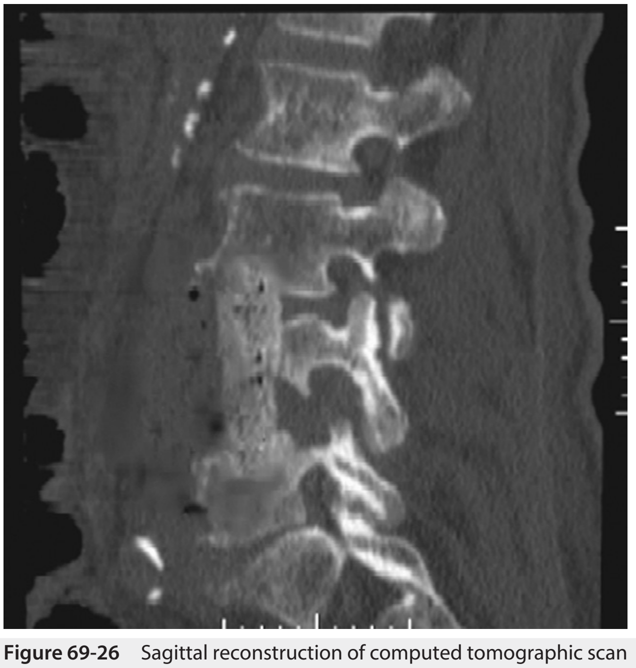

Figure 69-26 Sagittal reconstruction of computed tomographic scan performed after anterior débridement, decompression, and reconstruction with an iliac crest strut graft. Posterior stabilization was performed under a separate anesthesia.

Posterior Stabilization

- We routinely perform supplemental posterior fusion after noninstrumented anterior decompression and strut grafting in the lower lumbar spine. Such an approach allows early mobilization with minimal bracing requirements, and it promotes fusion.

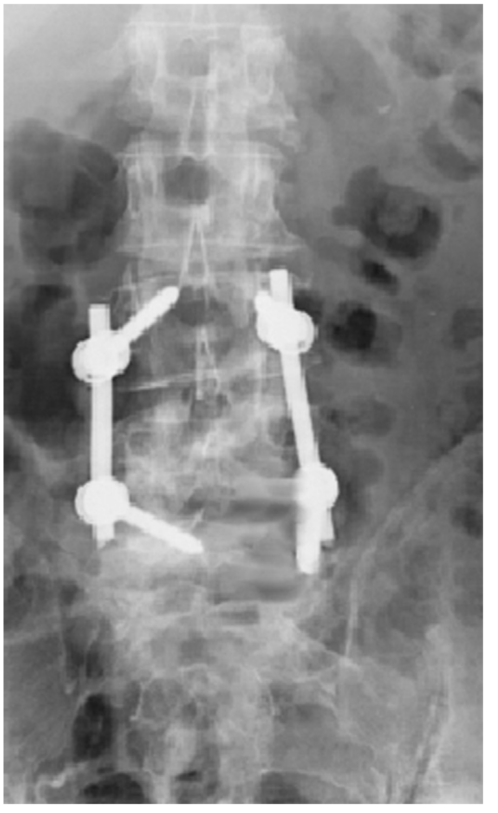

Figure 69-27 Pedicle screw constructs can be applied in routine fashion as described in earlier sections.

- Pedicle screw constructs can be applied in routine fashion as described in earlier sections. After supplemental posterior fusion, postoperative AP radiography was performed in the patient discussed in Figures 69-24 to 69-27.
- The decision to perform both procedures under the same anesthesia, versus operating in a staged manner, should be made on a case-by-case basis.
- In selected cases, posterior techniques may be used in the lower lumbar spine to treat diskitis and osteomyelitis. Posterior lumbar interbody fusion (PLIF) or transforaminal lumbar interbody fusion (TLIF) may be applicable as described elsewhere. Cases with more-limited bony involvement, with infection confined mostly to the disk space and end plate interface, are better suited to this approach. More extensive bony débridement and reconstruction are more readily performed with the AP approach.
- The use of expandable cages for anterior column reconstruction is gaining popularity. This technology may allow selected cases to be stabilized from a posterior first approach, followed by a second-stage anterior débridement. In cases associated with neurologic deficit as a result of epidural abscess (see below), this permits timely decompression from a posterior approach. If appropriate alignment has already been achieved and/or maintained, the cage can then be expanded to fit the defect and achieve stable seating.

TUBERCULOSIS AND FUNGAL INFECTIONS OF THE SPINE

- Fungal infections of the spine are managed in similar fashion to pyogenic infections. Antimicrobial therapy must be adjusted based on the culture results.
- Patients who experience fungal infections of the spine are commonly immunocompromised and malnourished. Consultation with medical and nutritional specialists is recommended.
- Tuberculosis (TB) infections of the spine commonly respond well to medical treatment with combinations of isoniazid, rifampin, pyrazinamide, ethambutol, and/or streptomycin. The diagnosis must be confirmed by biopsy. New testing methods that use polymerase chain reaction can decrease the amount of time required to definitively establish the diagnosis.
- Surgical indications are similar to those for pyogenic infections, although medical treatment appears effective even in the presence of large soft-tissue abscesses associated with TB.
- Operative techniques for management of TB spinal infections are similar to those used for pyogenic infections. As with pyogenic infections, recent studies have demonstrated the safety and efficacy of anterior instrumentation for treatment of TB infections, although this continues to be an area of controversy.

Illustrative Case

- A 49-year-old man came to medical attention with back pain and new-onset lower extremity paralysis.
- Sagittal T2-weighted MR demonstrated presumed Pott disease with anterior soft-tissue abscess, two-level involvement (including pathologic fracture), and preservation of the intervening disk (Fig. 69-28).
- The patient underwent anterior débridement and reconstruction involving two-level corpectomy, cage placement, and anterior instrumentation (Fig. 69-29). In a staged fashion, posterior stabilization was performed to increase the probability of fusion and decrease postoperative bracing needs (Fig. 69-30).

Figure 69-28 Sagittal T2-weighted magnetic resonance imaging demonstrates presumed Pott disease with anterior soft-tissue abscess, two-level involvement (including pathologic fracture), and preservation of the intervening disk.

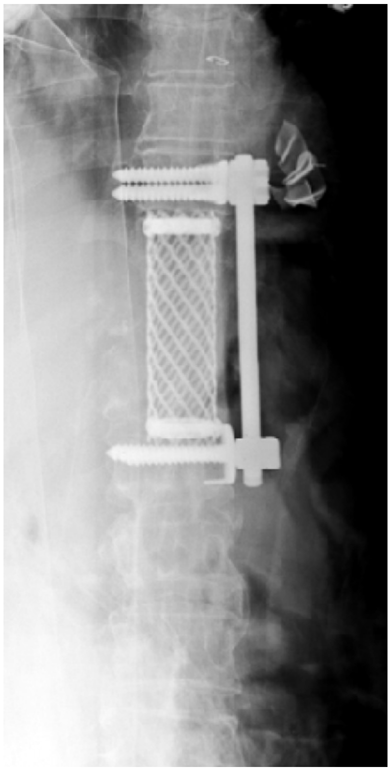

Figure 69-29 This patient underwent anterior debridement and reconstruction involving two-level corpectomy, cage placement, and anterior instrumentation.

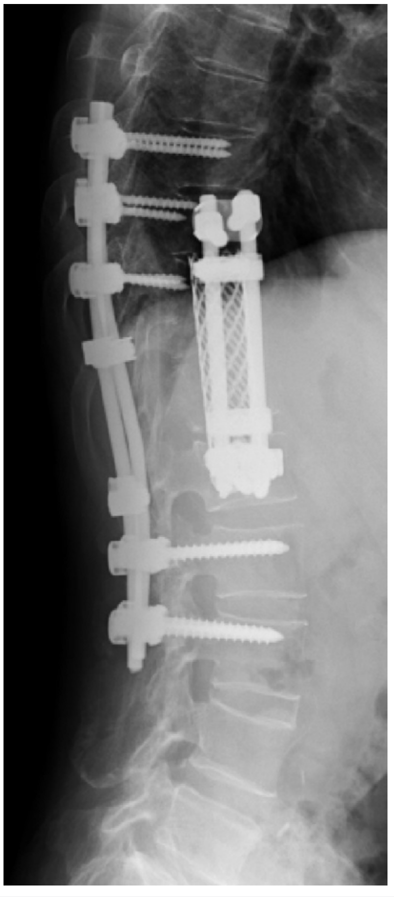

Figure 69-30 In a staged fashion, posterior stabilization was performed to increase the probability of fusion and to decrease postoperative bracing needs.

EPIDURAL ABSCESS

- Most often, epidural abscess presents with associated diskitis or osteomyelitis. Rarely it may result from direct hematogenous spread.
- Although commonly focal in nature, the abscess may extend over multiple motion segments. Most occur in the thoracic (51%) and lumbar (35%) spine within the posterior epidural space. In the cervical spine, epidural abscesses tend to occur in the anterior epidural space.
- Progressive neurologic deficits may develop if not addressed appropriately with early treatment.
- Surgical evacuation is the recommended treatment. Nonoperative treatment with IV antibiotics for up to 6 weeks may be considered for lumbar abscesses, if no systemic sepsis or neurologic deficit is present.[11] However, any signs of neurologic deterioration or lack of response to medical treatment warrants emergent surgical intervention using the techniques described in this chapter.
- A pseudocapsule often surrounds the dura. This typically requires careful separation and elevation from the underlying dura for adequate removal.

Postoperative Care

- Postoperative management is similar to that prescribed after performance of these procedures for degenerative or traumatic conditions.
- Empiric antibiotic coverage should continue until culture and sensitivity information is available.
- Appropriate antibiotic treatment should continue for approximately 6 weeks in pyogenic infections and 6 months to 1 year for TB. Infectious disease consultation is recommended to help manage antibiotic selection, dosing, and scheduling.
- Effectiveness of treatment should be monitored by serial evaluation of ESR and CRP. Postoperative radiographs and CT scans to monitor for evidence of hardware failure, pseudarthrosis, or recurrent abscesses may be helpful. The roles of MRI and nuclear studies to assess the postoperative progress are unclear.

Complications

- Complications of the surgical treatment of spinal infections are similar to those reported after the use of these techniques for degenerative and traumatic conditions. Failure to eradicate the infection may be due to inadequate débridement or improper antibiotic selection, dosing, or duration, and graft dislodgment may occur secondary to improper technique or failure to achieve adequate stability. In addition, malnutrition may contribute to delayed wound healing, postoperative wound infections, and dehiscence.

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SECTION J

Miscellaneous

70 Surgical Management of Gunshot Wounds to the Spine

GABRIEL TENDER

Overview

Gunshot wounds (GSWs) to the spine represent a major health problem in U.S. metropolitan areas as well as in military hospitals. With the perpetually escalating levels of violence, civilian GSWs to the spine have increased to 13% to 17% of all spinal cord injuries.[1,2] Because of the high potential for severe functional impairment, these patients require major socioeconomic expenditures.[3,4] Because of the high velocity of the ordnance, military GSWs to the spine are typically more severe and usually result in complete injuries, with decreased likelihood of neurologic recovery.[5] In both civilian and military spinal GSWs, thoracic injuries are most common, followed by lumbosacral and cervical injuries.[5]

Epidemiology

Civilian GSWs have reached epidemic proportions in the United States, being 90 times more frequent than in any other industrialized nation.[6] GSWs to the spine have increased proportionally and now represent the second most common cause of spinal cord injury in metropolitan areas. The typical GSW patient is likely to be young, single, African American or Hispanic, male, and unemployed, with a history of previous violent injuries or encounters with the criminal justice system.[6] Despite the fact that handguns represent only about 25% of the firearms in the United States, they are responsible for about 80% of GSW injuries.[1] Because of the increasing incidence of GSWs to the spine, most level 1 trauma centers have now become well versed in the treatment of these types of patients.

In the past 10 years, the United States has been involved in two simultaneous conflicts within the global War on Terror: Operation Iraqi Freedom (2003 through 2012) and Operation Enduring Freedom.[7,8] These two conflicts alone have resulted in over 50,000 casualties. Spine injuries are among the most disabling conditions affecting wounded soldiers. Associated injuries are frequent in this population, and these patients have higher rates of musculoskeletal, head, and chest trauma, as well as spine injuries at multiple levels, than their civilian counterparts. Delivery of medical care in a hostile combat environment can be challenging, and evacuation of the casualty and care provider to a safe location may take priority over a full medical evaluation while under fire.

Mechanisms of Injury

The energy of any moving object is determined according to the formula $E = \frac{1}{2} mv^2$, where E is kinetic energy, m is mass, and v is velocity. Therefore the bullet energy impacted to tissues increases exponentially with the velocity. Most civilian firearms, typically pistols and handguns, have muzzle velocities of less than 2000 feet per second and are considered "low energy," whereas military assault rifles, such as AK-47s and M-16s, have muzzle velocities greater than 2000 feet per second and are considered "high energy." The closer the range of a gunshot, the less energy will be lost during transit; thus more energy will be transferred to the victim in close-range shootings. Fragmentation of the bullet on impact, as occurs with hollow-point bullets, results in multiple trajectories and increased damage to tissues.[9]

Bullets may have a "jacket," a thin metallic layer covering its surface. Fully jacketed bullets are designed to hit long-range targets, are highly precise, and may incur clean entry and exit wounds. Partially jacketed or nonjacketed bullets are designed to hit close-range targets and expand on impact, resulting in fragmentation and increased tissue damage.

Most bullets are made of a lead core, whereas the jackets are made of copper, brass, or nickel. These materials can be toxic, particularly if the bullets are lodged in the intervertebral disk. Lead toxicity has been reported and can be determined by periodic measurements of the lead level or by indirect effects, such as hematopoietic or axonal changes. In animal studies, copper has also been shown to be toxic to the brain and spinal cord tissue when in direct contact with tissues.

Prehospital and Emergency Room Management

The initial treatment of GSW victims targets the maintenance of airway, breathing, and circulation—the ABCs. All patients should receive tetanus prophylaxis as soon as possible, and specific issues must be addressed depending on the level of injury.[9]

Cervical wounds are frequently complicated by airway injuries and often require immediate intubation or tracheostomy. Similarly, injuries to the major arteries in the neck result in pulsatile bleeding and may require placement of temporary stents to restore cerebral blood flow. Lesions of the pharynx and esophagus have a higher rate of infection and may mandate emergent surgical exploration and repair. These interventions should not be delayed by attempts to obtain radiographic clearance of the cervical spine in patients without neurologic deficit, because GSWs to the spine are rarely unstable. In patients with hypotension and bradycardia (i.e., neurogenic shock), the sympathetic input is diminished and should be treated with pressors rather than volume-replacement agents. Because the diaphragm is innervated by the C3–C5 spinal cord segments, patients with high cervical spinal cord injuries are usually unable to breathe and typically require immediate intubation for ventilation.

Thoracic GSWs are usually associated with lung injuries (hemothorax and/or pneumothorax) or cardiovascular injuries (heart perforation, cardiac tamponade, aortic disruption). The treatment of these lesions takes precedence over those of the spinal cord injury.

Lumbar and sacral GSWs are typically associated with abdominal and pelvic injuries, respectively. Particular attention should be given to colonic perforations, because they carry a higher risk of infection if not treated with the appropriate antibiotics for an adequate period of time.

Neurologic Evaluation

The neurologic examination begins with removing all the patient's clothing and log-rolling the patient to protect the spinal cord in case of an unstable injury. The number of entrance and exit wounds is recorded, and the difference between the two accounts for the number of bullets retained in the body. Entry wounds typically have clean and well-defined margins, whereas exit wounds have a ragged, "blown out" appearance. After local wound care, the wounds can be marked with radiopaque markers for later radiographic deduction of the missile paths.

Physical examination is focused on the level of injury and the presence of neurologic function below it. In the conscious patient, it is easy to determine the motor strength as well as sensory impairment. Comatose or sedated patients can be evaluated by their response to painful stimuli in the upper and lower extremities. Deep tendon reflexes are usually absent below the level of injury in patients with complete neurologic deficit (i.e., spinal shock). Particular attention should be given to the presence of the rectal sphincter tone and the bulbocavernosus reflex, which will determine whether the patient has a complete versus incomplete injury.

Radiologic Evaluation

The initial radiologic evaluation typically consists of plain radiographs, anteroposterior (AP) and lateral, of the involved areas. If the wounds are tagged with radiopaque markers, the bullet trajectories can be inferred, as can the potential tissue damage incurred on that path. Bullet fragments retained in the body can also be identified. If spinal instability is suspected (e.g., a patient has neurologic symptoms), particularly in the cervical spine, active flexion–extension films can be obtained.

The radiologic examination of choice for GSW to the spine is computed tomography (CT). Thin-slice (1 to 2 mm) CT images permit accurate bullet localization within the spinal segment as well as assessment of associated bony destruction. Coronal and sagittal reconstruction allows evaluation of the integrity of the three spinal columns and of the presence of focal kyphosis and/or scoliosis at the injured level.

Magnetic resonance imaging (MRI) has the potential of inducing bullet migration and thus worsening neurologic deficit. However, several studies have attested to the safety of MRI use in patients with spinal GSW. Advantages of MRI over CT include better definition of the soft tissues (disks, spinal cord, spinal nerves) and less artifact from the bullet.

Indications for Surgical Intervention

Preoperatively, all patients should receive broad-spectrum antibiotics. In cases of colonic perforation, antibiotics should be continued for 7 to 14 days and should include Gram-negative and anaerobic coverage.[10,11] In patients with visceral perforation and concomitant spinal injury, it appears that surgical débridement of the spinal lesion and bullet removal from the spine do not improve the outcome. Steroids are not indicated in GSW to the spine, because they do not improve neurologic function but do increase the rate of complications.

CEREBROSPINAL FLUID FISTULA

Cerebrospinal fluid (CSF) fistulas are easily recognized by the clear nature of the fluid persistently coming out of a GSW entry or exit wound.[12] In cases of occult leaks, β-2 transferrin analysis can confirm the diagnosis, because this protein is specific to CSF. Occasionally, patients may exhibit mental status changes and even cranial nerve palsies as a result of extreme loss of CSF.

The first line of treatment for CSF leaks is placement of a lumbar drain. This allows for controlled drainage of 10 to 15 mL/hour, or until severe headache ensues, and sealing of the defect created by the GSW. Because of the risk of meningitis if left untreated, if the CSF leak persists, a laminectomy is typically required that should include repair of the dural defect, either primarily or with a dural graft. Lumbar drainage is usually continued postoperatively to facilitate the sealing of the dural repair.

SPINAL INSTABILITY

A GSW to the spine rarely leads to instability. In the awake patient with no neurologic symptoms, it is safe to assume that the cervical spine is stable and to proceed with the emergent care without obtaining "radiographic clearance." In these cases, immobilization in a hard cervical collar for 2 weeks allows for the pain and spasms to subside and permits a better evaluation by flexion–extension radiographs. Spinal instability is more likely in high-energy injuries, because missiles moving at higher speeds have a wider circumference of damage because of the shock wave.

Spinal instability should be suspected in patients with comminuted fractures that involve the anterior and posterior elements, particularly if associated with abnormal focal angulation or subluxation. Progressive angulation over the course of weeks or months can also be interpreted as instability. Occasionally, MRI can identify the degree of ligamentous injury and can indirectly assist in the determination of the degree of instability.

