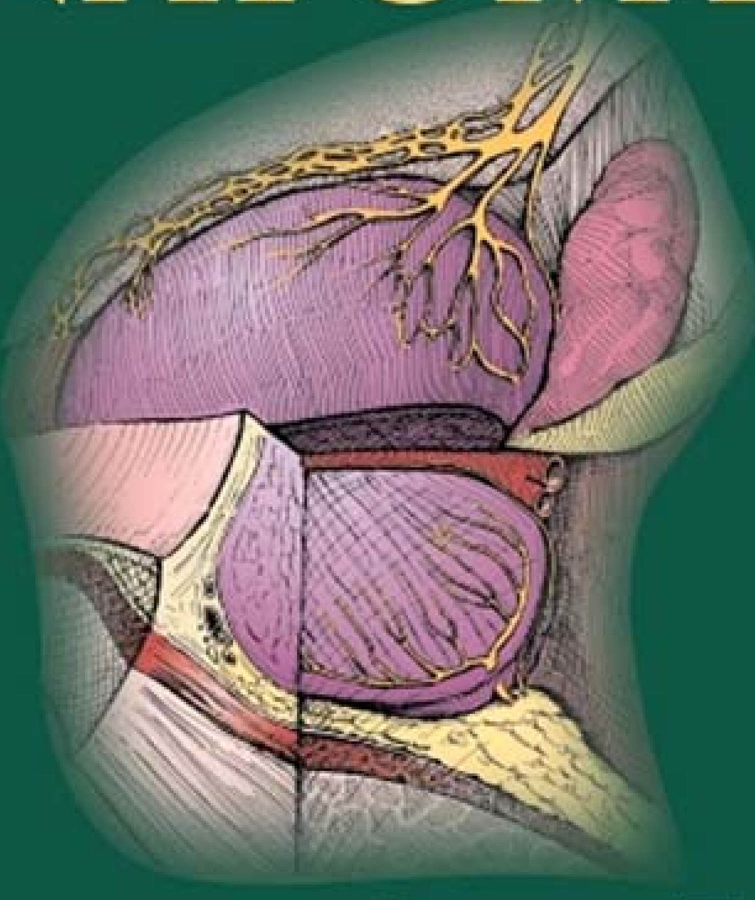
Hinman's Atlas of

UROSURGICAL ANATOMY

SECOND EDITION



Gregory T. MacLennan

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Hinman's Atlas of UroSurgical Anatomy

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Hinman's Atlas of UroSurgical Anatomy

Second Edition

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Dedication

This second edition of Dr. Frank Hinman, Jr.'s Atlas of UroSurgical Anatomy *is dedicated to my best friend, my wife, Carrol Anne MacLennan, and to the memory of Dr. Martin I. Resnick, who, as the Chairman of Urology at University Hospitals Case Medical Center in Cleveland, Ohio, was my mentor, my good friend, and my inspiration in many of my endeavors.*

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Foreword

Many characteristics define a good surgeon beyond simple technical skills. Good judgment, decisiveness coupled with appropriate caution, command of the operating field and arena, and compassion for the patient are all hallmarks of a superior surgeon. Undoubtedly, though, an essential underlying necessity is knowledge of surgical anatomy. Even the most highly skilled technician cannot achieve optimal results without an in-depth understanding of anatomic details and relationships between various anatomic structures.

Hinman's Atlas of UroSurgical Anatomy has been an invaluable resource for surgeons who perform procedures on the genitourinary systems. Other anatomy texts provide fundamental descriptions of anatomy, but the unique aspect of *Hinman's* is the organizational approach, which combines embryology with mature anatomy and then places the anatomic findings in a clinical perspective. Rather than a simple, dry presentation of anatomy, the book assumes a much more relevant role for clinicians through beautiful illustrations and tables. Further, imaging studies and pathologic photographs help create a comprehensive approach that relates the anatomy to other pertinent details of patient management.

The three sections of the atlas present unique but complementary approaches to surgical anatomy. Section I is organized by systems and allows focused study of vascular, lymphatic, neural, and other systems. Section II, the body wall, contains information and illustrations of great use for planning surgical incisions and approaches. Section III addresses individual organs and their anatomy and development. Each of these areas is crucial and the manner in which the book is arranged permits detailed focus on relevant anatomic findings and principles while interrelating different systems and organs.

Understanding normal anatomy is, obviously, essential, but a surgeon must also be prepared for anatomic variation. Moreover, understanding the embryology that may lead to abnormalities or aberrancy in anatomy allows not only recognition of the variation but also suitable planning for how best to address it. The book stands out in this regard. Surgically important variations in systems or organs are well described, illustrated, and complemented by imaging when appropriate.

Greg MacLennan, a widely respected and skilled pathologist, has brought his considerable expertise to his role as Editor of this revised edition of *Hinman's Atlas of UroSurgical Anatomy*. Surgeons are always reliant upon their pathology colleagues, and Dr. MacLennan has helped produce a text that serves as a wonderful complement to *Hinman's Atlas of Urologic Surgery*. The latter is the best comprehensive atlas for a step-by-step description of surgical procedures, but the information in it is greatly enhanced by understanding better the basic anatomy and principles underlying the described operations.

As new operations and surgical approaches arise, different or even novel aspects of anatomy become important. This revised edition incorporates and includes updated and relevant information of practical value to clinicians. Dr. Hinman recognized the need for a *UroSurgical Anatomy Atlas,* and Dr. MacLennan has continued the proud tradition of the text with this revised edition. Surgeons and their patients are the beneficiaries.

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Preface

In his preface to the first edition of *Atlas of UroSurgical Anatomy*, Dr. Frank Hinman, Jr. explained in detail his rationale for creating the book, the approach he took to presenting the material, and his expectations of the ways in which urologists and others might use the book to better care for patients. It is clear that he wished to compile anatomic information from many sources, including his own studies, into a single comprehensive and well-organized textbook that could be consulted quickly and efficiently by urologic surgeons to assist them in planning and conducting surgical procedures. Undoubtedly, surgeons in other specialties besides urology have benefited from his work. Upon reading the first edition, one is unavoidably humbled by the vast scope of the work that Dr. Hinman and his colleagues invested in this book. Readers are strongly encouraged to review Dr. Hinman's original preface before embarking on an exploration of its contents.

When the decision was made to create a second edition of the book, a number of principles were brought into play. It was decided early on that the original black and white illustrations could be made more visually appealing and perhaps more easily understood by colorizing as many of them as seemed practical and reasonable. Furthermore, it was believed that the details of surgical procedures should be described in and restricted to companion texts devoted to adult and pediatric urologic surgery, and therefore, being somewhat redundant, images of this nature were to be removed from this textbook. In addition, following the examples of other current textbooks of anatomy, it was believed that anatomy can be presented in ways other than line drawings, and with that in mind, it was decided to supplement Dr. Hinman's original material with a variety of other new and relevant images, including clinical photographs, intraoperative photographs from open surgical, laparoscopic, and endoscopic procedures, and images from the fields of radiology and pathology. While I have easy access to pathology specimens, I found it necessary to procure other types of images from a large and diverse group of colleagues, who were astonishingly helpful and graciously cooperative in this matter. In all cases, contributors are acknowledged by name in the figure legends, and it is hoped that this small acknowledgment is sufficient to convey my very sincere and profound gratitude to them for their generous assistance in enhancing the educational content and the visual appeal of this new edition.

In the early stages of planning this second edition, I was greatly pleased and enthusiastic about the notion of being able to carry out this work with my mentor and good friend, Dr. Martin Resnick, with whom I had previously collaborated on some very worthwhile projects. To my great distress and sorrow, and the sorrow of many others who knew and worked with him, Dr. Resnick fell ill and was unable to see this project through to completion. Nonetheless, this second edition is dedicated to his memory.

I am deeply impressed with the courtesy, efficiency, and professionalism of the staff of the Elsevier publishing company, and I am particularly delighted to have had the opportunity to work with Stefanie Jewell-Thomas, Arlene Chappelle, and Peggy Fagen. We all hope that you will find this second edition of *Atlas of UroSurgical Anatomy* useful in your work.

GREGORY T. MACLENNAN, MD

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Contents

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Section I

SYSTEMS

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Chapter 1

Arterial System

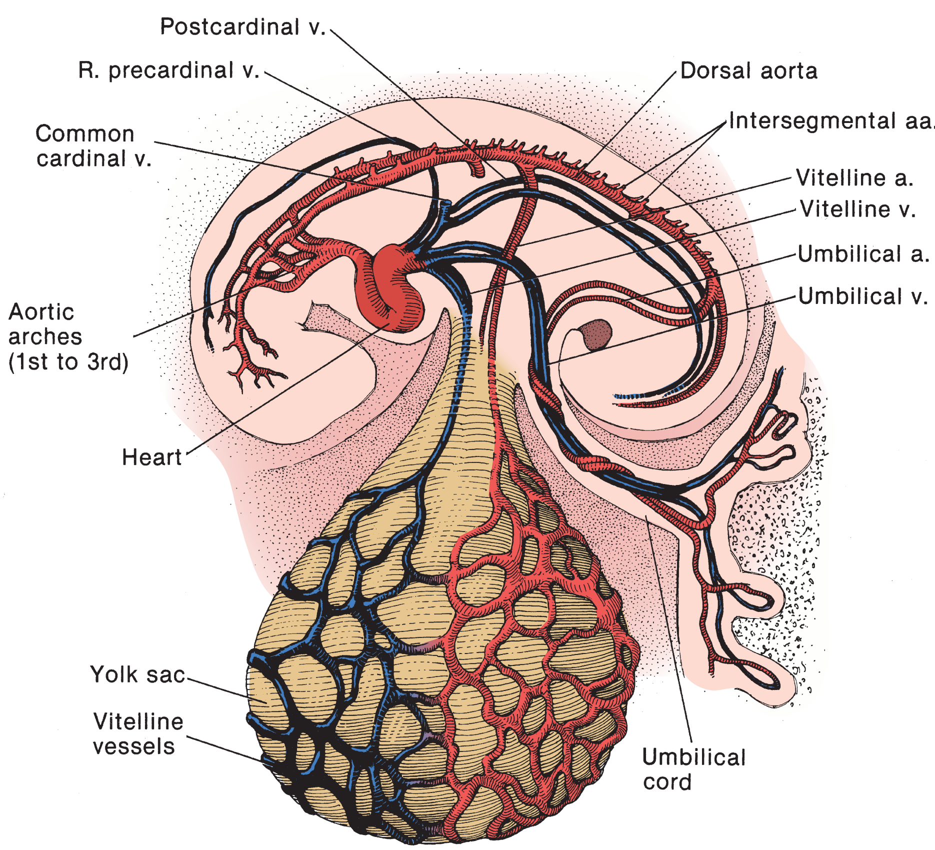

FIGURE 1-1. *(Adapted from Moore KL: The Developing Human, 4th ed. Philadelphia, WB Saunders Company, 1988.)*

A veyne called Arteria . . . to bere and brynge kindely heete from the herte to al the membres.

TREVISA
Barth. De P.R. V.lvi, 1398

DEVELOPMENT OF THE ARTERIAL SYSTEM

Dorsal Aorta

In the third week of gestation, the right and left **aortic arches** turn caudally to form the corresponding **dorsal** (descending) **aortas**. These connect with the **vitelline artery** over the **yolk sac**. The first of the longitudinal veins, the **postcardinal veins,** develop ventrally. The **intersegmental arteries** branch from each aorta (Fig. 1-1). A week later, the two dorsal aortas fuse to form the single dorsal (descending) aorta so that by 8 weeks, a single aortic arch and dorsal aorta are in place.

SEGMENTAL ARTERIES

The **dorsal aorta** at each dermatome gives off a pair of intersegmental arteries, the **dorsal somatic arteries**. Each of these arteries has a **dorsal branch** supplying the vertebral region and **neural tube** and a **ventral branch** having lateral and terminal branches to supply the **body wall** (Fig. 1-2). The posterior intercostal, subcostal, and lumbar arteries are derived from the dorsal somatic arteries. The enlarged 5th lumbar intersegmental artery, as the common iliac artery, will provide the blood supply to the pelvis and lower extremities.

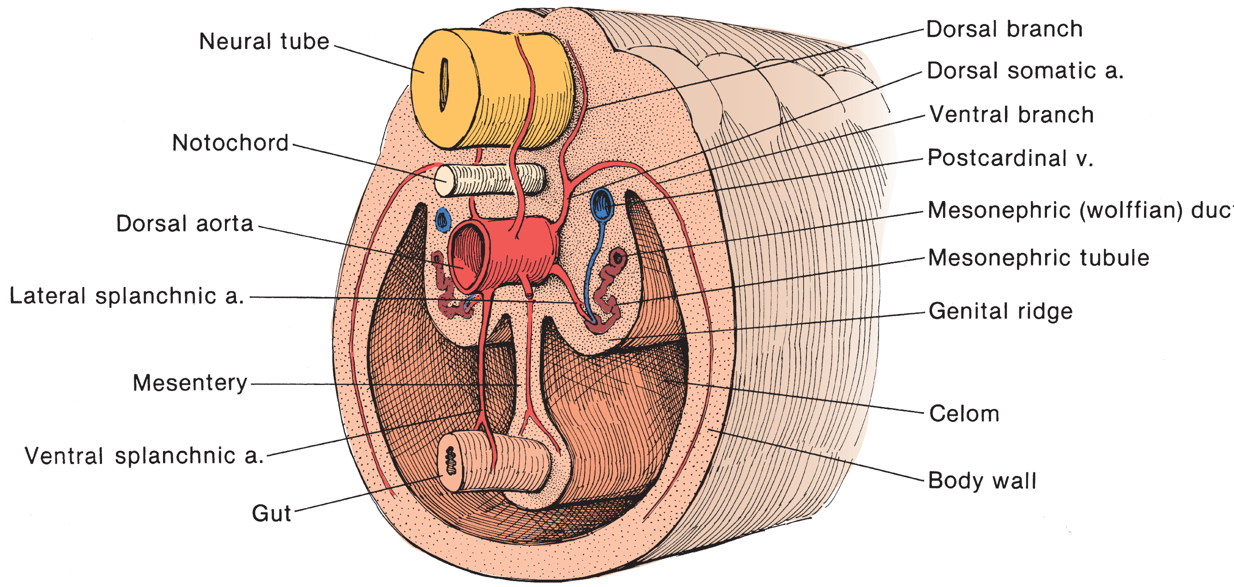

FIGURE 1-2.

Two other sets of segmental arteries are formed: (1) the ventral splanchnic arteries that extend to the yolk sac and gut and (2) the lateral splanchnic arteries that supply the urogenital system. After the dorsal aortas have fused, the paired **ventral splanchnic arteries** combine to form the celiac trunk and the superior and inferior mesenteric arteries. The **lateral splanchnic arteries** supply the **mesonephros** (and also the adult kidney) and the **genital ridge**, including the testis or ovary, and part of the adrenal gland.

Development of the Vasculature of the Body Wall

The segmental vasculature develops deep to the muscles of the body wall, following the pattern of the segmental nerves. At 5 weeks, the descending aorta gives off 30 pairs of **dorsal segmental arteries**, 1 pair at each dermatome. These have a **dorsal branch** supplying the vertebral region and neural tube and a **ventral branch** that, in turn, has lateral and terminal branches. These branches supply the major muscles of the trunk and overlying skin by way of the intercostal, subcostal, and lumbar arteries. The more anterior portion of the body wall is supplied by a "ventral aorta" through **anastomotic arteries,** which will form the internal mammary and superior and inferior epigastric arteries (Fig. 1-3).

From the segmentally arranged vessels such as the **intercostal** or **lumbar arteries**, branches run perpendicularly through the muscle as **perforators** to the skin, where they become **cutaneous vessels**.

Umbilical Artery

The **umbilical arteries** originate as ventral branches of the paired dorsal aortas and enter the **umbilical cord** lateral to the **allantois** (Fig. 1-4 A,B).

After aortic fusion, the umbilical arteries arise from the dorsally placed **5th lumbar segmental artery**, the vessel that is destined to become the **common iliac artery**. The umbilical artery eventually becomes a section of the superior vesical artery, and its distal portion becomes the obliterated hypogastric artery (Fig. 1-4C).

Fetal Circulation

The persistent **left umbilical vein** carries oxygenated blood from the placenta and delivers half of it to the hepatic sinusoids of the left lobe of the liver. After entrance of the **portal vein** into the umbilical vein, the combined placental and portal flow is discharged into the **inferior vena cava** through the **ductus venosus**, where sphincteric action regulates the relative flow. From the inferior vena cava, hepatic blood mixed with venous blood from the lower body passes into the right atrium and through the foramen ovale into the left atrium (Fig. 1-5). There, it is joined by blood from the pulmonary veins. After traversing the atrium, the blood goes through the left ventricle into the ascending aorta. Some blood remains in the right atrium to be directed by the valve of the foramen ovale into the right ventricle and on into the pulmonary trunk. Because pulmonary resistance is high, only a small portion of the blood goes to the lungs; most of it passes through the ductus arteriosus into the **aorta**. Most of the blood, with some addition from the left ventricle, has already circulated through the head and upper limbs. It passes down the aorta to supply the abdomen and lower extremities and into the right and left **umbilical arteries** to the placenta.

Circulatory Alterations at Birth

Five vascular structures become obsolete at birth: the foramen ovale, ductus venosus, ductus arteriosus, and the paired umbilical vessels. As the pressure in the left atrium rises from the relative increase in pulmonary flow over that

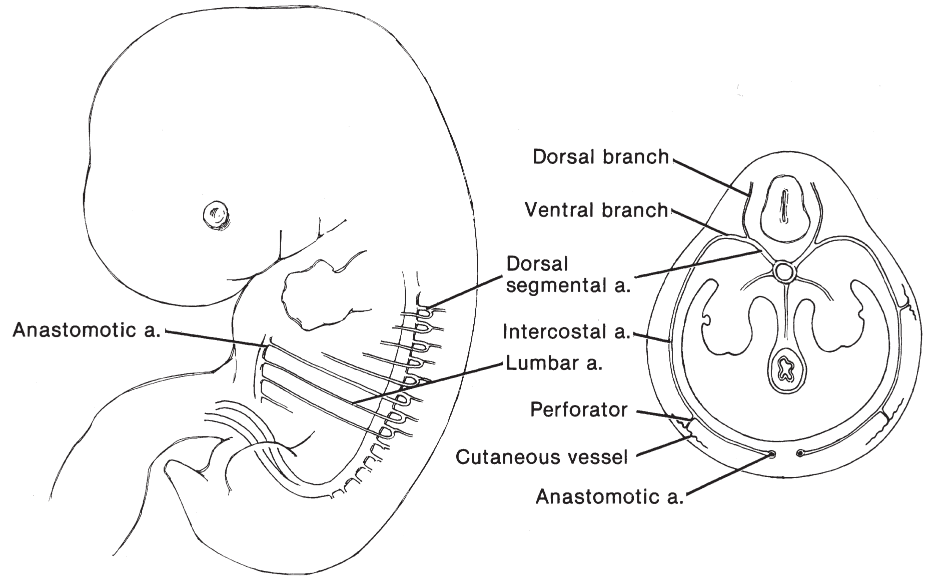

FIGURE 1-3.

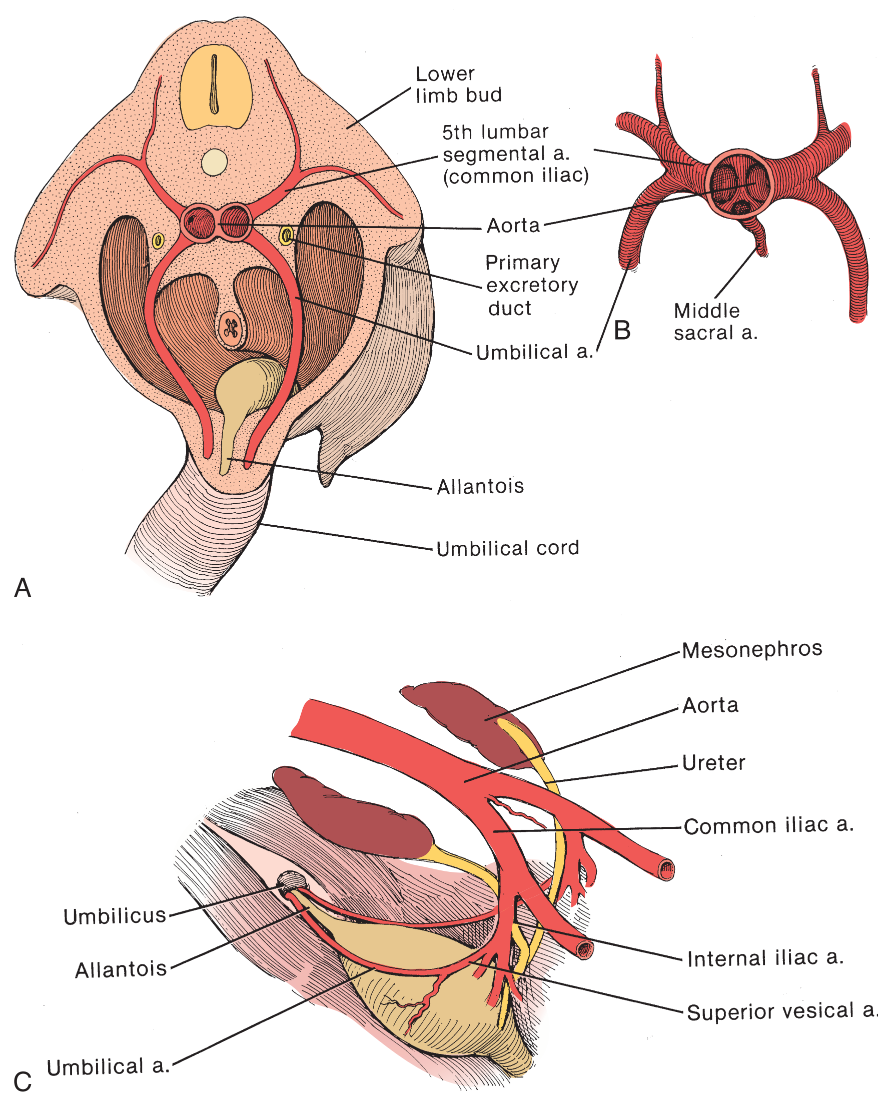

FIGURE 1-4.

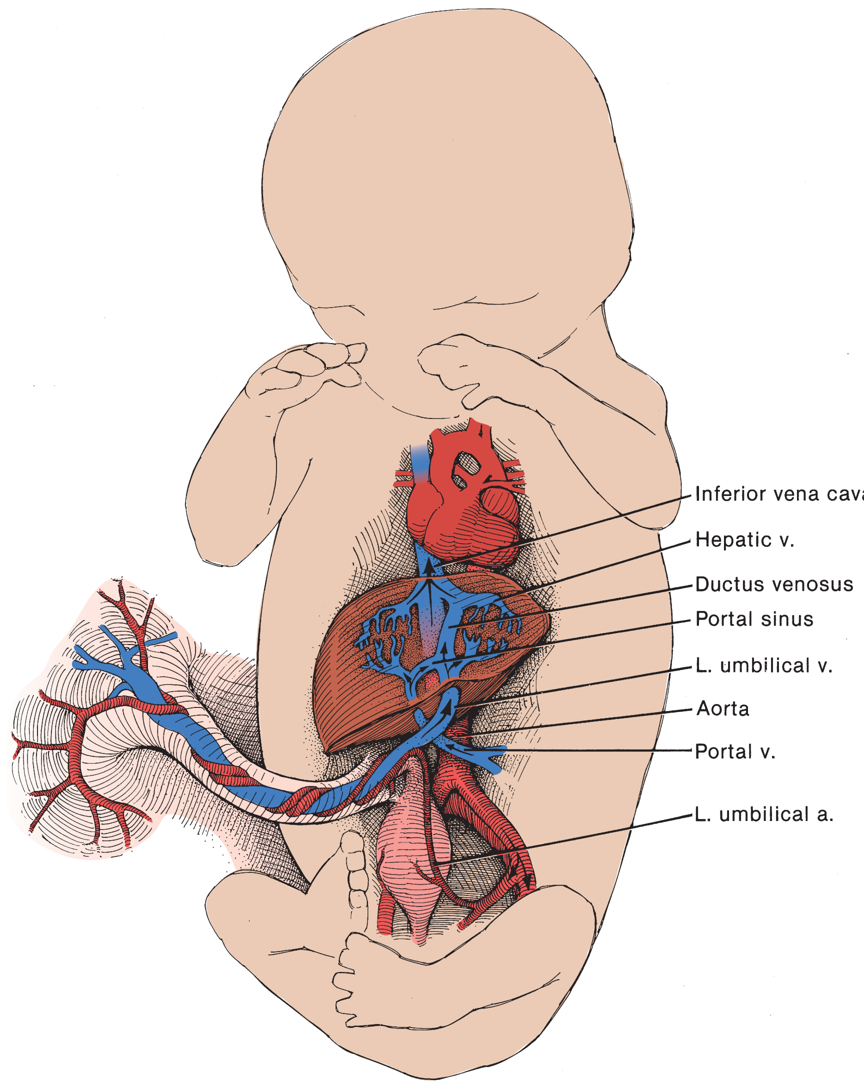

FIGURE 1-5.

of the right atrium, the valve of the foramen ovale closes. The ductus venosus in the liver closes to become the **ligamentum venosum**. The ductus arteriosus is constricted by bradykinin from the lungs. The portions of the umbilical arteries nearest the umbilicus thrombose to become the **median umbilical ligaments** (obliterated hypogastric arteries), leaving the superior vesical arteries functioning proximally. The thrombosed left umbilical vein becomes the **ligamentum teres** (Fig. 1-6).

ARTERIAL SYSTEM: STRUCTURE AND FUNCTION

The structure of blood vessels varies with their function. In general, as the distance from the heart and the degree of branching increase, the cross-sectional area of an artery decreases and conversely, its stiffness increases. At the arteriolar and capillary levels, the cross-sectional area becomes greater in keeping with the reduced flow and systolic and pulse pressures.

The response of a blood vessel to clamping, ligating, or suturing depends on its wall structure.

Structure of the Arterial Wall

All vessels have three analogous layers: **intima** (tunica intima), **media** (tunica media), and **adventitia** (tunica adventitia), as shown in the histologic cross-section of a medium-sized artery (Figs. 1-7 and 1-8). In arteries, the intima is composed of the single endothelial cell lining, supported by longitudinally oriented connective tissue. The media is a fibromuscular layer lying between the **internal** and **external elastic laminae** (Fig. 1-9). The adventitia is composed of longitudinally oriented connective tissue fibers and is covered by a thin **sheath**.

The **vasa vasorum** of the adventitia usually arises from the vessel itself but may come from an adjacent one. They nourish the outer portion of the media through a capillary network, whereas the inner portions are supplied by diffusion from within the artery. Stripping the adventitial sheath removes the vasa vasorum, but an adequate supply remains from within. Efferent sympathetic nerves supply constant stimulation to maintain the vasomotor tone of the vessels.

Arteries may be classified by function. The major arteries are *conducting arteries*, which are rich in elastic qualities and so can absorb the force of the heart and change it to a

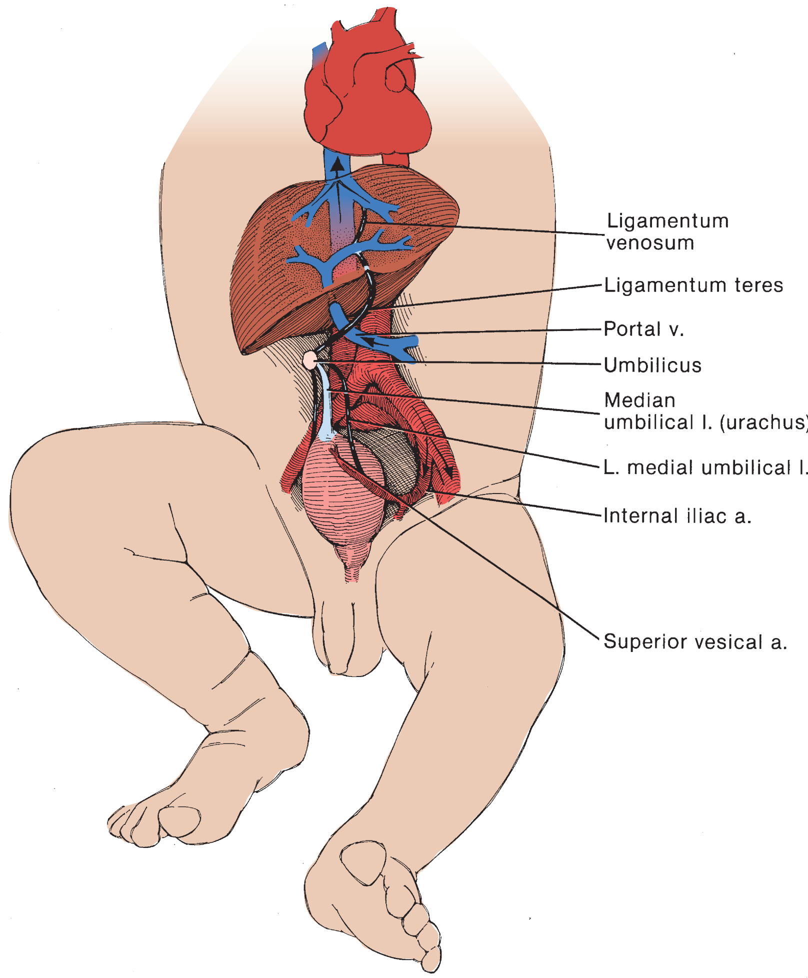

FIGURE 1-6.

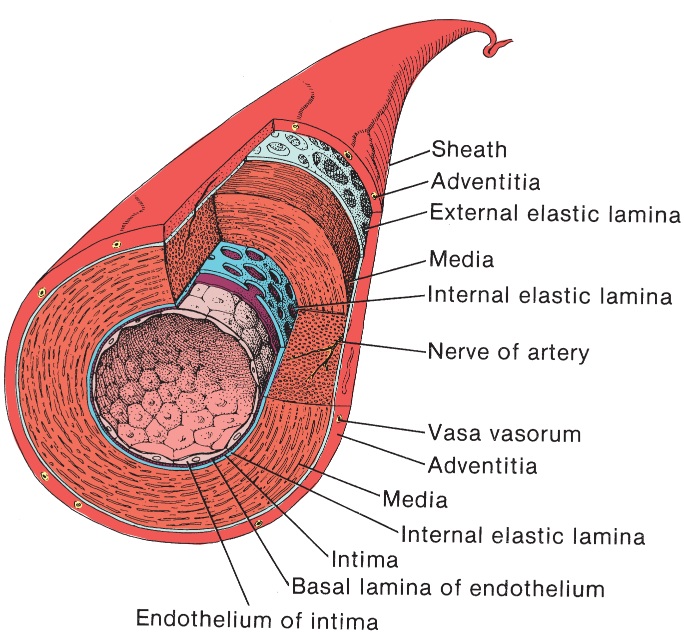

FIGURE 1-7.

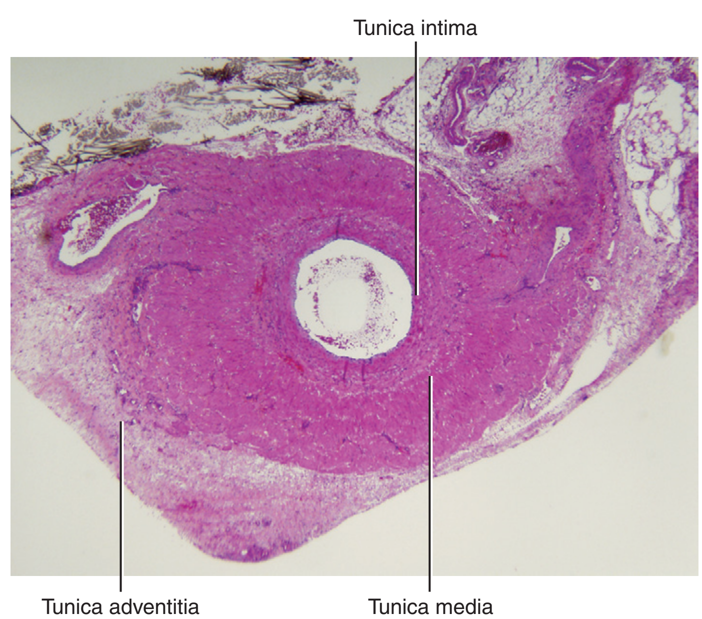

FIGURE 1-8.

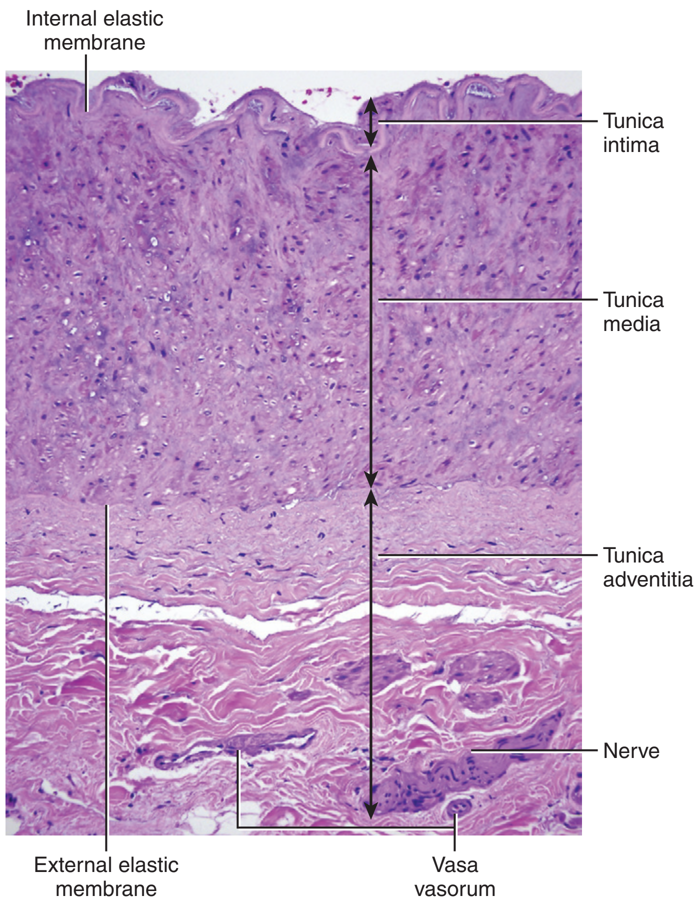

FIGURE 1-9.

less pulsatile flow. Medium and small arteries are *distributing arteries*, with muscular walls that aid in regulating flow. Arterioles are *resistance vessels*, which by restricting the flow affect the blood pressure. The capillaries, sinusoids, and postcapillary venules are *exchange vessels*, their function being to allow the ingress and egress of tissue fluid.