In patients with incomplete neurologic deficit, spine surgeons may choose to treat a potentially unstable fracture that may result in a worsening neurologic status if not surgically stabilized. This is particularly true for patients with retained bullet or bone fragments in the spinal canal, who can also undergo a surgical decompression at the same time.

In patients with complete neurologic deficit, the surgical goal is to provide sufficient spinal stability to allow the patient to undergo the strenuous physical therapy and retraining necessary to use their preserved motor function to accommodate daily needs.

The surgical approach typically involves instrumentation and depends on the particular configuration of the fracture. An unstable GSW that involves mostly the vertebral body can be addressed by performing a corpectomy and fixation, whereas those that predominantly involve the posterior elements are treated by a posterior multilevel fixation, with or without decompression. Occasionally, a circumferential fixation is required in severely comminuted fractures.

The timing of surgery is usually between 5 and 10 days from the injury. Earlier operations have a high risk of CSF fistulas, whereas operations later than 2 weeks have a higher incidence of arachnoiditis and infection.

NEUROLOGIC DEFICIT

Neurologic deficit is more often complete after a GSW to the spine (59%) than with blunt injuries (49%). The societal cost of these injuries is tremendous: not only do these patients have extensive stays in the intensive care unit (ICU), hospital, and rehabilitation facilities, they are frequently ventilator dependent for prolonged periods of time. In addition, they are typically young and were previously capable of independent living; often they are completely disabled after the GSW.

Neurologic deficit after GSW to the spine can be progressive, incomplete, or complete. Progressive or delayed new-onset neurologic deficit after GSW to the spine represents an indication for emergent decompression, but it is a relatively rare occurrence. Progressive neurologic deterioration may be due to a bullet or bone fragment in the spinal canal or to an expanding epidural hematoma. This neurologic progression is best detected if the serial examinations are documented in the chart following the same pattern of muscle groups (e.g., the American Spinal Injury Association [ASIA] scale chart), preferably by a single, experienced physician.

Incomplete neurologic deficit typically involves various degrees of weakness of the legs and/or arms below the injury level, but occasionally it may present as Brown-Sequard, central cord, anterior cord, or even cruciate hemiparesis syndromes. The role of surgical decompression in these patients is still a matter of debate. Some authors believe that decompressive operations should be done in all the patients with evidence of canal compromise,[13] but others have suggested that removal of bullet or bone fragments is beneficial only in the T12–L4 region.[14,15] Most authors have not found any benefit from spinal canal decompression after GSW. If surgery is performed, timing is optimal within the first 24 to 48 hours after injury.

Complete neurologic deficit is characterized by complete absence of motor or sensory function below the level of injury. Most of these patients do not benefit from surgical decompression, because their chances of neurologic recovery are minimal. The only possible exception is the rare patient with a GSW to the cervical spine and imaging evidence of compressive pathology by bone fragments or a bullet. Early decompression in these cases may provide recovery of one or two cervical spinal segments, with major positive effects on their future recovery of independence with activities of daily living (ADLs).

SPECIAL INDICATIONS

Disk Herniation

GSW to the spine may result in disk herniations with spinal canal or foraminal compromise. In these rare cases, the indications for surgery are the same as for other acute disk herniations: emergent diskectomy for decompression. Bullet removal in these cases is not necessary, unless it is technically easy to perform and does not jeopardize adjacent neural structures.

Lead Toxicity

Lead toxicity is an unusual occurrence reported in GSW with the bullet lodged in the intervertebral disk space.[16] The diagnosis is based on the presence of anemia and other hematopoietic alterations and requires determination of blood lead levels. The treatment consists of bullet removal and administration of lead-chelating agents.

Bullet Migration

Another rare situation is that of documented bullet migration. When associated with increased or new-onset neurologic deficit, surgical removal of the bullet is usually indicated.

Late Complications

Besides neurologic deficit, the most common long-term complication in both complete and incomplete injuries is neuropathic pain. Various studies report an incidence of neuropathic pain after spinal cord injury between 30% and 90%. This typically occurs in young patients who have major difficulties with basic self-care tasks, such as grooming and cleaning, as well as driving, job-related duties, and social activities. Moreover, patients in severe pain are prone to emotional imbalances, such as depression and anxiety, and they report a lower overall satisfaction with life. Neuropathic pain in these patients has a complex etiology and involves changes in structure, biochemistry, and genes in the peripheral and central nervous systems. Current pharmacologic and surgical therapies are often ineffective over time for these patients. Medications include neuroleptics, narcotics, antidepressants, and calcium-channel blockers (e.g., gabapentin). Surgical intervention for bullet removal has not been shown to improve the pain in this population. Other operations target the treatment of pain pathways (e.g., spinal cord stimulation or dorsal root entry zone ablative procedures) with variable reported successful outcomes.

Louisiana State University–New Orleans Experience

Between January 2007 and October 2011, 147 patients were admitted and received level 1 trauma services at Louisiana State University in New Orleans. Patient age ranged between 14 and 66 years (mean, 27 years). Interestingly, the mean age for African American patients was 25, whereas for whites, the mean age was 36. The patient group was composed of 123 African Americans (84%) and 13 Caucasians (9%). Most of the patients were male (92%), and most were single (97%). Interestingly, of the 88 patients tested for drugs, 73 (83%) tested positive, with the leading substances being tetrahydrocannabinol (THC), ethanol, and cocaine.

Of the 147 patients, 127 (86%) were treated conservatively (Figs. 70-1 and 70-2). Only 20 patients (13%) underwent a spinal operative procedure. Thirteen of these patients underwent operations on the spine below T11, and nine had decompressive procedures (Fig. 70-3) with no neurologic improvement, except for one patient who improved from ASIA class C to D; the other four patients had signs of unstable fractures and underwent stabilization procedures (Fig. 70-4). Three of the decompressive procedures were done in a minimally invasive fashion (Fig. 70-5), via a 22 mm retractor tube, with no postoperative complications (i.e., CSF fistula or infection). Cervical operations were performed on six patients, mostly for stabilization (Figs. 70-6 and 70-7). One patient developed a cervical spinal cord infarct after a GSW to the thoracic spine (Fig. 70-8) and underwent a cervical decompressive laminectomy and fusion without significant neurologic improvement.

Figure 70-1 Gunshot wound to the thoracic spine, through the spinal canal, with complete neurologic deficit (paraplegia) below the level of injury. This patient was treated nonoperatively.

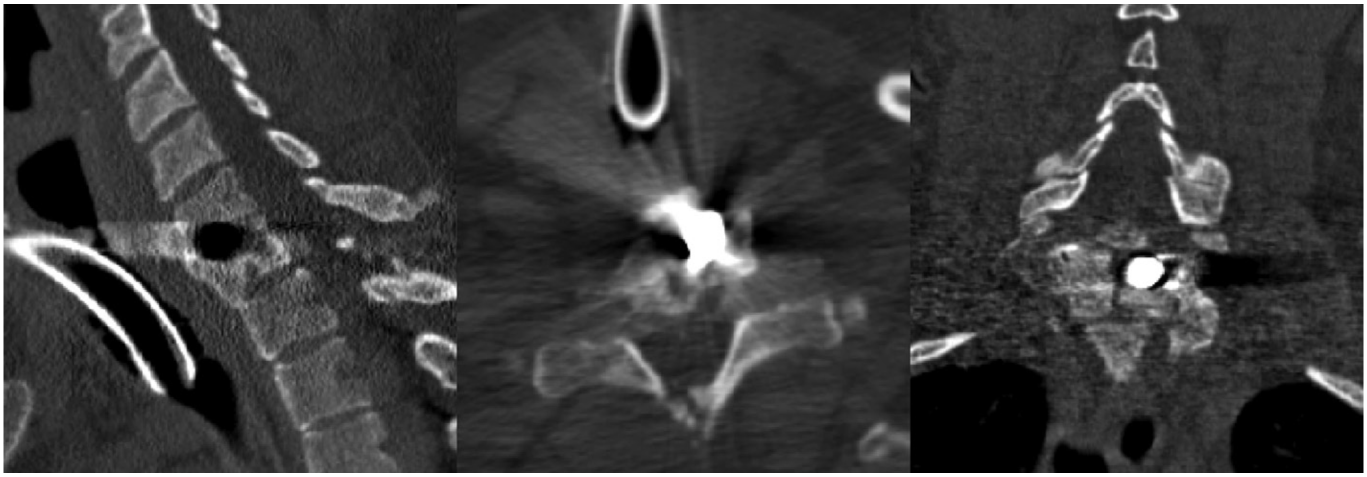

Figure 70-2 Gunshot wound to the cervical spine. The bullet went through the spinal canal, from posterior to anterior, and lodged in the vertebral body. The patient had a complete neurologic deficit and was treated conservatively.

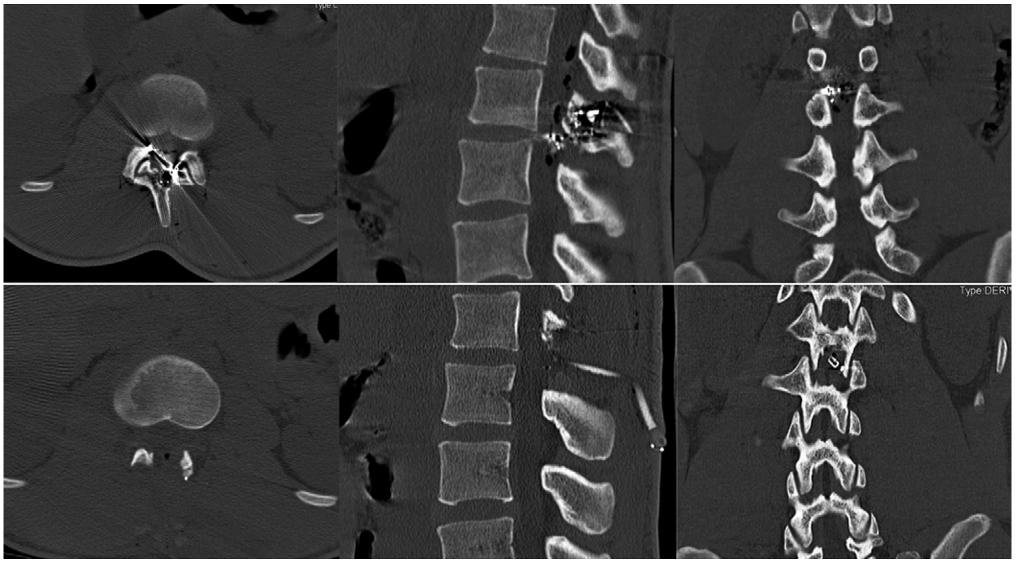

Figure 70-3 *Top:* Gunshot wound to L1 with incomplete neurologic deficit (American Spinal Injury Association class D injury) and bullet and bone fragments in the spinal canal. *Bottom:* An open decompressive lumbar laminectomy was performed without any immediate neurologic improvement.

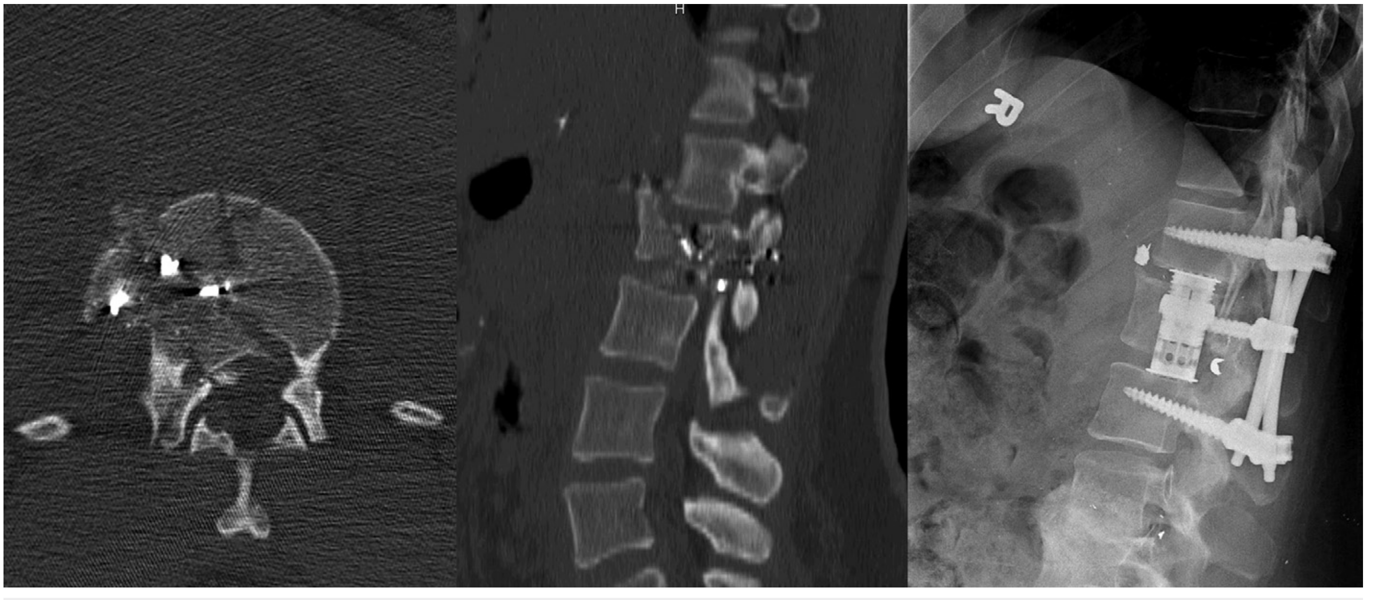

Figure 70-4 Gunshot wound to L1 with complete neurologic deficit. A right-sided corpectomy was performed, followed by placement of pedicle screws bilaterally, one level above and below the lesion, and placement of a left-sided pedicle screw in the remainder of the L1 vertebral body.

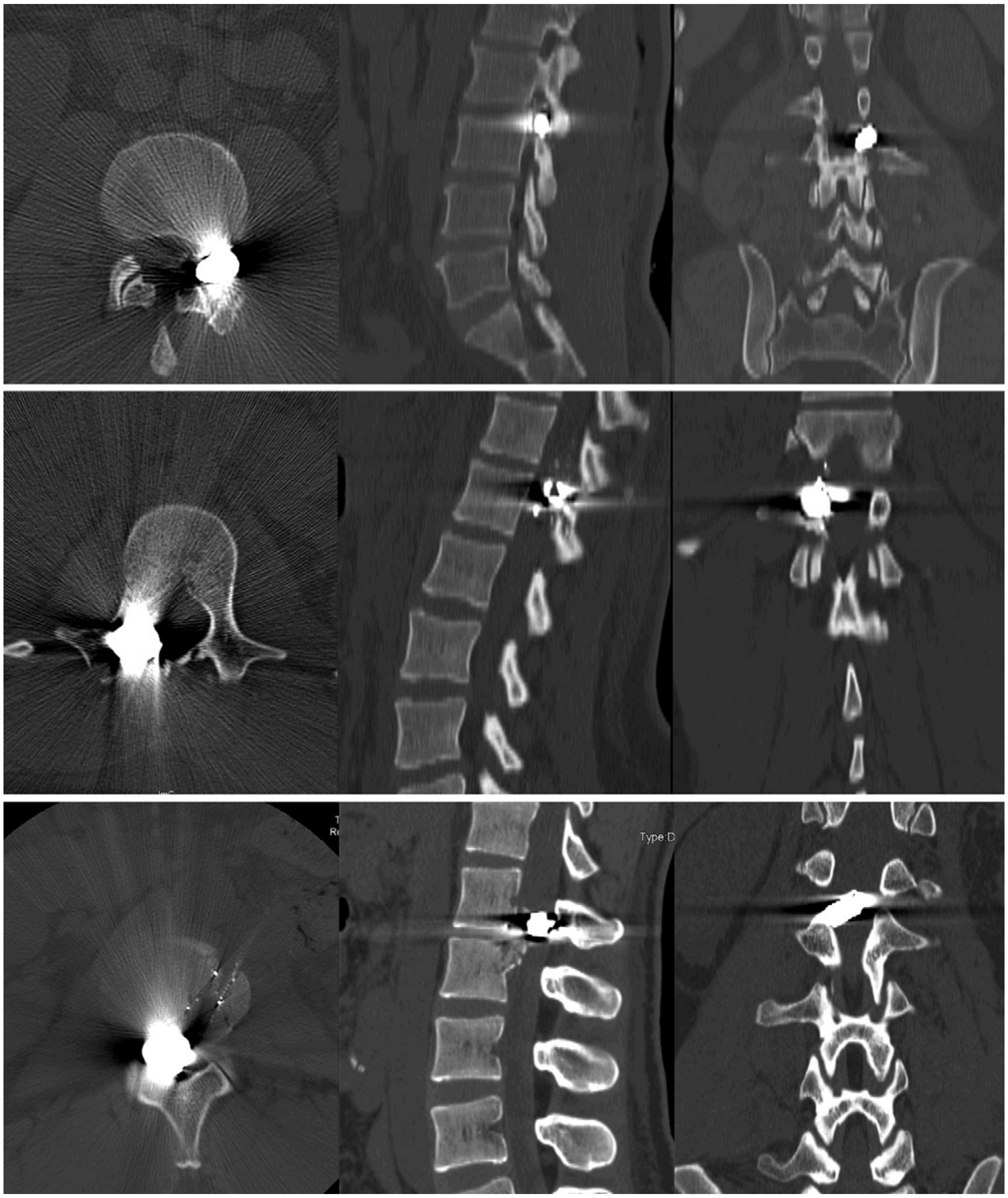

Figure 70-5 Three patients with gunshot wounds below T11 (L3, L1, and L2, respectively) and mixed neurologic deficits (American Spinal Injury Association [ASIA] class C, A, and A, respectively). These patients underwent a minimally invasive laminectomy for canal decompression and bullet removal via a 22 mm tubular retractor. None of the patients had postoperative cerebrospinal fluid fistulas or infections. Only the incomplete patient improved, going from ASIA class C to class D.

Figure 70-6 Gunshot wound to the cervical spine with comminution of the C6 anterior and posterior elements and complete C4 neurologic deficit. A C6 corpectomy followed by anterior and posterior fixation was performed to optimize neck stability for maximal rehabilitation efforts.

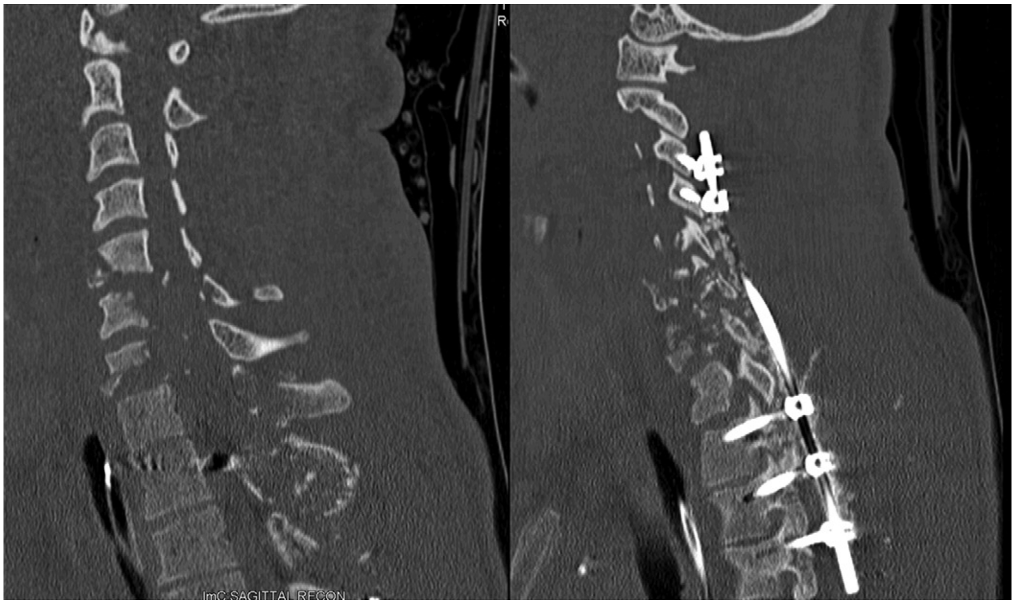

Figure 70-7 High-energy gunshot wound to the cervical spine. Anterior and posterior bony destruction over multiple levels was demonstrated on computed tomography. A long, posterior cervicothoracic fusion was performed.

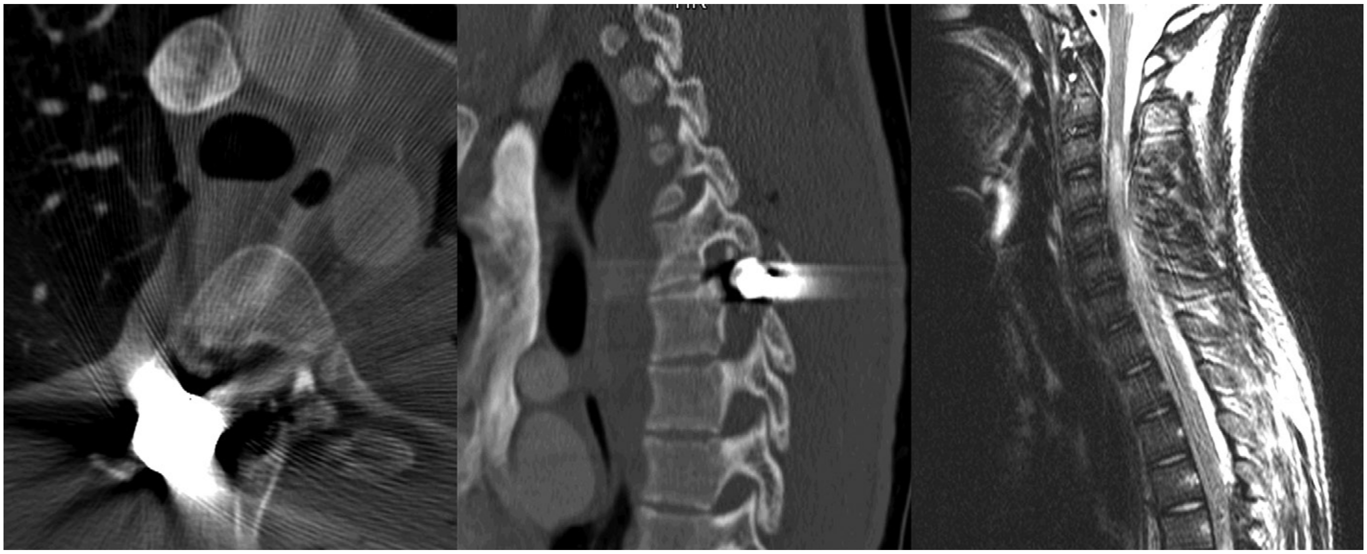

Figure 70-8 Gunshot wound to the thoracic spine that presented with T4 paraplegia. Two days later, the patient developed quadriparesis. Magnetic resonance imaging showed extensive edema in the cervical spinal cord. A decompressive cervical laminectomy was performed, and the patient recovered most of his upper extremity strength and remained neurologically complete below T4.

Another patient had a GSW through the foramen transversarium with occlusion of the vertebral artery and retained fragments in the spinal canal, but some neurologic improvement was seen in the first few days (Fig. 70-9).

Summary

GSWs to the spine represent an increasingly significant societal and clinical problem. Surgical intervention is clearly indicated in patients with segmental instability, persistent CSF leak refractory to lumbar drainage, and in those with progressive neurologic deficit (rare). Decompressive procedures are still controversial, but they may offer some benefits in patients with incomplete neurologic deficit and compressive pathology, particularly below T11. Patients with complete lesions and compression in the cervical spine may recover one or two cervical segments after surgical decompression and may thus be considered surgical candidates. The potential benefits of operative intervention must be carefully weighed against the risks of CSF fistula, infection, and increased neurologic deficit in each patient.

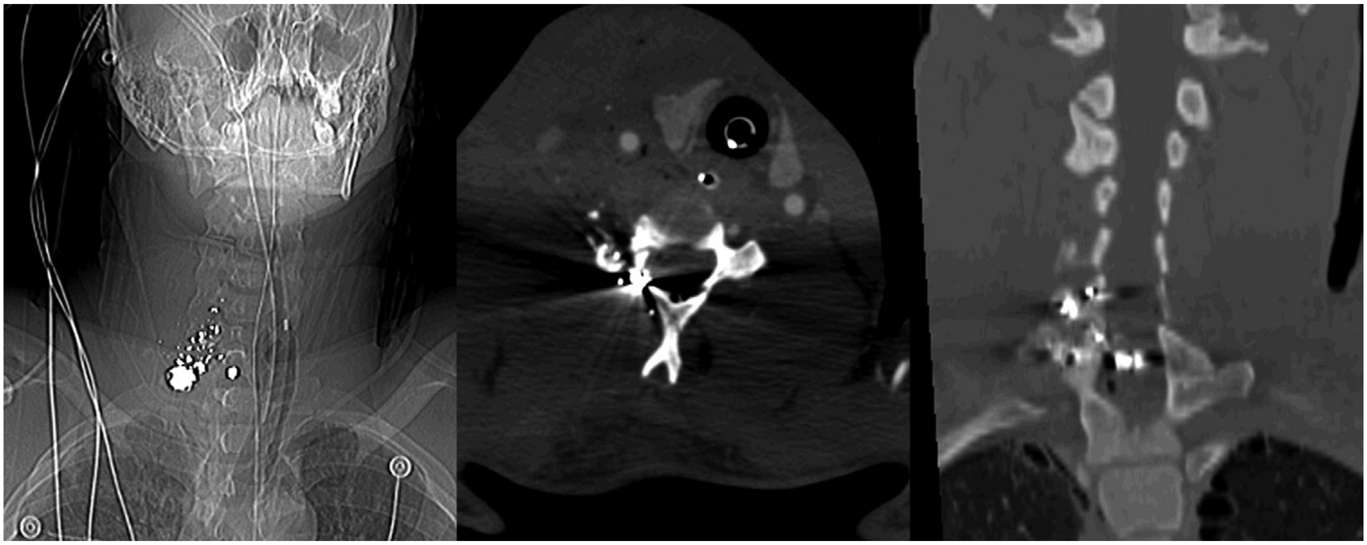

Figure 70-9 Gunshot wound to the cervical spine through the right vertebral foramen, with complete occlusion of the vertebral artery and residual bullet and bone fragments in the canal. The patient exhibited a central cord syndrome with predominant right-sided weakness. A cervical laminectomy with canal decompression was performed, followed by a fusion. The patient continued to improve neurologically and was able to ambulate with a cane.

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71 Vertebroplasty and Kyphoplasty

SOO YOUNG PARK and YONG-CHUL KIM

Overview

Balloon kyphoplasty and vertebroplasty are minimally invasive options for treating painful vertebral compression fractures. These procedures can be performed on an outpatient basis; they can provide successful pain relief, along with a return to activities of daily living immediately after the procedures; and they can stabilize vertebral fractures. In addition, balloon kyphoplasty can reduce spinal deformity by restoring vertebral body height.

The incidence of procedure-related complications such as cement leakage is low, especially in balloon kyphoplasty, whereas pain relief has been reported in more than 90% of patients. The medical cost of kyphoplasty is higher than that of vertebroplasty. Most patients (88%) who require vertebroplasty or kyphoplasty may also have facet joint pain adjacent to the corresponding affected vertebrae. Supplementary facet joint injections or medial branch blocks could, therefore, improve the level of pain relief in such cases. If the duration of nerve blocks is temporary, radiofrequency thermocoagulation of the corresponding medial branches will be required for long-term pain relief.

Treatment Objectives

The treatment objectives of kyphoplasty or vertebroplasty are pain relief and early return to function. In cases of kyphoplasty, restoration of the anatomy could be achieved by reducing and stabilizing the fracture, restoring vertebral height, and diminishing the spinal deformity.

Indications

Kyphoplasty or vertebroplasty is performed in patients who have recent vertebral fractures as a result of osteoporosis, angioma, myeloma, metastasis, and so on and who have pain refractory to conservative treatment, which includes bed rest, physical therapy, and medications. The best results are obtained when the vertebral collapse has occurred recently; that is, within 3 months of the patient's seeking medical attention.[1-3]

Contraindications

Contraindications to kyphoplasty and vertebroplasty may be absolute or relative.[1-4] Absolute contraindications are as follows:

- Coagulation disorders
- Local infection in the proposed site of access (osteomyelitis or spondylodiskitis)
- Unstable fractures or neoplasms with involvement of the posterior vertebral wall (i.e., complex fractures with or without retropulsed fragments) and accompanying spinal canal compromise
- Vertebra plana (complete vertebral body collapse)

Relative contraindications to the procedure are as follows:

- Less than one third of the original vertebral body height remains.
- Pedicles or articular facets are damaged.
- Tumor invasion into the spinal canal makes any potential leakage of even a small amount of cement into the already compromised canal especially hazardous.

Complications

Overall incidence of complications with the aforementioned procedures ranges from 0% to 9.8%.[5-10] The most common complication is cement extravasation, which may be avoided with the following precautions[11]:

- Adequate imaging with high-quality digital fluoroscopy, adequate cement opacification with sterile barium, and injection of cement that is not too liquefied can all prevent leakage.
- Filling the void with thick, toothpastelike cement under low injection pressure in kyphoplasty yields less cement leakage than filling the interstices of a fractured vertebra with thin, less viscous cement via a high-pressure injection, as is done in vertebroplasty.

Other rare complications are as follows:

- Pneumothorax and rib fracture during thoracic kyphoplasty
- Pulmonary embolism
- Bleeding or spinal epidural hematoma
- Radiculopathy
- Paraplegia
- Infection
- Cerebrospinal fluid leakage
- Transient acute respiratory distress syndrome

Preoperative Preparation

The physician should obtain a description of the symptoms from the patient, which may include complaints of motion limitation and varying degrees of local pain with or without radiation around the trunk and farther anteriorly. Physical examination at the level of the recent fracture reveals corresponding tenderness upon deep palpation and pain provoked by percussion.

The imaging diagnosis would include the following:

- Plain spine anteroposterior (AP) and lateral films
- Computed tomography (CT) scan with or without three-dimensional imaging to assess details of the bony architecture in cases of suspicion of a posterior cortical fracture (Fig. 71-1)
- Magnetic resonance imaging (MRI) to detect signal change caused by bone edema at the level of a recent fracture (Fig. 71-2, *A*)
- Bone scan to determine the most recent fracture in patients with multiple fractures (see Fig. 71-2, *B*)

Radiologic Anatomy for Kyphoplasty and Vertebroplasty

Radiologic landmarks for kyphoplasty or vertebroplasty should be identified as follows (Fig. 71-3):

- Pedicles, to define the starting point of the bone access needle on each side
- Spinous process, to gauge vertebral body rotation

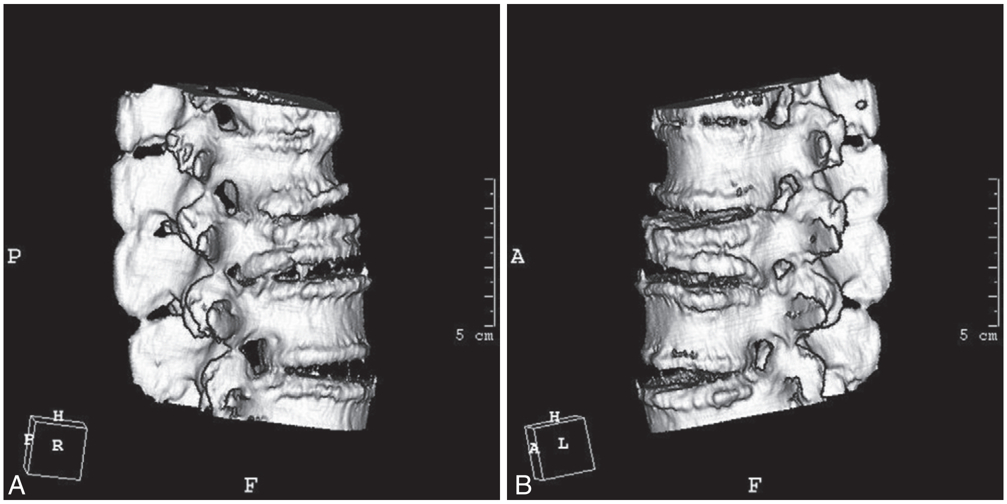

Figure 71-1 Computed tomography scan with three-dimensional images of a vertebral body fracture from the right (**A**) and left (**B**). (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Saunders Elsevier.)

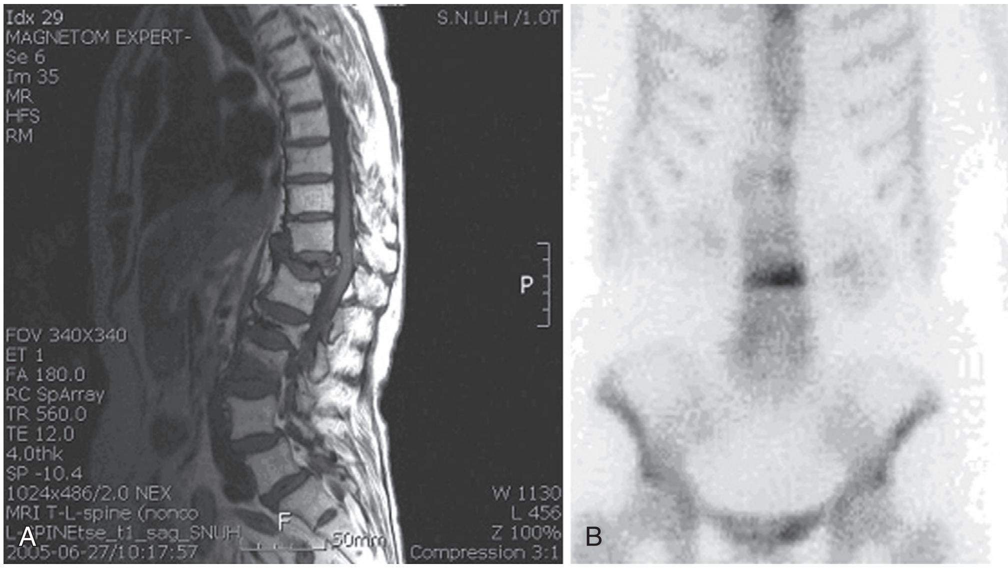

Figure 71-2 **A,** T1-weighted sagittal magnetic resonance imaging shows a complete vertebral body collapse (vertebra plana) at T12 and L2. A few fracture fragments at T12 compress the spinal cord anteriorly. **B,** Bone scan image shows no radiotracer uptake at the T12 and L2 levels, indicating chronic, rather than acute, fractures at these levels. At the L3 lower vertebral body, a loss of high signal intensity is seen on the T1-weighted image, with high uptake on the bone scan image, indicating an acute pathologic process. Kyphoplasty or vertebroplasty at the T12 and L2 levels is contraindicated, whereas at L3, either procedure is indicated. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Saunders Elsevier.)

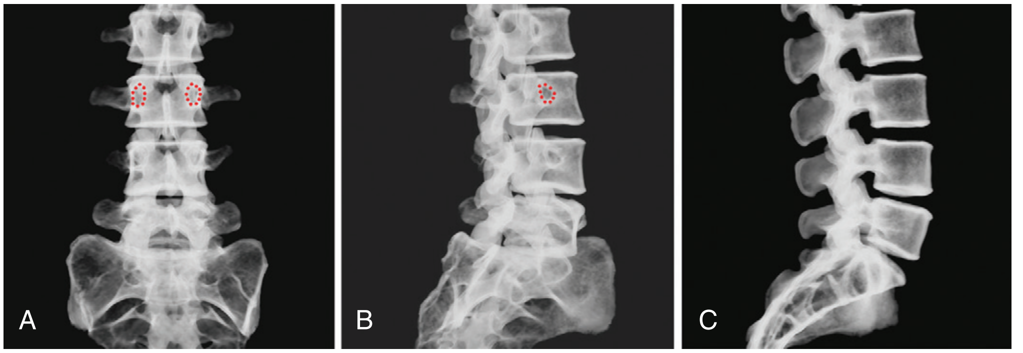

Figure 71-3 Fluoroscopic images of the lumbar spine. **A,** On a true anteroposterior (AP) image, the pedicles (*dotted circles*) should be equidistant from both lateral margins of the corresponding vertebral bodies, and the spinous process should be located at the midline of the width of the vertebral body. **B,** On an oblique image, the pedicle (*dotted circle*) should be visualized at its widest and most circular aspects. **C,** On a true lateral view, the two pedicles should be superimposed. For assessment of the location of the needle tip and its correct trajectory, frequent checks of the AP and lateral views are essential.

Figure 71-4 The instruments used for kyphoplasty. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

- End plates, to enable planning of a posterior–anterior trajectory
- Posterior cortical margin, to avoid the anterior margin of the spinal canal

Equipment for Vertebroplasty and Kyphoplasty

Various devices have been introduced for vertebroplasty and kyphoplasty. All photos in this chapter were obtained from the kits supplied by Kyphon (Sunnyvale, CA; Fig. 71-4).

Procedure

INSERTING TOOLS INTO THE FRACTURED VERTEBRAL BODY

Three approaches have been introduced to access the vertebral body using a bone access needle: *transpedicular, extrapedicular,* or *unipedicular-posterolateral* (Fig. 71-5). The selection of approach depends on fracture configuration and the patient's anatomy (Table 71-1).

Unipedicular Posterolateral Approach

As a result of needle placement in the center of the vertebra, rather than in the anterior quarter, the unipedicular

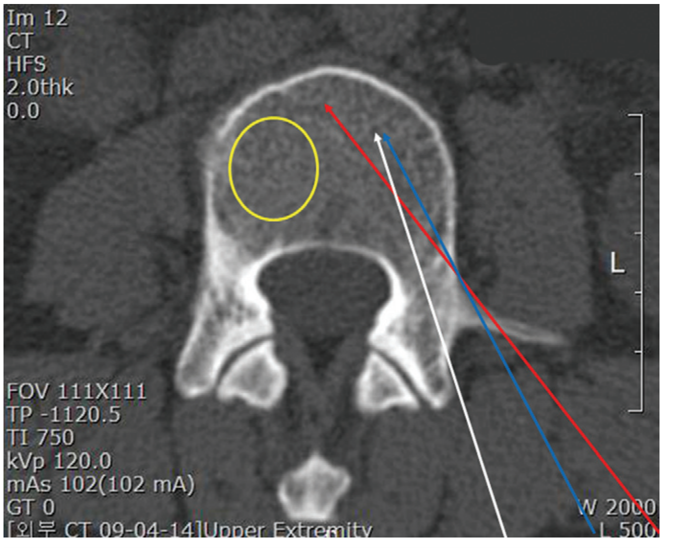

Figure 71-5 Imaginary approach lines of various techniques for vertebroplasty and kyphoplasty. *White arrow* denotes transpedicular approach. *Blue and red arrows* denote extrapedicular and unipedicular posterolateral approaches, respectively. *Arrow tips* represent the final target points of each approach from where bone cement is injected. A *yellow oval* represents potential area of cavity made by the inflation of the balloon during kyphoplasty.