Abdominal Aorta

The **abdominal aorta** extends from the **aortic hiatus** of the diaphragm at the level of the 12th thoracic vertebra to the level of the 4th lumbar vertebra. It gives off four sets of branches: The dorsal, lateral, and ventral branches correspond to the embryological development of the dorsal somatic, lateral splanchnic, and ventral splanchnic vessels (see Fig. 1-3). The dorsal branches enter the body wall as the **lumbar** and **middle sacral arteries**. The lateral branches supply viscera via the **inferior phrenic, adrenal, renal,** and **gonadal** arteries. The ventral branches, which supply the viscera of the digestive tract, are the **celiac trunk** and the **superior** and **inferior mesenteric arteries** (Figs. 1-10, 1-11, and 1-12). These vessels are described under the organs they supply.

The anterior aspect of the aorta lies under the celiac plexus and the omental bursa. The pancreas with the underlying splenic vein crosses the aorta, with the superior mesenteric artery and left renal vein between. Caudal to the pancreas, the third part of the duodenum crosses the aorta. Further down, the aorta is covered by the posterior parietal peritoneum and the mesentery of the bowel. The posterior aspect lies against the upper four lumbar vertebrae,

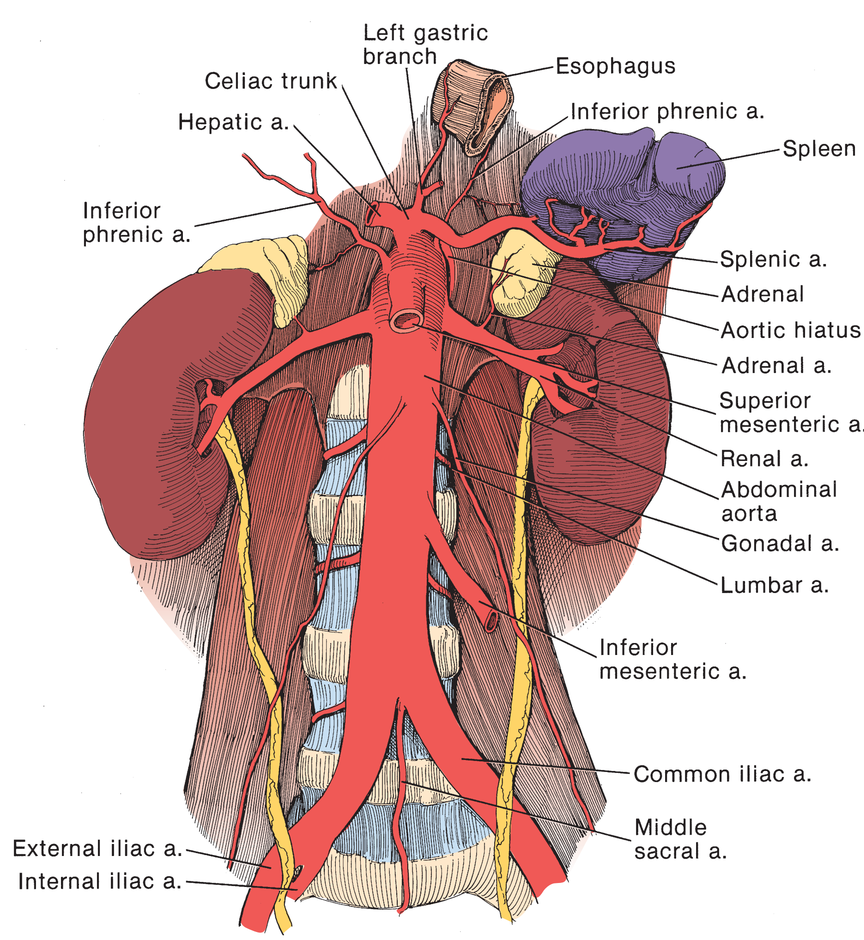

FIGURE 1-10.

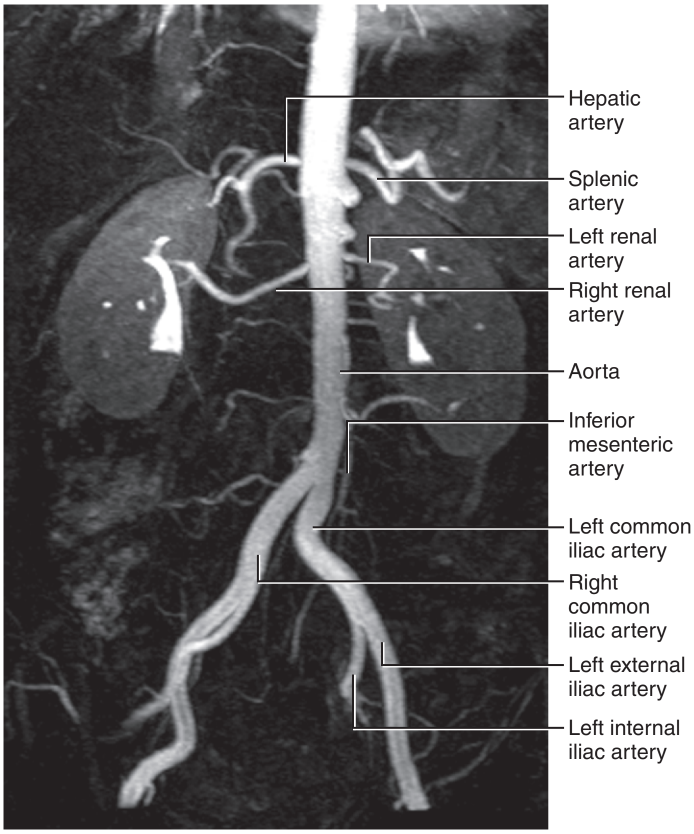

FIGURE 1-11. *(Image courtesy of Raj Paspulati, MD.)*

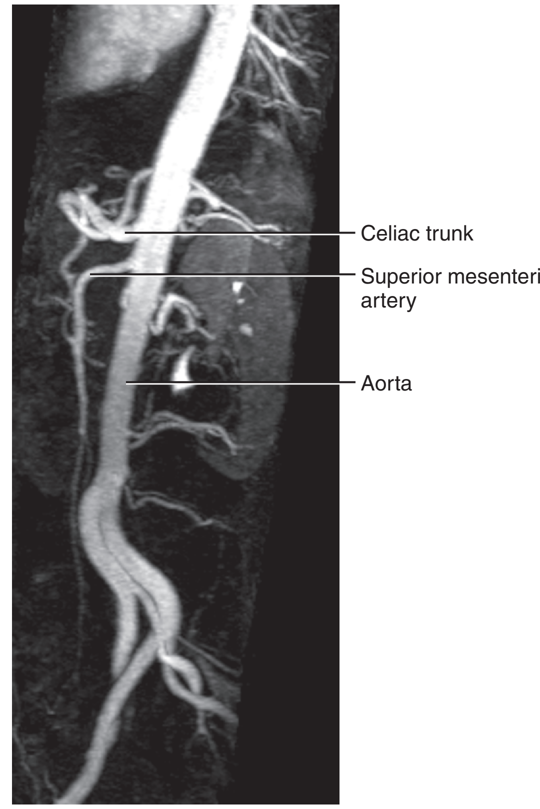

FIGURE 1-12. *(Image courtesy of Raj Paspulati, MD.)*

the corresponding intervertebral discs, and the anterior longitudinal ligament, with the 3rd and 4th lumbar veins intervening. The cisterna chyli, the thoracic duct, the azygos vein, the right diaphragmatic crus, and the right celiac ganglion lie to the right of the aorta. To the left are the left diaphragmatic crus and the left celiac ganglion, as well as the ascending portion of the duodenum and its junction with the jejunum and the sympathetic trunk.

The major arteries supplying specific parts of the genitourinary tract are described in the appropriate chapters.

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Chapter 2

Venous System

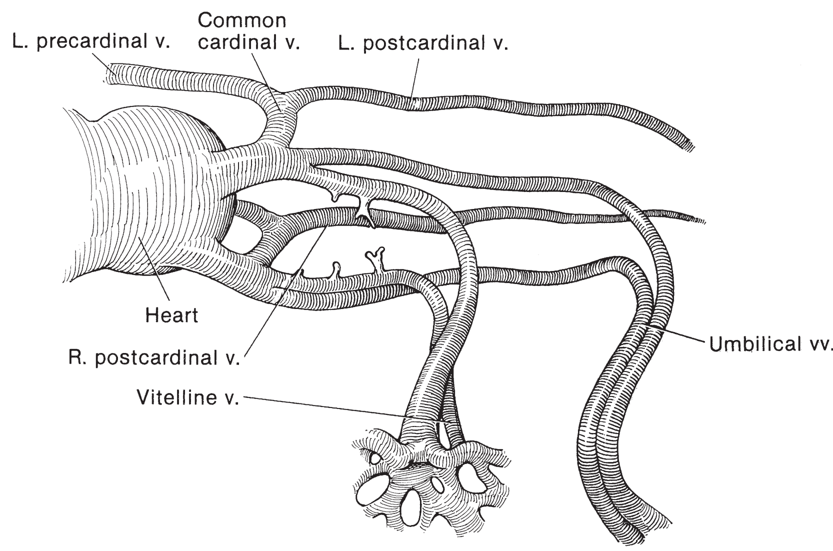


FIGURE 2-1.

For betynge of veynes is bettre i-knowe in þe vttre parties of bodies þan ynward abd in þe myddel wiþynne.

TREVISA
Higden (Rolls) I. 59., 1387

DEVELOPMENT OF THE VENOUS SYSTEM

Early Development of the Veins of the Trunk

At 4 weeks, as shown in Figure 2-1, three sets of veins drain through the sinus horn into the heart: the umbilical veins, the vitelline veins returning blood from the placenta and yolk sac, and the common cardinal veins returning blood from the head and trunk.

Precardinal, Postcardinal, and Subcardinal Veins

The common cardinal vein collects blood from the head through the paired precardinal veins and receives blood from the trunk through the paired postcardinal veins that run dorsal to the urogenital fold and mesonephros (Fig. 2-2).

Subcardinal veins develop parallel and medial to the **postcardinal veins**. Distally, the umbilical veins fuse, whereas proximally the right umbilical vein withers as the **left umbilical vein** enlarges. The paired **vitelline veins** fuse along the **yolk stalk**, but proximally they remain separate. The **right vitelline vein** becomes dominant as the **intervitelline anastomosis** forms at the site of the future liver.

Umbilical and Vitelline Veins

The proximal section of the left umbilical vein persists to bring fresh blood through the ductus venosus to the inferior vena cava. (In the adult, the remnant of the left umbilical vein becomes the round ligament of the liver.)

The **vitelline veins** join to form the **portal vein** and part of the inferior vena cava. As a result, blood carried by the three original systems now returns into the right sinus horn through the original **right vitelline** and **right** and **left common cardinal veins**, vessels that will form part of the inferior vena cava (Fig. 2-3).

Development of the Inferior Vena Cava

In a description of the basic developmental pattern of the venous system in forming the inferior vena cava, it must be emphasized that not only are the steps in its formation below the kidneys not yet fully understood but also many aberrations from the standard pathway occur.

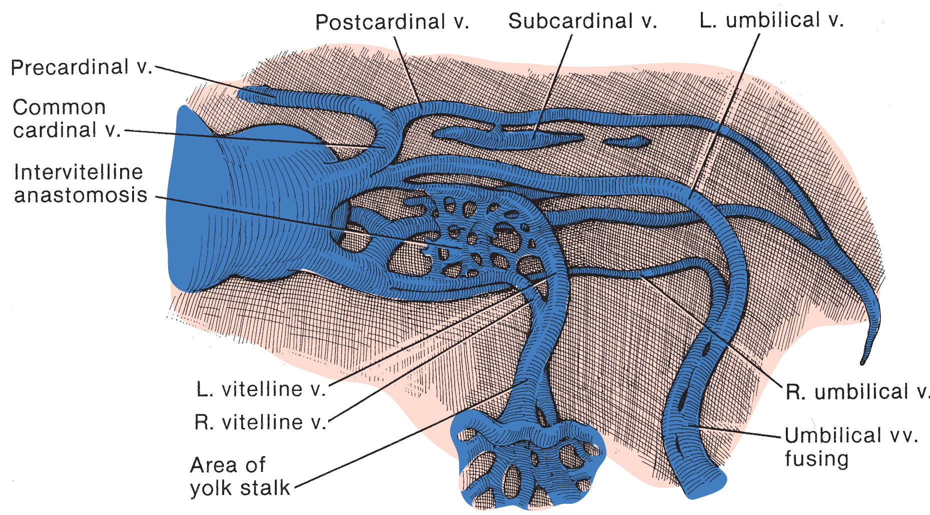


FIGURE 2-2.

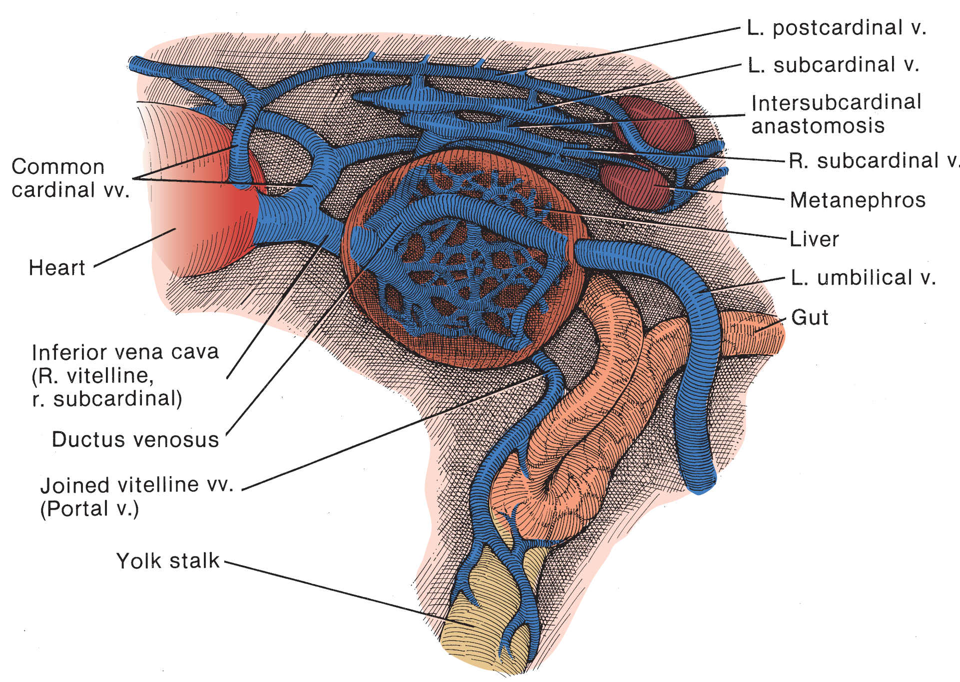


FIGURE 2-3. *(Adapted from Moore KL: The Developing Human, 4th ed. Philadelphia, WB Saunders Company, 1988.)*

The **postcardinal veins** drain the caudal portion of the embryo into the **common cardinal veins**, which, at the level of the heart, form the **sinus venosus** (Fig. 2-4). Caudally, they are connected by the important **interpostcardinal anastomosis**. The **subcardinal veins** have developed to form a second system, one that lies medial to the postcardinal veins in the trunk and forms multiple connections with them. In addition, the **intersubcardinal anastomoses** have formed between the right and left subcardinal veins, a complex that is destined to become the renal collar.

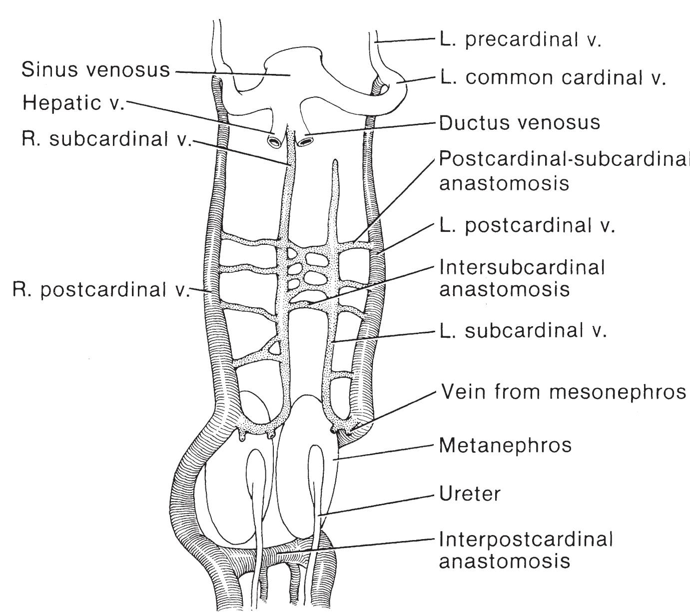


FIGURE 2-4.

Subcardinal and Supracardinal Veins

The proximal end of the right subcardinal vein joins the hepatic portion of the hepatocardiac vein to form the hepatic and the subhepatic segments of the inferior vena cava.

One more set of veins is formed. The **supracardinal veins** (in black) lie dorsal to the **postcardinal veins** and run parallel with them distally to join the **interpostcardinal**

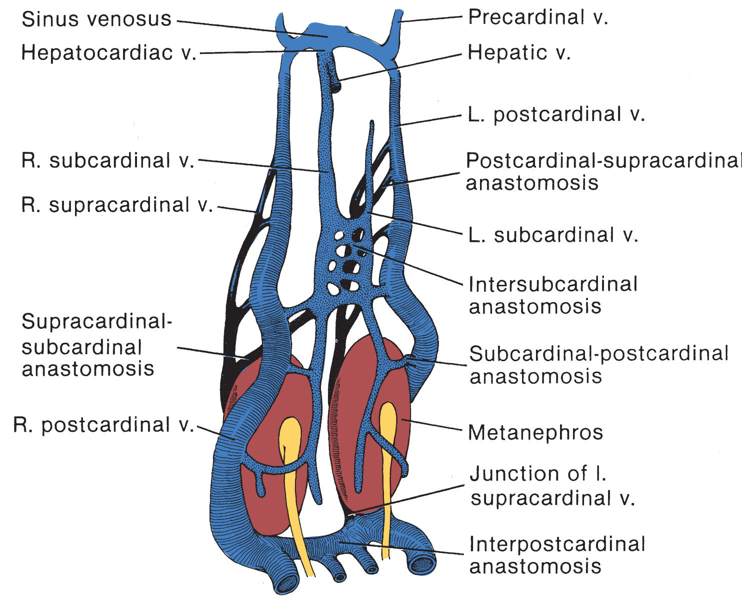


FIGURE 2-5.

anastomosis (Fig. 2-5). These veins connect proximally with the **intersubcardinal anastomosis** via the **supracardinal-subcardinal anastomosis**.

Regression of the Postcardinal and Supracardinal Veins

Cephalad to the interpostcardinal anastomosis, the postcardinal veins regress. To compensate for the reduced drainage, the supracardinal veins enlarge up to their connection with the intersubcardinal anastomosis. The supracardinals remain minor vessels beyond that juncture.

The increased blood flow arriving at the intersubcardinal anastomosis from the now enlarged **right supracardinal vein** is carried by the similarly enlarged proximal portion of the **right subcardinal vein** (Fig. 2-6). Thus, the main venous pathway becomes: interpostcardinal anastomosis—supracardinal veins—intersubcardinal anastomosis—right subcardinal—hepatocardiac vein—heart.

Dominance of the Right Subcardinal Vein

The function of the postcardinal veins cranial to the interpostcardinal anastomosis has been assumed by the subcardinal and supracardinal veins. The right supracardinal vein will become dominant, constituting the inferior vena cava caudal to the intersubcardinal anastomosis into which it drains. Cranial to this point, the supracardinal veins have become separated to form the azygos veins.

The **subcardinal veins** have begun to position themselves as the **gonadal veins** emptying into the **intersubcardinal anastomosis**, which, in turn, is destined to become the **left renal vein**. Proximally, the **right subcardinal vein** continues to be the main conduit as the **left subcardinal vein** becomes an **adrenal vein** (Fig. 2-7).

After the postcardinal veins have degenerated, the lower poles of the **metanephroi** are free to rotate laterally and ascend as the body straightens and lengthens (see Fig. 12-6).

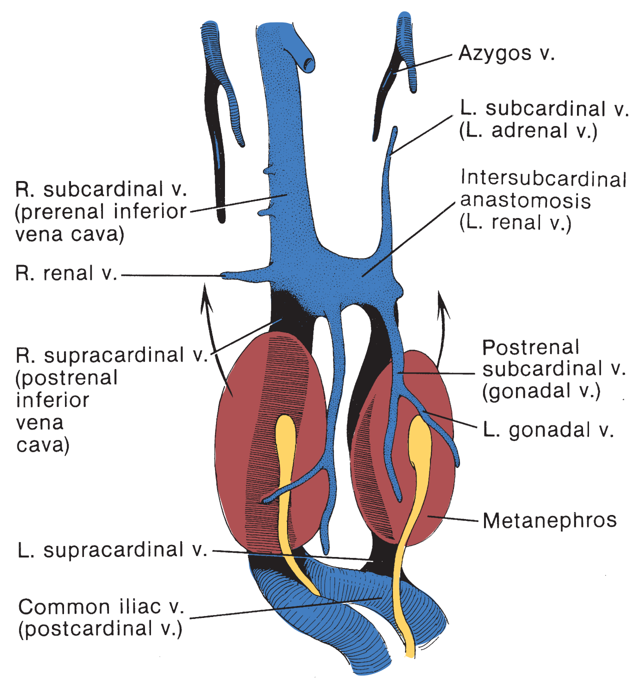


FIGURE 2-6.

Composition of the Inferior Vena Cava

The cranial segment of the inferior vena cava (above the renal veins) forms when the left supracardinal vein regresses. This leaves the right subcardinal segment as the only channel connecting with the hepatocardiac venous contribution, which, in turn, joins the heart. The junction for the renal, adrenal, and gonadal veins is provided by the intersubcardinal anastomosis (Fig. 2-8).

The caudal portion of the inferior vena cava is derived from the **right supracardinal segment**. The **common iliac veins** are formed from the **postcardinal veins** through the persistence of the interpostcardinal anastomosis.

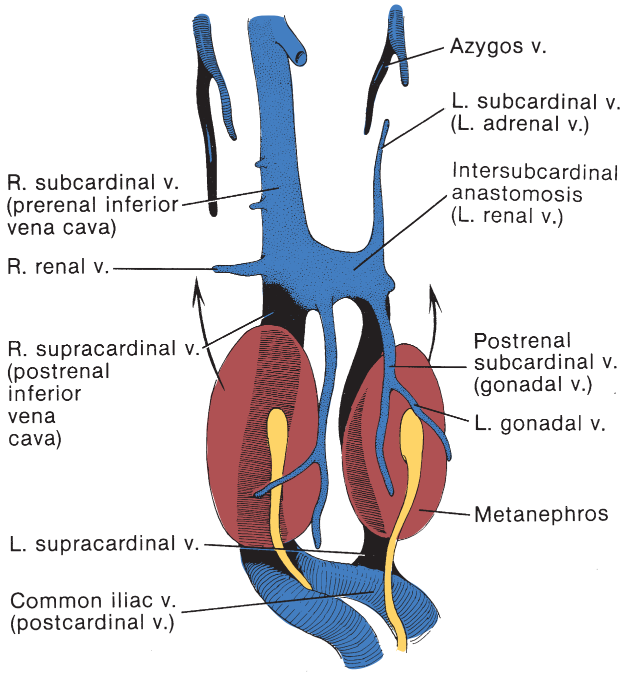


FIGURE 2-7.

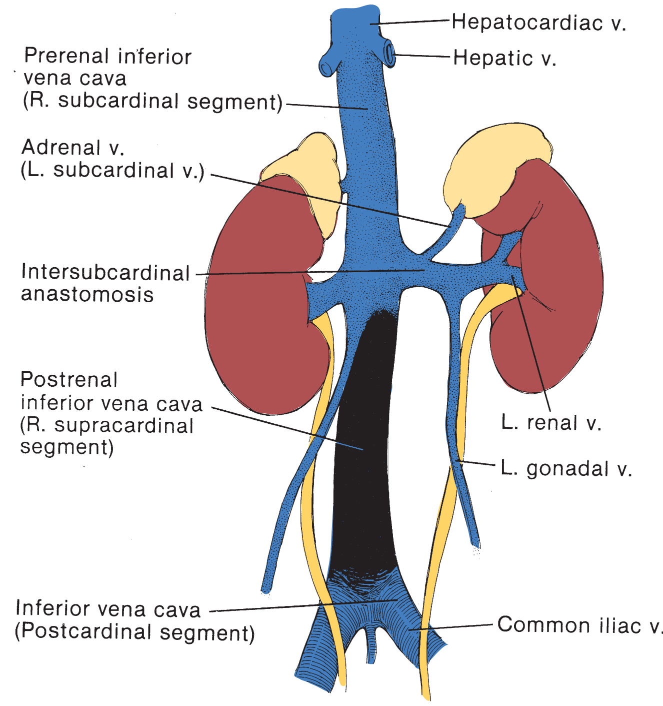


FIGURE 2-8.

TABLE 2-1

RELATION OF EMBRYONIC TO ADULT VEINS

Embryonic Structure	Adult Structure
Left umbilical vein	Round ligament of liver
Right subcardinal vein	Right gonadal vein; part of inferior vena cava
Left subcardinal vein	Left adrenal vein; left gonadal vein; part of left renal vein
Right sacrocardinal vein	Right common iliac vein; part of inferior vena cava
Left sacrocardinal vein	Left common iliac vein
Caudal veins	Median sacral vein

Table 2-1 compares the embryonic with the adult venous system.

ANOMALIES OF THE INFERIOR VENA CAVA

The normal type of postrenal vena cava that is found in 97.6% of cadavers is the result of persistence of the right supracardinal vein. Anomalies arise from persistence of three other embryonic veins: right postcardinal, left supracardinal, and left postcardinal. Although it has been calculated that 15 possible patterns could result from combinations of these three persistent veins, the only anomalies found in cadavers are persistence of the right postcardinal vein (retrocaval ureter) and left supracardinal vein. These anomalies may be detected preoperatively by computed tomography or ultrasonography. An inferior vena cavagram through a left femoral puncture will confirm the type of anomaly.

Preureteric Vena Cava (Retrocaval Ureter)

The complex development of the normal inferior vena cava allows ample opportunity for aberration (Fig. 2-9A; see also Fig. 2-4).

Should the ventrally situated **right postcardinal vein** remain dominant rather than give way to the dorsally situated **right supracardinal vein** (with or without persistence of a periureteral venous ring), the main channel will lie ventral to the ureter as the kidney ascends (Fig. 2-9B).

The vena cava then develops from the **right postcardinal vein** ventral to the ureter (Fig. 2-9C).

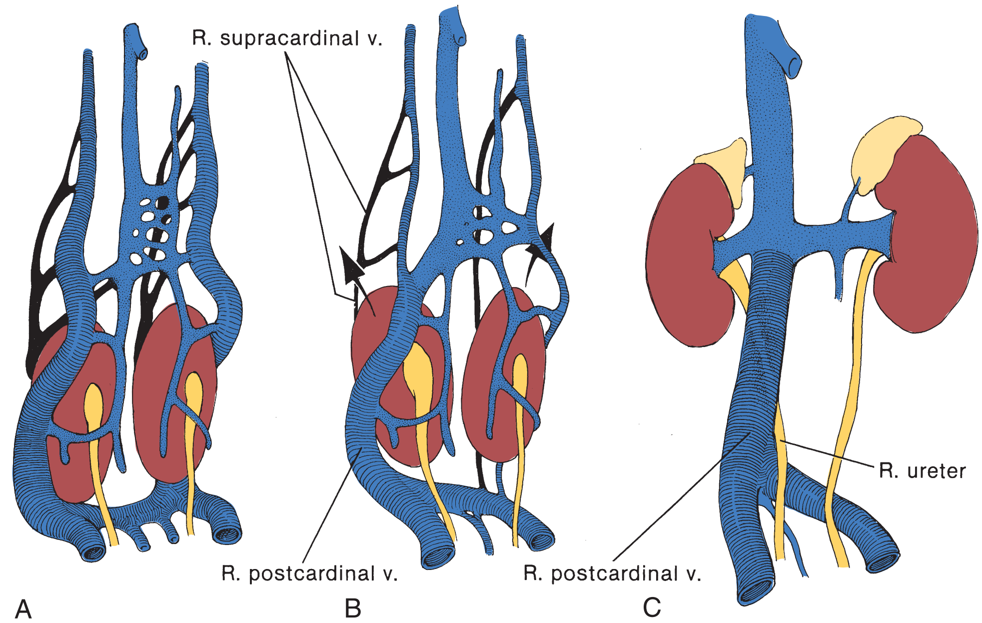


FIGURE 2-9.

Double and Left Vena Cava

Double Vena Cava

For duplication of the inferior vena cava, both supracardinal veins persist to run on either side of the aorta and join anteriorly at the level of the renal arteries, forming a suprarenal vena cava (Fig. 2-10A).

Left Vena Cava

Persistence of the left supracardinal vein forms a mirror image of the normal arrangement. The inferior vena cava on the left crosses over anterior to the aorta at the level of the renal arteries, and the gonadal vein, instead of emptying into the left renal vein, opens directly into the vena cava (Fig. 2-10B).

These two anomalies pose problems for exposure of the aorta. A retroaortic renal vein results from persistence of the posterior embryonic vein. Retention of the embryonic circumaortic venous ring leaves a retroaortic renal vein in addition to an anteriorly placed one and also influences the arrangement of the vessels related to the renal vein. Such anomalies of the renal vein, if not recognized, cause hazards during renal and adrenal operations.

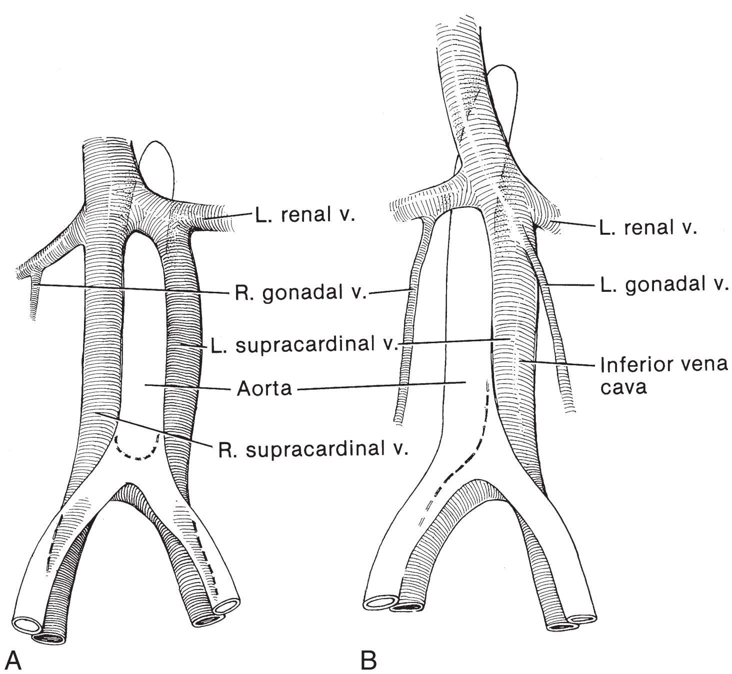


FIGURE 2-10.

VENOUS SYSTEM: STRUCTURE AND FUNCTION

Structure of Veins

Veins have three coats similar to those of arteries, but the layers are not as well-defined as they are in arteries. Veins and arteries differ in that arteries have thicker walls and a much larger media, whereas in veins, the adventitia is larger than the media. In small veins, the layers are difficult to distinguish (Fig. 2-11) and in none are they as distinct as is shown in the diagrammatic figure (Fig. 2-12).

The **intima** is composed of endothelial cells, called the **intimal epithelium**, surrounded by a thin layer of **collagen** fibers and fibroblasts. The **internal elastic layer** separating the intima from the media consists of elastic fibers in a connective tissue matrix, but this structure may be quite indistinct, even in large veins. The **media** is relatively thin and is composed of collagen fibers, a few fibroblasts, and variable amounts of smooth muscle. The combined structure of the **external elastic layer** and **adventitia** is similar to the adventitia of arteries, consisting of longitudinal elastic fibers in areolar tissue. In large veins, such as the renal vein, the adventitia is appreciably

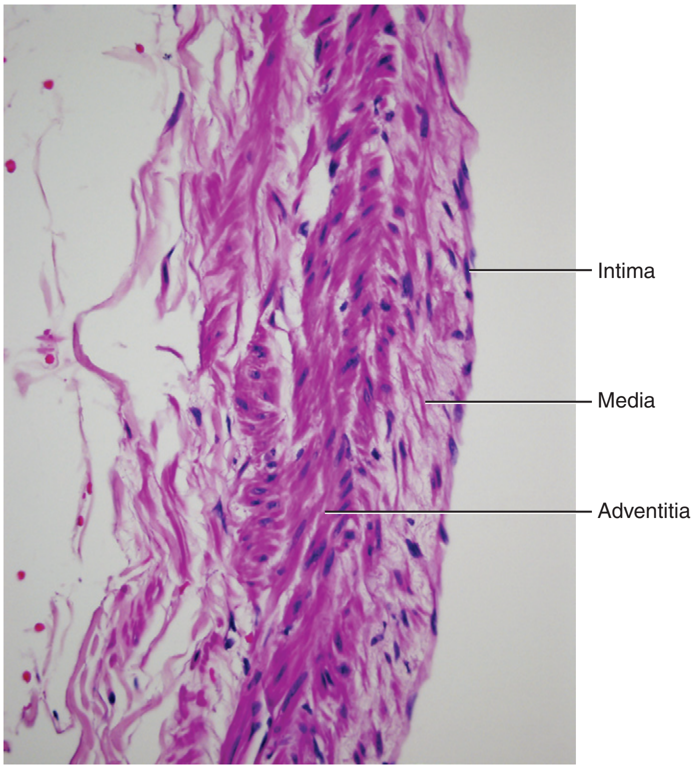


FIGURE 2-11.

thicker and contains prominent bundles of smooth muscle fibers (Fig. 2-13).