Table 71-1 Approach Methods for Percutaneous Vertebroplasty

Approaches	Indications
Transpedicular	Most osteoporotic and osteolytic compression fractures
Extrapedicular	Cancer invasion of the pedicle Pedicle screw fixation in place Compression fractures in upper and mid thoracic vertebrae
Unipedicular posterolateral	Special cases in which a transpedicular or extrapedicular approach cannot be performed

posterolateral approach could promote leakage directly via the epidural veins to the epidural venous plexus along the anterior aspect of the spinal canal (Fig. 71-6). Also, this approach carries the possibility of transecting the segmental artery, or even injuring the exiting nerve root, because the needle trajectory potentially endangers the nerve root and segmental artery.[12] This approach should only be performed by experienced physicians who have full understanding of radiologic anatomy and extensive experience in transpedicular and extrapedicular approaches.

Transpedicular Approach

The transpedicular approach is usually performed in lumbar and lower thoracic vertebrae as follows:

1. To determine the skin entry site for the bone access needle, align the pedicles between the maximally compressed superior and inferior end plates for a true AP fluoroscopic image (Fig. 71-7, *A*, and 71-8). Next turn the C-arm obliquely, until the pedicle can be visualized at its widest and roundest points (see Fig. 71-7, *B*). With this view, the skin entry point is at the center of the target pedicle.

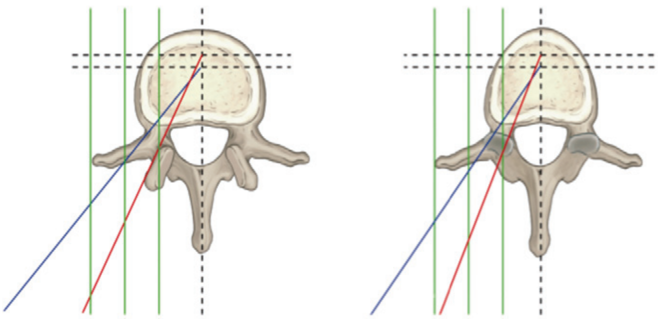

Figure 71-6 Imaginary approach line for safe unipedicular vertebroplasty. To prevent leakage of cement into the epidural space, the target point has to be at the anterior one fourth to one third and at the midline of the vertebral body. The skin entry point nearest to the midline will be the extension line from the anterior one fourth through the inner pedicle (*red*). The farthest skin entry point from the midline is the extension line from the anterior one third through the outer pedicle (*blue*). In most cases, the skin entry point is between 1.5 and 2.5 times the pedicular distance from the midline in the thoracic or lumbar vertebrae. Three vertical lines parallel the midline of the body, at one, two, and three pedicular distances (*green*). (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

2. After skin infiltration of local anesthetics, a 3-mm skin incision is made. Conscious sedation is the anesthesia of choice for kyphoplasty; we use 50 µg of fentanyl and 30 mg of ketorolac with or without 2 to 3 mg of midazolam intravenously. General anesthesia can be used for very anxious patients. For local anesthesia, an agent such as 2% lidocaine or 0.5% bupivacaine is used.
3. The bone access needle can be advanced through the center of the target pedicle with use of a tunnel vision technique (i.e., the needle is advanced parallel to the fluoroscopic beam) without concern for accidental pedicle and end plate damage (Fig. 71-9).
4. Verification of the needle trajectory is performed as follows:
   - *Midpedicular level:* When the bone access needle tip is presumed to be located at the midpoint of the pedicular diameter on the lateral view, its location on the AP view should be checked; here it should be central in the pedicle outline. If the tip is located too far laterally, the lateral cortical wall of the pedicle may be damaged, and ballooning of the bone tamp may not be possible. If the tip is located too far medially, the medial cortical wall of the pedicle may be damaged, thereby leading to spinal canal violation (Fig. 71-10).
   - *At the level of the posterior surface of vertebral body in a lateral view:* If the bone access needle reaches the posterior vertebral cortical margin on the lateral view, it should be just inside the medial border of the pedicle outline on the AP view and then is advanced slightly into the vertebral body. If the needle is placed too far laterally, it may damage the lateral cortical wall of the pedicle, and ballooning of the bone tamp may not be possible. If the needle is placed too far medially, it may result in accidental penetration of the medial cortical wall of the pedicle, thereby leading to spinal canal violation (Fig. 71-11).

Extrapedicular Approach

The extrapedicular approach is commonly used in upper and mid thoracic vertebra. In contrast to the transpedicular route, the skin entry point in the extrapedicular approach is more lateral than the pedicle, and the trajectory of the needle is more medially directed. The approach is performed as follows:

1. The skin entry point is lateral to the pedicle, either through the thoracic transverse process or along the transverse process–rib junction (Fig. 71-12).

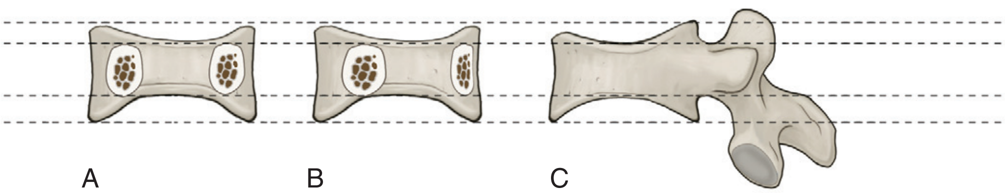

Figure 71-7 Placement of the bone access needle. **A,** Align the pedicles between the maximally compressed superior and inferior end plates in a true AP image. B, Turn the C-arm obliquely until the pedicle can be visualized at its widest and roundest. **C,** Lateral image of the vertebral body and pedicles shown for comparison. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

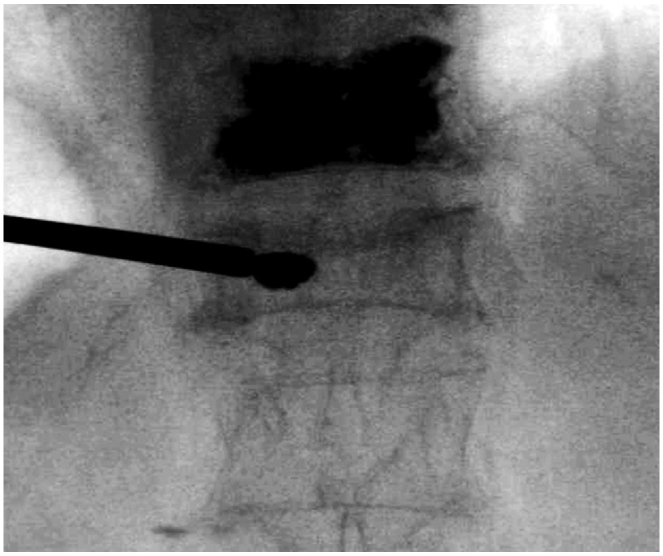

Figure 71-8 Adjustment of C-arm for kyphoplasty or vertebroplasty in an anteroposterior projection. Both pedicles are located between the superior and inferior end plates.

2. The bone access needle is advanced along the medial border of the rib, until the lateral border of the pedicle is reached on the AP image and the posterior vertebral body margin is reached on the lateral image. The tip should not pass medial to the lateral border of the pedicle on the AP image before the posterior aspect of the vertebral body is seen on the lateral image.
3. After correct needle placement has been confirmed on AP and lateral images, the bone access needle is advanced only about 5 mm beyond this position in kyphoplasty for the next steps of the procedure (Fig. 71-13), whereas in vertebroplasty, the needle is advanced about 5 mm before the anterior margin of vertebral body, and cement filling follows.

PLACING AND INFLATING THE BONE TAMP (BALLOON KYPHOPLASTY)

The bone tamp is placed (see Fig. 71-13) and inflated (Fig. 71-14) as follows:

1. The bone access needle is exchanged for an Osteo Introducer needle (Medtronic, Memphis, TN) over a guide pin.

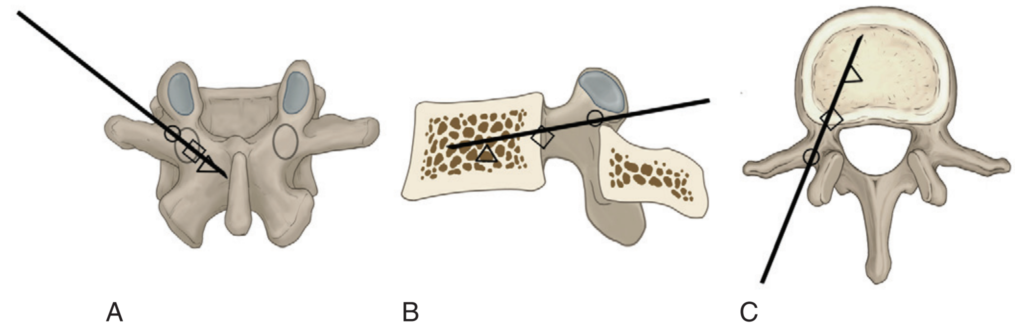

Figure 71-9 Trajectory of the transpedicular approach. **A,** Anteroposterior (AP) view. **B,** Lateral view. **C,** Axial representation. Symbols along the trajectory indicate the position of the bone access needle tip at various depths of insertion: *circles* show insertion point; *squares* show point at pedicle–vertebral body junction; *triangles* show midvertebral body. The needle tip should not pass medial to the medial border of the pedicle on the AP view until it is anterior to the posterior margin of the vertebral body on the lateral view. After penetration of the posterior margin of the vertebral body, the bone access needle is advanced only approximately 5 mm beyond this position. At that time, on the AP view, the tip should be located just medial to the medial border of the pedicle. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

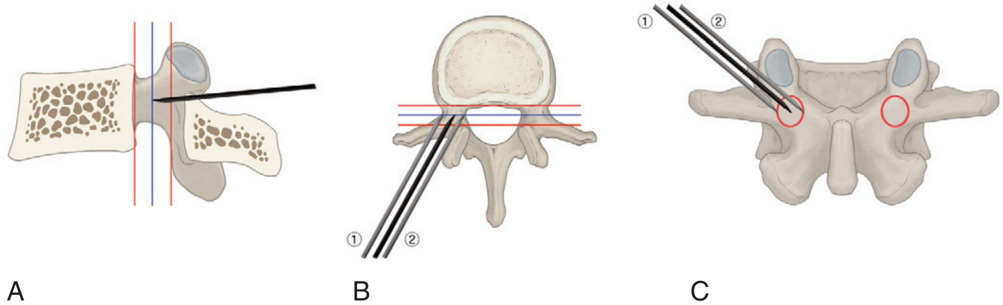

Figure 71-10 **A,** The bone access needle tip should be located at the midpoint of the pedicular diameter (*blue line*) on the lateral view. **B** and **C,** Its location on the anteroposterior view should be verified as central in the pedicle outline. If the tip is located too far laterally (1), the lateral cortical wall of the pedicle may be damaged, and ballooning of the bone tamp may not be possible. If the tip is located too far medially (2), the medial cortical wall of pedicle may be damaged, and thereby spinal canal violation may be anticipated (**B** and **C**). (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

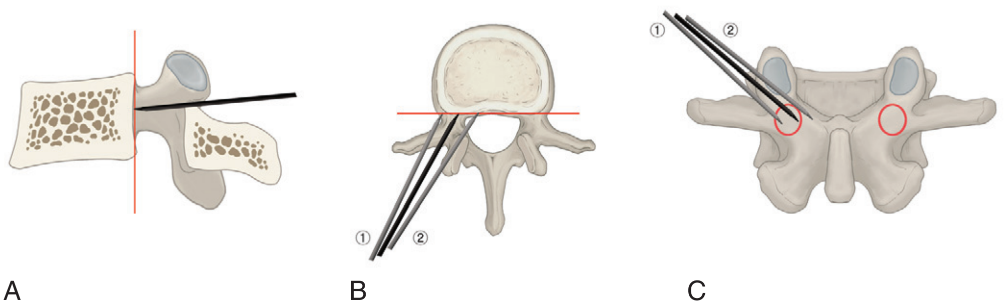

Figure 71-11 If the bone access needle reaches the posterior vertebral cortical margin on the lateral view (*red line*), it should be just inside the medial border of the pedicle outline on the anteroposterior view and is then advanced slightly into the vertebral body (**A**). On the schematic drawing, the black needle shows correct needle placement, when the needle reaches the posterior vertebral cortical margin on the lateral view. The first needle shows a placement of the needle that is too lateral and may damage the lateral cortical wall of the pedicle, and ballooning of the bone tamp may not be possible. The second needle shows a placement that is too medial and that may result in an accidental penetration of the medial cortical wall of the pedicle, thereby violating the spinal canal (**B** and **C**). (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

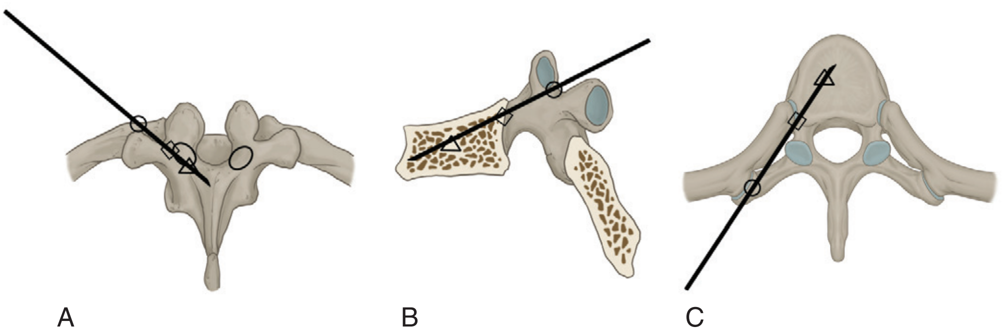

Figure 71-12 The trajectory of the extrapedicular approach for needle or bone access needle placement. **A,** Anteroposterior view. **B,** Lateral view. **C,** Axial representation. *Circles* show insertion point; *squares* show point at pedicle–vertebral body junction; *triangles* show midvertebral body. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

2. The Osteo Introducer needle is positioned near the posterior vertebral body margin, while the working instruments—the precision drill, bone tamp, and bone-filler device—are advanced anteriorly until they are approximately 5 mm from the anterior vertebral body border. Careful observation of the working instruments on a lateral view is very important to avoid accidental penetration of the anterior vertebral body border.
3. The inflatable bone tamp is inflated with liquid contrast media to 50 psi.

The allowable balloon pressure in cancellous bone ranges from 70 to 300 psi, and the maximum allowable pressure is 300 psi. The pressure will typically increase until the bone yields, allowing the balloon to expand. As the bone shifts, the pressure in the balloon will gradually decrease.

MIXING THE CEMENT AND FILLING THE VOID

The mixture of cement to be used (CMW1 bone cement, DePuy, Blackpool, UK) is 15 mL of powdered polymethylmethacrylate (PMMA), 8 to 9 mL of liquid PMMA, and 3 mL of barium sulfate as a guide. The factors related to the cement hardening time include the amount of barium sulfate, quantity of solvent, mixing time, and ambient temperature. Irrespective of the various hardening times for the multitude of cements available, the consistency must always remain constant.

1. Bone cement with a thick, pastelike consistency can be filled into the vertebral body cavity created by the inflatable bone tamp. As a result of the thicker consistency, the incidence of cement leakage in cases of kyphoplasty is significantly lower than that of vertebroplasty (Fig. 71-15).
2. Injection is continued until the void filling is achieved in kyphoplasty (Fig. 71-16). The incidence of cement leakage is relatively higher in vertebroplasty than in kyphoplasty. Filling is stopped immediately if any extravasation is noted into the surrounding veins, the spinal canal, or the disk space (Fig. 71-17).
3. After completing the injection, the Osteo Introducer needle is removed, and hemostasis is obtained by pressure.
4. The cement filler should be removed once the hardening time for the specific cement used has passed (Table 71-2).

Table 71-2 Sample Hardening Times for Polymethylmethacrylate (PMMA) Formulations*

Formulation	Time (Min)
CMW1 Original	8 to 9
CMW1 Radiopaque	8 to 9
CMW2	4.5 to 5
CMW3	8.5 to 9.5

*Products listed are manufactured by DePuy, Blackpool, UK.

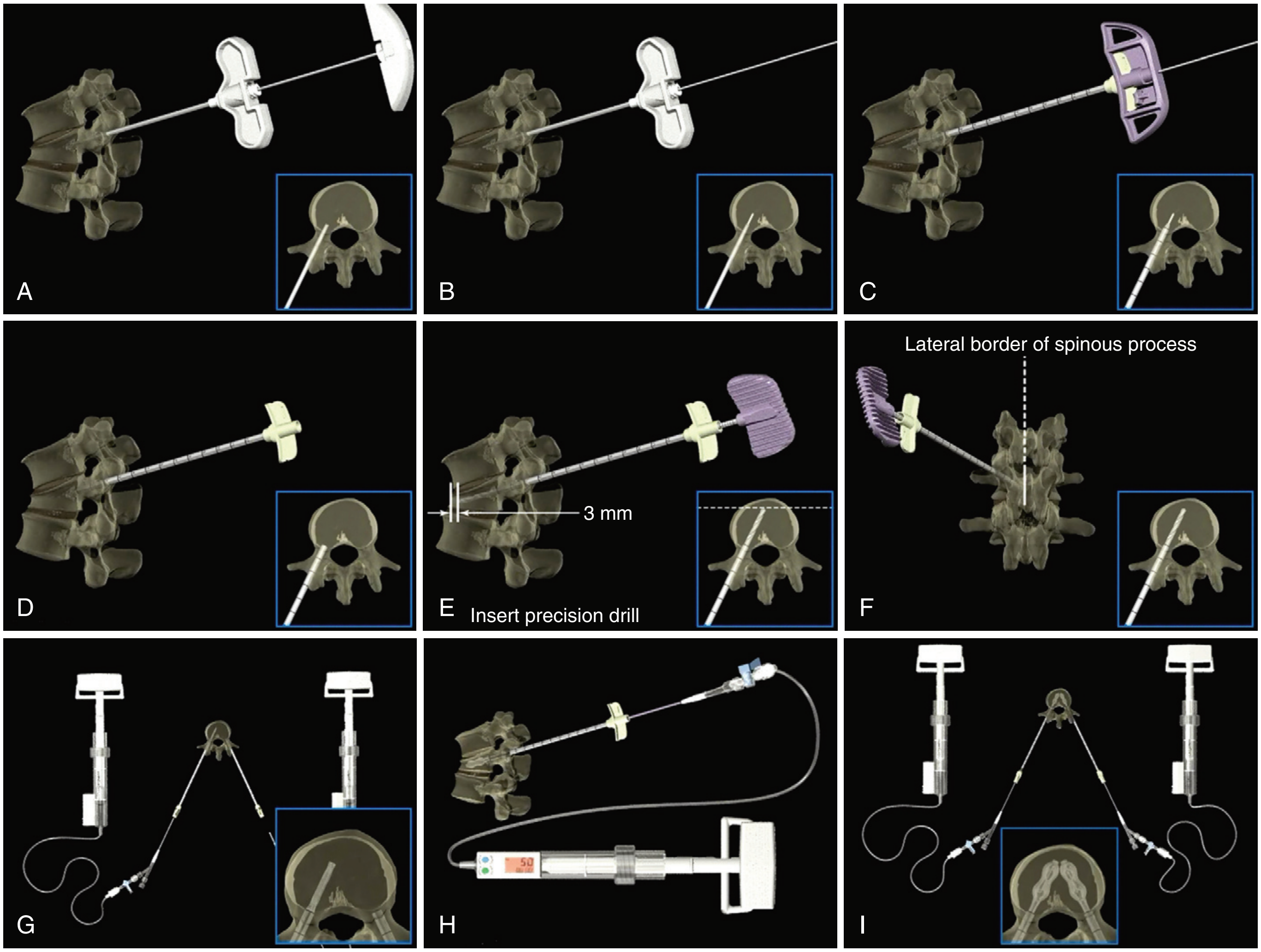

Figure 71-13 Sequence of procedures for the insertion of the bone tamp. **A** through **C**: The bone access needle is exchanged for an Osteo Introducer over a guidewire. **D** through **F**: The Osteo Introducer is positioned near the posterior vertebral body margin, while the working instrument is advanced anteriorly, until they are approximately 3 mm from the anterior vertebral body border. **G** and **H,** The inflatable bone tamp is positioned after removal of bone filler. **I,** The inflatable bone tamp is inflated with liquid contrast medium to 50 psi. (Courtesy Medtronic, Memphis, TN.)

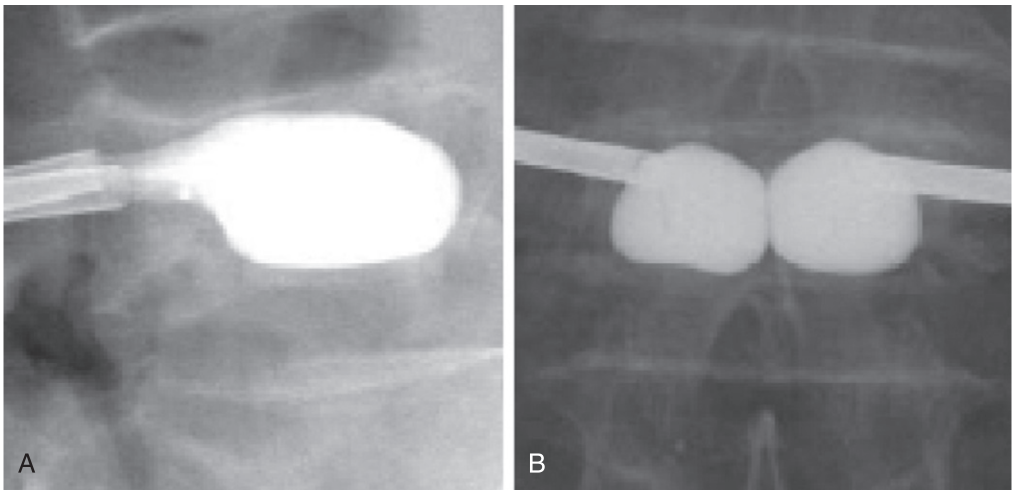

Figure 71-14 Inflating the bone tamp. Fluoroscopy shows the balloon filled with contrast media in lateral (**A**) and anteroposterior views (**B**). (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

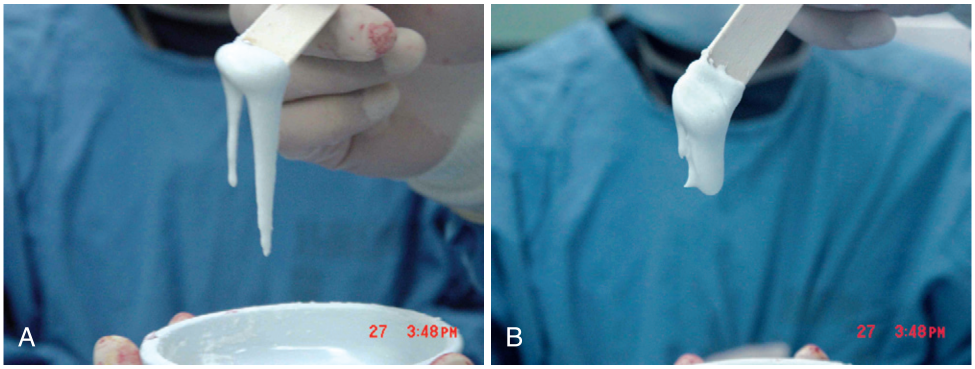

Figure 71-15 The consistency of bone cement for vertebroplasty (*left*) and kyphoplasty (*right*). (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

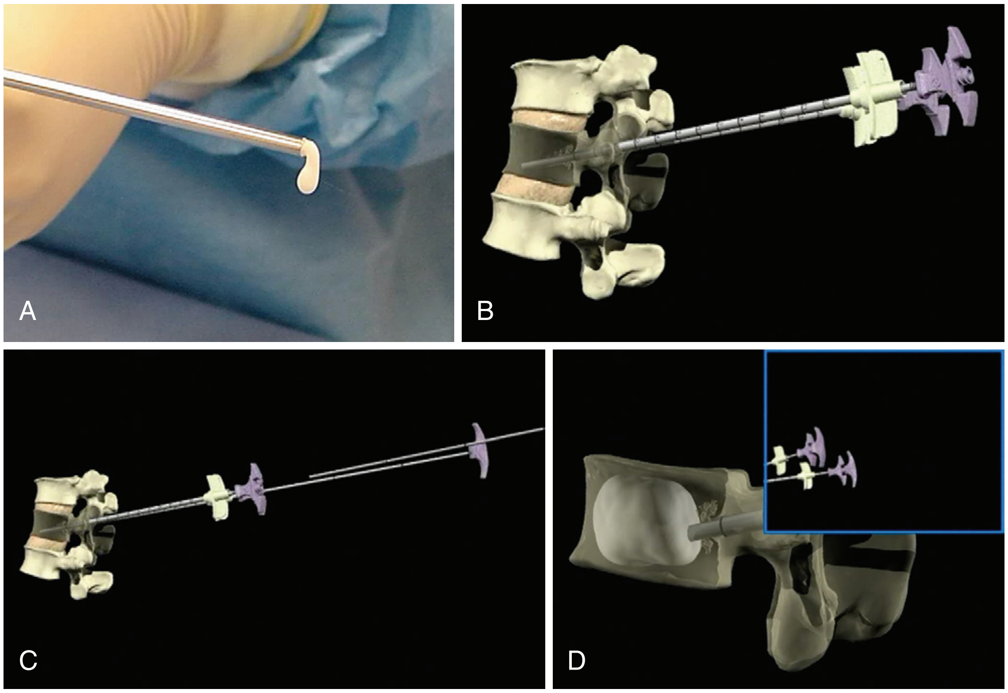

Figure 71-16 Filling the void. Bone cement with a thick pastelike consistency can be filled into the vertebral body cavity created by the inflatable bone tamp. **A,** Injection is continued until the void filling is achieved using cement filler (**B** and **C**). It is stopped immediately if any leakage is noted into the surrounding veins, the spinal canal, or the disk space (**D**). (Courtesy Medtronic, Memphis, TN.)

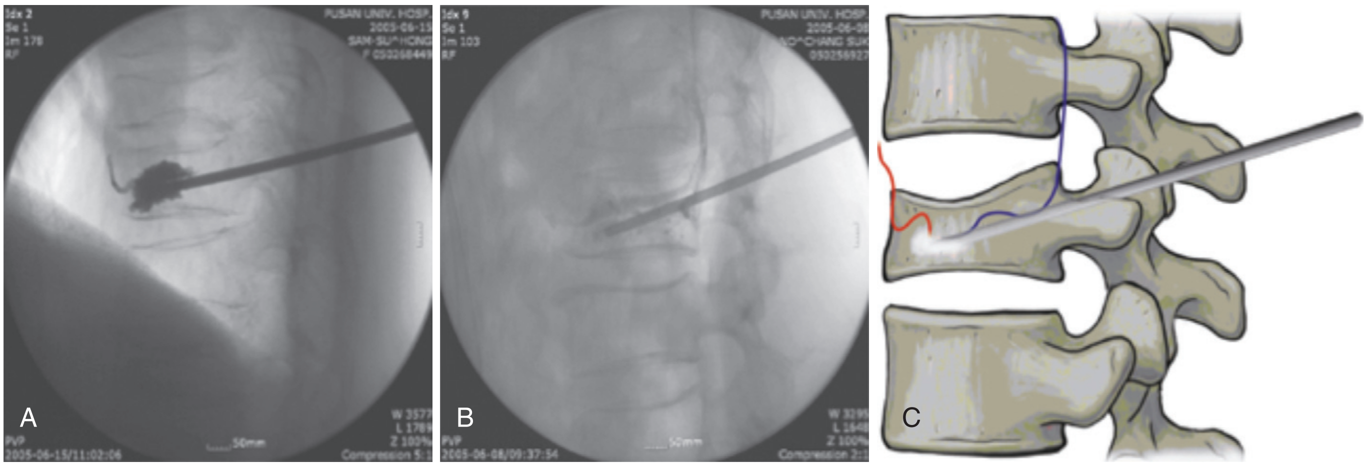

Figure 71-17 Test with contrast medium for leakage into the venous system and epidural space. Before injection of cement, check for leakage into the venous system (**A**) or into the epidural space (**B**) on the lateral view. **C,** Schematic drawing of possible cement leakage if test procedure is omitted. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

Postoperative Management

- Absolute bed rest with regular monitoring of vital signs is required for 2 hours after the procedure for fixation of PMMA.
- Most patients can be discharged on the day of surgery.
- Progressive return to full activities and physical therapy is recommended.
- Assistive devices, such as canes and walkers, may be useful for patients who have been unable to walk because of their painful vertebral fractures.
- Postoperative bracing is not applied routinely.

Potential Adverse Results

The potential adverse results of kyphoplasty are as follows:

- End plate rupture (Fig. 71-18)
- Uneven inflation of bone tamps (Fig. 71-19)
- Balloon rupture, which occurs in 20%[10]

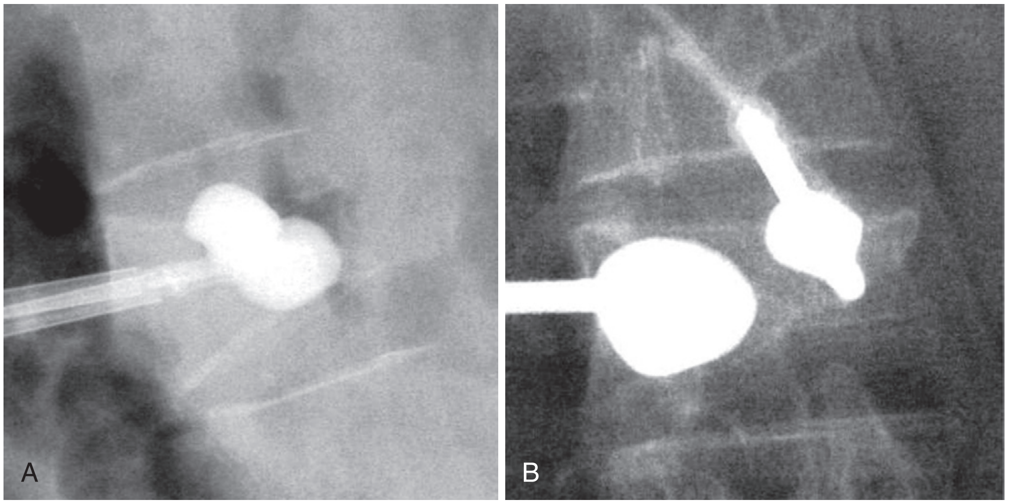

Figure 71-18 **A,** Superior end plate rupture was identified on lateral fluoroscopy. **B,** Bone cement was seen to be injected only from the left side. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

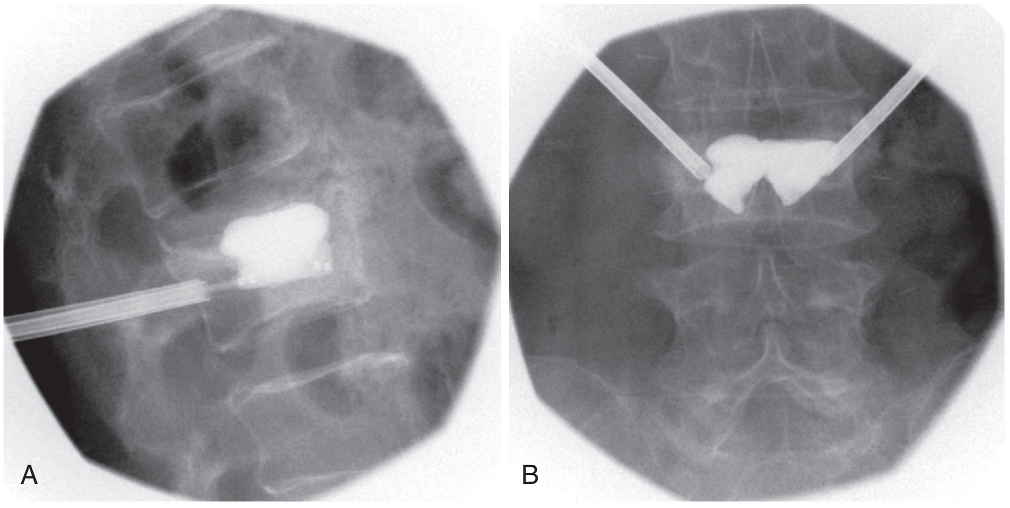

Figure 71-19 Uneven inflation of bilateral bone tamps. In many cases the balloons tend to inflate unevenly on the side of the fractured vertebra, which is the upper end plate in this case. Bone cement was seen to have leaked through the upper end plate in lateral (**A**) and AP (**B**) views. (Modified from Kim DH, Kim KH, Kim YC: *Minimally invasive percutaneous spinal techniques.* Philadelphia, 2011, Elsevier.)

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72 Bone Graft Harvesting Techniques

JEFFREY S. HENN and CURTIS A. DICKMAN

Overview

The success of many spinal procedures is determined by successful bone graft fusion. Although instrumentation can provide immediate rigid fixation, ultimately, bone fusion must occur to prevent long-term failure. Whether the person's own bone is harvested (autograft) or cadaveric allograft is used, the goal is the formation of a living, bony arthrodesis.

Selecting a Bone Graft

The type of bone graft used depends on the surgical procedure, the surgeon's preference, and occasionally the patient's preference. Autograft may be either cortical, cancellous, or mixed cortical and cancellous. Cortical bone is the strongest form of autograft and is typically used when strong structural support is required, such as fusion after anterior corpectomies.[1] Compared with cancellous bone, cortical bone has fewer living cells and less surface area. Autologous cancellous bone provides only 60% of the compressive strength of cortical bone but has very high rates of fusion in appropriate cases.[2] Cancellous bone provides the ideal combination of osteogenic, osteoinductive, and osteoconductive properties based on its composition of living cells and bone matrix proteins and its inherent architecture.[1] Typically, pure cancellous bone is used for posterior spinal fusions, which do not require the graft to withstand compressive forces.[1] Cortical-cancellous autografts are composed of both types of bone and offer the advantages of each. The grafts are stronger than cancellous bone, and they retain many of its advantages. A common example of cortical–cancellous bone is a tricortical iliac crest graft.

Although autograft remains the gold standard for successful formation of long-term arthrodesis, there are associated drawbacks. Complications associated with graft harvest can range from additional postoperative pain to more significant problems. The quality and quantity of autograft are sometimes inadequate. One alternative is cadaveric allograft. Unlike autograft—which is live, nonreactive, and genetically identical to the host—allograft is nonliving bone. Compared with autograft, allograft becomes vascularized more slowly. The rate of bone fusion is also slower, and the risks of bone resorption, rejection, and infection are higher. However, the distinct advantage of allograft over autograft is the lack of complications associated with harvesting. Similarly, a relatively new category of bone graft extenders may lead to successful fusion, despite not relying primarily on autograft or allograft.

Techniques of Bone Graft Harvest

Regardless of the type of bone graft, the chances of successful arthrodesis can be improved with meticulous surgical technique and adequate preparation of the bone graft and surfaces for spinal fusion.[3] Combination of this care and preparation with rigid internal fixation optimizes the likelihood of long-term fusion. In general, local trauma to tissue should be minimized to ensure maximum vascularity of the fusion site. Avoidance of monopolar coagulation and use of copious irrigation during drilling can minimize the risk of thermal injury to the bone. Periosteum and other soft tissue should be meticulously removed from the bone graft and fusion bed, because it can lead to a fibrous interface and nonunion. Typically, the fusion site should be decorticated to improve the chances of successful fusion. The bone graft should be shaped to fit precisely into the fusion site to maximize the surface area of bone-to-bone contact. In addition, space within the fusion bed should be eliminated, and all antiinflammatory medications should be avoided during the perioperative and postoperative period.

ANTERIOR ILIAC CREST GRAFTS

Historically, bone graft harvested from the anterior iliac crest was commonly used for anterior cervical spine procedures that required cortical–cancellous bone. This particular indication is less common because of the recognition that fusion rates are high with allograft. However, anterior iliac crest bone may still have a role in anterior cervical fusions in select patients at high risk for nonfusion, and it is still used with some frequency for anterior lumbar fusion procedures.

Anterior iliac crest bone is obtained through a linear incision made parallel to the iliac crest and directly over the harvest site. The bone should be harvested from at least 3 cm behind the anterior superior iliac spine to avoid disrupting the ilioinguinal ligament or creating an avulsion fracture (Fig. 72-1). A sandbag can be placed under the ipsilateral buttocks to assist with access to the anterolateral iliac spine.

Dissection proceeds through the subcutaneous tissue to the fascial layer. After retractors have been placed, the fascia is opened directly over the iliac crest, and subperiosteal dissection is performed. A fascial cuff and periosteum

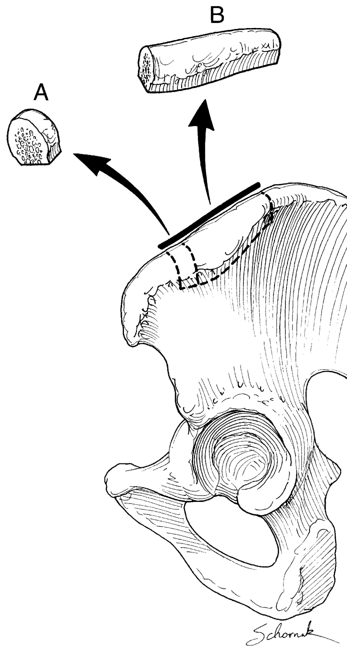

Figure 72-1 Bone graft harvested from the anterolateral ilium should remain 2 to 3 cm behind the anterior superior iliac spine to avoid an avulsion fracture. Tricortical bone grafts can be harvested for (**A**) single-level interbody fusions or for (**B**) multisegment vertebral body reconstructions.

are left intact for secure closure. To expose a tricortical graft, medial and lateral subperiosteal dissection continues with a periosteal elevator, until adequate bone has been exposed. Dissection along the medial iliac crest must be done with great care. The dissection must remain subperiosteal to avoid inadvertent peritoneal entry or injury to the iliohypogastric, ilioinguinal, or lateral femoral cutaneous nerves (Fig. 72-2).[4] Cauterization should be used sparingly to prevent the possibility of nerve injury.