Venous Valves

Valves that prevent the flow of blood in a centripetal direction are present in all but particularly large or very small veins. They usually have two cusps but may have one or three. An outpouching of the vein appears behind each cusp, forming a sinus.

CLASSIFICATION OF VEINS

Three sets of veins are recognized: systemic, pulmonary, and portal. The systemic veins, those that return blood from the periphery of the body, include the superficial veins lying in the superficial fascia, and the deep veins that run in a common sheath next to a corresponding artery in a relationship that promotes venous return by pulsatile arterial activity. Connecting veins join the two systems at various sites. Smaller arteries such as the inferior epigastric artery have smaller veins, venae concomitants, that run in pairs on either side.

Systemic veins include the veins that serve the heart directly, the superior vena cava, and the inferior vena cava that drains the structures of the urogenital system.

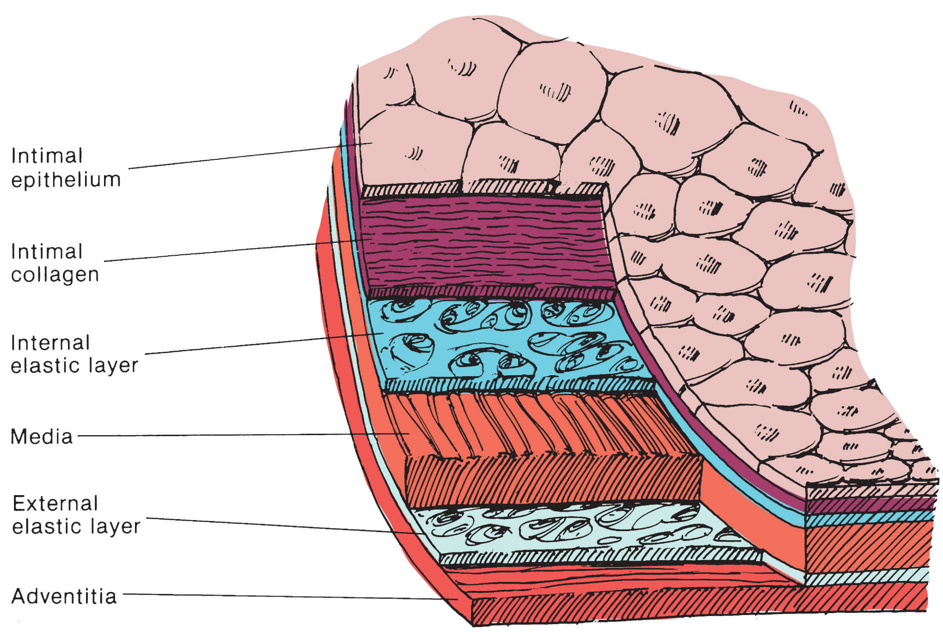


FIGURE 2-12.

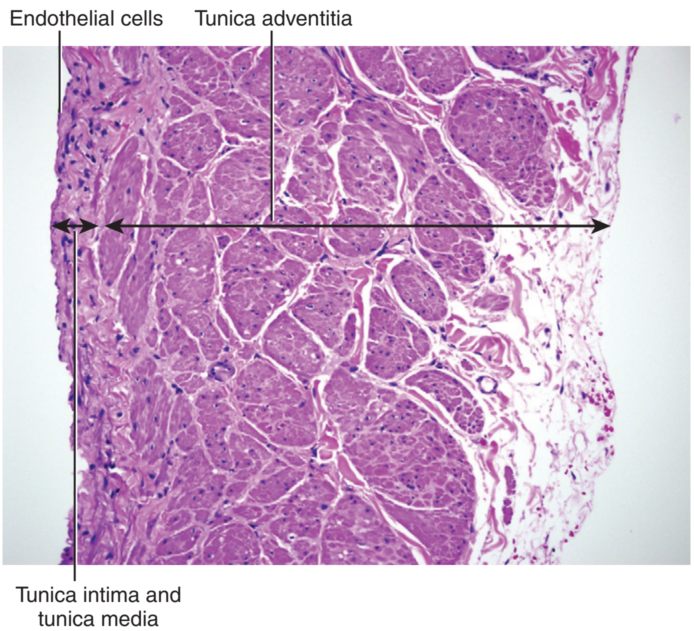


FIGURE 2-13.

INFERIOR VENA CAVA AND VERTEBRAL VENOUS SYSTEM

Inferior Vena Cava

The veins of the legs, pelvis, and abdomen drain into the inferior vena cava, which, in turn, empties into the right atrium of the heart (Figs. 2-14 and 2-15). The inferior vena cava runs anterior to the vertebral bodies on the right side of the aorta (Fig. 2-16) and reaches a deep groove on the posterior surface of the liver before passing through the diaphragm in the right portion of the central tendon to empty posteriorly into the lower part of the right atrium. The inferior vena cava has no valves. The tributaries of the inferior vena cava are listed in Table 2-2 and are described in the appropriate chapters.

Lumbar Veins

The lumbar veins drain the body wall. Each of the paired ascending lumbar veins has connections to the common iliac and iliolumbar veins. Ideally, each receives a subcostal vein and four lumbar tributaries, the lumbar veins. The left

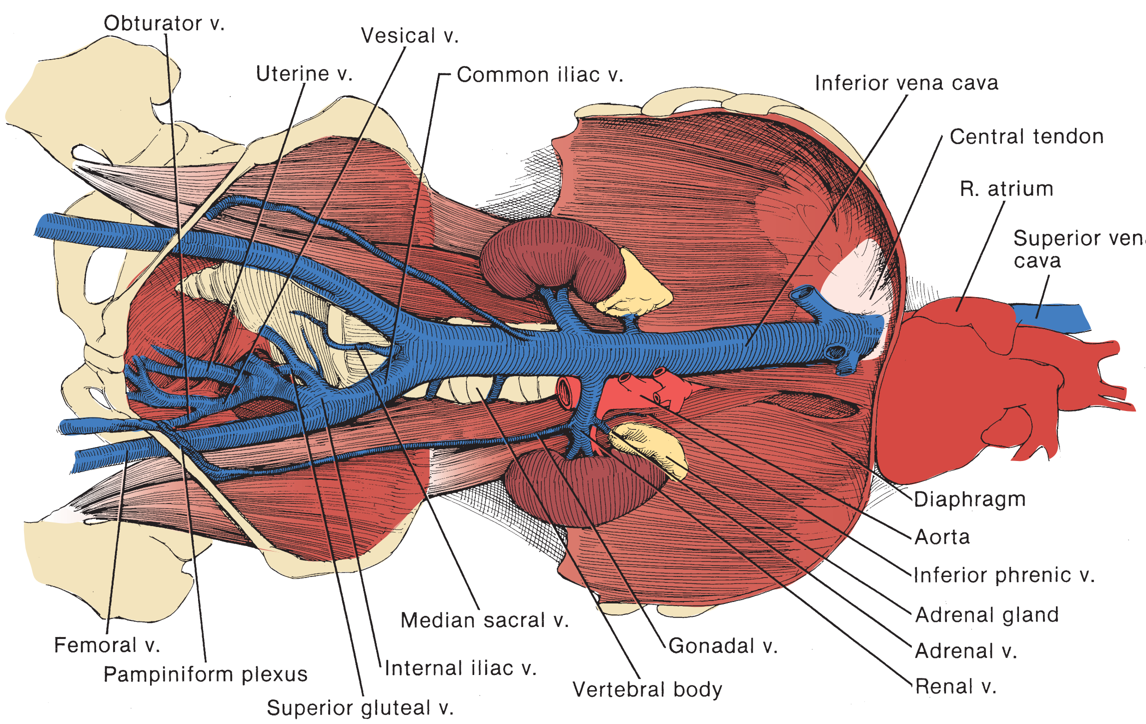


FIGURE 2-14.

FIGURE 2-15. *(Image courtsey of Raj Paspulati MD)*

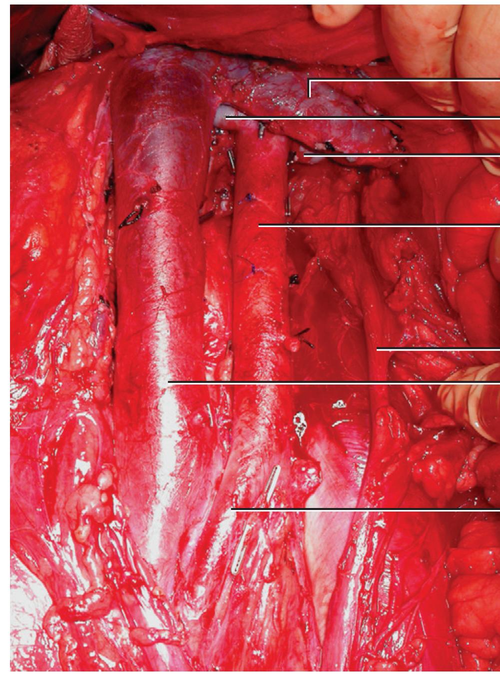


FIGURE 2-16. *(Image courtsey of Lee Ponsky MD)*

TABLE 2-2

TRIBUTARIES OF THE INFERIOR VENA CAVA

VENA CAVA	
Common iliac veins	Adrenal veins
Lumbar veins	Inferior phrenic veins
Right gonadal vein	Hepatic veins
Renal veins	
COMMON ILIAC VEIN	
Internal iliac vein	Medial sacral vein
External iliac vein	
EXTERNAL ILIAC VEIN	
Inferior epigastric vein	Pubic vein
Deep circumflex iliac vein	
INTERNAL ILIAC VEIN	
Superior gluteal vein	Rectal venous plexus
Inferior gluteal vein	Prostatic venous plexus
Internal pudendal vein	Vesical vein and plexus
Obturator vein	Dorsal vein of penis
Lateral sacral vein	Uterine vein and plexus
Middle rectal vein	Vaginal vein and plexus

ascending lumbar vein passes under the medial arcuate ligament of the diaphragm to continue as the hemiazygos vein (Fig. 2-17). Exceptions to this general plan are the rule.

The lumbar veins communicate with the vertebral plexuses (see Fig. 2-5). In the majority of cases, there is a communication between the **ascending lumbar vein** and the **left renal vein**. The courses of the lumbar veins are variable: the 3rd and 4th terminate in the **inferior vena cava**, and the 1st and 2nd may also empty there instead of into the ascending lumbar vein or in the **lumbar azygos vein**. Alternatively, the connections may be plexiform over the bodies of the upper lumbar vertebrae.

Vertebral and Paravertebral Veins

The veins associated with the vertebral column form plexuses within and outside the vertebral canal and make connections with longitudinal sets of veins (Fig. 2-18).

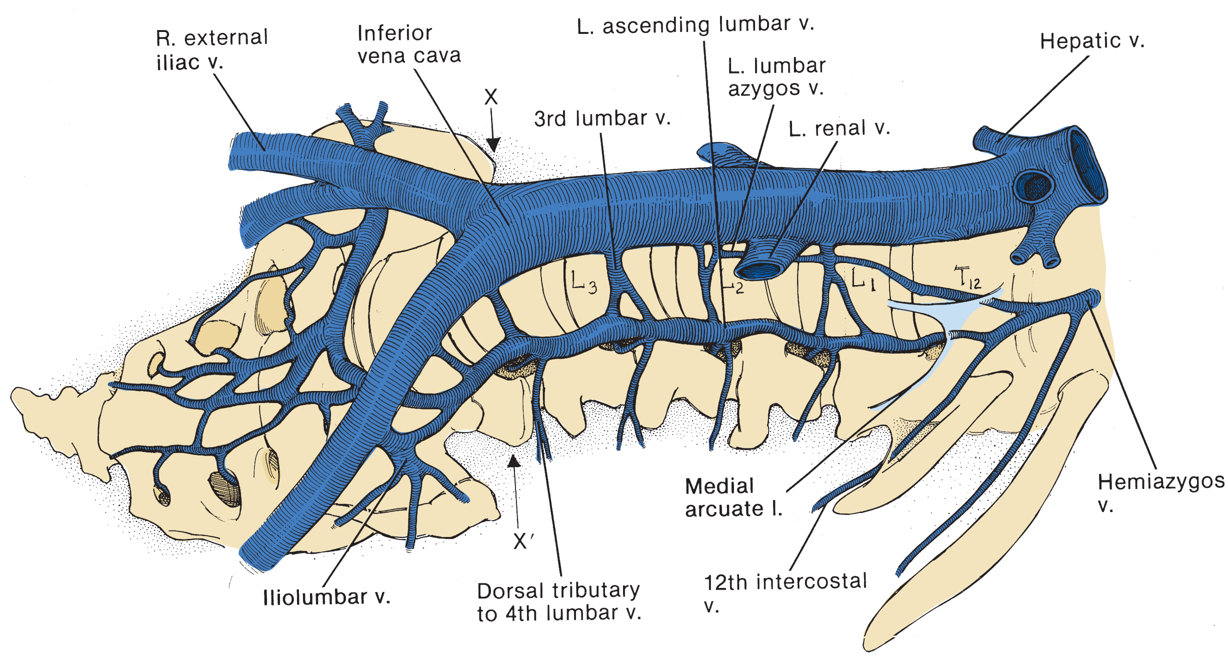


FIGURE 2-17.

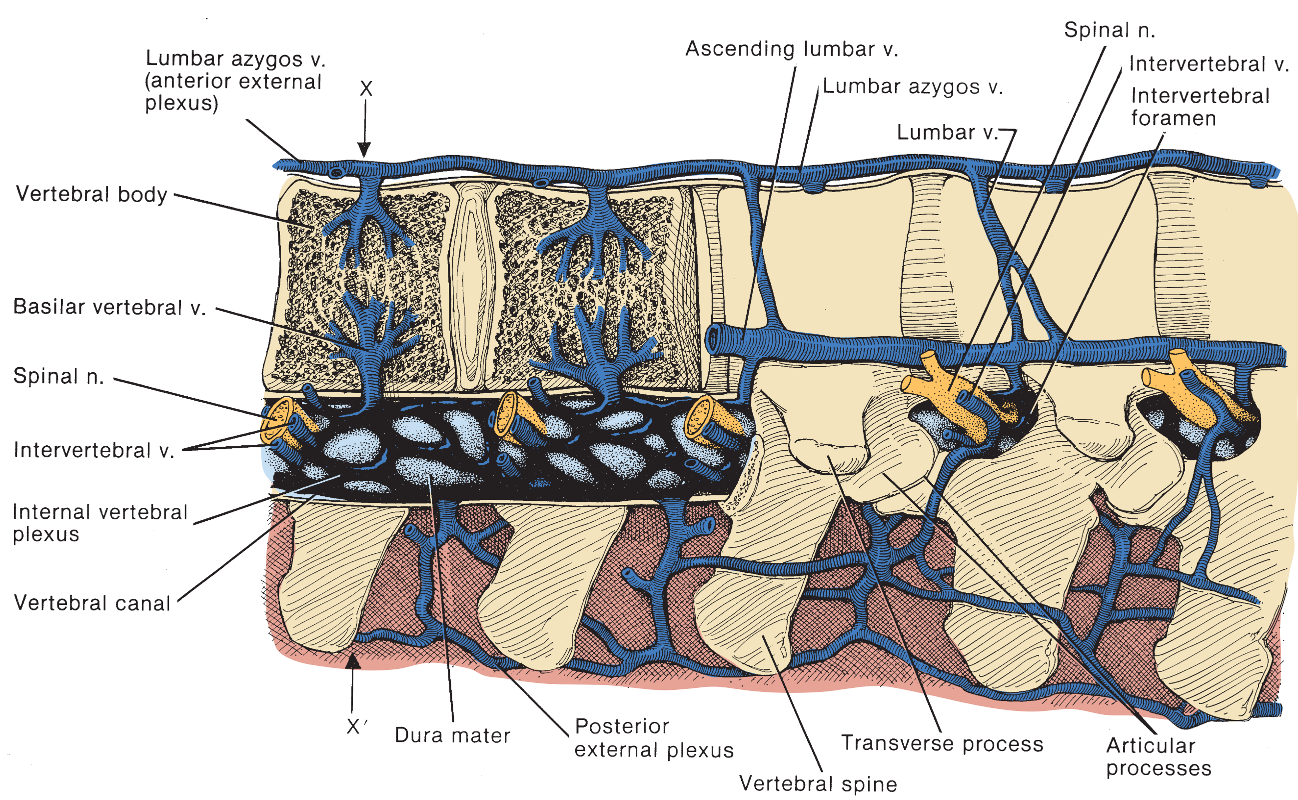


FIGURE 2-18.

The posterior external plexus is adjacent to the vertebral spines and articular processes. Anterior to the vertebral bodies is the anterior external plexus (lumbar azygos vein) that drains into the hemiazygos vein. The lumbar veins run around the vertebral body to connect the lumbar azygos vein with the ascending lumbar vein.

The basivertebral veins drain the vertebral bodies into the internal vertebral plexus within the vertebral canal outside the dura mater. The plexus receives blood from the cord and from the vertebrae.

Intervertebral veins are associated with the spinal nerves as they pass through the intervertebral foramina. They are in continuity with the external and internal plexuses and drain into the vertebral, intercostal, lumbar, or sacral veins, forming an interconnected set of veins designated the "Batson plexus" (Fig. 2-19). The vertebral veins are free of valves; tumor cells entering the pelvic veins are free to move throughout the body by reverse flow along this low-pressure system.

Vertebral Veins in Transverse Section

This section is taken at line X-X′ in Figures 2-17 and 2-18.

Two sets of veins are concerned with drainage of the vertebral column, the external and the internal vertebral venous plexuses, each of which has a posterior and an anterior portion (Fig. 2-20).

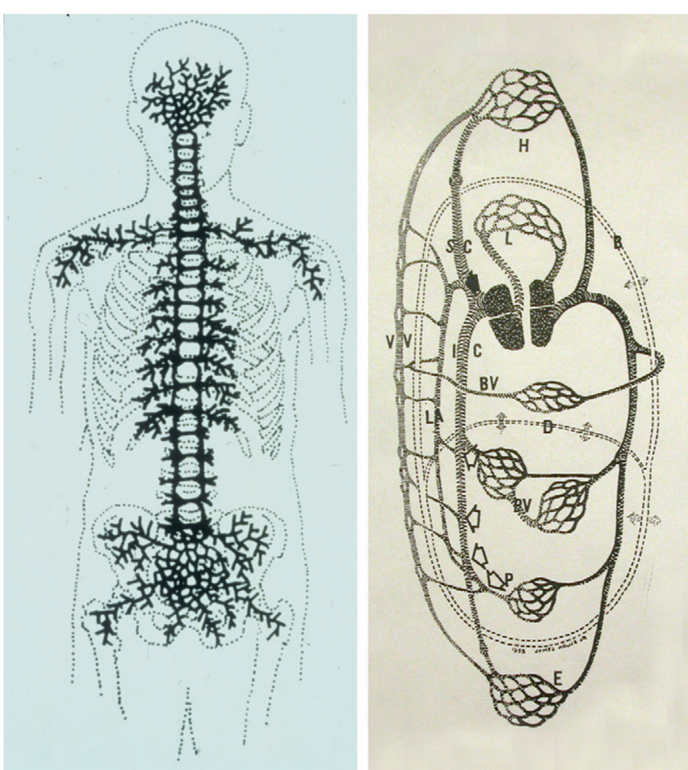


FIGURE 2-19. *(Modified from: Batson, OV. The vertebral system of veins as a means for cancer dissemination. Prog Clin Cancer. 1967;3:1-18.)*

External Plexus

The external vertebral plexus is divided into two parts—(1) an anterior portion, the anterior external venous plexus (lumbar azygos vein), situated adjacent to the vertebral body, and (2) a posterior portion, the posterior external vertebral plexus, distributed about the laminas, spines, and transverse processes of the vertebra. The two portions come together at their junction with the ascending lumbar vein, which is connected through the lumbar veins to the anterior external venous plexus, which, in turn, is associated with the lumbar azygos vein, which drains into the inferior vena cava.

Internal Plexus

The internal vertebral plexus is located outside the dura mater within the vertebral canal. The anterior portion, the anterior internal venous plexus, is adjacent to the vertebral body, and the posterior portion, the posterior internal venous plexus, lies next to the vertebral arches.

Communication Between the Plexuses

There is free communication between the two plexuses throughout the length of the vertebral canal. The external and internal plexuses connect with each other through the basivertebral veins in the vertebral body and through the intervertebral veins in the intervertebral foramina. Blood is carried to the lumbar veins as well as to the posterior intercostal veins.

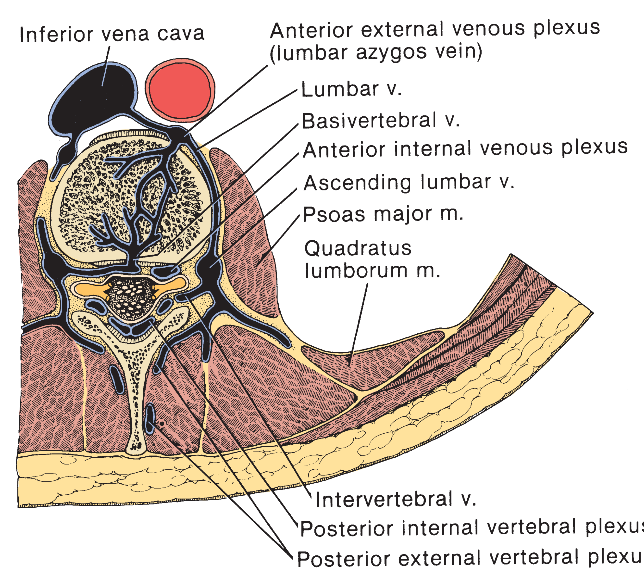


FIGURE 2-20.

Chapter 3

Lymphatic System

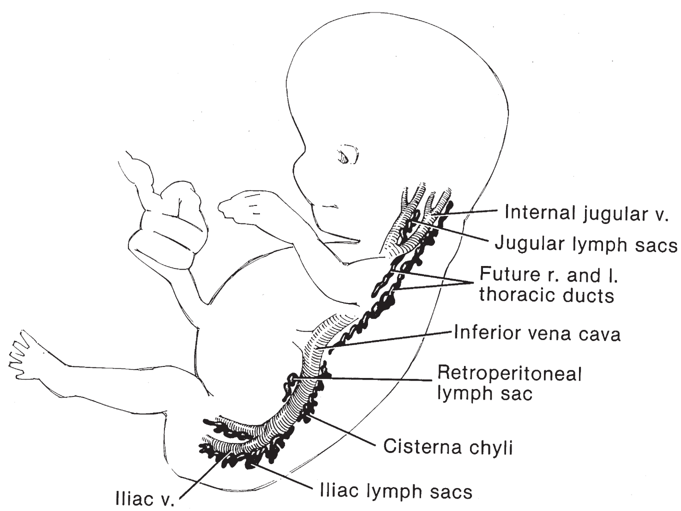


FIGURE 3-1.

The late anatomical discoveries of the motion of the chyle and lymphatick liquor . . . hath yet made men cure diseases much better than before.

BOYLE
Usef. Exp. Nat. Philos. II. v. x. 224, 1663

DEVELOPMENT OF THE LYMPHATIC SYSTEM

Lymph Sacs

Early in development, clefts lined with endothelium appear in the mesenchyme and form capillary plexuses. Six lymph sacs arise from the plexuses: **lymph sacs** in the neck, the paired **iliac lymph sacs** at the junction of the iliac and postcardinal veins, and the **retroperitoneal lymph sac** near the adrenals and the **cisterna chyli** at the L3 and L4 vertebral level (Fig. 3-1). Channels that will form the future **right** and **left thoracic ducts** will ascend from the cisterna. The iliac lymph sacs drain the legs, and the retroperitoneal sac drains the abdominal viscera.

The lymph vessels are formed as branches from the sacs and follow the course of the primitive veins. Alternatively, they are formed directly in the mesenchyme and become connected secondarily.

The sacs become divided by the formation of septa by encroaching mesenchymal cells and are invaded by lymphocytes early in fetal life to become groups of lymph nodes. The sinuses within a node (Figs. 3-3 and 3-4) represent the cavity of the original lymph sac. The exception is the upper portion of the cisterna chyli, which does not divide but may become plexiform. From each of these sacs, lymphatic vessels follow the main veins to the structure to be drained.

Thoracic Duct

Originally, the two **jugular lymph sacs** are connected to the **cisterna chyli** by the **right** and **left thoracic ducts**, between which an anastomotic channel forms. The left duct and part of the right thoracic duct regress, so that the final duct is formed from the caudal part of the right duct, the anastomotic channel, and the cranial part of the left duct (Fig. 3-2).

STRUCTURE AND FUNCTION OF THE LYMPHATIC SYSTEM

The superficial lymphatic vessels are associated with the superficial veins and are a system distinct from the deep lymphatics, which are associated with named arteries or veins. All of the lymph except for a small portion from the neck eventually reaches the thoracic duct.

Lymphatic Vessels and Lymph Nodes

Blind-ending lymph capillaries lying in the tissue spaces collect lymph through their permeable walls and channel it through larger trunks to collections of lymphoid tissue, the lymph nodes. Groups of lymph nodes drain particular regions, but connections between the individual nodes in a group are common and lymph may pass consecutively through several nodes before reaching a major collector.

Lymph nodes are small, somewhat flattened bodies that receive lymph from the several valved **afferent lymphatic**

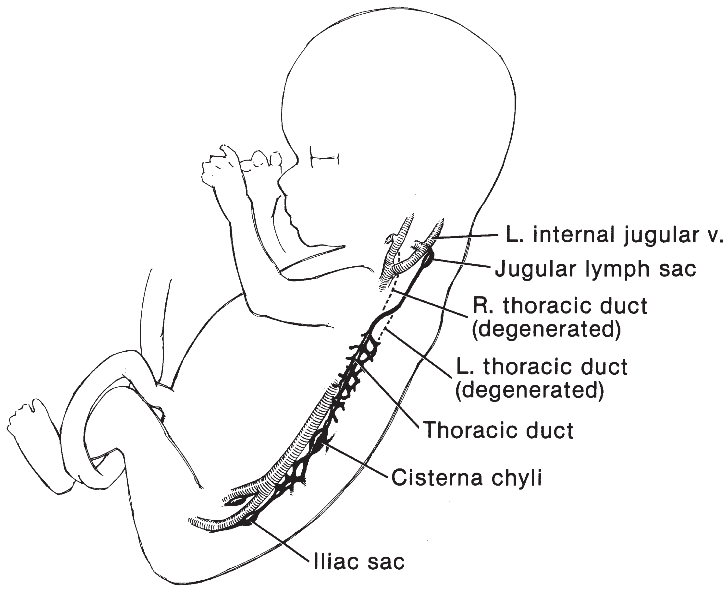


FIGURE 3-2.

vessels entering around the periphery (Figs. 3-3 and 3-4). The lymph first passes through the **subcapsular sinuses**, then into the **cortical** (trabecular) **sinuses**, and finally into **medullary sinuses** near the **hilum**. A capsule composed of dense connective tissue surrounds the node, and from the capsule extend trabeculae, which are surrounded by cortical sinuses and separate the lymph follicles. The trabeculae support a fine **reticulum** that fills the node and serves as a framework for the attachment of several types of cells. The reticulum provides for maximal contact between the cells and the circulating lymph. In the **cortex**, the entangled cells form dense aggregates, which are the lymph follicles that surround the **germinal centers**. The germinal centers contain lymphoblasts, which mature to small lymphocytes. These reach the marginal zone of the germinal center and the paracortex that surround the follicle before passing into the lymph sinuses. In the **medulla**, the lymphocytes (including plasma cells), macrophages, and granulocytes are less closely packed and form **medullary cords**.

A single (rarely more) **efferent lymphatic vessel** emerges from the **hilum**, adjacent to the vascular supply. The supply is provided by a **nodal artery** and a **nodal vein**, which divide within the node to become capillaries at the periphery. The capillaries form complicated **anastomotic loops** to supply the lymph follicles.

B-lymphocytes from the bone marrow and T-lymphocytes from the thymus arrive at the node from peripheral lymph channels. They also come from the bloodstream via the postcapillary venules. The lymphocytes proliferate in the node and recirculate, supplemented, especially on demand, by lymphocytes generated within the node.

Retroperitoneal Lymph Nodes

Two groups of nodes occupy the retroperitoneum of the abdomen and pelvis: (1) the lumbar and (2) the pelvic nodes (Fig. 3-5).

The *lumbar lymph nodes* consist of three groups, their source depending on which branch of the aorta supplies the organ that they drain. The **preaortic nodes** drain the intestinal tract. The **right** and **left lateral aortic nodes** on either side of the aorta are of most concern urologically. They directly drain those structures supplied by the lateral

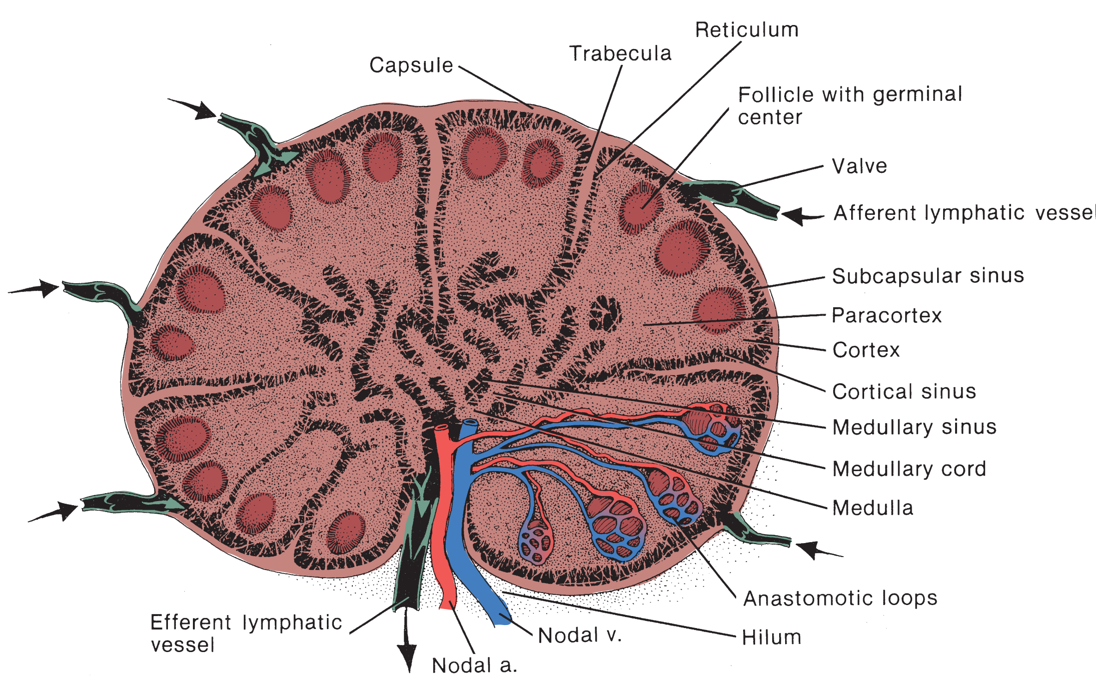


FIGURE 3-3.

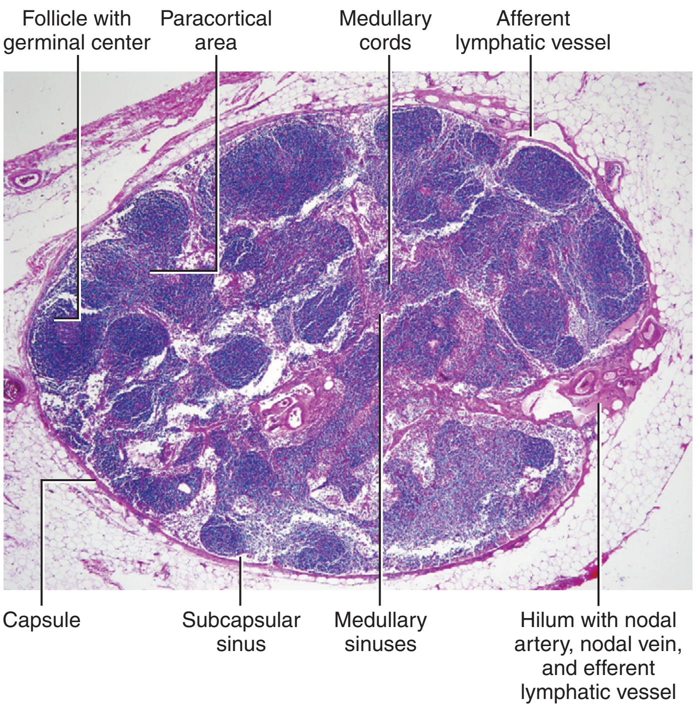


FIGURE 3-4.

and dorsal aortic branches: adrenal gland, kidney, ureter, testis, and ovary.

The *pelvic nodes*—external iliac, internal iliac, obturator, and sacral—collect lymph from the pelvic organs and drain indirectly into the lumbar nodes.

Lymph from the bladder drains into the **external iliac nodes**, but some lymph from the base may pass directly to the **internal iliac** and **common iliac nodes**, and some from the neck of the bladder may go directly to the **sacral nodes**.

Lymph from the prostate drains into the pelvic lymphatic chains by one of three sets of collecting trunks. One is along the prostatic artery in the vascular pedicle draining to the obturator and internal iliac nodes. The second, arising from the base and the proximal posterior portion of the prostate, drains into the external iliac nodes. The third collector, from the posterior part of the prostate, drains into the **sacral nodes** and also into an **internal iliac node** near the origin of the internal pudendal artery.

The collectors from the right testis join the aortic nodes lying between the take-off of the renal vein and the aortic bifurcation. Usually, several vessels join one of the **precaval nodes**, while an adjacent node may receive none. From the left testis, two-thirds of the collectors run to the lateral aortic nodes and the other third end in the preaortic nodes.

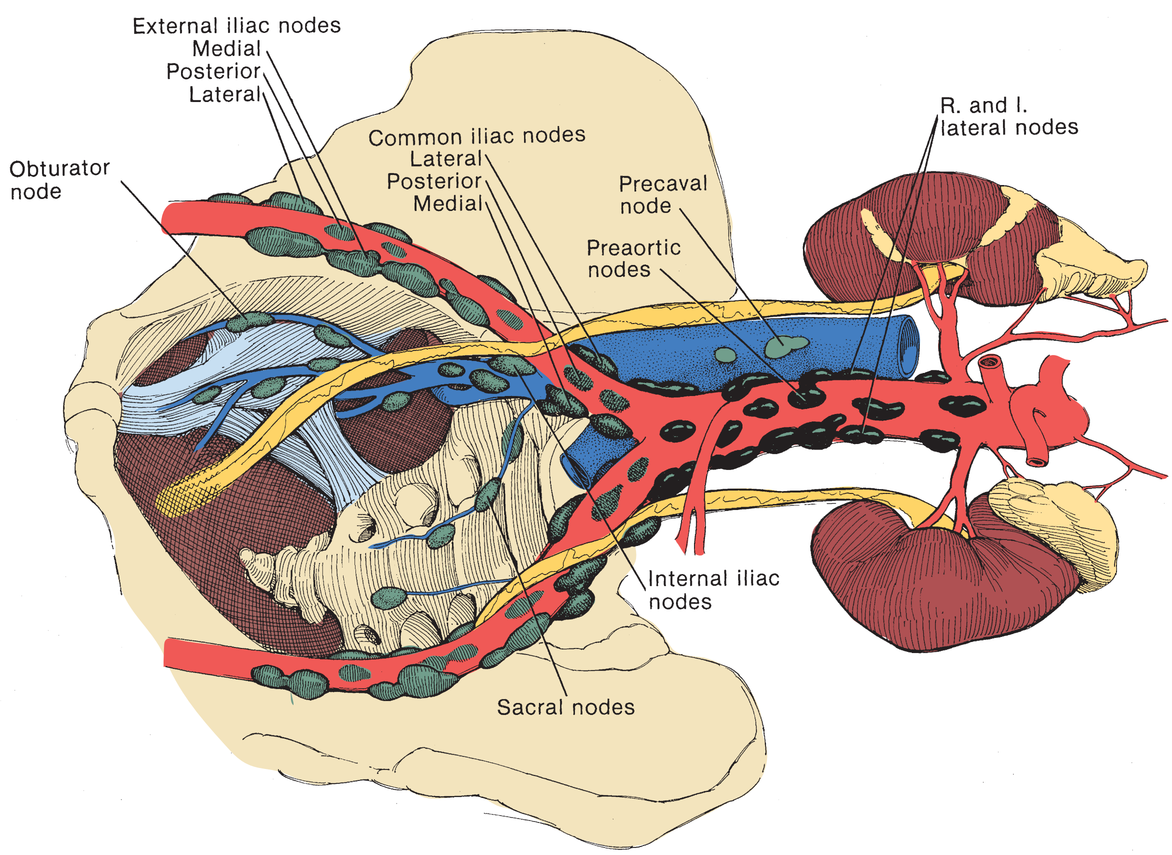


FIGURE 3-5.

Lumbar Trunks, Cisterna Chyli, and Thoracic Duct

The efferent lymphatic vessels from the lumbar nodes form the **lumbar trunks**, which, with the intestinal trunks, drain into an inconstant fusiform structure, the **cisterna chyli** (Fig. 3-6). The cisterna lies opposite the first two lumbar vertebrae, slightly below the level of the **left renal vein**, and is often hidden by the **median arcuate ligament** and the medial edge of the **right crus of the diaphragm.** It could be considered merely an expansion of the **thoracic duct** into which it drains. The thoracic duct drains most of the lymph of the body, returning it to circulation at the junction of the internal jugular and subclavian veins through the left brachiocephalic (innominate) vein. The exception is for a small portion (from the head and neck, right upper arm, right side of the thorax, and right side of the heart) that passes through the right lymphatic duct into the right brachiocephalic vein.

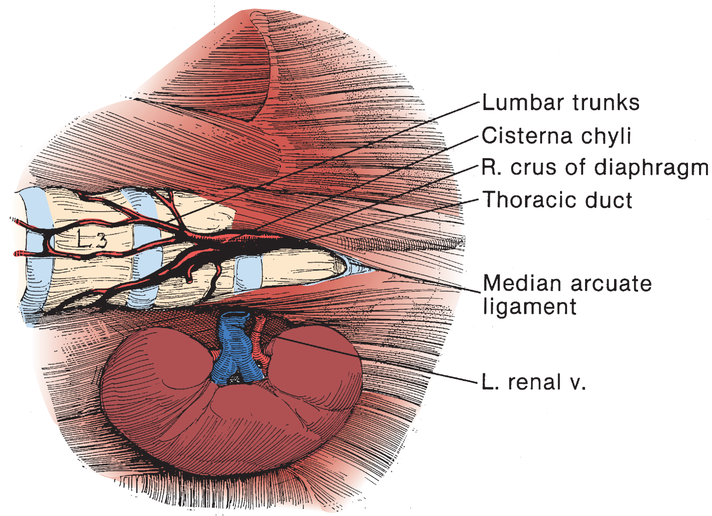


FIGURE 3-6.

Chapter 4

Peripheral Nervous System

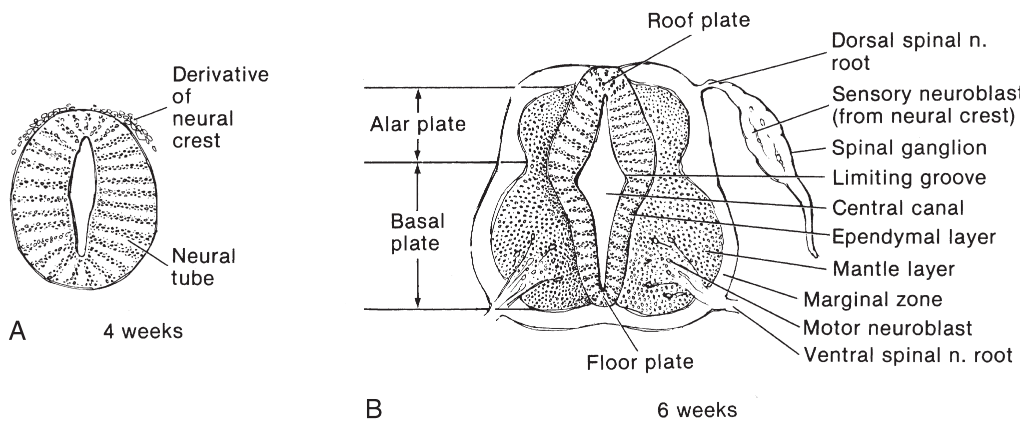


FIGURE 4-1.

Thys ordur, unyte, and concord, whereby the partys of thys body are, as hyt were, wyth senewys and neruys knyt togyddur.

STARKEY
England II. i.158, 1538

DEVELOPMENT OF THE PERIPHERAL NERVOUS SYSTEM

Formation of the Neural Tube: Neuroblast Formation

Neural Tube and Crest

The **neural tube** is formed by fusion of the edges of the neural plate. Cells from the edges of the plate that remain dorsal to the tube during fusion create the **neural crest** (Fig. 4-1A). The tube becomes the central nervous system of the brain and spinal cord, whereas the crest forms part of the peripheral nervous system of the cranial, spinal, and autonomic ganglia and nerves.

Neuroblasts and Nerve Roots

Neuroepithelial cells expand in the wall of the neural tube, forming the **ependymal layer** of gray matter from which all the neurons and microglial cells of the cord arise. Outside this layer, other neuroepithelial cells form a **marginal zone** that will become the white matter after invasion by the axons of nerve cell bodies lying in the cord or dorsal root ganglia.

Some cells in the ependymal layer develop into neuroblasts, which after developing axons become neurons. As the cord develops, a **limiting groove** forms on each side, indicating the division into alar dorsal and basal ventral plates (Fig. 4-1B). In the **alar plates**, the posterior gray columns (horns) develop, composed of cell bodies destined to form the afferent nuclei. From each alar plate, a **dorsal spinal nerve root** leads to the **spinal ganglion** containing **sensory neuroblasts** that were derived from the neural crest. In the **basal plates**, the lateral and anterior gray columns develop from cell bodies that send out bundles of axons from the **motor neuroblasts** to form the **ventral spinal nerve roots**.

Migration of Neural Crest Neuroblasts

Neural crest cells at first lie as a strip on either side of the neural plate. As the neural tube forms, they are carried to a dorsal position in the cord and then migrate extensively to the **primitive spinal ganglia**, the **lateral vertebral chain ganglia** (sympathetic), the **preaortic ganglia**, and the **visceral ganglia** (Fig. 4-2). They also travel to the adrenal cortical area, where they form the pheochromocytes of the **adrenal medulla** and to the primitive **gonad** to provide **paraganglion cells** (see Table 4-1).

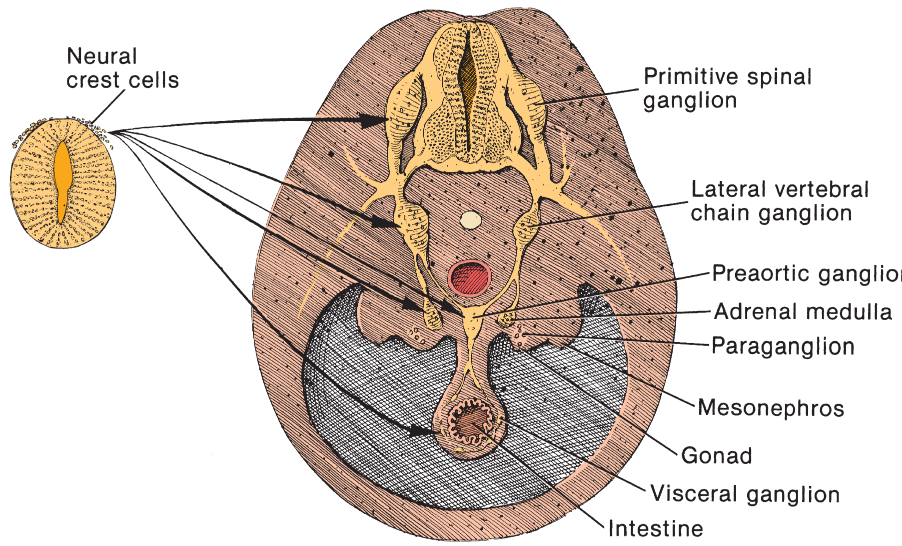
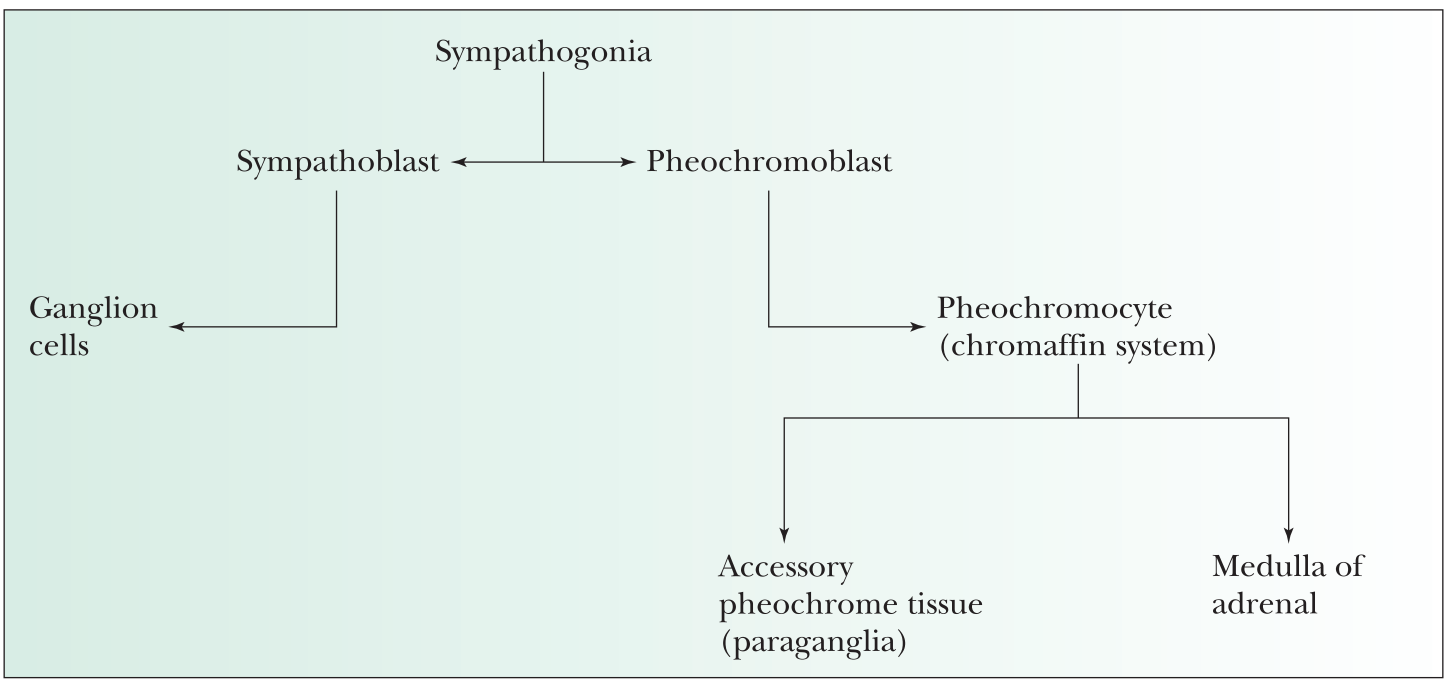


FIGURE 4-2.

TABLE 4-1



Neural crest cells develop into the sensory neurons of the dorsal root ganglia of the spinal nerves, both somatic and sympathetic, into the main sympathetic and parasympathetic postganglionic neurons in the sympathetic chains, and into the mesenteric, renal, and vesical plexuses. The neural crest cells also form part of the amine precursor uptake and decarboxylation system, the diffuse neuroendocrine system that includes the adrenal medulla, the paraganglia, the para-aortic bodies, and other aberrant chromaffin tissue (see Chapter 12; Fig 12-39).

Autonomic Nervous System

The neuroblasts from which the autonomic system are derived come from the neural crest. The central axons of these neurons enter the spinal cord from the **dorsal root ganglia** as the **dorsal roots of the spinal nerves** and either end locally in the gray matter or ascend centrally to the brain in the dorsal white columns. Their peripheral processes run in the spinal nerves and are distributed through the **sympathetic ganglia** and **sympathetic trunk** of the sympathetic chain to the viscera through ganglia such as the **preaortic ganglion**.

The cells from the *basal plate* of the neural tube have their cell bodies in the **lateral horn** of the spinal cord at the T1 to T12 and L1 to L2 levels and are distributed by way of white **rami communicantes** to the splanchnic nerves (see Fig. 4-5).

Divisions of the Spinal Nerves

The spinal nerves are attached to the spinal cord through dorsal and ventral roots (Fig. 4-3).

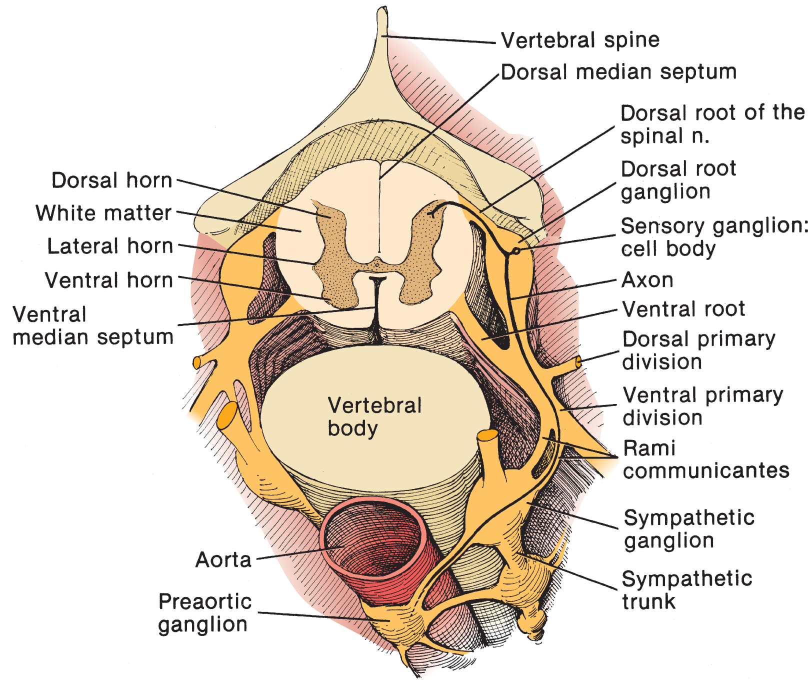


FIGURE 4-3.

Dorsal Roots

The neural crest neuroblasts, in migrating from their position beside the neural tube, form the spinal ganglia (dorsal root ganglia), which contain the cell bodies of the sensory neurons and form sympathochromaffin cells. The dorsal primary division of the spinal nerves supplies the dorsal part of the body; the larger ventral primary division supplies the ventral part, including the arms and legs. The third division is made up of the rami communicantes, which connect the spinal nerves to the sympathetic ganglia.

Ventral Roots

Neuroblasts in the intermediate zone of the cord pass through the ventral roots into the myotomes of the mesodermal somites.

NERVE SUPPLY OF THE GENITOURINARY SYSTEM

Spinal Cord

Structure of the Lower Spinal Cord, Arteries, Coverings, and Veins

Meninges and Venous Drainage

Meninges. The coverings of the spinal cord occur in three layers within the vertebral canal: (1) the dura mater, (2) arachnoid membrane, and (3) pia mater (Fig. 4-4A).

The **dura mater** is a layer of collagen mixed with elastic fibers. At the exit site of a nerve, the dura becomes continuous with the perineurium. The delicate **arachnoid** membrane lies beneath the dura and is partially adherent to it, leaving only a narrow space, the **subdural space**, which has little or no fluid within it. The arachnoid envelops the cord and the nerves up to their point of exit from the vertebral canal. It encloses the **subarachnoid space**, which contains the cerebrospinal fluid and the major blood vessels supplying the cord. A vascularized membrane, the **pia mater**, closely covers the cord in two layers—an outer epipia, carrying blood vessels, and an inner pia intima, lying over the glial capsule that actually covers the cord. The pia mater extends over the exiting nerves and joins their sheaths.

Venous Drainage. Two sets of veins drain the vertebral column—(1) the external and (2) the internal vertebral venous plexuses—each of which has a posterior and an anterior portion (for details see Figs. 2-18 and 2-20).

The **external vertebral vein** and plexus is divided into two parts: (1) an anterior external venous plexus situated about the vertebral body and (2) a posterior intervertebral plexus distributed about the laminae, spines, and transverse processes of the vertebra. The two portions of the external plexus come together at their junction with the **ascending lumbar vein**, which, in turn, is connected through the **lumbar veins** to the anterior external venous plexus that is associated with the **lumbar azygos vein**, to drain into the inferior vena cava.

The **internal vertebral plexus** is located outside the dura within the vertebral canal. The anterior internal venous plexus is adjacent to the vertebral body, and the **posterior internal venous plexus** lies next to the vertebral arches.

There is free communication between the internal and external plexuses throughout the length of the vertebral canal. The two plexuses connect with each other through the basivertebral veins in the vertebral body and through the **intervertebral veins** in the **intervertebral foramina**. Blood from the vertebral system is carried to the lumbar veins as well as to the posterior intercostal veins. The intervertebral veins lack valves, so reverse flow probably occurs

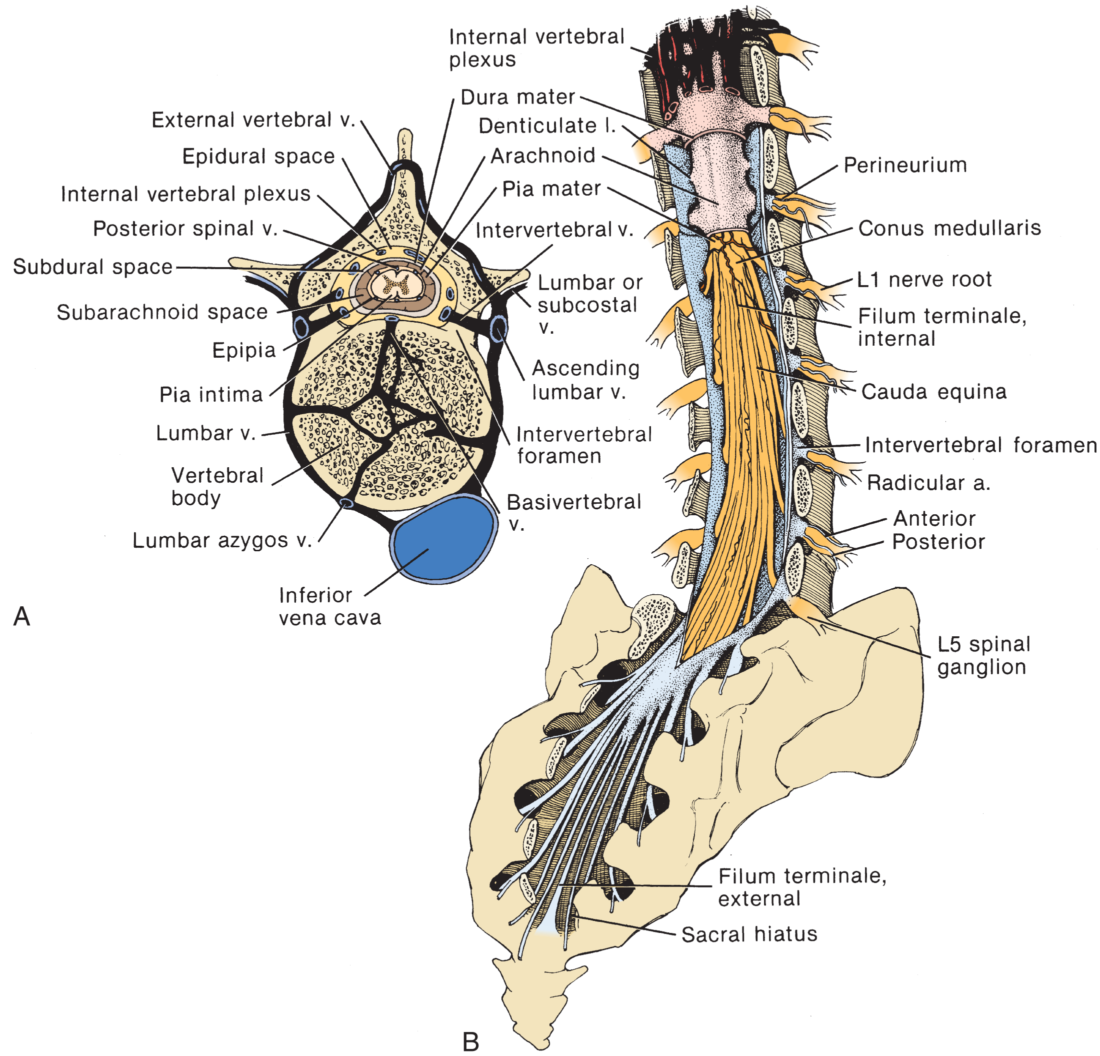


FIGURE 4-4.

during abdominal straining, thus allowing pelvic neoplasms to spread to the spine.

Spinal Cord. The cord extends from the atlas to the first lumbar intervertebral disk. It may only reach the 12th thoracic vertebra, or it may extend one vertebra lower. Enlargements occur in the cervical and lumbar regions where large nerves emerge (Fig. 4-4B). The ventral surface of the cord has an anterior medial fissure, and the dorsal surface has a posterior median sulcus that is connected to a posterior median septum that extends well into the cord. A posterolateral sulcus indicates the site of entry of the dorsal roots.

The **conus medullaris** of the cord ends in the **filum terminale**, which is covered by the dura around a large subarachnoid space (suitable for spinal puncture) except for a part covered only by adherent dura. Dorsal and ventral roots of spinal nerves emerging along the cord pass through the dura individually to unite as paired roots.

At the midlevel of the sacrum, which contains the **cauda equina** and **filum terminale**, the subarachnoid and subdural spaces become obliterated. Here the lower spinal nerve roots and the filum terminale pass through the arachnoid and the dura. Both the filum terminale and the 5th sacral spinal nerve emerge from the **sacral hiatus**.

Arterial Supply. The intercostal and lumbar arteries give off spinal branches to the cord in the trunk as anterior and posterior radicular arteries that enter along the ventral and dorsal nerve roots. The supply is supplemented by contributions from the anterior and the paired posterior spinal arteries. Longitudinal branches ascend and descend within the cord.

SOMATIC NERVOUS SYSTEM

Organization of the Somatic Nervous System

Somatic Motor Nerves

Somatic motor functions are performed by a single neuron, the **somatic motor neuron** (white line, Fig. 4-5). The neuron is composed of a **central cell body** in the **anterior gray column** (anterior horn) and an **axon** extending to a muscle. The axon exits through the **ventral root** and passes along the **spinal nerve** to a **motor end plate** on **muscle fibers**. Somatic motor neurons can stimulate but not inhibit contraction of striated muscle, in contrast to autonomic motor neurons, which can both stimulate and inhibit smooth muscle contraction.

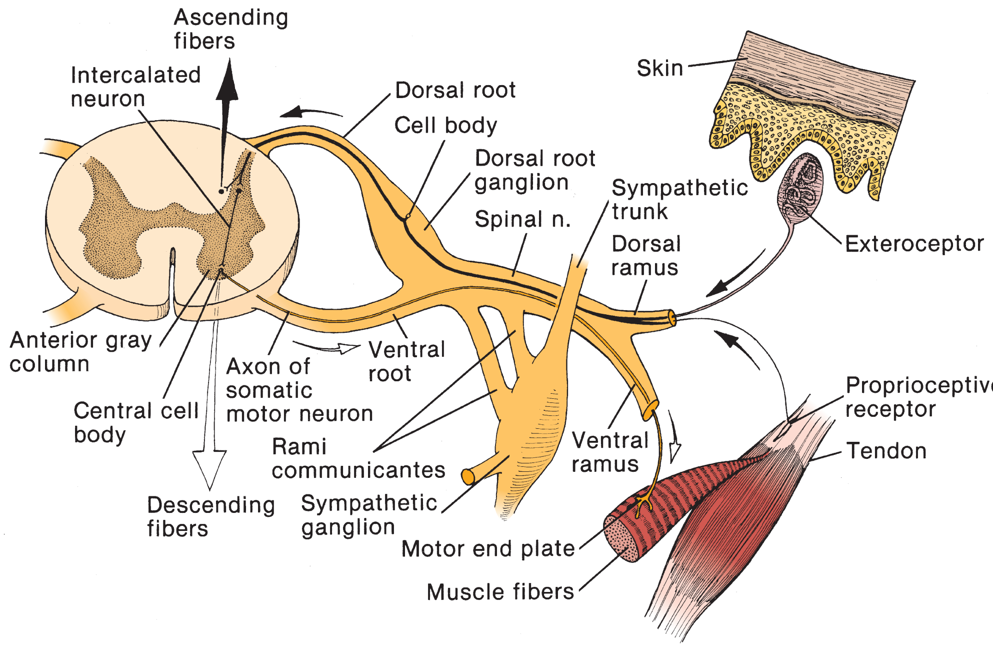


FIGURE 4-5.

Somatic Sensory Nerves

The somatic sensory neuron (black line) has its **cell body** in the **dorsal root ganglion**. It carries positional sensation from **proprioceptive receptors** on skeletal muscle and tendons and transmits the sensations of touch, pressure, heat, cold, and pain via **exteroceptors**, principally in the skin. These neurons pass along the **spinal nerves** to the medial and lateral ganglia of the dorsal root ganglia.

Reflex Arc

A connection between the motor and sensory neurons is created by **intercalated neurons** in the gray matter. **Ascending** and **descending fibers** connect each level with the others.

Somatic Nerve Supply to Abdomen and Pelvis

The junction of the **dorsal** and **ventral roots** forms a **spinal nerve**, which divides into dorsal or posterior and ventral or anterior rami (Fig. 4-6).

The **posterior rami** run dorsally, then separate into medial and lateral branches supplying the muscles and skin of the posterior part of the trunk.

The **anterior rami** in the thoracic region are larger than the posterior rami. The anterior rami of the lower six thoracic and the first lumbar nerves innervate the skin, muscles, and peritoneum over the anterior abdomen. The anterior rami of the first three and part of the fourth nerves of the lumbar cord form the lumbar plexus. The branches of the ventral division of the plexus are the iliohypogastric, ilioinguinal, genitofemoral, and obturator nerves. Those of the dorsal divisions are the lateral cutaneous nerves of the thigh, the femoral nerve, and the nerves to the psoas and iliacus. The 4th lumbar nerve contributes to the lumbosacral trunk.

AUTONOMIC NERVOUS SYSTEM

In contrast to the somatic system, each unit of the autonomic nervous system involves two neurons and two cell bodies. The axon of a *preganglionic neuron*, whose cell body is in the central nervous system, extends to a second cell body in a ganglion near the organ. A *postganglionic neuron* arises from this cell body, and its axon enters the wall of the organ to innervate it.

Both a *sympathetic division* and a *parasympathetic division* are found in the autonomic nervous system. Most organs are dually innervated, with the sympathetic system acting to increase activity and the parasympathetic system acting to modulate it. The sympathetic system is the more primitive of the two and acts through the neurotransmitters epinephrine and norepinephrine (supplemented by discharges from the adrenal medulla). It may prepare the animal for fighting or for escaping by constricting the blood vessels in the skin and gut, increasing the heart rate, decreasing intestinal motility, and tightening the outlet of the urinary bladder. The functions of the parasympathetic system are more focused. For example, parasympathetic stimuli increase intestinal motility and secretion and activate the urinary bladder.

Confusion may arise because the name *splanchnic* (from the Greek for viscus) is given to three distinct parts of the autonomic system, two sympathetic and one parasympathetic. The greater, lesser, and least splanchnic nerves are the most cranial and arise from thoracic sympathetic ganglia. The lumbar splanchnic nerves come from the lumbar sympathetic ganglia. The pelvic splanchnic nerve carries parasympathetic fibers from the sacral outflow.

Organization of the Sympathetic Nervous System

The *afferent system* is shown in the upper spinal segment (Fig. 4-7).

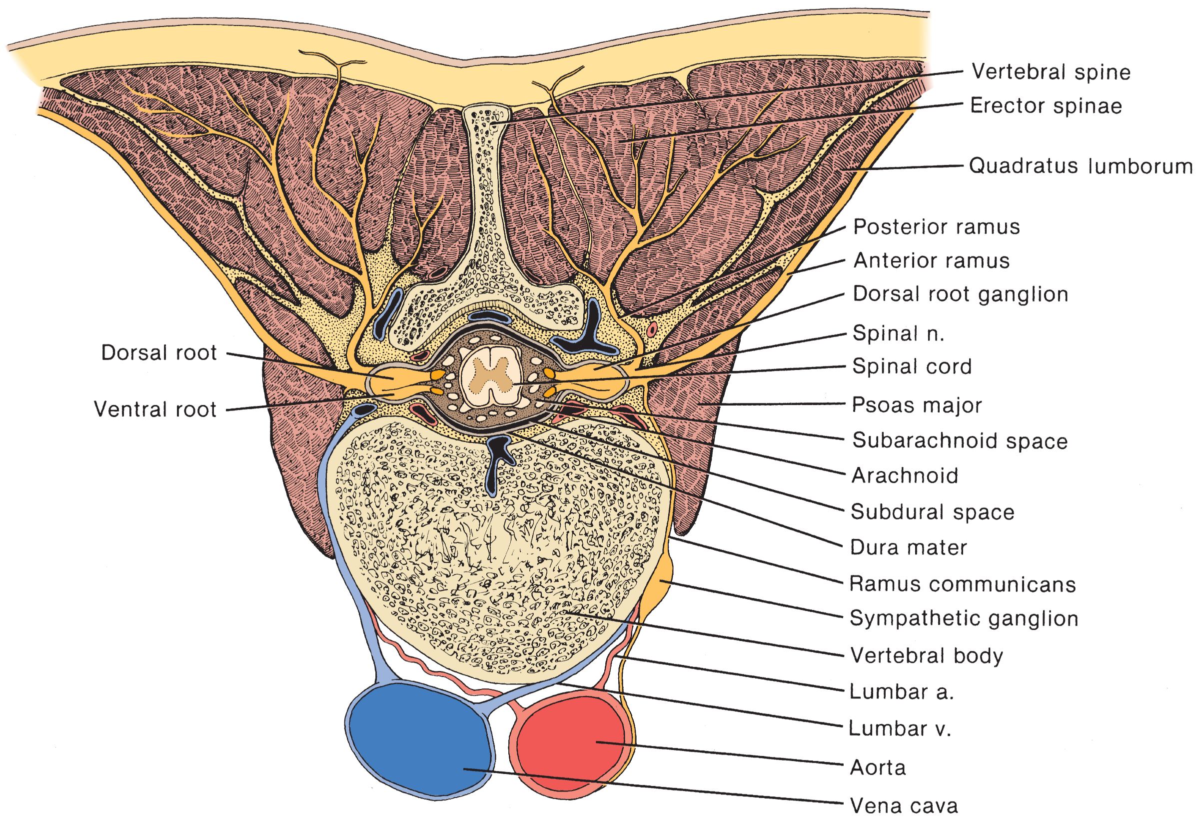


FIGURE 4-6.