After the retractors have been deepened to provide excellent exposure to the tricortical graft, the bone may be harvested using either oscillating saws or osteotomes. If the graft will serve a weight-bearing function, oscillating saws are preferred, because osteotomes can cause microfractures that can weaken the graft. Some surgeons temporarily pack the medial and lateral exposure to avoid injury to the muscle or peritoneal cavity.

After the graft has been harvested, bleeding is controlled with bone wax or Gelfoam soaked in thrombin. Drains are rarely needed, and the wound is closed in multiple layers; the periosteal layers and fascial layers are closed with interrupted sutures.

POSTERIOR ILIAC GRAFTS

The posterior iliac region can be used to obtain tricortical grafts, cortical matchstick grafts, cortical-cancellous plates, or cancellous bone strips (Fig. 72-3). Bone can be obtained from the iliac crest or in a subcrestal fashion. When a posterior iliac crest tricortical graft is planned, the graft is harvested from the posterior superior iliac spine (PSIS) or lateral to the PSIS to avoid the sacroiliac joint and sciatic

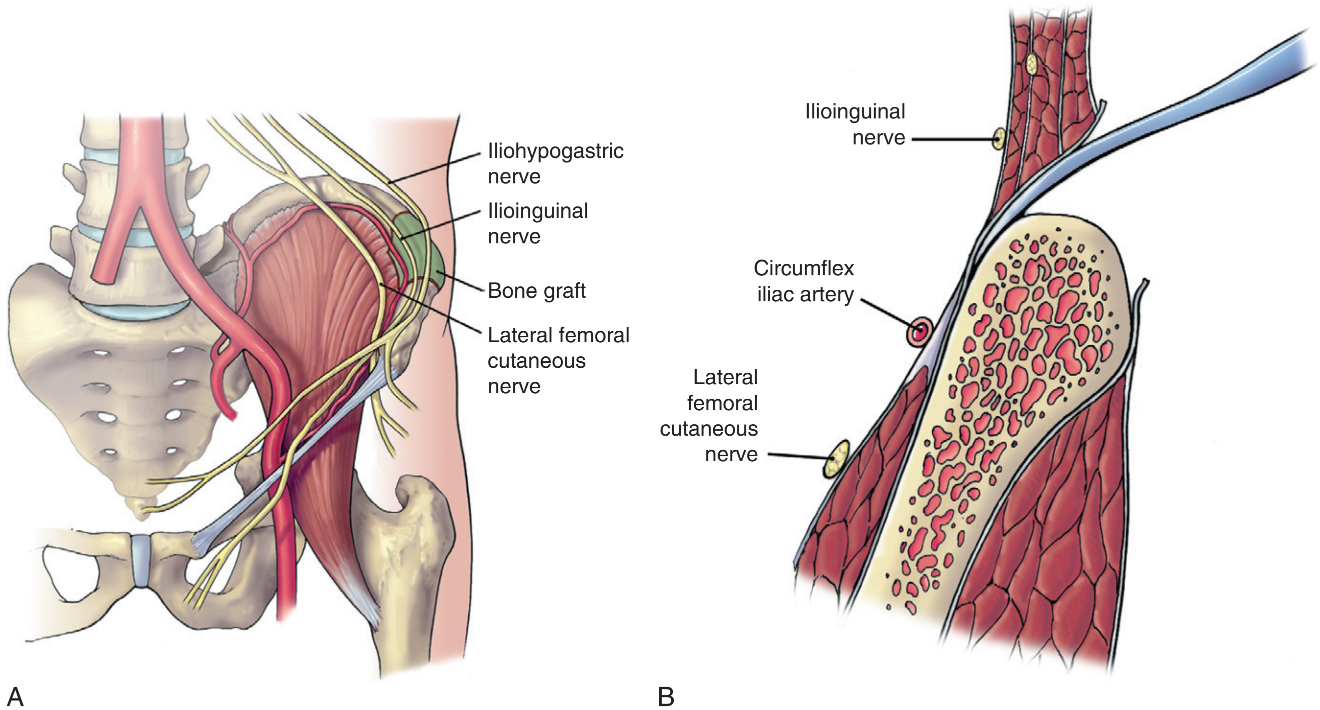

Figure 72-2 **A,** Fascial and periosteal incisions used for exposure of bone over the anterolateral iliac crest. **B,** The dissection should remain in a subperiosteal plane, and cautery should be avoided to prevent injury to the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves.

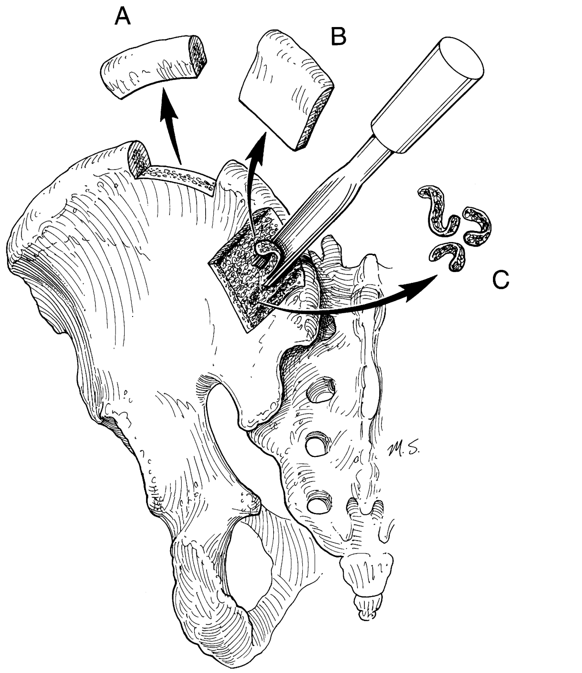

Figure 72-3 A variety of bone graft can be harvested from the posterior ilium. **A,** Tricortical strut graft. **B,** Cortical-cancellous plate. **C,** Cancellous bone strips.

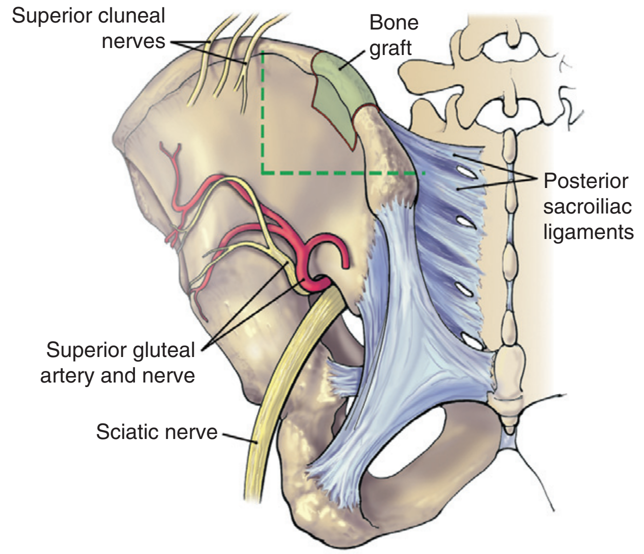

Figure 72-4 Graft taken from the posterior iliac crest should be kept above the line that intersects the posterior superior iliac spine. Care is taken to protect the sacral iliac ligaments medially, the sciatic nerve caudally, the gluteal vessels caudally and submuscularly, the superior cluneal nerves laterally, and the ureter anteriorly.

notch.[4-6] However, the graft should not be taken more than 8 cm from the iliac spine to avoid the risk of injury to the superior cluneal nerves, which can cause buttock numbness or painful neuromas (Fig. 72-4).

Several variations of incision are used. Some surgeons prefer a vertical incision directly over the PSIS. Others prefer a curved skin incision beginning at the PSIS and extending superolaterally. Dissection proceeds through the subcutaneous tissue, and the fascia is opened directly over the iliac crest. Dissection continues medially and laterally in a subperiosteal fashion to avoid injury to the gluteal artery branches, which can cause brisk bleeding. Great care should also be used to avoid dissection in the region of the sciatic notch, where the main trunk of the superior gluteal artery, sciatic nerve, and ureter can be injured. Medial dissection involves stripping off part of the iliacus muscle. Care must be exerted to remain subperiosteal to avoid injury to the ilioinguinal nerve or pelvic contents. Subperiosteal dissection also avoids injury to the ureter, which lies within the retroperitoneal fat pad.

Grafts are obtained using a combination of oscillating saw, osteotomes, and bone gouges or curettes. Hemostasis is obtained with bone wax or Gelfoam soaked in thrombin. Drainage is rarely necessary, and the wound is closed in layers; interrupted sutures are used to approximate the periosteal and fascial layers, and a layered closure is critical to avoid herniation of the abdominal contents.

If tricortical bone is unnecessary, an alternative technique, known as the *subcrestal exposure,* can be used to harvest unicortical and cancellous bone. In this case, an incision is centered just lateral to the posterior iliac spine, and dissection proceeds along the posterior surface; the gluteal fascia is detached lateral to the PSIS so that an adequate cuff of connective tissue is left for closure. The dissection avoids the sciatic notch, which can easily be palpated. When dissection is adequate, a Taylor retractor can be used to assist with exposure. A window of cortical bone can be removed using straight osteotomes. If additional cancellous bone is required, it can easily be obtained using bone gouges. The inner cortical table should not be breached. Cancellous bone and cortical-cancellous matchsticks are ideal for occipitocervical posterior fusions. After hemostasis has been obtained using bone wax or Gelfoam, the gluteal fascia must be reapproximated to the periosteum to avoid gait disturbances. Again, the wound is closed in layers; meticulous closure of the periosteum and fascial layer prevents abdominal herniation.

ALTERNATIVE AUTOLOGOUS SITES

In most cases, the iliac crest is the preferred site for autologous bone graft, but bone can also be harvested from the rib, fibula, and calvarium. Ribs have a relatively thin cortex, are mechanically weak in resisting compressive loads, and provide a relatively small volume of bone. However, they are sometimes a useful alternative, if other sites cannot be used.[7-9] Because of their limited mechanical strength, rib grafts should not be used to reconstruct major spinal deformities without the application of a rigid internal fixation device.

To harvest a rib graft, a linear incision is made in the skin directly over the rib's surface (Fig. 72-5). The outer surface of the rib is exposed by incising the overlying muscles and periosteum. Blunt dissection with a Doyen rib dissector is used to detach the intercostal muscles and parietal pleura from the undersurface. Care is taken to avoid injury to the neurovascular bundle, which lies just along the inferior surface of each rib. The ends of the rib grafts are dissected sharply using a rib cutter or oscillating saw. In most cases, we prefer the oscillating saw, because the rib cutter can

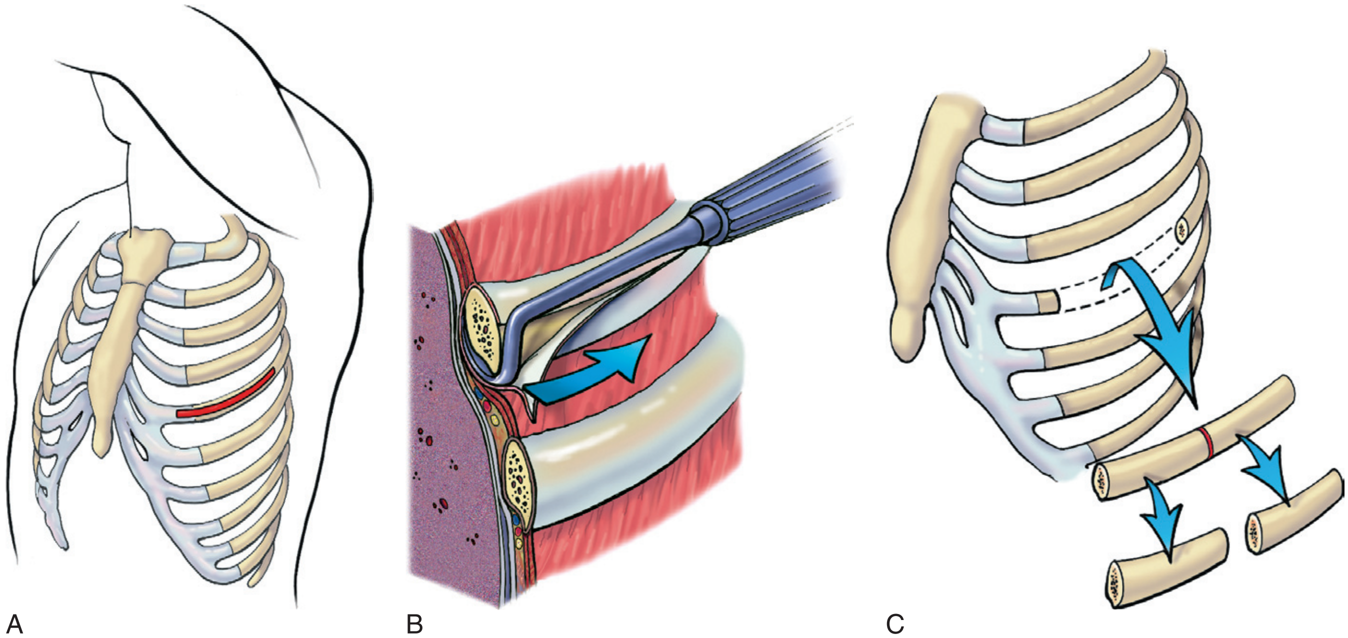

Figure 72-5 **A,** The incision exposes a rib along a curved segment. **B,** A Doyen periosteal elevator is used to dissect the neurovascular bundle and muscle attachment from the rib, remaining extrapleural. **C,** The rib is cut sharply with a cutting tool.

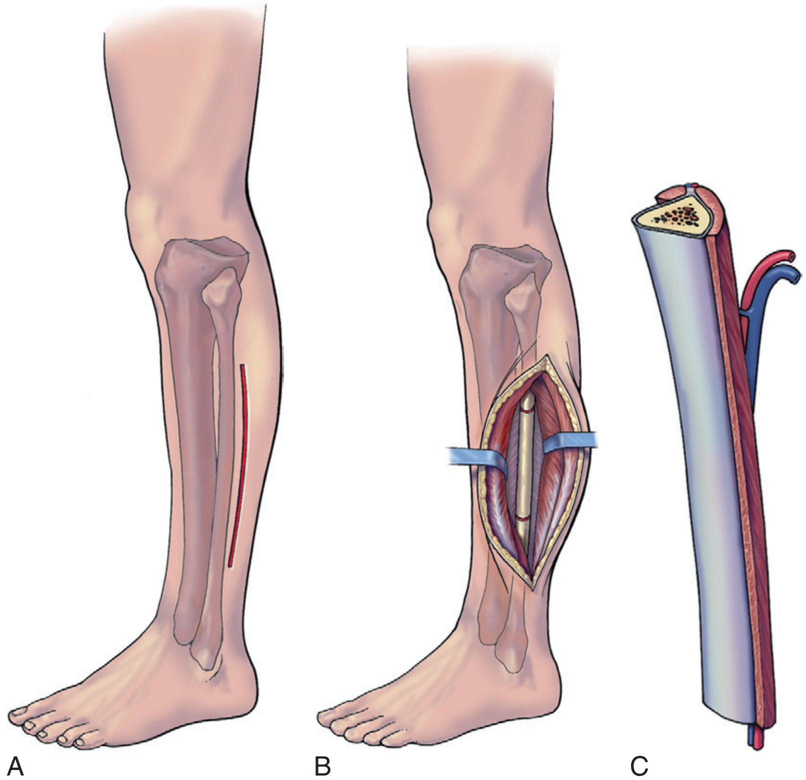

Figure 72-6 **A,** Incision to obtain a fibular strut graft. The incision is made parallel to the fibula to expose the middle-third segment of the fibula. **B,** A nonvascularized graft can be obtained by performing a subperiosteal dissection circumferentially around the desired segment. **C,** Vascularized graft may be obtained by preserving a muscular cuff around the fibular graft along with the nutrient vessels.

crush, splinter, and weaken the ends of the ribs. The remaining bone edges are smoothed and waxed to prevent pleural puncture and to avoid pneumothorax. After hemostasis is obtained, and the wound has been closed in multiple layers, a routine postoperative chest radiograph is obtained to rule out pneumothorax.

Fibular grafts are obtained from the middle third of the fibular shafts (Fig. 72-6) to avoid injury to the peroneal nerve at the proximal fibular head and to preserve ankle function distally.[9-13] Overall, functional consequences are avoided. The incision parallels the fibula over the lateral surface of the middle of the leg. In most cases, a nonvascularized graft is obtained by performing a subperiosteal dissection circumferentially around the desired segment. Fibular graft provides strong, dense cortical bone that is ideal for reconstruction in areas under large loads or stress.

However, because there is little cancellous bone, fusion may be relatively slow. Occasionally, a vascularized graft is preferred, in which case a muscular cuff is preserved around the fibular graft along with nutrient vessels. The muscles and fascia are dissected from the ends of the fibular surface, and a vascular vessel of the peroneal artery and vein is preserved. The bone is transected proximally and distally to the measured length with a Gigli or oscillating saw. After hemostasis is obtained, the wound is closed in routine fashion using multiple layers.

In the case of vascularized grafts placed in the anterior cervical region, the vessels are usually anastomosed with the superior thyroid artery and vein or other accessible vessels. Posteriorly, the graft can be anastomosed to the occipital artery. Vascularized grafts have the advantage of being living tissue; hence they are incorporated rapidly. However, more surgical time and technical expertise is needed for harvesting and placement.

Calvarial bone grafts are used for fusions in young children, because the iliac crest and fibula remain nonossified.[9,14-17] Alternatives include a full-thickness graft, which can be obtained from the midline occipital bone, or split-thickness grafts, which can be obtained from the parietal bones (Fig. 72-7). In the case of a suboccipital graft, a linear incision is used to expose the suboccipital skull; one or two burr holes are used to expose the dura, and the atlantooccipital membrane is dissected along the edge of the foramen magnum. The bone is removed in standard fashion using a high-speed drill. In the case of split-thickness grafts, a bicoronal or C-shaped incision is made at the vertex to expose a paramedian craniotomy. Midline bone is left intact over the superior sagittal sinus if bilateral craniectomies are needed. A reciprocating saw is used to split the diploic layers of the bone longitudinally, and the top half of each of the grafts is reattached to the skull with miniplates. The split-thickness graft can then be contoured to the desired shape for fusion.