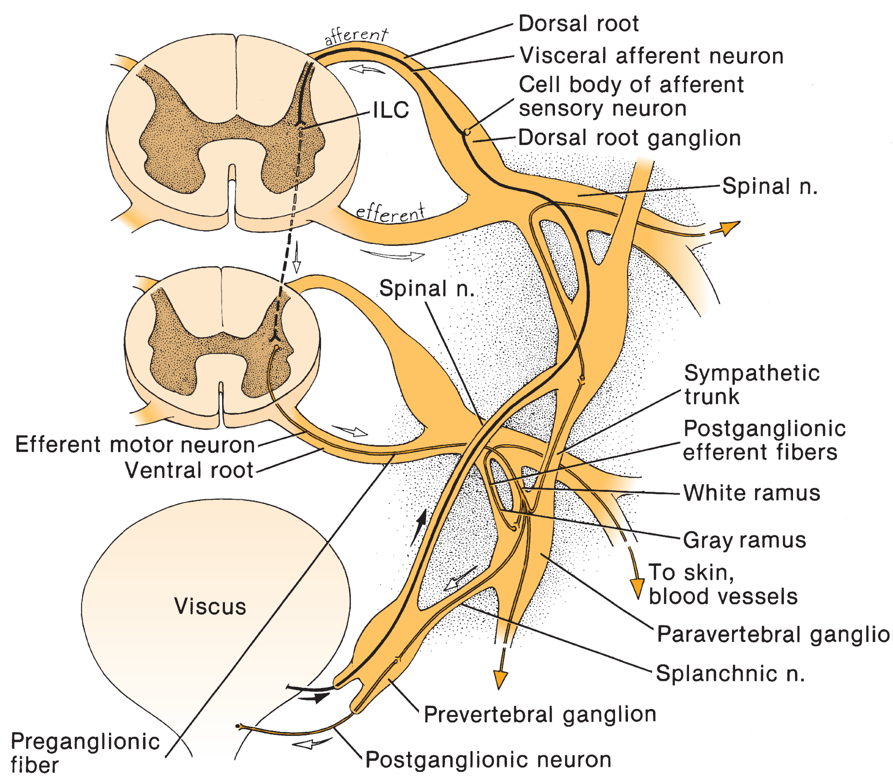


FIGURE 4-7.

The **cell bodies** of **afferent sensory neurons** lie in a **dorsal root ganglion**, so the neuron (black line) passes without synapse from the **viscus** to the spinal cord. Within the cord in the intermediolateral gray column (labeled **ILC**), it synapses with other afferent neurons or with motor neurons at various levels and in several nuclei.

The *efferent system* is shown in the lower segment.

An **efferent motor neuron** (white line) starts in a cell body in the **ILC** of the spinal cord. It passes as a **preganglionic fiber** through the **ventral root** of the **spinal nerve** and then through the **white ramus** (as myelinated fibers) to reach the corresponding **paravertebral ganglion** along the

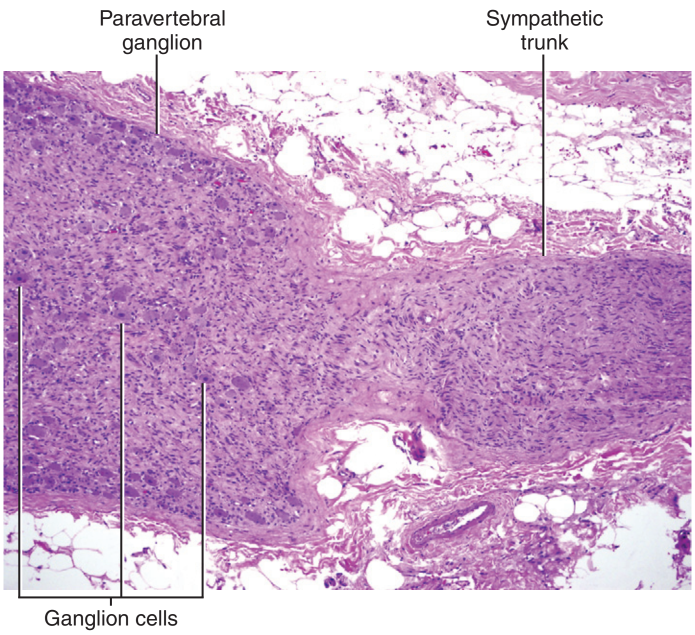


FIGURE 4-8. This image illustrates the junction between a sympathetic nerve trunk, at right, and a paravertebral ganglion, at left, which is an aggregation of neurons (ganglion cells) outside the central nervous system.

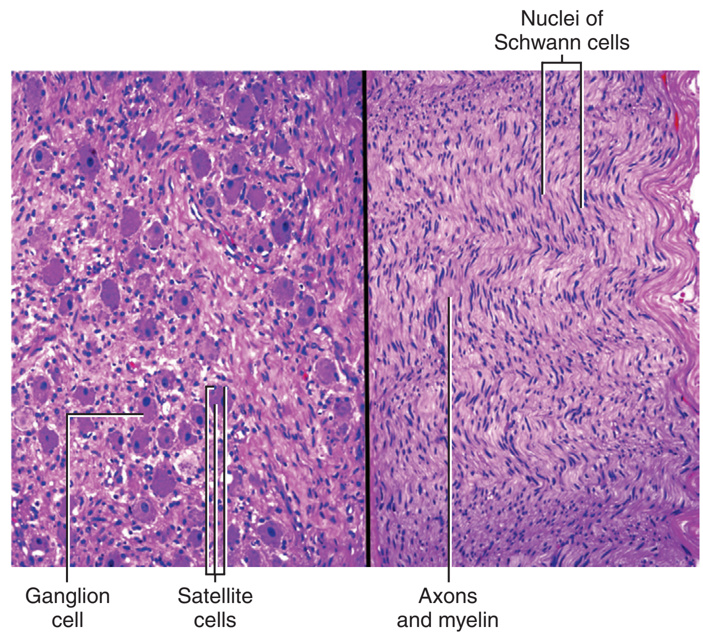


FIGURE 4-9. The left half of the image is a higher-power view of a ganglion. The large individual ganglion cells are encircled by flattened rather inconspicuous satellite cells; both ganglion cells and satellite cells are derived from the neural crest. The right half of the image is a higher-power view of the sympathetic trunk. The cellular component consists of the nuclei of Schwann cells, which are also derived from the neural crest. The lightly eosinophilic material consists of nerve fibers (axons and myelin sheaths); the individual nerve fibers cannot be distinguished at this power. Schwann cells surround one or more axons, which are housed within cytoplasmic infoldings of the Schwann cell cytoplasm and cell membrane. Myelinated nerve fibers are invested with variable numbers of double layers of cell membrane—the myelin sheath—which improves the conductive ability of the axon.

sympathetic trunk (Figs. 4-8 and 4-9). There it may take one of three courses. It may arborize and synapse with **postganglionic neurons** at the same level, it may pass through the ganglion intact to leave the trunk and synapse at another cell station in a **prevertebral** or terminal **ganglion**, or it may run up or down within the trunk to synapse at another level. The number of connections is large, because a preganglionic neuron connects with several ganglia and synapses many times within them.

Some of the **postganglionic efferent fibers** originate in synapsing cell bodies in the paravertebral ganglion and pass through the **gray ramus** (nonmyelinated fibers) to the **skin** and **blood vessels** by way of a **spinal nerve**. Other **postganglionic fibers** originate in prevertebral ganglia at the termination of preganglionic fibers and continue on to innervate a viscus.

Organization of the Parasympathetic Nervous System

The *parasympathetic division* of the autonomic nervous system originates as preganglionic neurons from the 3rd, 7th, 9th, and 10th cranial nerves and from the anterior rami of the 2nd, 3rd, and 4th sacral spinal nerves. For this reason, it is known anatomically as the craniosacral division. Its pharmacologic effectors are cholinergic.

Only **efferent motor neurons** are found in the parasympathetic system (Fig. 4-10). They are distributed to the pelvic viscera through the **pelvic splanchnic nerves**. As **preganglionic neurons**, they pass to the **viscus**, where they enter small pelvic ganglia or ganglia in the viscus itself, join branches from the sympathetic pelvic plexuses, and synapse with **postganglionic neurons** that terminate in the smooth muscle of the viscus.

Efferent Autonomic Paths

Sympathetic Division

This division arises from the thoracic and lumbar spinal segments (solid and dashed lines in Fig. 4-11). Anatomically, it is called the thoracolumbar division, but pharmacologically, it is called either adrenergic if its effectors are mediated by epinephrine (or norepinephrine) or cholinergic if its effectors are mediated by acetylcholine. Urogenital organs receive sympathetic innervation from the lower seven thoracic and upper three lumbar paravertebral **sympathetic ganglia** of the **sympathetic trunk**.

Part of the **greater splanchnic nerve**, from T10 and T11 ganglia, supplies the testis through the celiac renal and aortic plexuses. The **least splanchnic nerve** (or renal nerve), arising from T12, innervates the kidney through the same plexus.

The sympathetic supply to the kidney is preganglionic through the **lesser splanchnic nerve** to the renal plexus, where the neurons synapse with postganglionic neurons to innervate the kidney. The testis is innervated similarly

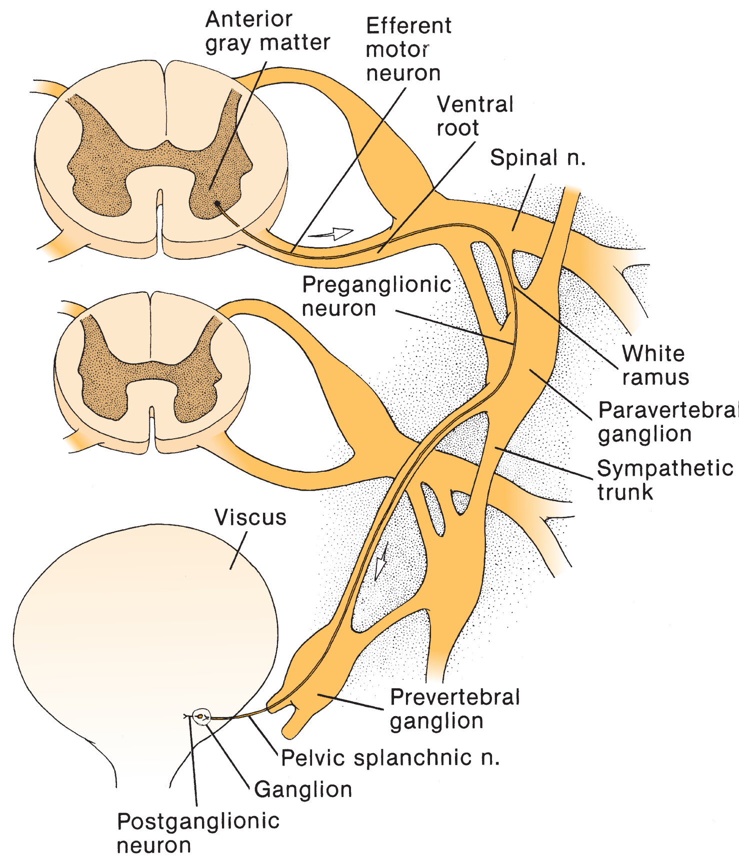


FIGURE 4-10.

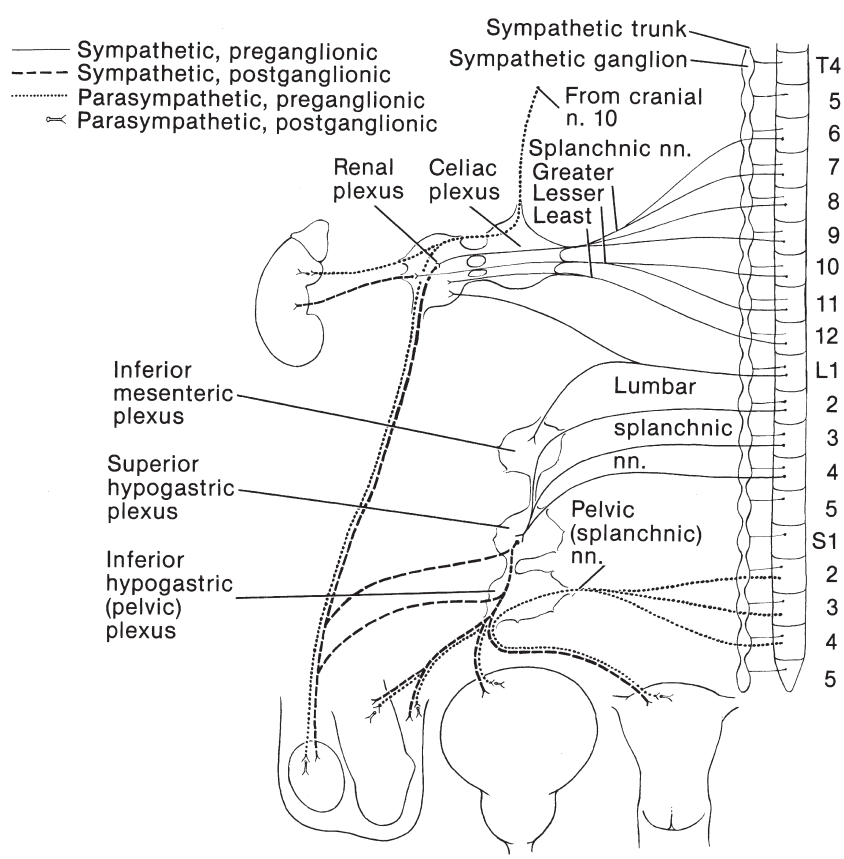


FIGURE 4-11.

through the **renal plexus** as well as through the superior hypogastric and inferior hypogastric (pelvic) plexuses. The preganglionic neurons for the bladder, prostate, uterus, penis, and scrotum end in the inferior hypogastric (pelvic) plexus, synapsing there with postganglionic neurons that innervate these organs.

Three or four **lumbar splanchnic nerves** come from the ganglia at L1, L2, L3, and L4 that lie in the extraperitoneal connective tissue over the vertebral bodies in the groove formed by the psoas major. The 1st lumbar splanchnic nerve arises from the first lumbar paravertebral ganglion and runs to the **renal** and **celiac plexuses**. The 2nd lumbar splanchnic nerve originates in the 2nd ganglion and goes to the **inferior mesenteric plexus**. The 3rd lumbar splanchnic nerve, arising from the 3rd or 4th ganglion, joins the **superior hypogastric plexus**; the 4th, from the lowest ganglion, runs to the lower part of the superior hypogastric plexus.

The four or five ganglia of the pelvic portion of the sympathetic trunk lie in front of the sacrum. Fibers from the two cephalad ganglia join the **inferior hypogastric (pelvic) plexus**. The two trunks terminate at the coccyx by fusing to form the ganglion impar.

Sympathetic ganglia are present not only in the sympathetic trunk but in the autonomic plexuses and in subsidiary ganglia that lie in large plexuses such as the celiac and superior and inferior mesenteric.

Parasympathetic Division

Cranial nerve 10 provides some innervation to the kidney through the **renal plexus** (dotted and double lines in Fig. 4-11). Those preganglionic neurons from the sacral portion of the cord (**S2, 3,** and **4**) are concerned with the pelvic organs and form the **pelvic (splanchnic) nerves** that join the **inferior hypogastric (pelvic) plexus**. Through the plexus, preganglionic fibers continue to ganglia adjacent to or within the walls of the organs. The bladder is provided with motor fibers and the urethral sphincter with inhibitory fibers. The penis and clitoris are supplied with vasodilatory fibers, as are the testes, ovaries, and uterus. The prostate, lower colon, rectum, and reproductive organs are also supplied with parasympathetic fibers.

Anatomic Distribution of Autonomic Nerves

Interconnections among the sympathetic and parasympathetic preganglionic and postganglionic neurons occur in plexuses connected with the ganglia distributed along the preaortic and presacral areas (see Table 4-2). Although at dissection the autonomic nerves and their plexuses are not as discrete as anatomic descriptions would lead one to believe, the aortic, inferior mesenteric, superior hypogastric, and inferior hypogastric (pelvic) plexuses can be identified. Otherwise, only general representation is possible.

The **celiac plexus**, the largest of the abdominal plexuses, lies at the level of the lower margin of the 12th thoracic vertebra (Fig. 4-12). The plexus joins the two **celiac ganglia** that are found between the adrenal gland and the take-off of the celiac artery. Each of these ganglia is connected

TABLE 4-2

CONTRIBUTIONS TO AUTONOMIC PLEXUSES

Anatomic Feature	Plexus
Celiac ganglion	Adrenal plexus
Celiac plexus	
Greater splanchnic nerve	
Celiac ganglion	Renal plexus
Celiac plexus	
Aortorenal ganglion	
Lowest thoracic splanchnic nerve	
First lumbar splanchnic nerve	
Aortic plexus	
Renal plexus	Testicular plexus
Aortic plexus	
Superior hypogastric plexus	
Hypogastric nerve	
Hypogastric plexus	
Hypogastric nerve	Pelvic (inferior hypogastric) plexus
Hypogastric ganglia	
Pelvic plexus	Vesical plexus
Pelvic plexus	Prostatic plexus
Pelvic plexus	Uterovaginal plexus

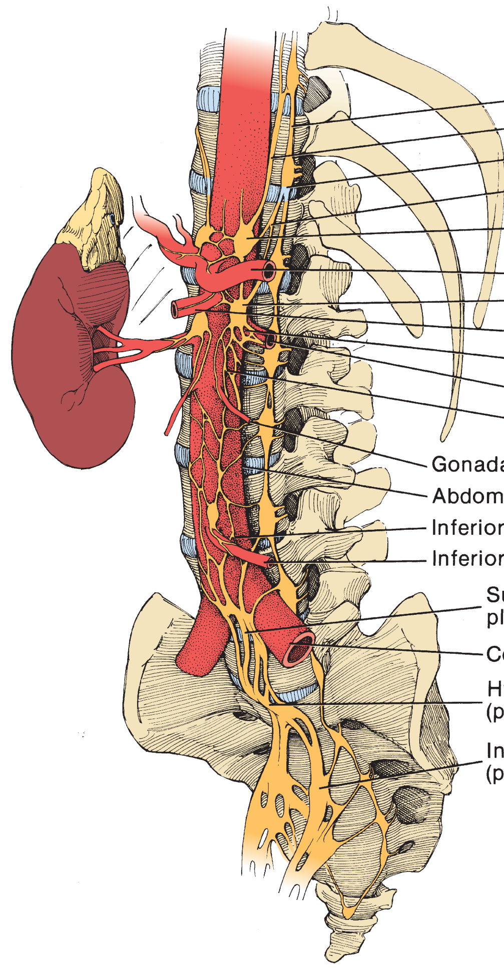


FIGURE 4-12.

above to the **greater splanchnic nerve** and is attached below, as the **aortorenal ganglion**, to the **lesser splanchnic nerve** originating from T12. This ganglion, in turn, supplies the **renal plexus** that lies at the base of the renal arteries.

Situated below the aortic bifurcation is the **superior hypogastric plexus**. It is connected above with the **inferior mesenteric plexus** and below with the bipartite **inferior hypogastric (pelvic) plexus**, which contain the hypogastric ganglia. The plexiform connection between the superior hypogastric plexus and the inferior hypogastric (pelvic) plexuses is known as the **hypogastric** or **presacral nerve**. The inferior hypogastric plexus connects with the vesical plexus, the prostatic plexus, and in the female, the uterovaginal plexus. Details of the terminal innervation are found in the relevant organ chapters.

Sensory Innervation of the Ventral Body Surface

Cutaneous Nerves

The pattern of innervation of the body wall is described in Chapter 8; Fig 8-20.

Peripheral nerves may be injured during a surgical procedure. Projections on the skin of the several spinal levels are useful not only to predict the effects of injury to or sectioning of a peripheral nerve but also for harvesting pedicle flaps. Deficits may be represented by peripheral nerve of origin and by spinal segment.

The *cutaneous innervation* by the ventral rami of the spinal nerves is outlined in Fig. 4-13A. They include the **lateral cutaneous rami** of the 7th to 12th **intercostal nerves**, which supply the lateral side of the thorax to a level below the 12th rib, and the **anterior rami**, which supply a smaller strip over the rectus. The **iliohypogastric nerve** divides as it passes between the transversus abdominis and the internal oblique into a lateral cutaneous ramus that supplies the gluteal region and an anterior cutaneous ramus going to the abdominal surface above the pubis. The **ilioinguinal nerve** supplies the skin of the upper thigh, the skin about the base of the penis, and the upper part of the scrotum. The genital ramus of the genitofemoral nerve supplies the cremaster and the lower part of the scrotum. The **femoral ramus** of the **genitofemoral nerve** supplies the skin over the upper part of the femoral triangle. The **lateral femoral cutaneous nerve** supplies the anterior and lateral surfaces of the upper leg. The intermediate and medial femoral cutaneous nerves supply the front of the thigh to the knee.

Spinal segmental distribution to the skin is directly related to innervation of the internal organs (Fig. 4-13B). This is important for evaluating bladder innervation and for treating losses with electronic pacemakers. Effects on bladder innervation from stimulation, excision, or injury of sacral spinal nerves 2, 3, and 4 can be determined from changes in the cutaneous innervation of the posterior thigh and perianal regions.

The segments curve around the body obliquely, starting with the 10th thoracic nerve that supplies the umbilical segment.

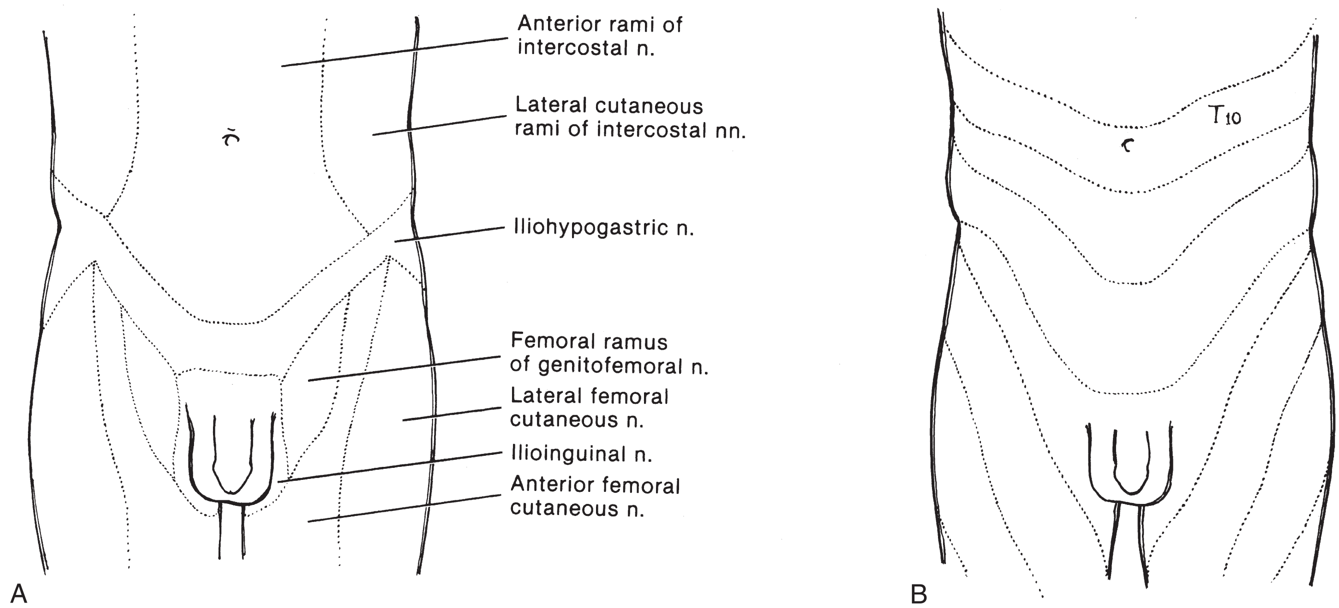


FIGURE 4-13. *(Adapted from Hansen K, Schliack H: Segmentale Innervation. Stuttgart, Thieme, 1962.)*

Distribution to the Dorsal Body Surface

Cutaneous innervation of the posterior surface of the trunk is supplied by the **lateral cutaneous branch** of the **intercostal nerves** and the **dorsal rami** of the thoracic **spinal nerves** (Fig. 4-14A). The **iliohypogastric nerve** innervates the hip area. The **posterior rami** of the **lumbar** and **sacral nerves** supply the buttocks. The distribution of the lateral femoral cutaneous nerve extends posteriorly on the thigh.

The segmental innervation is illustrated, showing the sacral elements innervating the perineum (Fig. 4-14B).

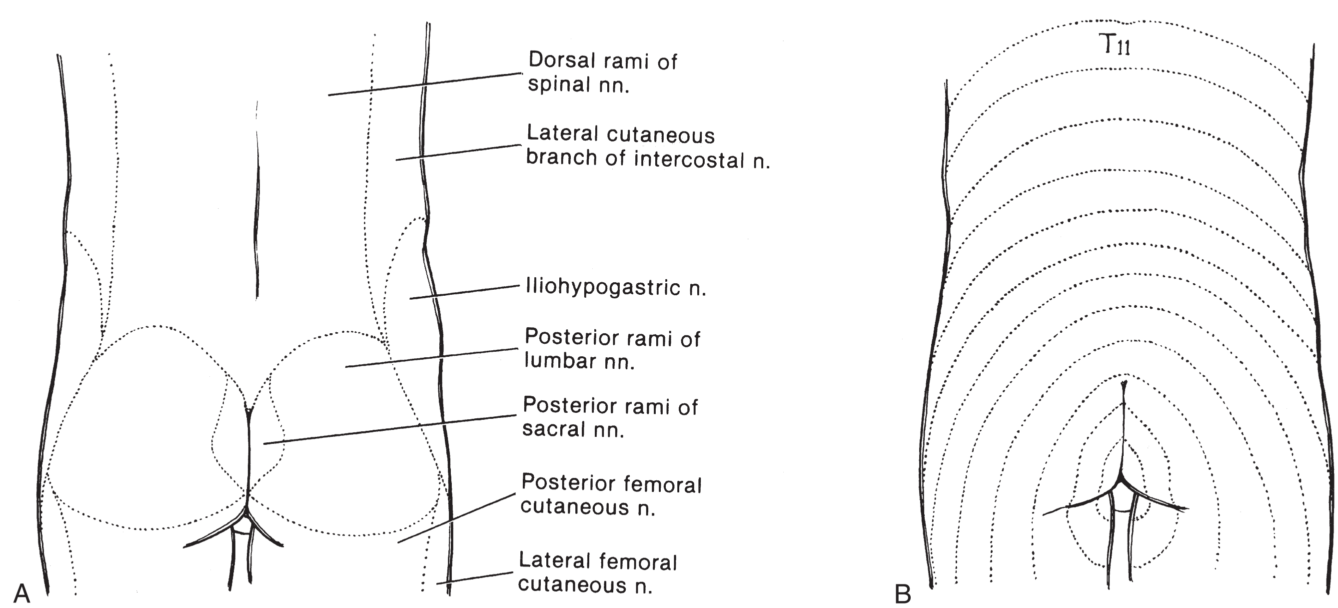


FIGURE 4-14.

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Chapter 5

Skin

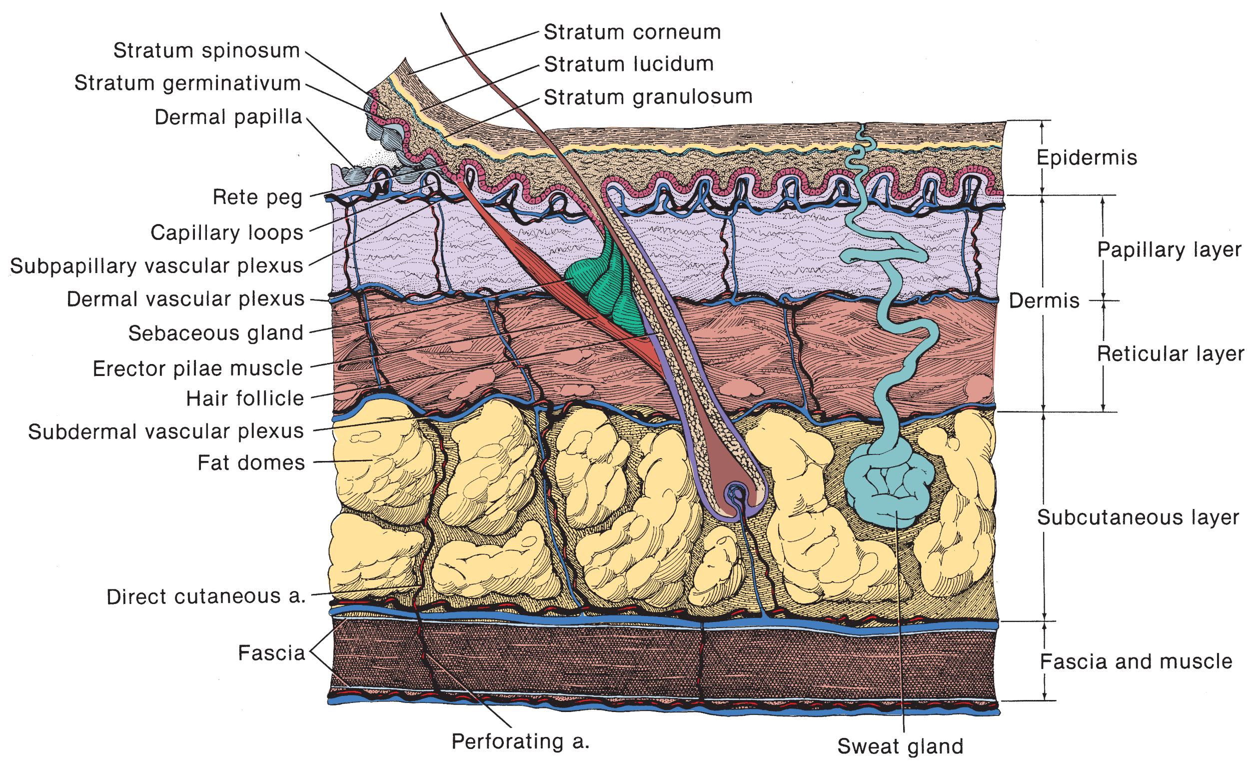

FIGURE 5-1.

Betwixt the fleshy membrane and the skinne runne certaine vessels called ***skin-veines****.*

CROOKE
Body of Man, 118, 1615.

DEVELOPMENT OF THE SKIN

The epidermis originates from the embryonic ectoderm and forms the skin and its appendages, the hair, nails, and glands. The dermis has a separate origin, developing from the mesoderm of the somatic layer of the dermatomes of the lateral walls of the somites.

After 3 months of fetal life, the dermis can be identified as a mesodermal condensation under the epidermis. Hair bulbs and papillae appear as ingrowths of the epidermis into the dermis, and later, the sudoriferous and sebaceous glands are similarly formed by ingrowth.

STRUCTURE AND FUNCTION OF THE SKIN

Epithelial tissue covers the internal and external surfaces of the body. Its usually specialized surface is exposed. The unexposed surface adheres by a basement membrane to the underlying connective tissue that supplies blood to the surface cells. The cells are held in apposition by intercellular substance and, if damaged, are readily replaced by new ones. Epithelia may be one cell thick (simple) or appear as more than one cell thick but with all cells adherent to the basement membrane (pseudostratified), or they may be made up of many cells (stratified). The cells may be flattened (squamous), of the same height and width (cuboidal), higher than wide (columnar), or able to change shape with stretching (transitional).

The *skin*, as the surface in contact with the environment, facilitates body movement and furnishes contacts for sensory and emotional responses. It limits the effects of heat and cold, injury, chemicals, and ultraviolet light, as well as that of hypotonic and hypertonic substances, but it can absorb and excrete and has strong antibacterial properties. Finally, it acts as a heat exchange regulator (Table 5-1).

Composition of the Skin

The skin has two layers—(1) the **epidermis**, arising from the ectoderm, and (2) the **dermis**, or corium, from the mesoderm. The dermis overlies areolar and fatty connective tissue, the **subcutaneous layer** (Figs. 5-1 and 5-2).

Epidermis

The **epidermis** covers the entire body with a layer of stratified squamous epithelium. Its principal component is the malpighian stratum, arranged in three poorly defined layers: (1) a basal layer called the **stratum germinativum** lying on the dermis, from which the epidermis gets its support and blood supply; (2) the **stratum spinosum**; and (3) the **stratum granulosum.** Overlying the malpighian stratum is the **stratum corneum**, a relatively impermeable layer of desquamating, nonnucleated cells. It provides the surface covering for the skin. Beneath the malpighian layer and against the dermis is the **stratum lucidum**. The epidermis contains no blood vessels and depends on the dermis for nutrition.

It has been estimated that each cell in the stratum germinativum of the malpighian layer takes 19 days to reach the surface. As the cells are displaced outward, they become increasingly keratinized, the keratin either remaining soft, as in the skin, or becoming hard, as in the nails and hair. In either case, the stratum corneum forms a tough layer that serves as a barrier to the environment.

TABLE 5-1

FUNCTIONS OF THE SKIN

Facilitates:
- Body kinetics

Provides:
- Sensory contact
- Emotional response (vascular, muscular)

Limits effects of:
- Heat and cold
- Trauma
- Chemicals
- Ultraviolet light (pigmentation, vitamin D metabolism)
- Hypotonic and hypertonic substances
- Microorganisms

Regulates:
- Heat exchange

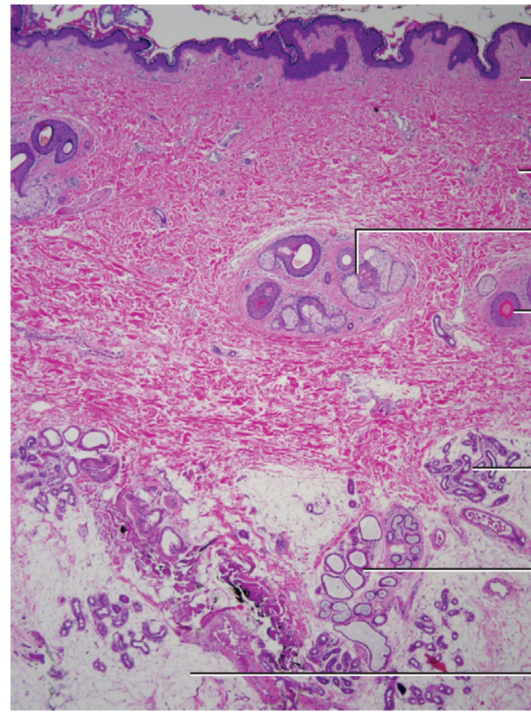

FIGURE 5-2.

At the junction between the epidermis and the dermis, **rete pegs** project into the dermis among **dermal papillae** vascularized by **capillary loops.**

Dermis

The **dermis**, made up of collagen and elastic fibers in a diffuse ground substance, is the matrix for nerves, vessels, and glands. It is composed of two layers—(1) a superficial **papillary layer** of delicate fibers and (2) a deep **reticular layer** of much coarser branching fibers of collagen lying more or less parallel to the surface amid elastic tissue.

Near the epidermis, the collagen fibers in the papillary layer become finer to act as a protecting buffer between the coarse collagen fibers below and the epithelial cells above. The interspersed elastic fibers are interconnected and serve to return stretched collagen fibers to their resting position. The ground substance and accompanying fluid acts as a lubricant between the fibers, each fiber lying within its mucopolysaccharide sheath.

In the relaxed skin, the collagen fibers of the reticular layer are markedly coiled, especially in young individuals; in the stretched skin, they become parallel and resist further stretching. With age, they are straighter at rest, and the ground substance, previously gel-like, gradually becomes replaced by fibrous intercellular tissue, accounting for wrinkling of the skin. In any given area, the collagen bands of the reticular layer lie in parallel bundles that follow Langer lines (see Figure 5-3). Incisions that split the bundles longitudinally result in less scar formation than those that cut across them.

Three systems of vessels in succession distribute the blood to the skin after delivery by **perforating arteries**.

These are (1) the **subdermal vascular plexus** (cutaneous rete) between the subcutaneous layer and the reticular layer, (2) the **dermal vascular plexus** between the dermal vascular layer and the papillary layer, and (3) the **subpapillary vascular plexus** at the junction of the papillary layer with the epidermis, from which the **capillary loops** emerge. These systems are interconnected by a complex network of vessels of varying sizes. If the dermis becomes excessively deformed, the rigidity of the surrounding collagen may compromise the lumens of these vessels with resulting ischemia. It must be appreciated that the principal function of the cutaneous vasculature is not for skin nutrition but for thermoregulation and is under neural control.

Hair follicles, present in most parts of the body, transfix the dermis and probably restrict its mobility. **Sebaceous glands** are part of the hair follicle structure. **Sweat glands** lie in the base of the dermis. They are both eccrine (secretory) glands, some of which respond to stress and some regulate temperature, and apocrine (shedding) glands that release the apical portion of the gland, producing a secretion with a characteristic odor.

After placement as a graft, the skin temporarily loses the normal lubrication from these glands and, unless protected with bland creams until glandular function returns, it becomes dry and susceptible to injury.

Subcutaneous Layer

The **subcutaneous layer** is fatty and serves principally as insulation. It contains free and encapsulated nerve endings for several types of sensory input and for control of the vascular supply. The subcutaneous tissue sends protrusions of fat, the **fat domes** or adipose columns, into the dermis. When the skin is cut at this level, a collagen network, which has interstices into which fat protrudes, is exposed. Hair follicles descend into the fat domes, and sweat glands lie among them. These extensions of elements of the skin into the subcutaneous tissue account for the reepithelialization that occurs in the donor site after split-thickness grafts are harvested or after deep burns. Strands of collagen run through the subcutaneous layer to attach the dermis to the underlying muscle. These strands vary in size and length, and determine the mobility of the skin. For example, over the penis, they are small and flexible; over the ilium, they are dense and firm.

The skin maintains its physical characteristics on transplantation, making cosmetic matching difficult.

PHYSICAL PROPERTIES OF SKIN

The three qualities that are important for the surgeon working with the skin are the viscoelastic, tensile, and extensile properties.

Viscoelasticity derives from two responses of the collagen and elastic fibers: one is creep, the continued elongation response of skin to stretch, and the other is stress relaxation, the reduced force necessary to keep it stretched. Both are dependent on the time that the force is applied so that repeated stretching may be needed for maximal lengthening. Stress relaxation may become apparent some time after the skin has been held stretched to the limit.

Skin tension, the second property, plays an important role in wound healing. Tension is the result of stretch of the elastic fibers and varies from point to point about the body. The crease lines are the lines of zero tension applied perpendicular to the crease. Scars form when tension across the suture line rises above a critical level, a level that varies by site (low tension on the skin of the penis and scrotum) and with age (low tension in the skin of the elderly). Continuous elevated tension from tissue expanders may cause the skin to expand over time. High tension may also rupture the dermis, producing striae in the tears.

When tension deforms the collagen network sufficiently, the dermal vessels become obstructed. The result is blanching, which may sometimes be relieved by preliminary physical stretching of the skin to produce creep.

Skin extensibility is the third property. When skin is extended, it contracts to a similar degree at right angles to the force. The potential for extensibility can be estimated by pinching a fold of skin between thumb and forefinger. Langer lines represent the lines of minimal extensibility. Expressed as tension, these lines indicate maximal tension along the line and hence minimal tension on the edges of a skin defect that runs parallel to them.

Skin Lines

The response of the skin to physical force varies with its site and depends on the weave of the collagen fibers in the dermis. *Skin lines* indicate the lines of greatest tension; the direction of least tension lies at right angles to the skin lines (Figs. 5-3A and 5-3B).

Incisions made parallel to the creases are readily closed (Fig. 5-3C). Those made across them are under tension after closure and the result will be greater scarring.

Blood Supply to the Skin

Three levels of vessels supply the intradermal arterial system: segmental arteries, perforators, and cutaneous arteries.

The aorta gives off ventral and dorsal segmental arteries (Fig. 5-4).

Ventral Segmental Arteries

Anastomotic arteries (see Fig. 1-3) from the **ventral segmental arterial system** (composed of such vessels as the inferior epigastric artery) divide into multiple **perforating arteries** (perforators) that enter the **superficial fascia. Branches of the perforating arteries** run over the fascia parallel to the skin and give off the **direct cutaneous arteries** to the skin of that portion of the body wall.

Dorsal Segmental Arteries

The **dorsal segmental arteries** arise directly from the aorta to supply the major muscles and much of the skin of the trunk. Branches from these vessels run perpendicularly

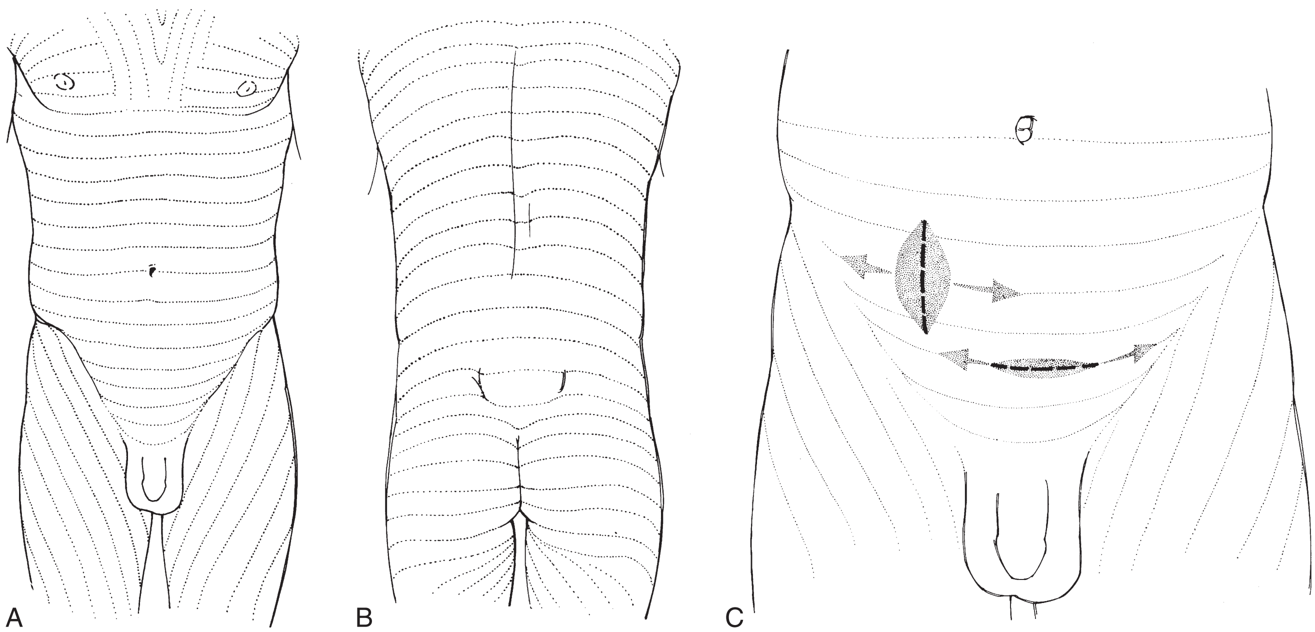

FIGURE 5-3. **A,** Anterior view. **B,** Posterior view. **C,** Placement of incisions.

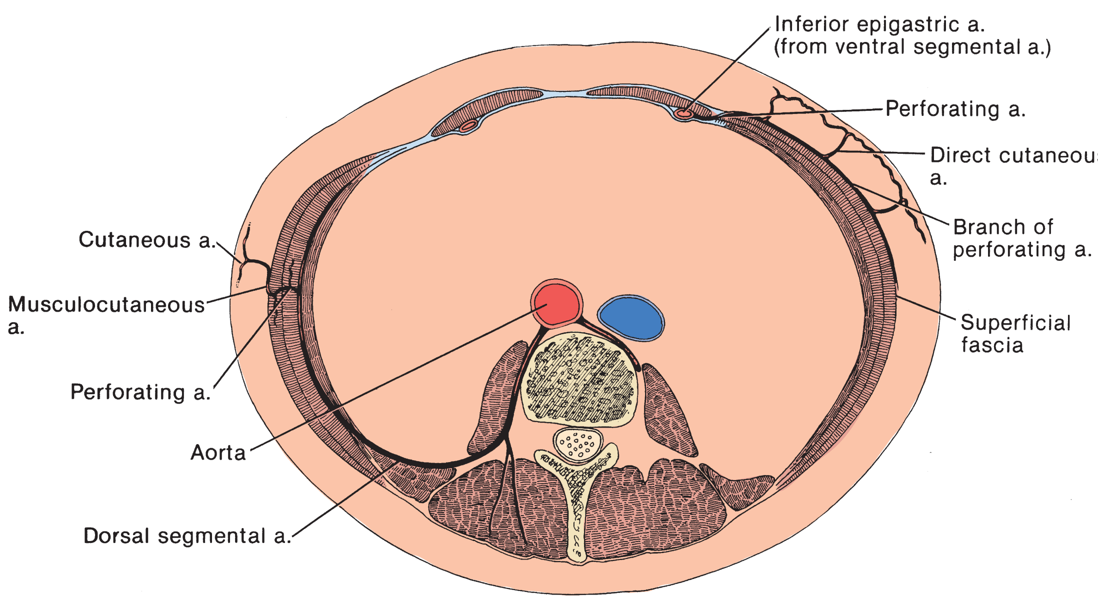

FIGURE 5-4.

through the muscle to the skin as **perforating arteries**, supplying the muscle during the passage. On piercing the superficial fascia as **musculocutaneous arteries,** they branch in the subcutaneous fat as **cutaneous arteries** to supply the dermis and epidermis. The musculocutaneous distribution is different from the direct cutaneous type arising from the ventral segmental arteries because it includes the muscle layer.

The distribution of the two arterial types, direct cutaneous and myocutaneous, are compared in Table 5-2.

Cutaneous flaps are supplied by the musculocutaneous vessels in their pedicles. An *arterial flap* is supplied by a specific direct cutaneous artery, achieved by making an incision paralleling the course of the vessel and incorporating the subcutaneous tissue. The *island flap* is supplied by an essential artery and vein in a narrow pedicle. Flaps on the trunk are raised by a dissection between the deep and the superficial fascias, a plane through which relatively few vessels cross. However, any vessel that is encountered needs to be controlled because hematoma formation may prevent graft adherence and cause

TABLE 5-2

MUSCULOCUTANEOUS AND DIRECT CUTANEOUS ARTERIES

Musculocutaneous	Direct Cutaneous
Dominant blood supply	Supplemental
Numerous	Limited number
Size variation by region	Anatomical variations
Limited area supplied	Very large area supplied
Perpendicular to skin	Parallel to skin
Single vein	Paired vein; associated named vein

Adapted from Daniel RK, Williams HB: The free transfer of skin flaps by microvascular anastomosis; an experimental study and a reappraisal. Plast Reconstr Surg 52:1831, 1973.

interference with its circulation, fostering infection. Many flaps will require removal of much of the underlying fat to make them suitable for the recipient site. This can be achieved without jeopardizing the circulation in axial flaps because the vessels lie deep in the superficial fascia near the point of origin and only become superficial to the fascia toward the distal end of the flap. With magnification, the subdermal vascular plexus can be protected as the fat is dissected from the fat domes. At the same time, care must be taken not to disturb the deeper circulation arising from the axial vessels. In addition, fat at the edges of a flap may interfere with approximation by bulging into the suture line, a problem solved by trimming the edge obliquely.

The *myocutaneous flaps* useful in urology are formed by elevating skin and muscle, together with their independent cutaneous vascular territory, on a single pedicle on the superficial inferior epigastric, superior epigastric, or superficial circumflex iliac arteries.

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Chapter 6

Gastrointestinal Tract

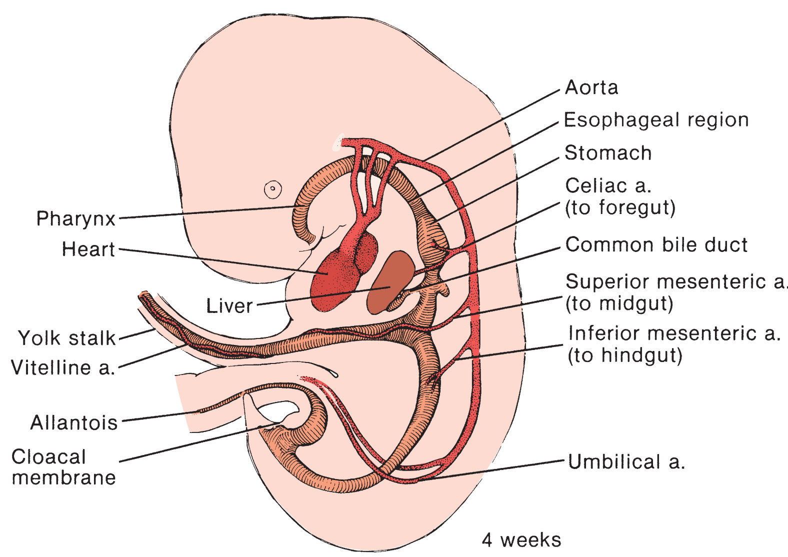

FIGURE 6-1.

The bowelles ben cominly called the guttes.

TREVISA

Barth. De P.R. v.xlii (1492) 1398.

DEVELOPMENT OF THE GASTROINTESTINAL TRACT

The epithelium and glands of the gastrointestinal tract are endodermal in origin except for ectodermal contributions to the primitive mouth and to the proctodeum.

The Primitive Gut

The three divisions of the primitive gut are based on the three branches of the dorsal aorta: (1) the foregut on the **celiac artery,** (2) the midgut on the **superior mesenteric artery**, and (3) the hindgut on the **inferior mesenteric artery** (Fig. 6-1).

The **foregut** extends from the mouth to the site of entrance of the **common bile duct** into the duodenum. At first, the **pharyngeal** portion is dominant, but the caudal portion elongates and at the beginning of the fifth week the **stomach** is formed as a dilation just proximal to the opening into the **yolk stalk**. The stomach appears to descend because of differential growth of the cephalad structures. A mesogastrium develops, continuous with that of the small intestine. The left side of the tubular stomach develops more rapidly than the right, so that the stomach appears to rotate, placing the greater curvature to the left. Rugae appear and are followed by gastric pits and glands.

Midgut And Hindgut

The *midgut* is based on the left side of the **superior mesenteric artery**, where numerous branches extend to supply the proximal part of the umbilical loop as far as the **yolk stalk** (Fig. 6-2). The midgut becomes the **jejunum** and **ileum**, the **cecum** and appendix, the **ascending colon**, and the majority of the **transverse colon**. It is supplied by the **ileocolic** and the **superior mesenteric arteries**, which together form a large loop centered on the **terminal ileum** that extends from the point of the entry of the common bile duct just proximal to the future splenic flexure of the transverse colon.

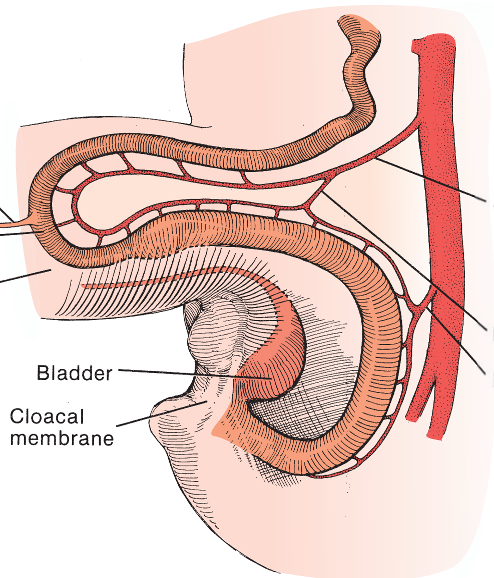

FIGURE 6-2.

During the fourth week, the previously open communication with the yolk sac becomes the narrow **yolk stalk**. The persistence of the proximal part of this stalk creates Meckel diverticulum (ileal diverticulum), which may be found in adults on the antimesenteric border of the ileum about 40 cm from the ileocecal valve.

As the midgut lengthens, the midgut loop expands into the base of the umbilical cord, the **umbilical celom**. At 6 weeks, a diverticulum appears at the distal end of the loop; this sac will form the rudimentary **cecum** and appendix. By the tenth week, the midgut lies once again within the abdominal cavity.

The *hindgut*, based on the **inferior mesenteric artery**, starts medial to the distal third of the transverse colon and terminates at the **cloacal membrane**. From it will develop the distal part of the **transverse colon**, the **descending** and **sigmoid colon**, the **rectum**, and the upper part of the **anal canal** to the level of the anal valves at the juncture of the cloaca with the proctodeum and also part of the **bladder** and urethra.

GREATER AND LESSER OMENTA

Formation of the Greater and Lesser Omenta

As part of the transverse septum, the **dorsal mesogastrium** joins the **spleen** and **stomach** to the dorsal body wall (lienorenal ligament and gastrosplenic ligament), whereas the **ventral mesogastrium** joins the stomach and liver to the anterior wall (**lesser omentum** and **falciform ligament**) (Fig. 6-3A). At about 16 weeks, the **greater omentum** develops by caudal extension of the free margin of a fold of the primitive mesogastrium.

From the dorsal mesogastrium, a posterior fold arises consisting of a layer of mesenchyme between peritoneal covers; its vasculature comes from the left gastroepiploic artery. An anterior fold develops from the ventral mesogastrium, supplied by the right gastroepiploic artery. The two folds form the greater omentum, with its two-layered blood supply (Fig. 6-3B).

Maturation of the Omenta and Fusion of the Peritoneal Surfaces

The double-thickness anterior layer of the **greater omentum** extends caudad from the **greater curvature** of the **stomach**, passes anterior to the transverse colon as **anterior leaves**, and returns to the pancreas as **posterior leaves**, thereby forming the **lesser sac** or omental bursa behind the stomach (Fig. 6-4A).

The **anterior** and **posterior leaves** of the **greater omentum**, each composed of two layers of peritoneum, fuse distally. The dorsal surface of the greater omentum becomes attached to the underlying transverse mesocolon and anterior surface of the **transverse colon**. The final result of the rotation is to place a triple layer of peritoneum over the kidney and adjacent structures that consists of two layers of colonic peritoneum and one layer of primary

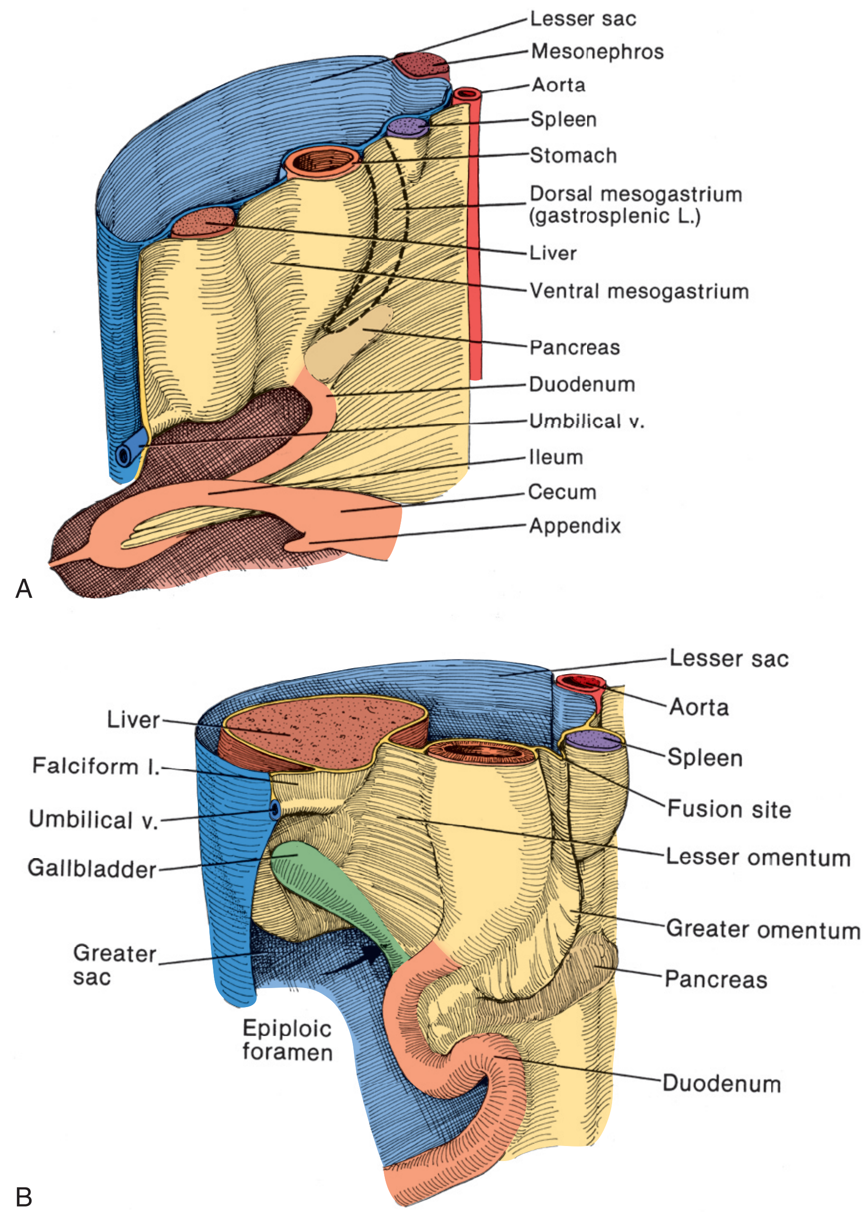

FIGURE 6-3.

dorsal peritoneum (called primary because it subsequently is covered by the secondary peritoneum of the colonic mesentery) (Fig. 6-4B). Over the right kidney, the fused mesoduodenum is interposed between the colonic layer and the primary peritoneal surface (see Fig. 6-6).

INTESTINAL ROTATION

Rotation of the Intestine

In the sixth week, the primitive intestine forms a simple arc, the **midgut loop**, with the yolk stalk at the apex (Fig. 6-5A). Rotation of the gut about the axis of the yolk stalk begins at this time in a counterclockwise direction. The effect is to transpose the mesentery, placing the *left* side to face posteriorly and the *right* side, anteriorly.

The coils of small intestine returning to the abdomen force the descending colon against the primary peritoneum that covers the left posterior body wall, where the *left* surface of the colonic mesentery fuses with the original dorsal peritoneum. In this way, the descending colon loses its mesentery. The rotation places the ileocolic artery above and to the right of the superior mesenteric artery and leaves the colon inverted.

On the right, the future **ascending colon** lies at first at an oblique angle over the **duodenum** with the **ileum** below and medial to it. The **ileocolic artery** now lies above and lateral to the **superior mesenteric artery** (Fig. 6-5B).

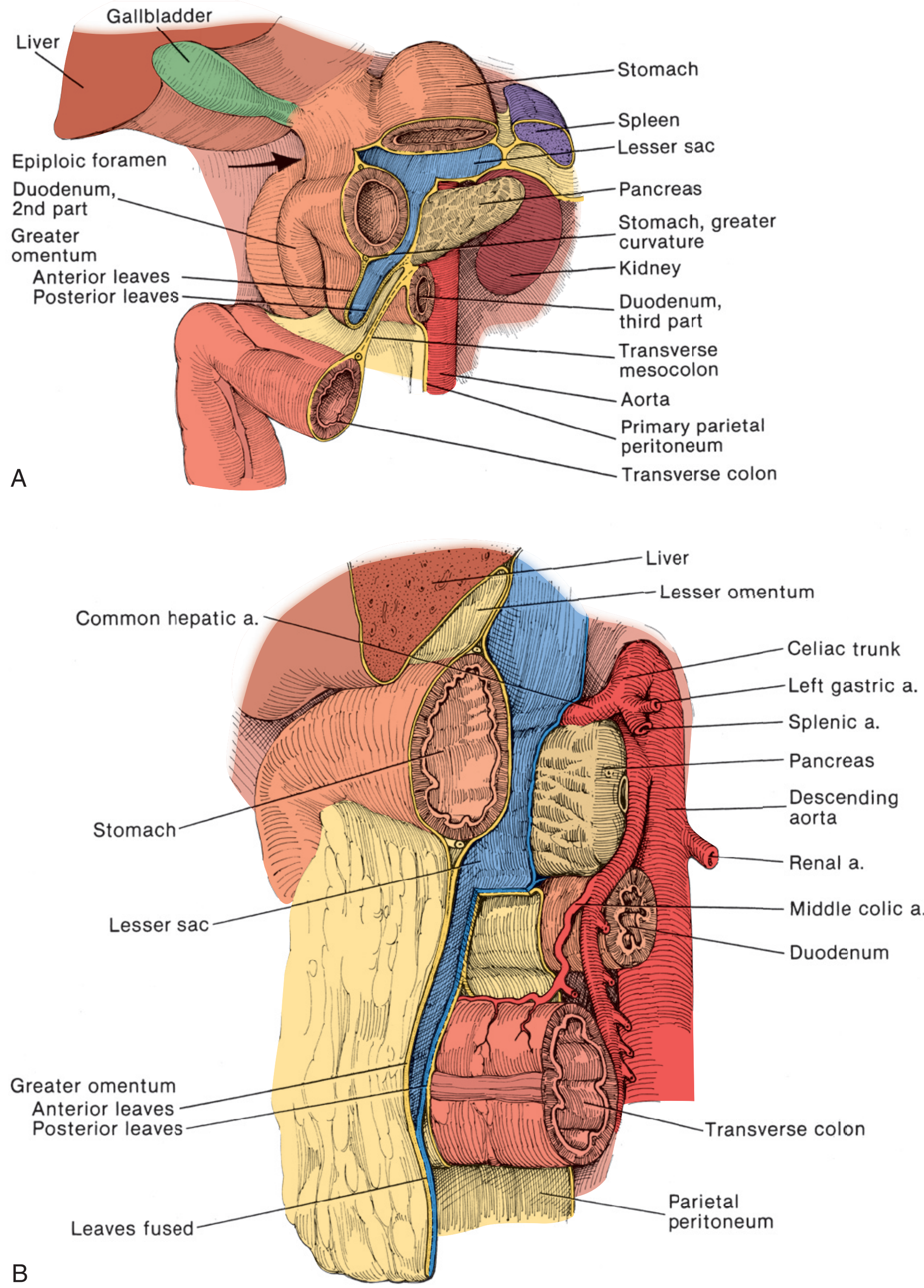

FIGURE 6-4.

As the **cecum** descends, the adjacent bowel is formed into the **ascending colon** and the **transverse colon** (Fig. 6-5C). The *left* side of the mesentery of the ascending portion is fixed to the *right* primary dorsal peritoneum in the same way as it is on the left, with fusion occurring between the *left* mesenteric surface and the primary peritoneum. This portion of the large bowel thus loses its mesentery. The colon adheres to the **duodenum** as it passes anteriorly, but in its transverse portion, it maintains its mesentery, which is attached to the pancreas. As noted in Fig. 6-5A, the mesentery to the **descending colon** disappears and the bowel becomes fixed to the body wall.

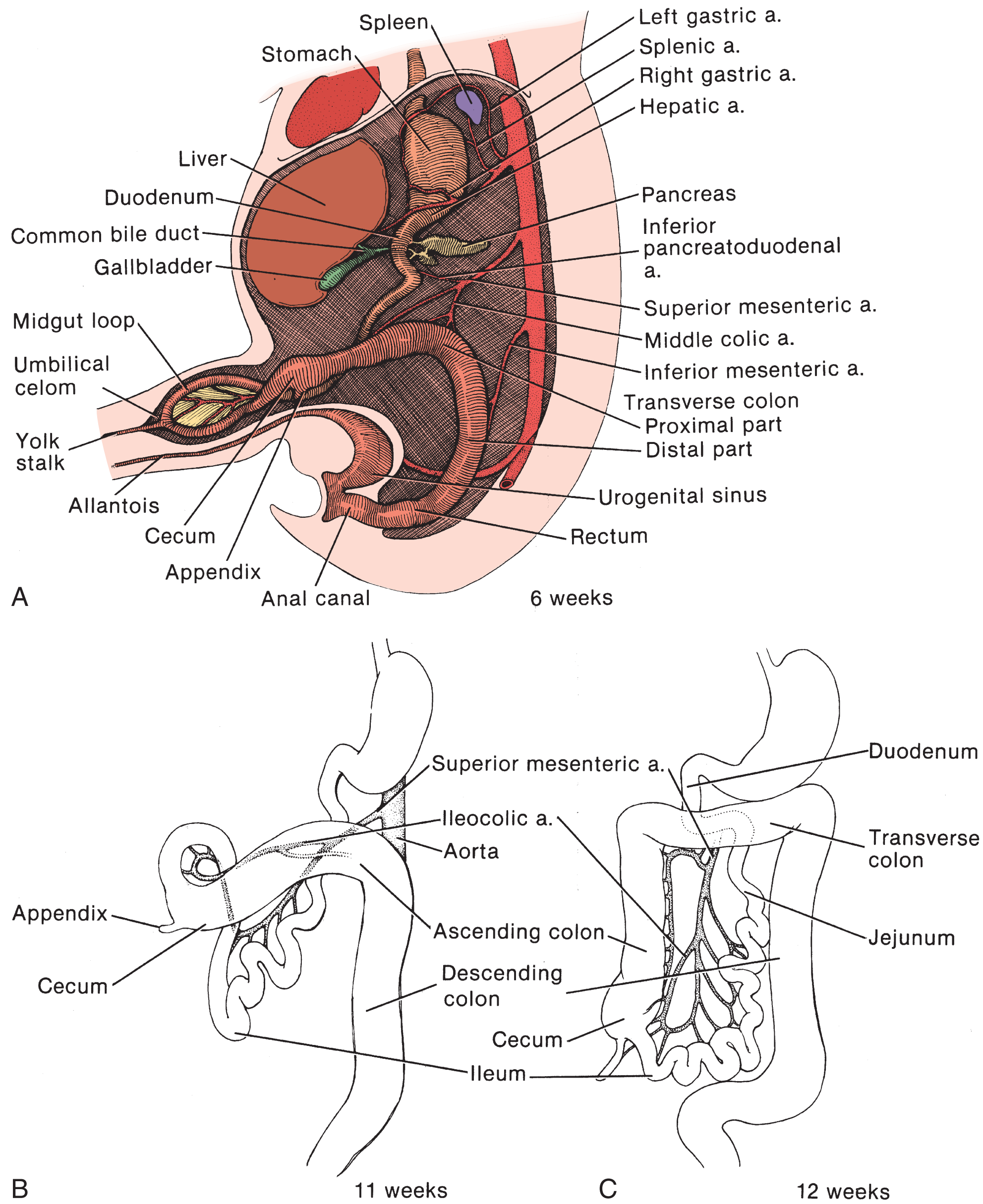

FIGURE 6-5.

DEVELOPMENT OF THE CECUM AND RECTUM

Cecum

The cecum is at first short and cone-shaped, but as it develops, it elongates, principally in the upper part, leaving the appendix in a more dependent portion. Two saccules usually develop on either side of the anterior tenia, the right one growing faster than the left. The result is formation of a new apex from the extension of the right saccule, moving the former apex with the appendix toward the left. Alternatively, the fetal conical cecum (or some variation) may persist. In any case, the tenia of the longitudinal muscle coat terminate at the base of the appendix. The distal part of the diverticulum forming the cecum does not expand as fast as the proximal part but remains as the vermiform appendix.

During the seventh month, lymph nodules form in the wall; these will increase in number until puberty.

Rectum and Anal Canal

This terminal part of the gut is formed from the portion of the hindgut caudal to the connection of the allantoic duct. Their development is closely associated with that of the bladder (see Fig. 13-8).

An imperforate anus may present as a low defect involving the anus or as a high anorectal defect. Low defects include anal stenosis, membranous atresia, and anal agenesis (with or without a fistula); anorectal defects include anorectal agenesis (with or without a fistula) and rectal atresia. In addition, the cloaca may persist.