ALLOGRAFT AND FUSION SUPPLEMENTS

Although autograft remains the gold standard for arthrodesis, many procedures are performed using cadaveric allograft. For example, fibular allografts are routinely used for anterior cervical arthrodesis.[18] Occasionally, fibular, tibial, or femoral strut grafts are used in the thoracolumbar spine. In the case of single-level diskectomies of the cervical spine, autografts and allografts have similar rates of fusion. For multilevel fusions or for fusions in patients who have a history of smoking, autografts have a slightly higher rate of fusion than allografts.[19,20]

Allografts are procured by bone banks using established standards. Typically, they are harvested in a sterile fashion, processed, and then freeze-dried or processed in a fresh-frozen manner. Donors are routinely screened, and serology is tested to minimize the risk of infection. The risk of contracting the human immunodeficiency virus (HIV) through allograft transplantation has been estimated to be less than 1 in 1 million.[21] To minimize the risk of immunogenetic reaction, allografts are treated with ethylene oxide, freezing, or freeze-drying.[21] This bone must then be reconstituted in sterile saline before being shaped or cut. To optimize the

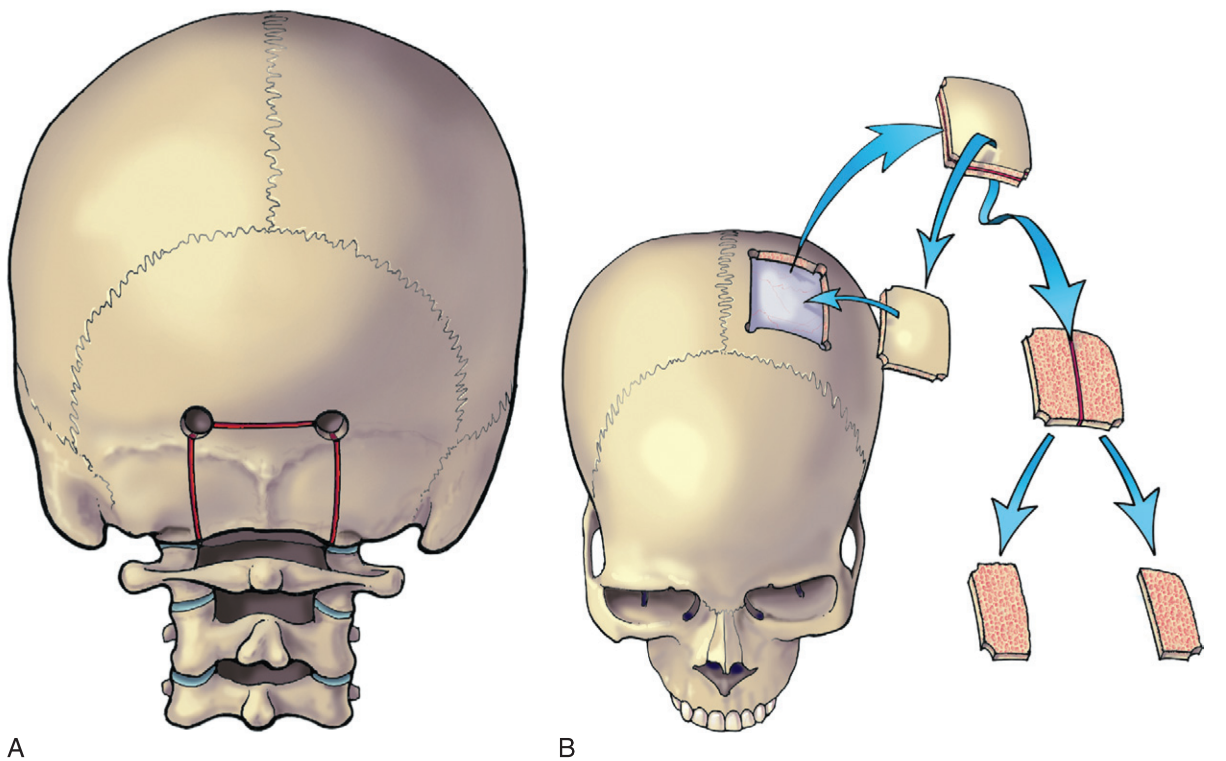

Figure 72-7 Calvarial bone grafts. **A,** Suboccipital, full-thickness rectangular bone graft is harvested. **B,** Split-thickness parietal calvarial graft is obtained. A full-thickness bone flap is removed and then divided with a reciprocating saw. The upper layer of the calvarial flap is reattached with miniplates.

chance of successful fusion, the hollow center of the allograft may be packed with autograft bone obtained during the surgical decompression.

Occasionally, methylmethacrylate (MMA) is used in place of bone grafts or spinal fusion. However, MMA does *not* lead to bone fusion, because it is *not* osteoconductive, osteoinductive, or osteogenic. It does provide strength to resist compression, but it routinely fails under tension and must be anchored to the bone. It can also elicit a foreign-body reaction. Consequently, MMA is reserved for patients who are expected to place only minimal mechanical stress on their construct or in those whose life expectancy is short.

Several developments have improved the rate of bone fusion, and numerous studies have shown that pulsed electrical or electromagnetic fields promote fusion, especially in long bones.[22] Although fewer studies have evaluated the effects of electrical and electromagnetic stimulation in spinal fusion, they also appear to increase fusion rates in the spine.[22] However, the technology is expensive, and patient selection is critical, because overall fusion rates are already relatively good.

Other contemporary techniques to improve the rates of bone fusion rely on advances in molecular biology. The degree and strength of fusion are enhanced by a variety of osteoconductive proteins known as *bone morphogenic proteins* (BMPs), which can lead to higher rates of fusion with allograft; in addition, combinations of allograft and BMP have the potential to obviate the need for autologous bone graft.[23-27] In fact, recent experience shows excellent fusion rates, even when BMP is used without autograft or allograft.

Conclusion

Successful bone fusion is essential in cases of spinal fixation. The odds of having a successful fusion can be improved by handling the tissue gently, preparing the bone graft and fusion bed meticulously, and avoiding all antiinflammatory medication perioperatively and postoperatively. Autograft tends to be associated with a higher rate of fusion than allograft, but the benefits and risks of obtaining autograft must be considered. When it is necessary to harvest autograft, the risk of complications can be minimized by meticulous surgical technique and a thorough understanding of the regional anatomy. New developments in molecular biology are providing additional alternatives.

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73 Dural Tears

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Overview

In spinal surgery, the occurrence of dural tears, both incidental and nonincidental, is not uncommon. Dural tears are more common with certain spinal procedures, such as revision laminectomy surgery, and they can be encountered incidentally, as with burst fractures and lamina fractures.[1] Durotomies are also necessary for the resection of intrathecal lesions and for tethered cord releases. Although an effort has been made to study the frequency with which dural tears occur, there does not seem to be a consensus. In one review of the records, based on operative reports of 641 patients who underwent a decompression of the lumbar spine, 88 (14%) sustained an operative dural tear.[2] Other studies have observed dural tear rates of 5.3% for open diskectomies, 17.4% for reoperation of herniated disks, 7.6% during primary lumbar surgery, and 15.9% for revision cases.[3,4] Higher incidences may be associated with larger procedures and revision procedures, in ankylosing spondylitis, and with advanced age; the risk for complications in spinal surgery, including dural tear, increases in older patients.[3-5]

Although finding a durotomy intraoperatively can be a source of frustration and anxiety for the surgeon, it is extremely important to find and treat the tear efficiently. Fortunately, many effective techniques of treatment are available. In this chapter we will describe various methods for diagnosing dural tears, and we will discuss intraoperative and postoperative techniques available for treatment.

Anatomy Review

The dura mater is the outermost of the three layers of the meninges that surround the brain and spinal cord and confine cerebrospinal fluid (CSF). The Latin *dura mater* literally means "tough mother" or "hard mother," and this layer is so named because of its leathery exterior, and because it serves to protect the other two meningeal layers, the *pia mater* and the *arachnoid mater.* The dura is more prone to longitudinal tears, because most of the internal fibers run in a longitudinal direction. The dura extends distally to the S2 segment, envelops the arachnoid mater, and forms a sac filled with CSF (the thecal sac). The spinal cord lies within the subarachnoid space with its terminal portion, the conus medullaris, at the L1–L2 level.[6] CSF fills the space over the spinal cord and is reabsorbed into venous sinus blood via arachnoid granulations. About 500 mL of CSF are made per day, and CSF is turned over about three times daily; it flows from the lateral ventricles to the third and fourth ventricles, enters the basal cistern, and continues to the cortical and spinal subarachnoid spaces.[7]

A dural tear can range in size from a tiny hole invisible to the naked eye to a large defect that requires dural regeneration or patching. Any maneuver performed near the dura puts it at risk for damage. For example, tears can transpire directly during both soft and sharp dissection of soft tissues or during removal of bony material. Most commonly tears occur during dissection with a Kerrison rongeur, but they may also occur as a result of adhesion of dural matter to removed bone, postoperative contact of the dura with a remaining spicule of bone from surgery, or erosion of the dura in chronic stenosis.[8] Further, puncture of the thecal sac can occur during medical procedures other than surgery, such as epidural injection or myelography.[5]

Often, a dural tear does not initially result in serious danger to the patient, but it can produce pain and discomfort until it is treated. Short-term symptoms of unrepaired dural tears may include a moderate to severe positional headache; nausea and vomiting; photophobia; and/or CSF drainage from the wound. There is also greater risk for deep infection. If left untreated or undiagnosed, long-term complications as a result of persistent dural tears and CSF leaks can occur, with the potential for significant morbidity. Specific complications include, but are not limited to, persistent CSF fistula, pseudomeningocele, nerve injury, arachnoiditis with subsequent chronic pain, and in rare cases meningitis. Also, intracranial bleeding and basilar herniation have been reported after dural tears as a result of the change in CSF pressure.

Clinical Diagnosis

Frequently, a dural tear is recognized intraoperatively as a visible leak of CSF at the durotomy site. It may be a gush of fluid, or it may be as subtle as blood getting washed off of the dural surface from a pinhole leak. Excessive, clear output through a chest tube or subfascial drain can also be a sign of durotomy. A collapsed thecal sac or excessive epidural bleeding indirectly implies a dural tear intraoperatively.[9] If detected, the dural tear should be repaired by the attending surgeon at the time of surgery.

If not detected intraoperatively, imaging techniques can assist in diagnosing a dural tear. A magnetic resonance image (MRI), for example, can confirm a diagnosis of pseudomeningocele with the presumption of a dural tear.[5]

Conventionally, a T2-weighted MRI is used to detect extraarachnoid fluid collections. MRI is preferred as a noninvasive imaging technique, however, the interpenetration of fluid and solid compositions of the spine with MRI can make the detection of dural leaks difficult.[10] It is also not feasible to directly visualize dural tears smaller than 1 cm using MRI.[11] Further, epidural hematoma after a laminectomy procedure is quite common and may be impossible to differentiate from CSF.

In contrast, radionucleotide cisternography provides visualization of small leaks; radioactivity outside the subarachnoid space indicates a CSF leak. However, if there is no active leakage at the time of the test, or if the tear is smaller than the image resolution, identification of the leak via cisternography is impossible.[12] Additionally, the injection is radioactive and therefore presents undue risk to the patient.

Computed tomographic (CT) myelography is another frequently used imaging technique that can identify multiple CSF leaks, is sensitive, and illustrates the relationship of bony structures to extradural CSF collections. In many practices, CT myelography is the modality of choice if a dural tear requires a definitive diagnosis. However, the invasive nature of an injection may result in pial irritation, and the x-rays present a risk of ionizing radiation.[10] Complications may also arise from a new CSF leak at the injection site or from infections that can originate at the dural puncture.

Proteins are another option for confirming the existence of a dural tear: β-2 transferrin is a protein unique to CSF and inner-ear perilymph; and if in question, immunofixation electrophoresis is an option. The assay takes about 3 hours and requires one to two decontaminated drops of the fluid. Sensitivity of the assay is reported to be near 100%, and specificity is about 95%.[13] The high concentration of another protein in CSF, β-trace protein, provides an alternative assay to β-2 transferrin. The β-trace protein assay takes about 20 minutes. A study of 176 samples found a sensitivity of 99% and a specificity of 100% for the β-trace protein assay.[14] Unfortunately, many hospital labs do not offer these tests, and sample results may not be available for days.

Conservative and Nonsurgical Treatment of Dural Tears

Conservative treatment of a patient should begin with a thorough evaluation. If the patient is suspected to have a CSF leak but is asymptomatic and does not have CSF leakage from the wound, no treatment is immediately necessary, although the patient should continue to be monitored. Postural headache is a common symptom of a dural tear and is believed to occur both because of meningeal irritation and increased CSF leakage as the lumbar fluid pressure increases in the upright position. Thus bed rest is often prescribed after lumbar durotomy. Caffeine is a vasoconstrictor and is therefore often prescribed because of its ability to provide relief to patients with postural headaches. Acetazolamide, a carbonic anhydrase inhibitor, may be used to reduce the normal volume of CSF produced, theoretically allowing the tear to more effortlessly seal itself. Resewing the superficial skin sutures under local anesthetics and with antibiotic prophylaxis may seal the leak; however, this method has the potential to increase back pressure caused by the CSF.[8] Alternatively, products such as Dermabond (Ethicon) can be used as a skin sealant.

Overall, the goals of the aforementioned solutions are to reduce CSF leakage, relieve pain, and enable the tear to resolve on its own. However, more substantial, nonsurgical alternatives should be considered if symptoms fail to resolve after conservative treatment. Daily or continuous CSF drainage through a closed subarachnoid catheter in a separate dural site may reduce subarachnoid pressure and facilitate healing of the tear.[15] In a study of 107 patients, 94% reported that CSF fistula or pseudomeningocele were cured or prevented by a lumbar subarachnoid drain. Complications were found to occur that included an infection rate of 5% (meningitis, wound infection, and diskitis); CSF overdrainage with nonpermanent neurologic deterioration, headache, nausea, and vomiting in 3% of patients; and temporary nerve root irritation in 14% of patients.[16]

Because of the risks of subarachnoid drain placement, some physicians recommend that subarachnoid drains should only be used if the leak is persistent and cannot be repaired operatively.[2] When used, the lumbar drain is typically set at a height to encourage 10 to 15 mL/hour of drainage. Alternatively, the drain may be set at a height just below the level of the tear to ensure that low pressure is seen at the tear. For example, the drain can be opened at the cervicothoracic junction for cervical tears with the patient sitting in an inclined position. Overdrainage should be carefully guarded against, and frequent neurologic evaluations should be performed on any patient with a lumbar drain. Overdraining may mimic cerebral herniation, with altered mental status, cranial nerve deficits, respiratory anomalies, and papillary abnormalities. In such cases, the drain should be immediately clamped, and the patient should be placed in the Trendelenburg position. In the event of a lumbar tear, lumboperitoneal or ventriculoperitoneal shunting may be considered in refractory cases,[17] however, the need for this is extremely rare.

An epidural blood patch offers another nonoperative solution. In this approach, blood is withdrawn from the antecubital vein and injected, typically under fluoroscopic or CT guidance, into the epidural space near the fistulous tract.[18] Blood-clotting factors form a patch over any holes in the dura to prevent further leakage of CSF while enabling normal healing. Complications of epidural blood patch have been reported that include vertigo, dizziness, ataxia, and tinnitus during injection, as well as a temporary increase in temperature, mild backache and/or stiffness, and transient or residual paresthesia, especially in the legs and toes.[19,20] In a study of 118 patients, epidural blood patches successfully relieved headache in 89% of patients with severe headache after lumbar puncture. Of the remaining patients, a second epidural blood patch was performed on 11 patients, and it was successful in 91% for an overall success rate of 97.5%.[19]

A percutaneous fibrin glue injection is another nonoperative treatment for CSF leaks. A solution of cryoprecipitate is simultaneously injected with a calcium chloride and thrombin solution into the space overlying the CSF leak (Tisseel, Baxter Healthcare, Deerfield, IL; Fig. 73-1). Placement of the fibrin glue aggregate may be established using

Figure 73-1 An injection of a percutaneous fibrin glue, such as Tisseel (Baxter Healthcare, Deerfield, IL), is another nonoperative treatment for cerebrospinal fluid leaks.

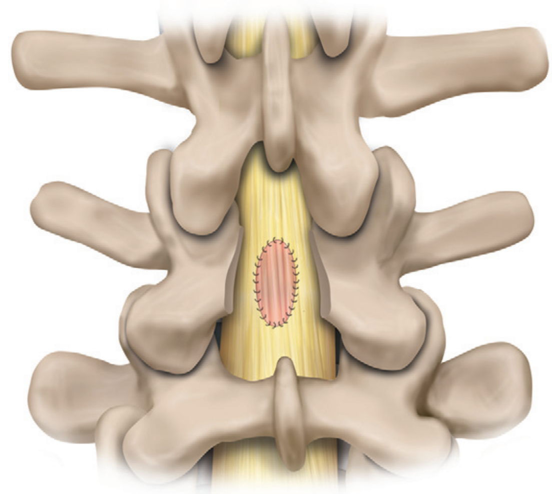

Figure 73-2 Running sutures secure a dural patch.

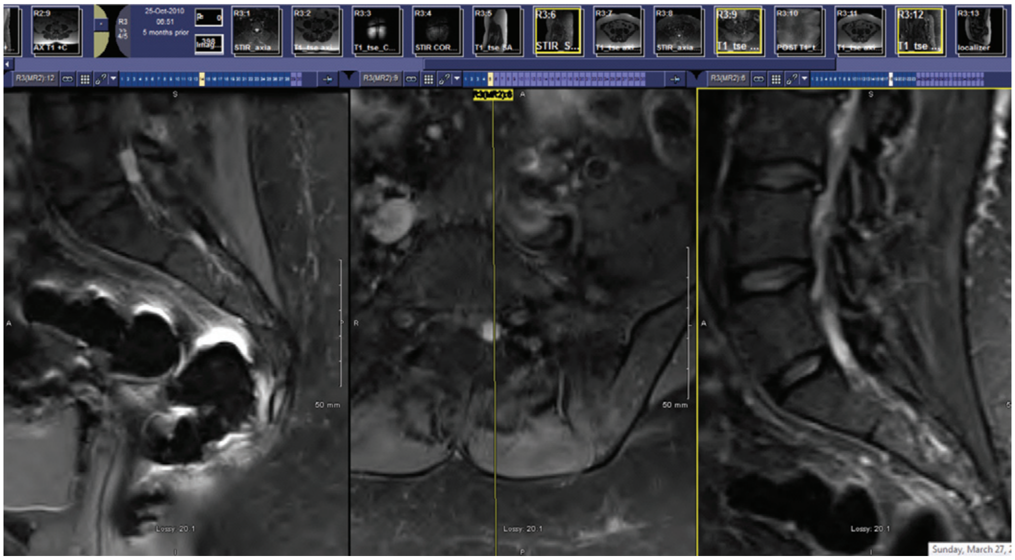

Figure 73-3 Running sutures mend a dural tear.

CT imaging. Using this procedure on six patients, a group of researchers successfully resolved CSF leaks in 50%; the three patients in whom leaks remained unresolved underwent surgery.[21]

Intraoperative Surgical Repair

For tears found intraoperatively, or if nonoperative treatments are unsuccessful in postoperatively discovered tears, surgical treatment is advised. Techniques for surgical repair of dural tears vary based on the size, complexity, and accessibility of the tear. A simple, linear tear is typically repaired with a secure suture closure, using a running or an interrupted technique. A sealant may be added to reinforce the closure and eliminate leaks from the suture holes. A large tear can be patched with a dural substitute alone or in combination with sutures and/or a sealant (Figs. 73-2 and 73-3). A complex, unapproachable tear, such as an anterior or lateral tear, can be repaired using an onlay graft with or without a sealant.