SPLEEN

Although not a part of the digestive tract, the spleen is encountered during renal and adrenal surgery and its development will be discussed here. At 8 weeks, the mesenchyme on the left side of the mesogastrium enlarges and becomes covered with mesothelium. The mesothelium becomes peritoneum, and the mesenchyme differentiates into splenic tissue, first with the appearance of sinuses and later with hemopoietic tissue. Only after birth will splenic nodules form.

Accessory spleens are occasionally found but are rarely of surgical importance. They most often occur near the splenic hilum but may appear at a distance from the spleen.

FASCIA OF THE INTESTINAL ORGANS

The primitive retroperitoneal tissue differentiates into three strata—(1) an outer stratum associated with the body wall, (2) a middle stratum about the urinary tract, and (3) an inner stratum consisting of a thin layer of connective tissue that develops as the supporting tissue for the mesothelium (see Fig. 12-43B). The inner stratum lies just beneath the peritoneum and constitutes the adventitia of the several organs imbedded within it. Because the mesenteries are covered with peritoneum, their contained vessels and nerves are also within this stratum, as is the connective tissue over the spleen, pancreas, and liver.

Perirenal Fascial Layers

As the right and left colon rotate, their mesenteries come to lie parallel with the posterior body wall. When the peritoneum of the original left side of the mesentery fuses with the dorsal peritoneum of the body wall (the primary peritoneum), the colon becomes fixed over the entire kidney on the left, which also is covered by the fused mesoduodenum. On the right, it is adherent to the lower part of the kidney. The posterior fixation extends to the sigmoid on the left and to the end of the cecum on the right. Laterally, the free margin of the colonic mesentery ends with fixation to the primary peritoneum, indicated by the white line of Toldt. In fetal life, the recess between the margin of the colon and that of the posterior body wall is large, extending behind the kidney; the same configuration may persist into the adult state.

Retroperitoneal Fusion-fascia

Colonic rotation and fixation results in multiple layers covering the left kidney, as shown in Fig. 6-6A. As the **descending colon** is pushed to the left and posteriorly, the overlying so-called **primary dorsal peritoneum**, that surface of the posterior peritoneum that originally covered the kidney before colonic rotation, becomes fused with the overlying layers of colonic mesentery. Thus, the original **right** and **left leaves** of the **mesocolon**, now fused, form three layers if the fusion layer between is counted as one. Being fused, they do not possess a potential space, so that medial mobilization of the ascending or descending colon requires entering the plane behind this fusion fascia between it and the anterior lamina of the renal fascia. The lateral margin of the fusion is marked by the **white line of Toldt**.

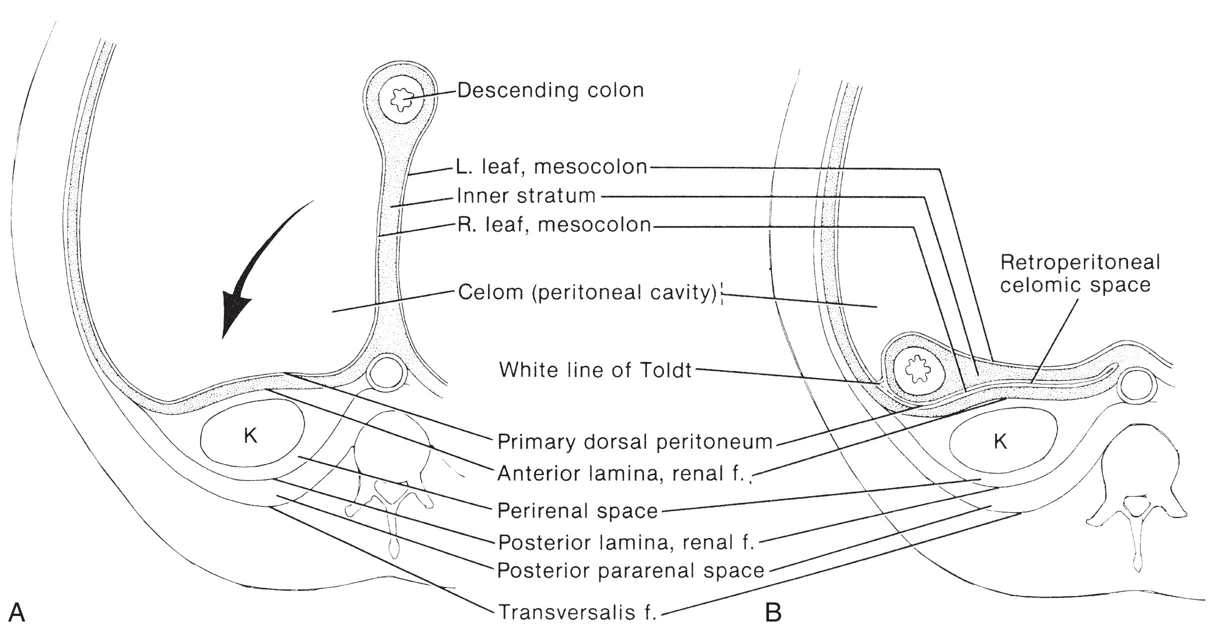

FIGURE 6-6.

The resulting layers over the kidney are transversalis fascia, posterior pararenal space, posterior lamina of the renal fascia, perirenal space, and anterior lamina of the renal fascia (Fig. 6-6B).

STRUCTURE OF THE GASTROINTESTINAL TRACT

Peritoneal Cavity

The colon divides the peritoneal cavity into two compartments, supracolic and infracolic. The infracolic compartment is further divided into abdominal and pelvic parts. The cavity is also divided laterally by the obliquely oriented mesentery of the small intestine into right supramesenteric and left inframesenteric compartments. In addition, the ascending and descending colon delineate right and left paracolic gutters.

VISCERAL PERITONEUM

Unlike the parietal peritoneum that, on the anterior portion, has somatic sensory nerves that register pain, the visceral peritoneum has only autonomic nerves that respond to distention. Its blood supply is that of the underlying bowel, through the celiac trunk and the superior and inferior mesenteric arteries.

Stomach

The stomach wall has four layers. The **serosa** covers the entire surface except for space for entry of vessels at the attachment of the **lesser** and **greater omenta** and at the attachment of the gastrophrenic and gastropancreatic folds. The **muscularis** has three layers: (1) superficial **longitudinal** fibers, (2) middle **circular** fibers that extend throughout the stomach, and (3) more sparse **oblique** fibers of the body and cardiac orifice (Fig. 6-7A). The **submucosa** overlies the **mucosa**, which is raised into longitudinally oriented rugae on contraction of the muscular coat (Figs. 6-8 and 6-9).

The **cardia** marks the junction with the **esophagus**. The stomach ends where it joins the **duodenum** (Fig. 6-7B). As a somewhat flattened J-shaped organ, the stomach has two borders: (1) the **lesser curvature** medially and above and (2) the **greater curvature** laterally and below. The **fundus** is that part lying above the cardiac orifice; the **body** extends to the notch at the angle of the J, the **incisura angularis;** and the **antrum** joins the narrower **pyloric canal**, the entrance to the duodenum (Figs. 6-10, 6-11, and 6-12).

Blood Supply to the Anterior Aspect of the Stomach and Greater Omentum

The short **celiac trunk** arising from the aorta branches into the left gastric, the splenic, and the common hepatic arteries (Fig. 6-13).

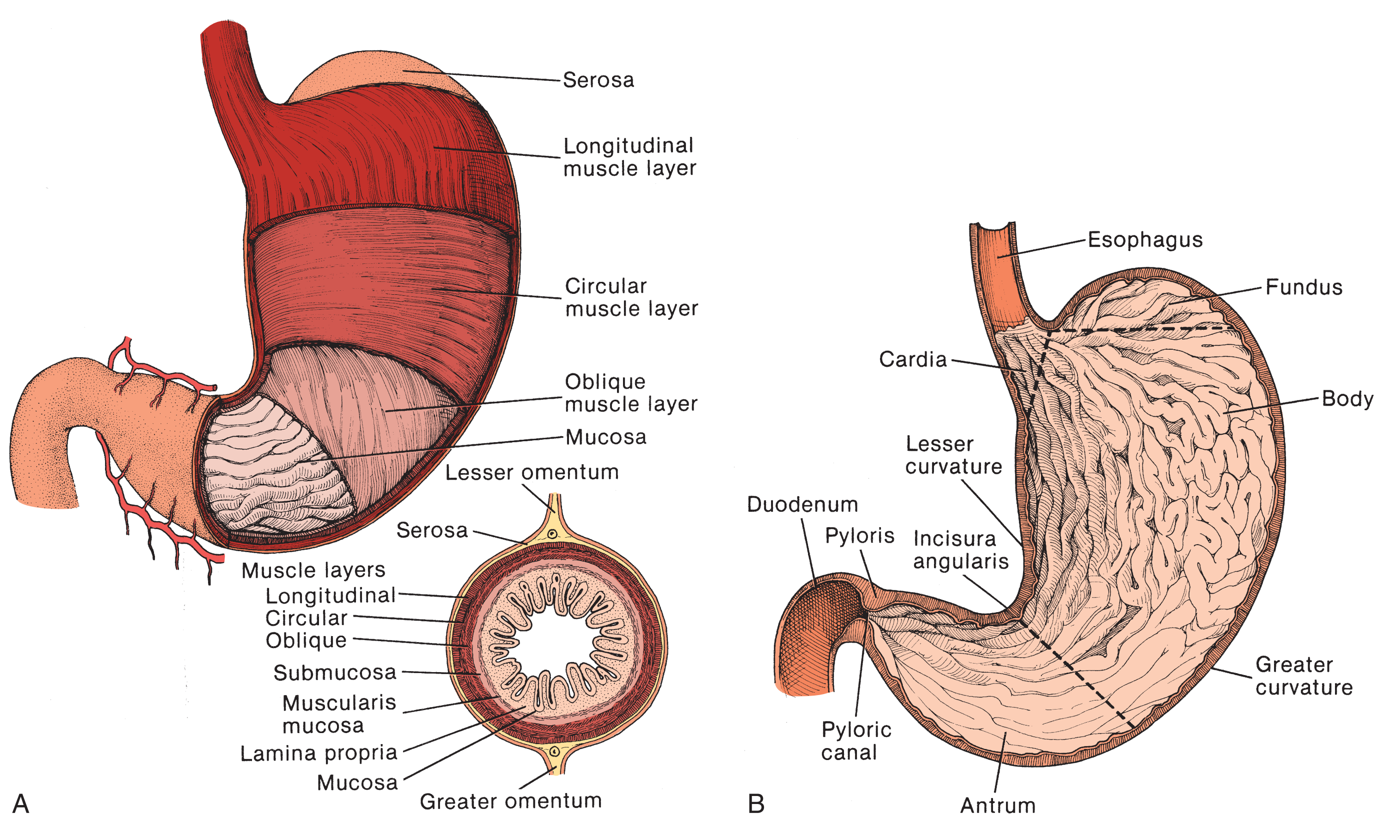

FIGURE 6-7.

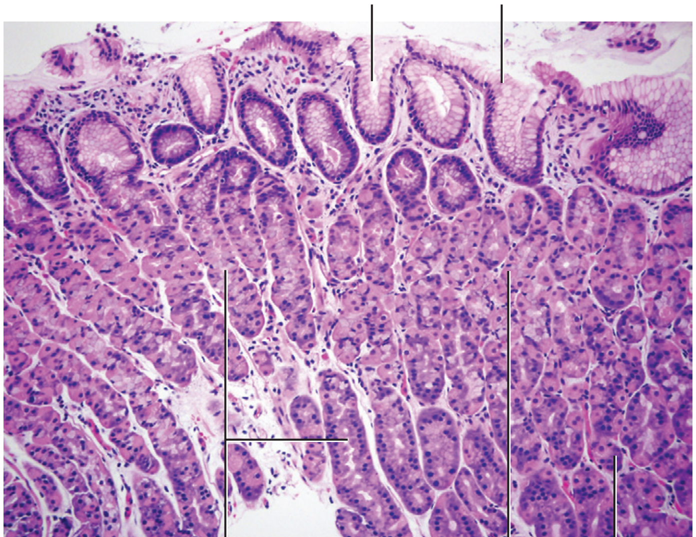

FIGURE 6-8. Gastric fundic mucosa. The surface is covered by tall columnar mucus-secreting epithelial cells. Pits (also known as crypts or foveolae) punctuate the surface and are quite shallow in the fundus. Tightly packed, relatively straight gastric glands empty into the pits. The glands are lined by a mixture of pepsin-secreting chief cells, which stain purplish, and acid-secreting parietal cells, which stain light pink.

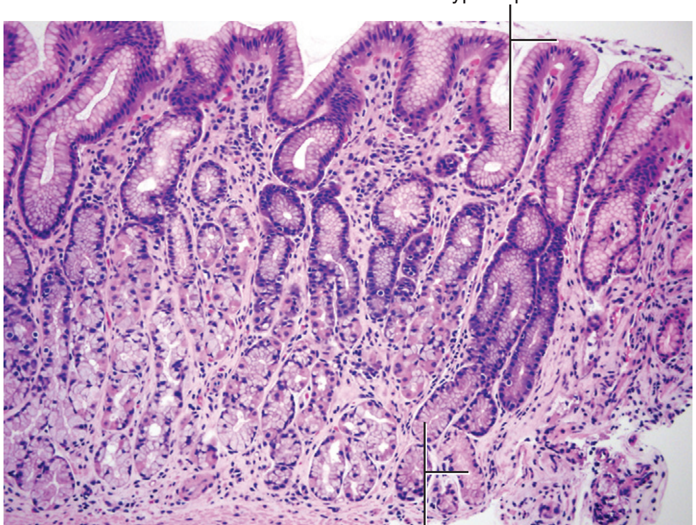

FIGURE 6-9. Gastric antral mucosa. The pits are deeper than in the fundus. The glands are coiled and exclusively mucus-secreting, although occasional parietal cells may be present. The cells lining the glands contain bubbly, foamy-appearing cytoplasm with an appearance quite different from that of the cryptal and surface epithelial cells.

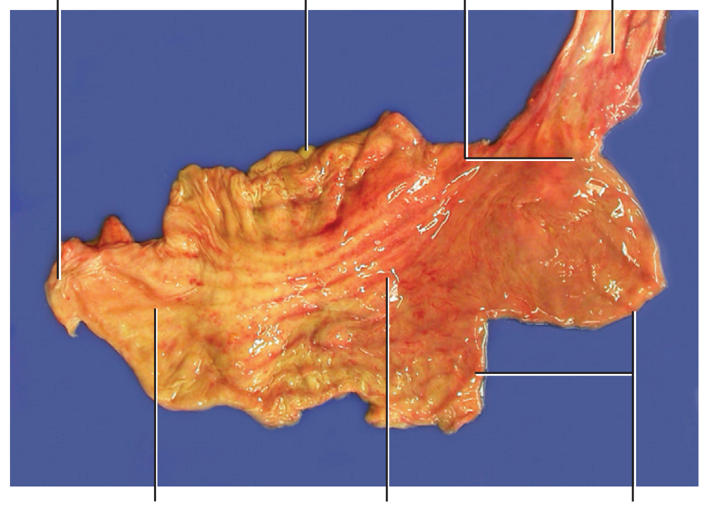

FIGURE 6-10. Distal esophagus and stomach from an autopsy case, opened. The gastric body exhibits prominent rugal folds. *(Image courtesy of Dawn Dawson, M.D.)*

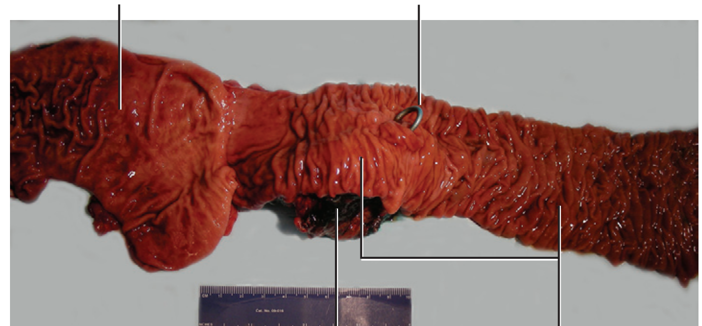

FIGURE 6-11. Distal stomach, portion of duodenum and head of pancreas, resected for pancreatic cancer (Whipple procedure). A stent via the ampulla of Vater marks the entry of the common bile duct and pancreatic ducts. *(Image courtesy of Christina Bagby, M.D.)*

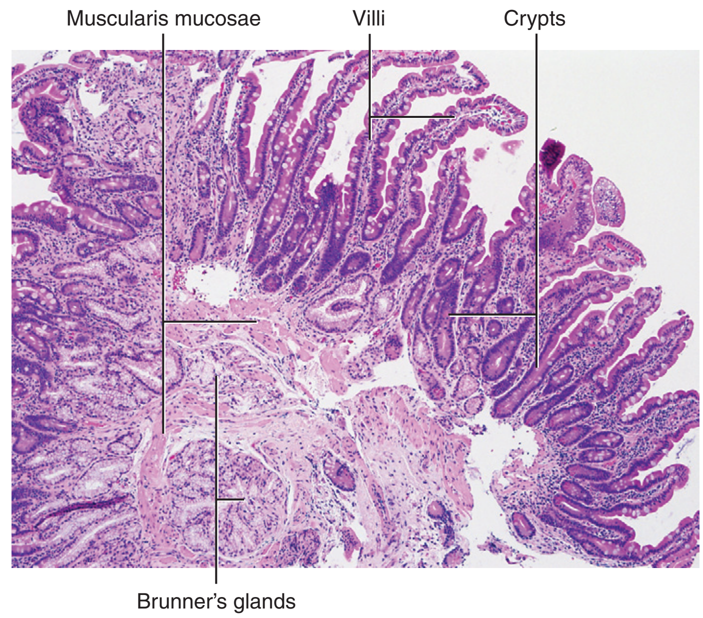

FIGURE 6-12. Duodenal mucosa. The length of the villi is variable. Mononuclear cells are relatively abundant in the lamina propria. Lobular collections of tubuloalveolar Brunner's glands, lined by cells that are distinctively different from those that line the crypts, are present both above and below the muscle bundles of the muscularis mucosae; they are a distinctive finding in this portion of the small bowel.

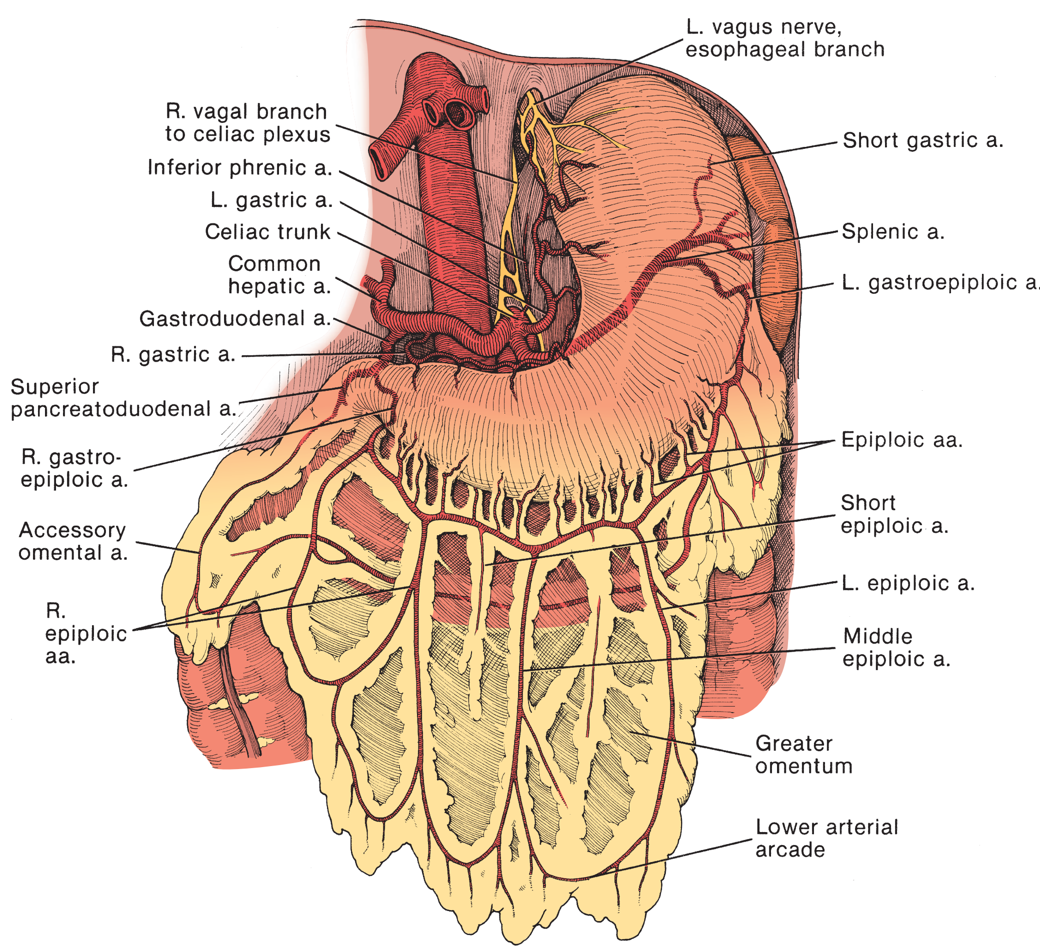

FIGURE 6-13.

The small **left gastric artery** runs behind the omental bursa (lesser sac) to the esophagus and along the lesser curvature inside the lesser omentum.

The **splenic artery** gives off the **left gastroepiploic artery** just before it divides to enter the spleen.

The **common hepatic artery** provides the **right gastric artery**, which runs from the first part of the duodenum along the lesser curvature from right to left within the lesser omentum. It then anastomoses with the branches of the **left gastric artery** coming from the left. More distally, it divides into the **superior pancreaticoduodenal artery** and the **gastroduodenal artery**, which, in turn, gives off the **right gastroepiploic artery** that runs in the greater omentum along the greater curvature.

Veins accompanying the arteries carry venous drainage into the portal system.

Greater Omentum

The greater omentum receives its blood supply from the right and left gastroepiploic vessels. The **right gastroepiploic artery** arises from the **gastroduodenal artery** (or rarely, from the superior mesenteric artery), and the **left gastroepiploic artery** is the last branch of the **splenic artery**. The right artery is lower than the left and in most cases is larger, supplying from two-thirds to three-quarters of the omentum. The right and left arteries form the gastroepiploic arterial arcade; however, in one tenth of cases, the arcade is incomplete on the left side. The arteries join by means of numerous collaterals and through the capillary network of the gastric wall. The major vessels to the omentum arising from the arcade are the **right epiploic artery** (from the right gastroepiploic artery), the **middle epiploic artery** (arising at the junction of the two gastroepiploic arteries), and the **left epiploic artery** (from the left gastroepiploic artery). In addition, an **accessory epiploic artery** leaves the arch immediately before the takeoff of both the right omental artery and the **short epiploic arteries** that fill in the spaces between the major vessels.

The right and left distal arterial arcades, which together form the **lower arterial arcade**, are formed by junction of the right and left epiploic arteries in the posterior reflection toward the inferior margin of the omentum. These arcades are inconstant, being composed of smaller vessels that cannot be depended on to supply the omentum if the gastroepiploic arcade is divided.

The omental veins are valved, are larger than the arteries, and usually run in pairs with them. The left gastroepiploic vein carries venous drainage from the posterior layer of the omentum into the portal system; the right gastroepiploic vein empties blood from the anterior layer into the superior mesenteric vein and then into the portal vein. The lymphatics follow the epiploic arteries.

Anterior and posterior vagal trunks carry parasympathetic stimuli from the esophageal plexus on the esophagus via the **anterior branch** of the **left vagus nerve** to supply the anterior surface of the stomach.

Blood Supply to the Posterior Aspect of the Stomach

The **pancreas** and the vessels beneath it are exposed as the **stomach** and omentum are elevated. On the right, the **gastroduodenal artery** takes off from the **common hepatic artery** (Fig. 6-14) It branches to form the **right gastroepiploic artery**, which, in turn, divides into the **epiploic arteries** for the right side of the omentum. The **left gastroepiploic artery** arises from the **splenic artery** before that vessel branches to enter the **spleen**. It terminates in epiploic arteries for the left side of the omentum. The **left gastric artery** originates from the

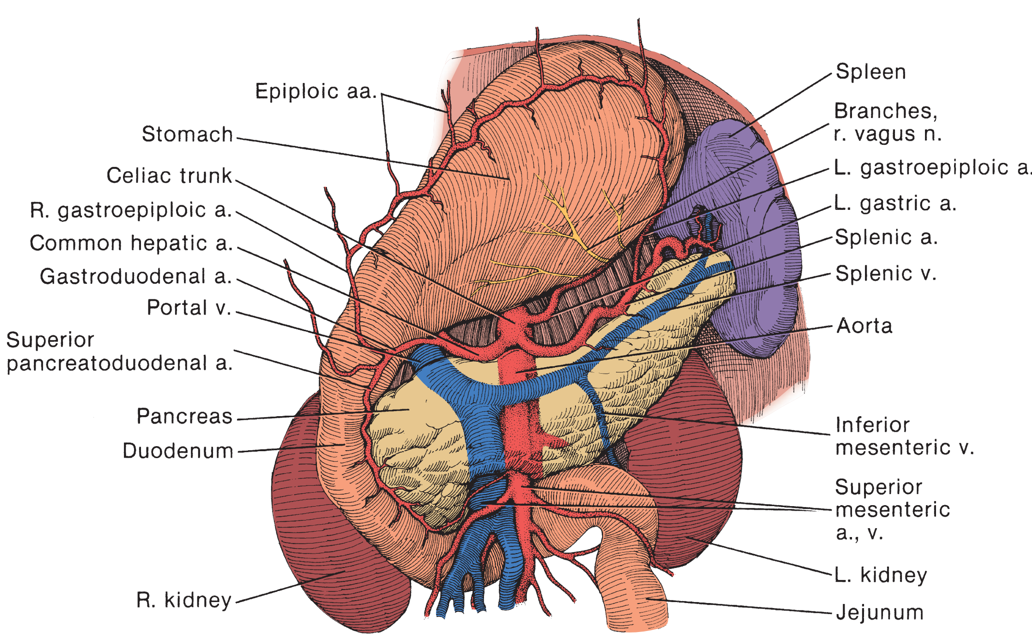

FIGURE 6-14.

celiac trunk. The **superior mesenteric vein** and the **splenic vein** drain into the **portal vein** behind the pancreas.

The **right vagus nerve** through the posterior trunk joins the celiac plexus and supplies the posterior surface of the stomach.

Lesser and Greater Omenta and Omental Bursa, Sagittal Sections

Developmental Stage

Both the lesser omentum and the **greater omentum** are formed from double layers of peritoneum that contain fatty tissue from the inner stratum of retroperitoneal connective tissue between them.

The embryologic **ventral mesentery** that will form the lesser omentum is composed of two layers of peritoneum. It runs from the liver to the lesser curvature of the stomach and contains the left and right gastric vessels. This peritoneal sandwich splits to enclose the stomach, then the layers fuse caudally again to form the embryonic **dorsal mesentery** that will become the anterior and posterior layers of the greater omentum (Fig. 6-15A). The layers ascend to enclose the **pancreas**. The more posterior layer turns caudally at this level to form the **anterior leaf** of the **transverse mesocolon**. After enclosing the **transverse colon**, it runs cephalad as a **posterior leaf** that is fused to the anterior leaf before it continues as the parietal peritoneum of the body wall. At this stage, the deep **omental bursa**, or **lesser sac**, lies behind the lesser omentum and the stomach and continues caudally between the layers of the greater omentum. The greater sac is the peritoneal cavity itself.

The dorsal mesentery overlies the **transverse mesocolon**, but at this stage both hang free in the peritoneal cavity.

Adult State

The anterior layer of the **lesser omentum** lies over the anterior aspects of the hepatic artery, the common bile duct, the portal vein, and the hepatic nerve plexus. The posterior layer covers these structures posteriorly. The margin on the right side where the two layers fuse forms an opening into the omental bursa, the **epiploic foramen**, which lies immediately above the first part of the duodenum.

The lesser omentum provides a **hepatogastric ligament**, connecting the **left lobe** of the **liver** to the stomach, and continues as a **hepatoduodenal ligament**, attaching the liver to the duodenum (Fig. 6-15B).

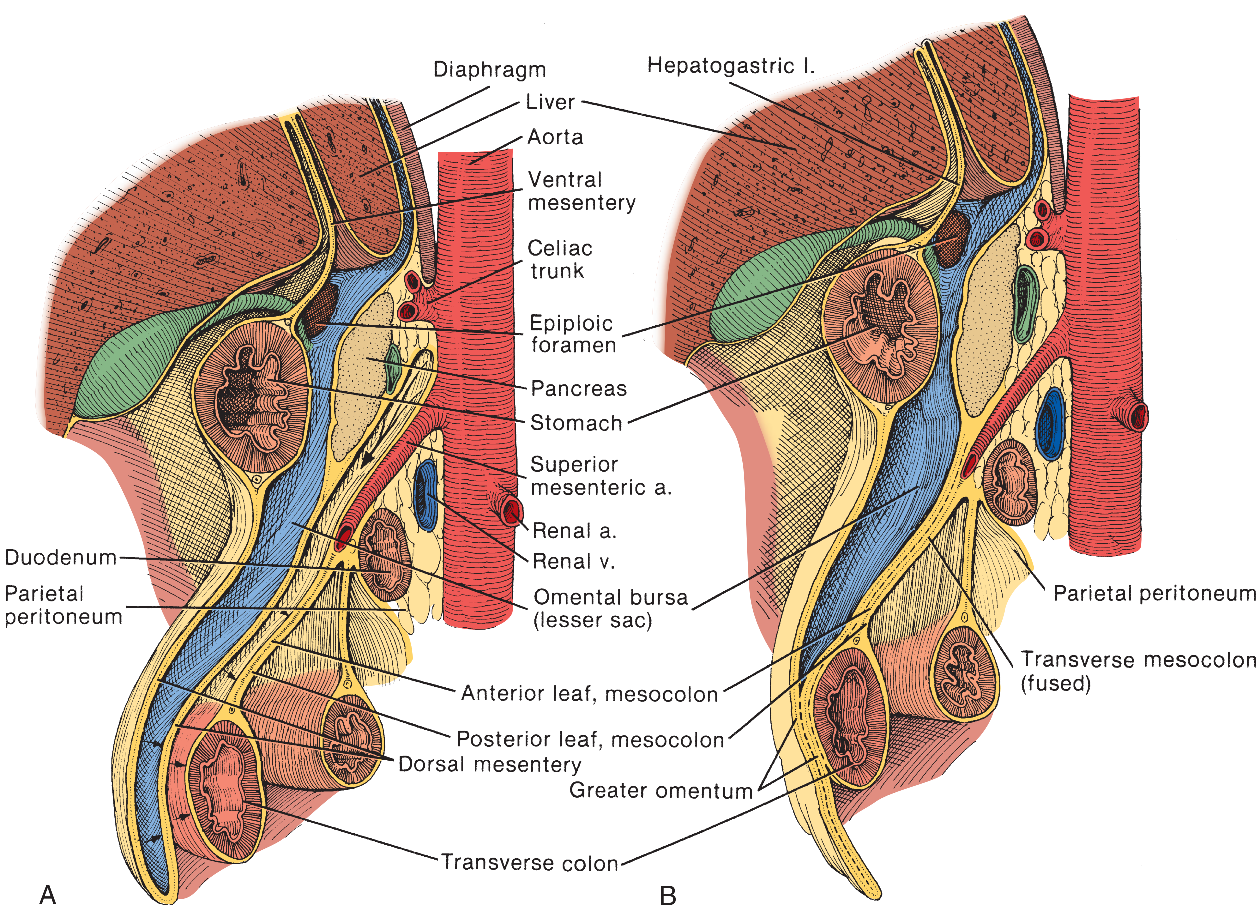

FIGURE 6-15.

The two layers of the dorsal mesentery fuse so that the greater omentum is made up of four layers of peritoneum in two folds, with each of the folds consisting of two surfaces of peritoneum (dotted line) covering a layer of fatty areolar tissue. The space between the two folds becomes fused (dashed line) but contains the blood supply.

The space between the dorsal mesentery and the transverse mesocolon is also obliterated (dashed line) as the greater omentum becomes partially fused to the transverse mesocolon.

The greater omentum is attached to the lower portion of the greater curvature of the stomach and to the first part of the duodenum. It descends a variable distance anterior to the intestines before folding back and fusing to itself. It adheres loosely to the upper surface of the transverse colon and the upper layer of the transverse mesocolon. One layer from the posterior leaf of the greater omentum continues cephalad to cover the **pancreas**; the other continues caudally to form the **anterior leaf** of the **mesocolon** and subsequently the coat of the **transverse colon** before becoming the parietal peritoneum inferiorly.

The **omental bursa** (or lesser sac) communicates with the peritoneal cavity (greater sac) through the **epiploic foramen.** It lies behind the stomach and the greater omentum and is bounded posteriorly by the **parietal peritoneum.** The bursa extends caudally from behind the lesser omentum, now the **hepatogastric ligament**, and the anterior fold of the greater omentum to the level of the fusion of the posterior fold with the mesentery of the transverse colon.

An understanding of the layers related to the omentum and transverse colon is aided by following the *course of the peritoneum.*

Starting over the anterior surface of the **lesser omentum**, the peritoneum continues caudally over the **anterior leaf** of the greater omentum. At its lower end, the peritoneum turns under and partially fuses, thereby closing the caudal end of the **omental bursa**. The peritoneal surface ascends to cover the **posterior leaf** of the **greater omentum**, then descends to fuse with the **anterior leaf** of the **transverse mesocolon**. It ascends again to form the **posterior leaf** of the **mesocolon**. After enclosing part of the duodenum, the peritoneum turns again caudally to become the **parietal peritoneum**.