SURGICAL METHODS AND MATERIALS

Suture

To suture the dura, small diameter, nonabsorbable sutures are typically used with a tapered needle. Suture materials include:

- Nurolon (Ethicon), a braided nylon
- Gore-Tex, a monofilament of expanded polytetrafluoroethylene (PTFE)[9]
- Prolene (Ethicon), a monofilament of polypropylene
- Silk (Ethicon)

Some surgeons prefer Gore-Tex, because the needle hole is smaller than the suture itself, which decreases the risk of suture hole leaks. Others prefer silk (Fig. 73-4), because fibrin and blood stick to the suture, which ultimately helps to seal the leaks. In a retrospective review, 338 dural tears were successfully repaired with silk sutures and a running, locking stitch; only 1.8% of patients developed a postoperative CSF leak that required surgical repair.[4]

Prior to attempting repair using sutures, the nerves should be carefully protected and manipulated back into the intradural space. This can be facilitated by allowing some of the CSF to leak out, decreasing intradural pressure. Some surgeons also advocate for irrigation of any hematoma out of the intradural space prior to closure to reduce nerve irritation and possibly reduce arachnoiditis. However, one risk in the dural closure suture process is injury to the nerve root, because it can be difficult for the surgeon to distinguish between the nerve tissue and the dura mater. Therefore, use of an operating microscope is encouraged to minimize this risk. After sutures are placed, a procoagulant such as Floseal (Baxter; Fig. 73-5) or a patch such as DuraGen (Integra LifeSciences, Cincinnati, OH; Fig. 73-6) can be placed over the suture line to help seal the leak.

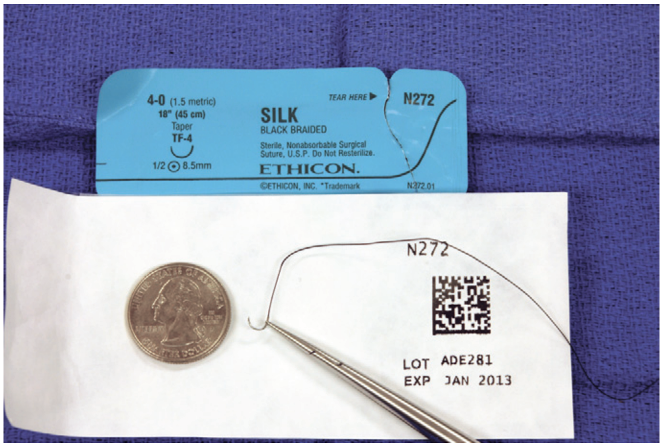

Figure 73-4 Silk sutures are often preferred because fibrin and blood stick to the suture, which helps seal the leaks.

Figure 73-5 After sutures are placed, a procoagulant such as Floseal (Baxter Healthcare, Deerfield, IL) can be placed over the suture line to help seal the leak.

Dural Substitutes

The criteria for an ideal dural substitute varies, but it generally includes that the substitute should:

- Repair CSF leaks and produce a watertight closure
- Induce no inflammatory or immunogenic response
- Cause no adhesion to the spinal cord, brain, meninges, or nerve roots
- Not increase the risk of infection or bleeding
- Have mechanical properties similar to native dura
- Not swell excessively
- Be easy to utilize, cost-effective, and readily available
- Be nontoxic, noncarcinogenic, and inert

Various types of allografts, autogenous dural substitutes, and synthetic or chemically modified tissues are used as dural substitutes. Some are assessed below.

Allografts. Cadaveric dura mater and fascia lata allografts were eliminated from use in dural tear repair because of the risk of infectious agents, including those that have been linked to Creutzfeldt-Jakob disease. As a result, AlloDerm (LifeCell, Bridgewater, NJ) was developed, an acellular human dermis allograft placed after removal of all of the epidermis and cells that could potentially lead to rejection. It should be noted, however, that each donor is tested for infectious agents to minimize the potential for infection. Advantages of AlloDerm include the following:

- It is immunologically inert.
- It does not produce adhesion formation or result in rejection.
- Because the cellular ultrastructure remains, it enables vascular and cellular ingrowth.
- It is easy to use.

Figure 73-6 A patch, such as DuraGen (Integra LifeSciences, Cincinnati, OH), can also be placed over a suture line to help prevent leaks.

- AlloDerm is convenient when an autograft harvest is impractical.[22,23]

A study used AlloDerm in 200 craniotomies for duraplasty; sutures secured the graft to the dura or cranium. At a minimum follow-up of 1 year, only 3.5% of patients required subsequent surgery, 1.5% developed postoperative CSF leaks, and 2% developed superficial wound infections.[23]

Autogenous Dural Substitutes. Fat is a useful autogenous dural substitute, because it is impermeable to water and is believed to cause little scarring. It is recommended for dural tears that are difficult to access or those that cannot be repaired by standard suture techniques.[24] Autogenous tissues are a good choice for a dural substitute because they 1) are nontoxic, 2) produce no immunologic reaction, and 3) carry no risk of infection to the patient. However, the addition of a second surgical site makes autografts unpopular. Also, it can be difficult if not impossible to suture the fat in a watertight fashion around the dural defect. A group of researchers used this procedure on 27 patients, using a large sheet of fat from the patient's subcutaneous layer to cover both the dural tear and all of the exposed dura. Excess fat was tucked into the lateral recess to prevent peripheral CSF leaks, and the fat was tacked to the dura with sutures. Fibrin glue was then spread over the fat and covered with either Surgicel or Gelfoam. This procedure successfully repaired the dural tears in 96.3% of patients.[25]

Synthetic or Chemically Modified Materials. Synthetic and chemically modified dural substitutes include expanded polytetrafluoroethylenes (ePTFEs), collagen matrices, and polyglactin derivative grafts. Given that synthetic dural substitutes can differ significantly, the advantages and disadvantages of each vary. In general, synthetic dural substitutes are often preferred, because they easily conform to the desired size and shape; are generally strong, pliable, and convenient; and are less susceptible to irregularities and/or necrosis. However, they can be expensive.

In a study of 34 patients, ePTFE with continuous sutures was used to repair the dura mater. Mild CSF accumulation occurred postoperatively in 14.7% of patients, and 17.6% of patients underwent reoperations unrelated to the dural tears between 1 and 15 months after repair, and the strength of the ePTFE sheet was found to be preserved. A thin layer of granulation tissue had formed between the ePTFE sheet and the brain, but no adhesion between the sheet and scalp, subcutaneous tissue, or brain tissue was found.[26] Another study reported a postsurgery CSF leak in 20% of patients when ePTFE and sutures were used alone; this rate decreased to 3% when fibrin glue was used in combination with ePTFE and sutures.[27] In a study of 83 patients that used ePTFE as a dural substitute, the infection rate was 9.6%.[28] Although successful with no immunogenic response and little adhesion to living tissues,[26] a watertight closure with ePTFE can be difficult to obtain because of leaks through the suture holes in the ePTFE sheet.[27]

Examples of collagen matrices and collagen-derivative grafts include DuraGen, Durepair (TEI Biosciences, Boston, MA), and Dura-Guard (Synovis Surgical Innovations, St. Paul, MN). Each may be applied as an onlay or a suturable graft and is often augmented with a dural sealant; porous collagen grafts with type I collagen fibers provide a matrix that supports neovascularization and fibroblast activity.[29] Although each brand of collagen varies in regard to mechanical properties and the success of the repair, in general, collagen-based substitutes are used for four reasons: because they 1) promote fibroblast ingrowth, 2) form well to the application surface, 3) can be applied as an onlay, and 4) usually do not cause adhesion or an immunogenic response.

Vicryl Collagen (Ethicon) is a resorbable mesh made of polyglactin 910, a copolymer of glycolide and L-lactide, coated with bovine collagen. In a study that used Vicryl Collagen as a dural substitute in 78 patients, 6.4% developed subcutaneous fluid collection. Four resolved without intervention, and one required a lumboperitoneal shunt. In addition, 5.1% of patients developed infections: two contracted aseptic meningitis, one had a superficial wound infection, and one experienced a severe extradural infection that required graft removal.[30] The surgeons liked Vicryl Collagen because it is watertight and biocompatible, it causes minimal adhesion, and it resorbs within 2 months. However, quick resorption may not provide enough time for fibrous ingrowth, especially if an inflammatory reaction destroys the integrity of the barrier.[30] Concerns regarding bovine spongiform encephalopathy (BSE), or "mad cow" disease, have led to the removal of Vicryl Collagen from the marketplace in many countries.

In addition to the synthetic dural substitutes listed above, many other nonautologous products may be considered for use as dural substitutes: Duraform, a collagen matrix, and Ethisorb Dura Patch, an absorbable material comprising polyglactin 910 and polydioxanone (Codman & Shurtleff, Raynham, MA); DuraMatrix (Stryker, Kalamazoo, MI), a collagen matrix; and Durasis (Cook Biotech, West Lafayette, IN), a porcine small intestinal submucosa.

Dural Sealants

Dural sealants are commonly used in dural repair to augment techniques using sutures and/or dural substitutes to create a watertight seal; they are not intended to replace sutures or dural substitutes. A sealant may be used to bond the dural edges, or one may be applied over a dural substitute and the native dura. The surgical area should be as dry as possible, and the CSF leak should be repaired before applying a sealant.[9] Commonly used dural sealants include fibrin adhesives and polyethylene glycol (PEG) hydrogel.

Human- or bovine-derived fibrin adhesives may be used to augment the repair of dural tears. Mixing a solution of fibrinogen and other clotting factors with calcium chloride and thrombin facilitates the conversion of fibrinogen to fibrin, which adheres to the native tissue. Fibrin sealants may be sprayed, spread in multiple layers, or applied in a single layer using a cannula. A comparison of these three application techniques in an in vitro histologic analysis and a pressure-resistance test found that the spray method was optimal.[31] Fibrin dural sealants offer several advantages: they 1) are adhesive to tissue and help to form a watertight seal with a dural substitute or sutures; 2) promote coagulation and invoke minimal inflammation; 3) are pliable and easy to handle, and 4) are readily available.[19,32] In addition, an animal model using fibrin glue found that epidural

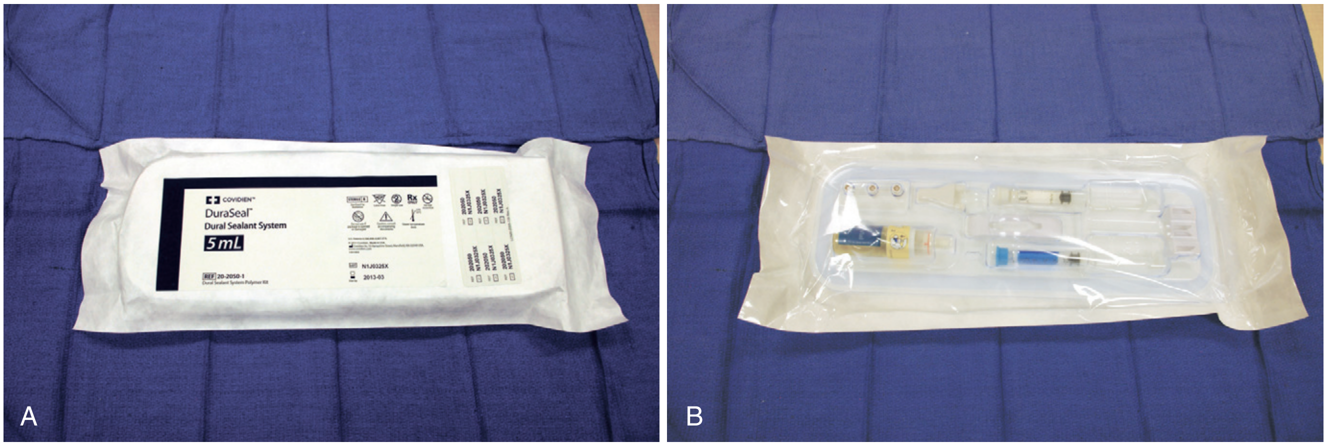

Figure 73-7 **A** and **B,** DuraSeal is an absorbable polyethylene glycol hydrogel sealant that is sprayed on or layered over sutures in dural repair.

scarring and fibrosis were diminished, and the coagulation cascade was promoted.[33]

A study of 20 patients that used sutures and fibrin glue found that 75% had no symptoms of a CSF leak after repair. One patient (5%) required reoperation because of a stitch loosening; however, there were no serious complications.[34] Another study found no statistical difference in the postoperative CSF leak rate when fibrin glue was used to augment various dural repair techniques using sutures—and, at the discretion of the surgeon, a fascial or muscle patch (n = 278, 50.8%)—to repairs in which fibrin glue was *not* used (n = 269, or 49.2%).[35]

Concerns regarding fibrin sealants include timing: they take approximately 20 minutes to prepare, 3 to 5 minutes are required after application for optimal adherence, and 2 hours are needed for them to reach “full strength.” Further, they may inhibit bony fusion.[35,36] Additionally, communicable disease transmission is a possible consequence of blood-based sealants.

DuraSeal (Covidien, Mansfield, MA) is an absorbable PEG hydrogel sealant that is sprayed on or layered over sutures in dural repair (Fig. 73-7). Advantages include that it is biocompatible, nonbiologic (no risk of virus transmission), absorbable, flexible, and adherent to tissue. However, Food and Drug Administration (FDA) approval of DuraSeal cautioned that it should not be applied to confined bony structures where nerves are present, because hydrogel swelling of up to 50% in any direction could result in neural compression.[37] DuraSeal was applied after sutures in 111 patients with dural tears who underwent cranial surgery; using one or two applications of the sealant as needed, this method was 100% effective in stopping CSF leaks intraoperatively. However, 4.5% of patients developed a postoperative CSF leak (one incisional and four pseudomeningoceles), and 7.2% of patients developed deep surgical site infections. Another report describes postoperative cervical cord compression induced by DuraSeal,[38] and a third lists worsening quadriparesis of a patient after expansion of the hydrogel sealant.[39]

Although not sealants, Gelfoam and Surgicel have hemostatic properties and are often used with sutures or dural substitutes to increase the success of a dural repair (Fig. 73-8). In a study of 88 patients with dural tears, 97.7% were successfully managed with Gelfoam and silk interlocking sutures and a closed-suction subfascial drain in intraoperative primary repair.[2] Gelfoam has also been used successfully with fat grafts and fibrin glue.[24]

Figure 73-8 Surgicel is a compressed sponge with hemostatic properties. It is often used with sutures or dural substitutes to increase the success of a dural repair.

Other Dural Tear Surgical Solutions

The benefits of using titanium nonpenetrating clips include 1) ease of application, especially in anatomically restricted areas; 2) their nonpenetrating nature, which theoretically minimizes postoperative CSF leaks; and 3) their compatibility with MRI scanning.

A study using titanium nonpenetrating clips (Fig. 73-9) in the closure of spinal dura in 58 patients found that 13.8% of patients developed a postoperative CSF leak, and 10.3% developed infections (five superficial and one epidural).[40] Concerning the rates of CSF leak and infection, the group’s initial experience with the clip system was that these complications might have been due to a learning curve. In another study of 26 patients who underwent 27 operations over a 20 month period, only one patient required reoperation 13 months after clip placement, and no significant complications were identified in the follow-up period, which ranged from 1 to 24 months.[41]

Figure 73-9 A titanium nonpenetrating clip system.

Laser tissue welding for dural closure has also been considered for use alone and in combination with traditional suture techniques. Simply put, this method uses laser energy to connect tissues. A study in cadaveric dura mater compared dural closure using only sutures ($n = 25$) sutures and laser tissue welding ($n = 25$), or laser tissue welding alone ($n = 25$). The study found a statistically significant increase in leak pressure and tensile strength in the closures performed with sutures and laser tissue welding. Conversely, laser tissue welding alone provided an immediate leak-free closure that had poor tensile strength. However, using laser tissue welding alone can prove to be useful when space constraints make traditional dural tear suture techniques difficult.[42]

POSTOPERATIVE SURGICAL REPAIR

Following any surgical repair, dural defects should ideally be deemed watertight to the Valsalva maneuver and the reverse Trendelenburg test. Also, it is absolutely imperative that the fascial closure is watertight to create an additional seal.

The use of subfascial drains after dural surgical repair is controversial, because such drains may lead to the formation of a cerebellar herniation or durocutaneous fistula, if the dura should leak after repair. However, some physicians advocate using a subfascial drain, because it may allow the fascia and skin to heal. Other physicians consider factors such as the procedure performed, dural tear size, repair quality, tissue quality, and intraoperative blood loss to determine whether a subfascial drain should be used.[5] If a drain is used, caution should be taken to prevent overdrainage, which could lead to headache, neurologic changes, subdural hematoma, or herniation.[9] Chest tubes and wound VACs should not be placed on suction in the setting of dural tears, because the high pressure has the potential to further damage the torn tissue when the devices are removed.

Postoperative bed rest is believed to reduce hydrostatic pressure on the repaired dura to enable faster healing[4]; however, recommendations for bed rest after surgical repair of a dural tear vary from zero days to early mobilization (24 hours) to several days.[2,4,34] Physicians often recommend bed rest positions that will ultimately minimize pressure over the tear. For example, patients with lumbar tears are often advised to lie flat, whereas those suffering from cervical tears may experience less transmural pressure in an inclined position. Patients and nurses should be informed that it is okay for the patient to roll from side to side, but the patient may not sit up or raise his or her head in bed. Mobilization should start gradually by first raising the head of the bed for 1 to 2 hours before allowing the patient to stand.

Summary

- Conservative treatment is the first step if a CSF leak is suspected and the patient is symptomatic after surgery or after a lumbar puncture. This is also the case when surgical repair is not possible. Bed rest, acetazolamide, resewing superficial skin sutures, or Dermabond may reduce CSF flow, relieve pain, and enable the dura to repair itself.
- More substantial, nonoperative solutions include drainage through a closed subarachnoid catheter or an epidural blood patch. CT-guided percutaneous fibrin glue injection has been found to not have high rates of success. CSF drainage is more commonly used in surgical dural tear treatment to decrease the CSF pressure.
- If a tear is noted intraoperatively, or if a patient remains symptomatic after nonsurgical solutions, surgical intervention is necessary. In surgical repair, small and easily accessible tears can be repaired with sutures and, as needed, a dural sealant. Sutures, often of Gore-Tex or silk, have been successful in repairing small, simple dural tears alone or with a dural sealant.
- Fibrin-based sealants have been successfully used, but risk of viral contaminants must be eliminated prior to use. Caution should be taken regarding the maximum amount used, and fibrin-based sealants should be taken with PEG hydrogel sealants, because fibrin-based sealants swell. Cyanoacrylate polymer adhesives should not be used because of toxicity.
- Large or inaccessible tears may be repaired with the onlay of a dural substitute that may be augmented with sutures and/or a dural sealant as needed. Cadaveric allografts should not be used because of the risk of infectious agents. AlloDerm (an allograft), fat (an autograft), ePTFE sheets, collagen matrices, and polyglactin-based products show promise. However, the techniques to use and the situations in which to best use them are as yet unproven.
- Further analysis of surgical and nonsurgical treatment plans for dural tears will continue. Experience with dural repair techniques and materials have often been based on small numbers of patients with a high variability in the type and complexity of their tears.

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