The greater omentum usually lies folded about the upper abdominal organs, but its free edge may migrate to areas of inflammation. Not only is this tissue highly vascularized, but it has a well-developed system of lymphatic drainage; both are qualities that make it ideal for protective duties. It has a plentiful supply of fixed macrophages, seen as "milky spots" on the surface, for delivery as free macrophages to sites of inflammation. In addition, it is a fat depot.

Omental Bursa and Epiploic Foramen

The **epiploic foramen**, indicated by the large arrow (Fig. 6-16A), is the entrance to the **omental bursa** (lesser sac) at the medial edge of the **hepatoduodenal ligament** that runs between the **liver** and the first part of the **duodenum**. The **hepatic** and **cystic ducts** and the portal vein pass over the foramen in the margin of the **hepatogastric ligament**.

Transverse section cut at **x–x′** in Fig. 6-16A, viewed from below, is shown (Fig. 6-16B). The **omental bursa** is bounded anteriorly by the **stomach** and the **lesser omentum** and posteriorly by the **parietal peritoneum**. The entrance to the bursa from the **greater sac** is the **epiploic foramen** at the right edge of the lesser omentum behind the **common bile duct, hepatic artery**, and **portal vein**. At the left margin of the omental bursa is the **gastrosplenic ligament**, which lies adjacent to the **lienorenal ligament.**

Peritoneal Attachment of the Gastrointestinal Organs

The **parietal peritoneum** leaves the posterior body wall as the **visceral peritoneum** at mesenteric roots. It covers the mesenteries of the small intestine and the ascending, transverse, descending, and sigmoid portions of the colon. The **anterior** and **posterior layers** of the **lesser omentum** (shown as cut edges) surround the **bile duct, portal vein**, and **hepatic artery** and are separated from the parietal peritoneum over the great vessels to provide for the **epiploic foramen**, the entrance to the omental bursa (Fig. 6-17). The **transverse mesocolon** is distinct from the overlying double-layered greater omentum. The **inferior duodenal recess** lies behind a fold of peritoneum, the **inferior duodenal fold**, that extends from the **ascending part** of the **duodenum** to the **descending mesocolon** on the right of the **inferior mesenteric vein**. Above it, a similar fold of peritoneum forms the entrance to the superior duodenal recess (not shown) that marks the site where the duodenum passes under the jejunum. The **root of the mesentery** connecting the small bowel to the retroperitoneum runs obliquely from the cecum to the ascending part of the duodenum.

The roots of the mesenteries form ligaments that hold the intestinal organs in position, such as the **hepatogastric ligament**, the **left triangular ligament of the liver**, and the **gastrolienal ligament** behind the spleen.

Spleen

The **spleen** lies behind the stomach and under the lower ribs, adjacent to the upper pole of the **left kidney**, where it may be injured during renal operations even though it lies almost entirely intraperitoneally. The diaphragmatic surface of the spleen faces dorsally. The visceral surface faces ventrally and is shaped by the underlying organs to form the gastric, pancreatic, colic, and renal impressions. The site of entrance of the splenic artery and vein forms a splenic hilum. The spleen is held in place by the lienorenal ligament, which represents the junction of the peritoneum lining the omental bursa with that covering the general peritoneal cavity between the left kidney and the spleen. The gastrosplenic ligament is a similar junction of peritoneum extending between the stomach and the spleen. The gastrosplenic ligament contains the short gastric arteries and the left gastroepiploic branches from the splenic artery.

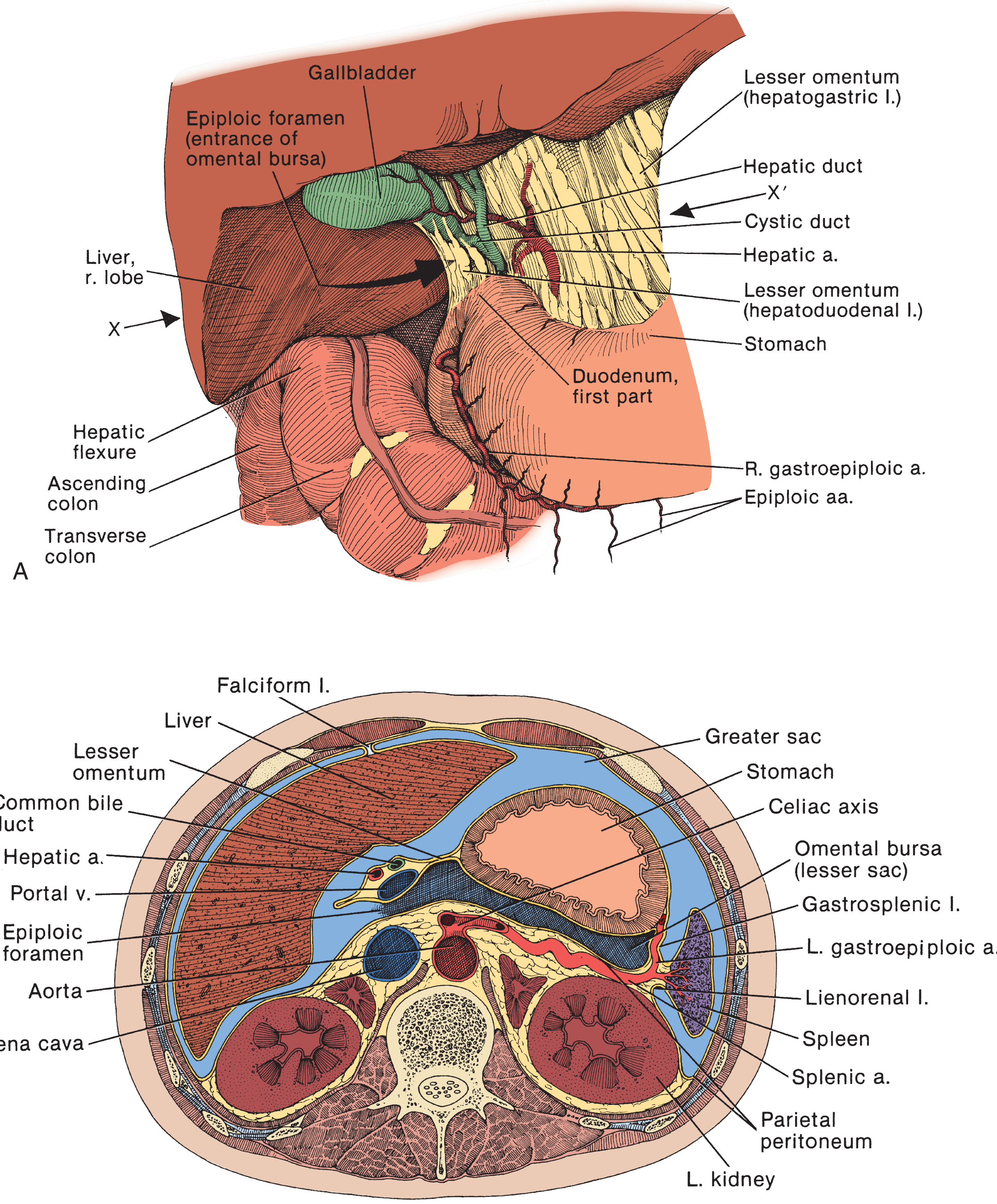

FIGURE 6-16.

Blood supply to the spleen is from the celiac artery through the **splenic artery** that runs in the lienorenal ligament and gives off branches to the pancreas before terminating in the **splenic hilum** (Fig. 6-18). Additional branches are the **left gastric artery** (to the fundus of the stomach) and, more distally, the **left gastroepiploic artery** (to the greater curvature). The splenic artery divides in the hilum into five or six terminal branches that follow the trabeculae inside the spleen into separate compartments. Because of this segmental arrangement, partial splenectomy is feasible after trauma such as that occurring during renal surgery. Venous drainage occurs through five or more veins that, after leaving the hilum, join to form the **splenic vein** that runs in the lienorenal ligament to enter the **superior mesenteric vein** (and not infrequently, the inferior mesenteric vein) before it empties into the **portal vein**.

The spleen has two coats. The external serous coat is the peritoneum; it covers the entire spleen except for the small

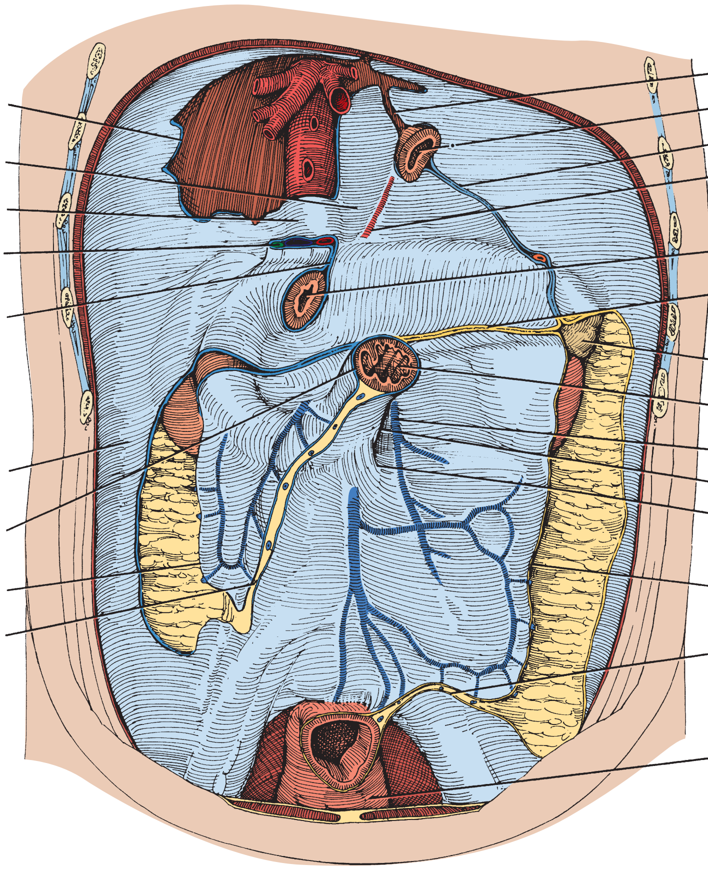

FIGURE 6-17.

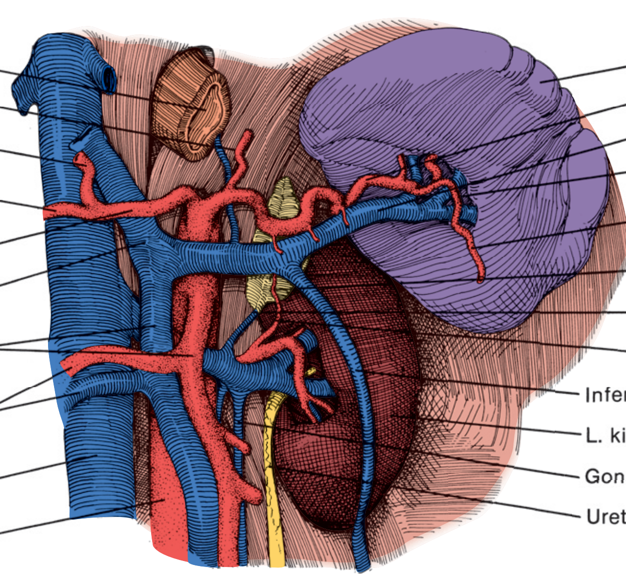

FIGURE 6-18.

FIGURE 6-19. Spleen and distal pancreas, removed together for a distal pancreatic lesion. The splenic pulp is enclosed within a distinct but easily disrupted coat composed of a fibroelastic capsule fused to overlying peritoneum. *(Image courtesy of Nicholas Houska.)*

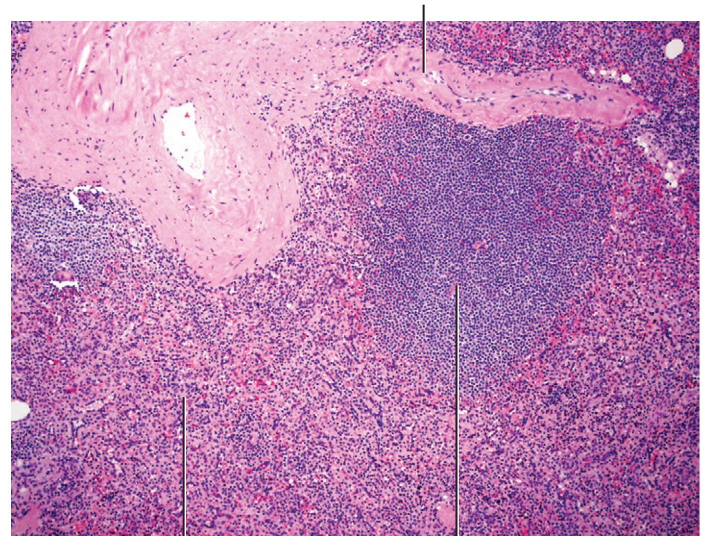

FIGURE 6-20. Spleen. Arteriolar branching often occurs at right angles. The red pulp comprises 75% of splenic volume and acts as a filter. Normal red cells are able to traverse a barrier of macrophages at the terminal end of capillaries, red pulp cord tissue, and venous sinus endothelium to re-enter the circulation. Abnormal red cells are filtered out and retained, or transported to the liver. The white pulp consists of B and T lymphocytes, which are typically adjacent to arterioles, and play a role in splenic immune function.

portion involved with the two ligaments (Fig. 6-19). The inner coat, the capsule, is composed of fibroelastic tissue that extends into the substance as trabeculae to provide a scaffold for the splenic pulp (Fig. 6-20). A few muscle cells are found in the capsule. Combined, the two coats are relatively friable and are unsuitable for suturing under tension.

Pancreas

The pancreas has four parts: (1) head, (2) neck, (3) body, and (4) tail (Figs. 6-21 and 6-22). The **head** of the pancreas lies anterior to both the inferior vena cava and the right renal vessels and is thus a possible site of injury during renal operations. The **neck** joins the head and body. Behind it are the **portal vein** and **hepatic artery**. The **body** crosses the **aorta** and the origin of the **superior mesenteric vessels**. It lies over the **left renal vein** and the anterior surface of the **left kidney**. The **tail** of the pancreas, along with the splenic vessels, lies within the lienorenal ligament and thus is not strictly retroperitoneal, but its proximity to the left kidney can be of concern to the urologist.

The **main pancreatic duct** is within the pancreas that runs to the head, where it is joined by the **common bile duct**. The two ducts form the **hepatopancreatic ampulla** before entering the **second portion** of the **duodenum** on its medial surface through the **major duodenal papilla**. The blood supply enters through branches of the celiac and superior mesenteric arteries and drains into the portal system.

The histologic features of normal pancreatic tissue are shown in Fig. 6-23.

Ileum and the Ileocecal Valve

The **ileum** is continuous with the jejunum and forms three-fifths of the total length of the small intestine. The lumen tapers distally, with the terminal ileum having the smallest luminal area. The terminal ileum turns upward to meet the medial surface of the cecum. Because the **ileal mesentery** is about 16 cm long, the ileum is freely mobile within the abdomen and pelvis.

Peritoneal folds, as **mesenteries**, support the small intestine, appendix, transverse colon, and sigmoid colon. The **mesentery of the small intestine** may be 20 cm wide in the center but is shorter at either end, which is significant in vesical augmentation. The origin or **root of the mesentery** extends on the posterior abdominal wall for about 14 cm. It consists of two layers of peritoneum, between which lie the jejunal and ileal branches of the superior mesenteric artery and their associated veins and lymphatics as well as fat. The right layer of peritoneum is continuous with that over the ascending colon; the left is continuous with that over the descending colon. These facts aid in orienting the bowel to determine the direction of peristalsis.

The **ileal wall** has four layers (Fig. 6-24A). The **serosa** is the peritoneum. The muscular layer proper is composed of

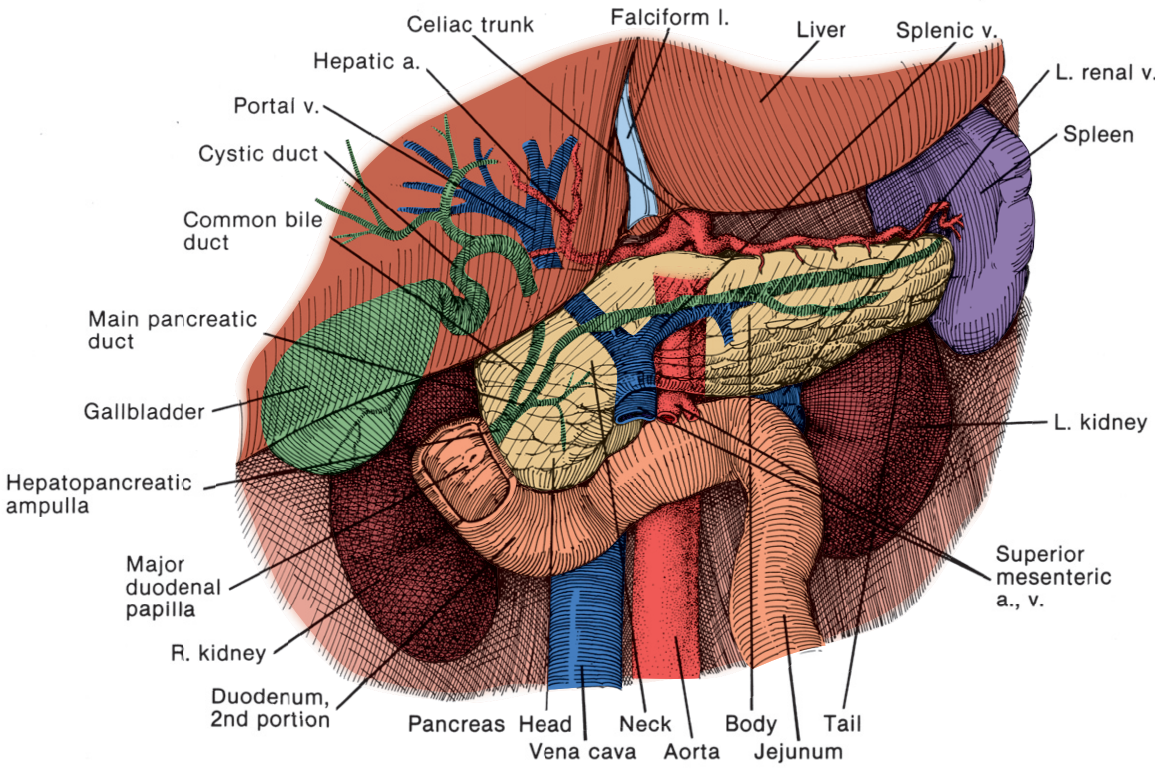

FIGURE 6-21.

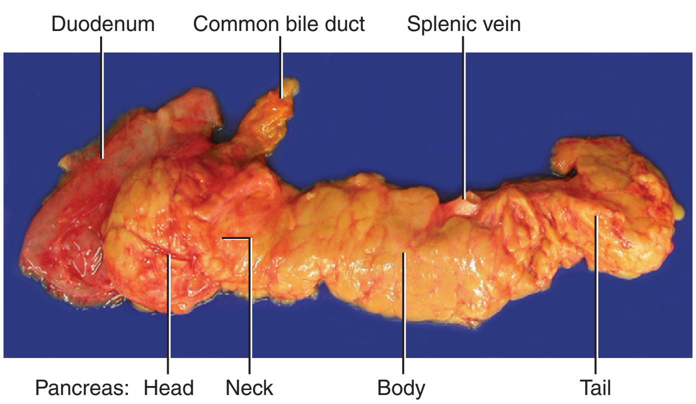

FIGURE 6-22. Normal pancreas from an autopsy case.

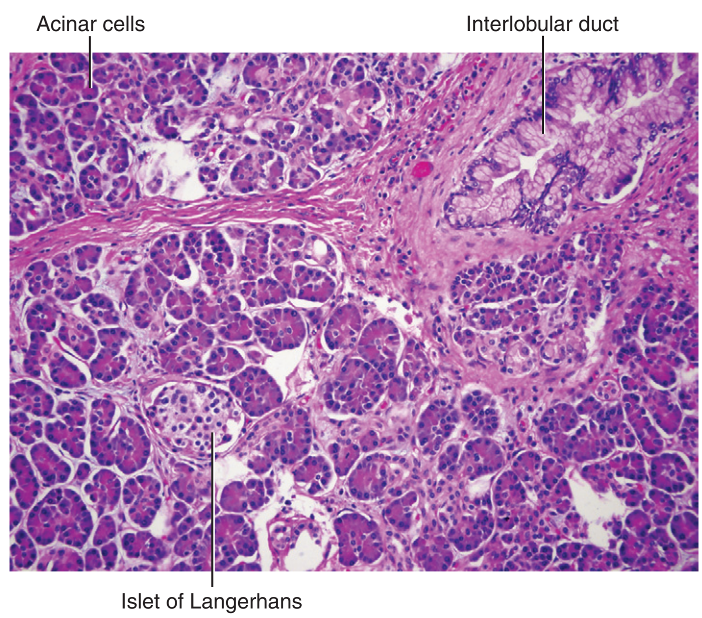

FIGURE 6-23. Pancreas, normal histology. Acinar cells are arranged around a tiny central lumen; they contain zymogen granules. Ducts become progressively larger as they join with one another: intercalated ducts, intralobular ducts, interlobular ducts invested with collagenous tissue, and major ducts. Islets of Langerhans are aggregates of endocrine cells, which comprise only about 1–2% of the bulk of the adult pancreas. They produce a variety of substances, such as insulin, somatostatin, and glucagon.

outer longitudinal muscle and **inner circular muscle**, the inner layer being thicker. The **submucosa** contains the vessels and nerves in fibrous tissue that is loose but constitutes the strongest element of the wall (in meat processing, it is this layer that is used for sausage casing). It is the essential layer for suturing in bowel anastomosis. The mucosa itself is composed of three layers: (1) muscular, (2) **lamina propria,** and (3) **mucosa** (Fig. 6-25). The **muscularis mucosae** possesses outer longitudinal and inner circular layers. It lies over the **lamina propria** composed of reticular tissue that, in turn, supports the mucosa. The mucous membrane is redundant unless the bowel is distended, so that it appears to have permanent circular folds from which the intestinal villi project. These folds are fostered by contraction of the

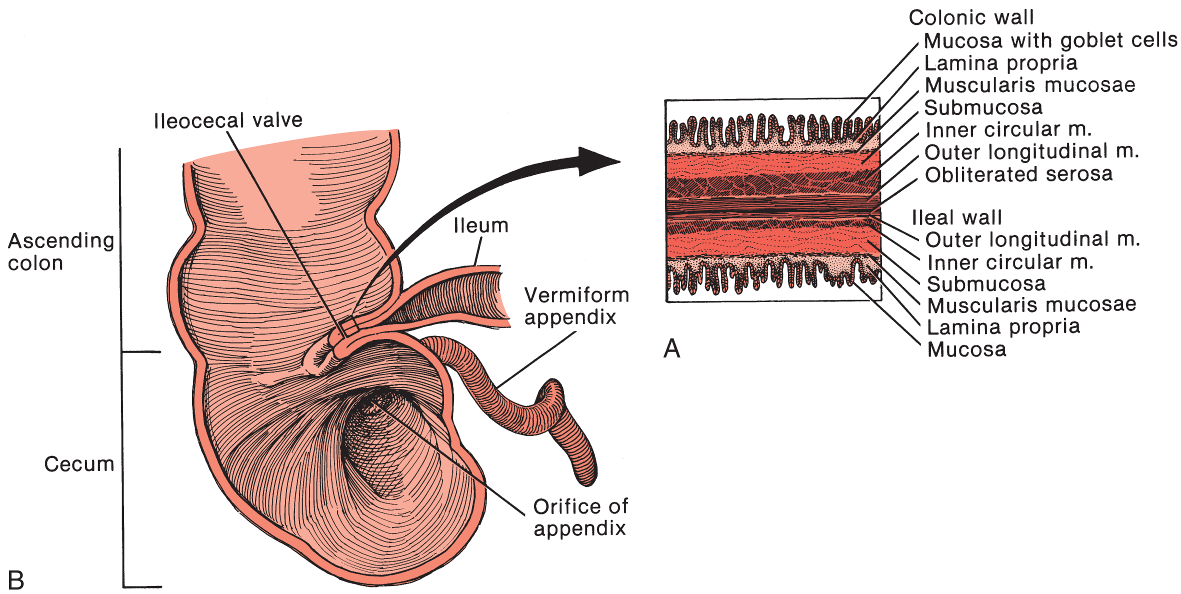

FIGURE 6-24.

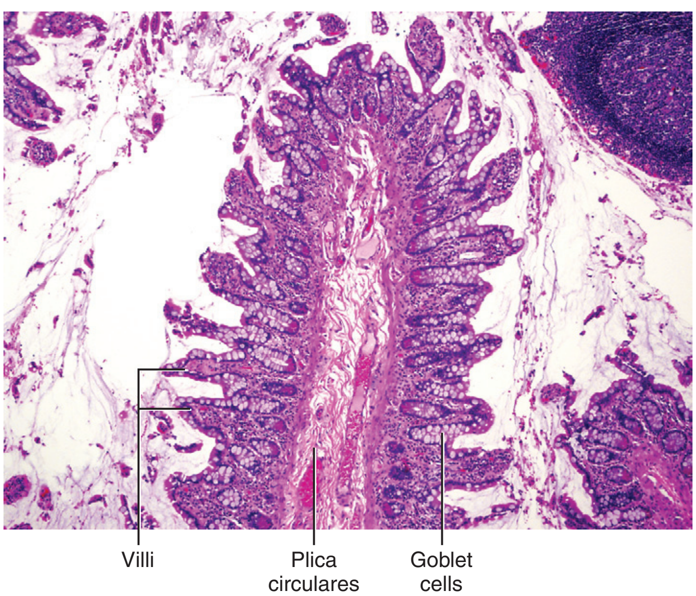

FIGURE 6-25. Ileum, normal histology. Section shows one of many permanent circular folds (plicae circulares). The ileal villi are relatively much shorter than jejunal villi (see Fig. 6-35). The villi are lined by abundant goblet cells, with relatively few tall columnar absorptive cells in comparison to jejunal villi.

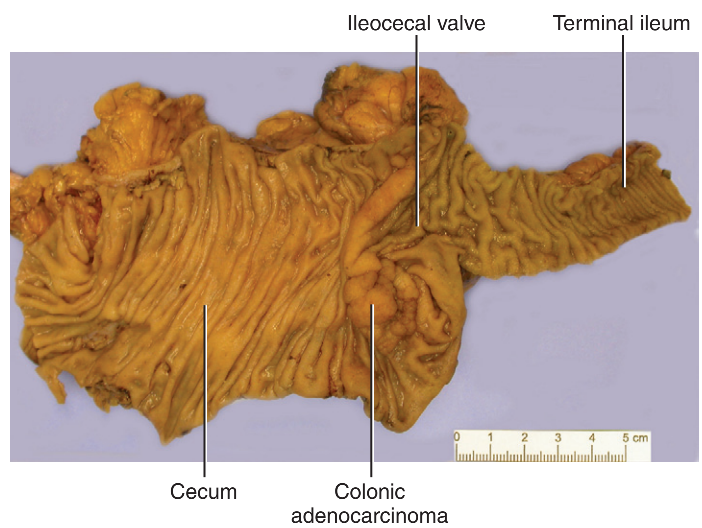

FIGURE 6-26. Terminal ileum, ileocecal valve, and cecum excised because of the presence of a low-grade superficially invasive adenocarcinoma involving the region of the ileocecal valve. *(Image courtesy of Pedro Ciarlini, M.D.)*

muscularis mucosae and are more prominent in the jejunum than in the ileum, especially in its terminal portion.

The **ileocecal valve** lies at the junction of the ileum and the cecum. The ileum takes an oblique S-shaped course to join the medial aspect of the cecal wall at a right angle about 2 cm above the insertion of the **appendix** and just medial to the mesocolic tenia (Figs. 6-24B and 6-26). The terminal portion of the ileum projects for 2–3 cm into the cecal lumen as a papilla where the wall bulges between the anterior (free) and posterolateral (mesocolic) tenia, pushing the apex of the valve and the appendix to the left. Lymphoid tissue is arranged in clumps as Peyer patches (Fig. 6-27).

The valve itself is a two-layered structure resembling an intussusception in that it is formed by the continuation of the circular and longitudinal muscle of the ileum through the thicker circular and longitudinal muscle of the cecal wall, both muscle coats tapering as they approach the tip of the valve. In cadavers, the result is an inferior and a superior flap projecting into the cecal lumen, the margins of which are fused to form the commissures of the ileocecal valve. These commissures run along the cecal wall to reach two horizontal folds, the frenula of the ileocecal valve. In living subjects, flaps and commissures are not seen; rather, the designation *papilla* is most descriptive. The colonic mucosa

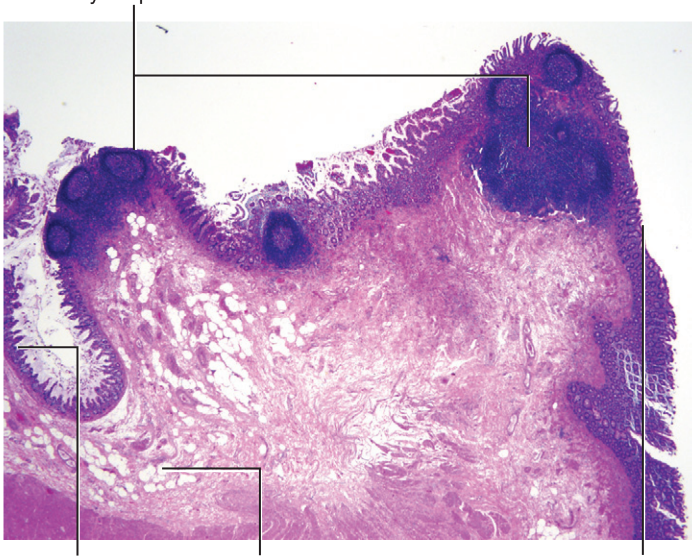

FIGURE 6-27. Histology of ileocecal valve. The mucosa undergoes a gradual transition at the ileocecal valve, from the villi typical of the ileum to the flat mucosa of large intestine. Submucosal fat is typically present. This section also illustrates the presence of Peyer's patches—specialized groups of lymphoid follicles that are commonly prominent in the mucosa and submucosa of the terminal ileum.

covers the exposed portion of the papilla; the lumen is lined with ileal mucosa.

The projecting musculomucosal papilla is supplemented by a complex of veins that acts very much like the complex about the internal anal sphincter. The papillary structure of the junction may serve as a pressure-equalizing valve to prevent reflux of cecal contents back into the ileum, but it is probably ineffective alone. Whether an actual sphincter exists is in dispute, although the complex of circular and longitudinal muscle may function as a sphincter to hold up and release ileal contents. It acts through the gastroileal reflex, because after ingestion of food, the papilla enlarges as the terminal ileum empties.

Vermiform Appendix

The **vermiform appendix** is a narrow tube about 9 cm in length (it is relatively longer in children) that is attached to the cecum 2 cm below the **ileocecal junction** (Figs. 6-28, 6-29, and 6-30). Its site is marked by convergence of the three **teniae** of longitudinal muscle of the ascending colon and cecum that terminate at the base of the appendix, where the cecal smooth muscle continues as the outer longitudinal layer of the appendix. It is held by a triangular **mesoappendix** to the terminal part of the **ileal mesentery**. The wall has four layers—mucous, submucous, muscular, and serous—similar to those of the bowel. Two peritoneal folds are associated with the appendix and ileocecal junction. The **vascular fold of the cecum** runs anterior to the **terminal**

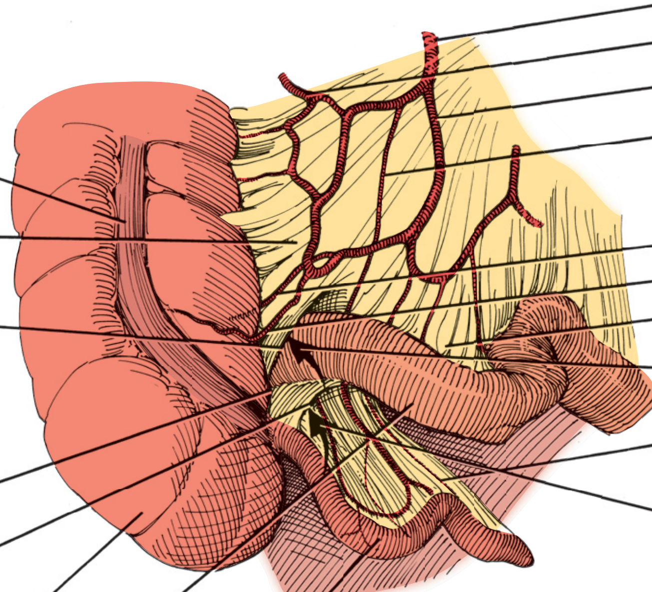

FIGURE 6-28.

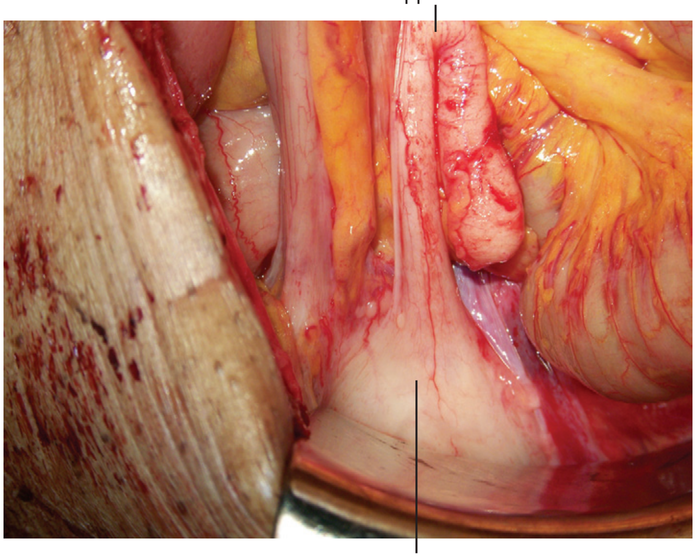

FIGURE 6-29. Intraoperative photo of cecum and appendix. *(Image courtesy of Martin Resnick MD.)*

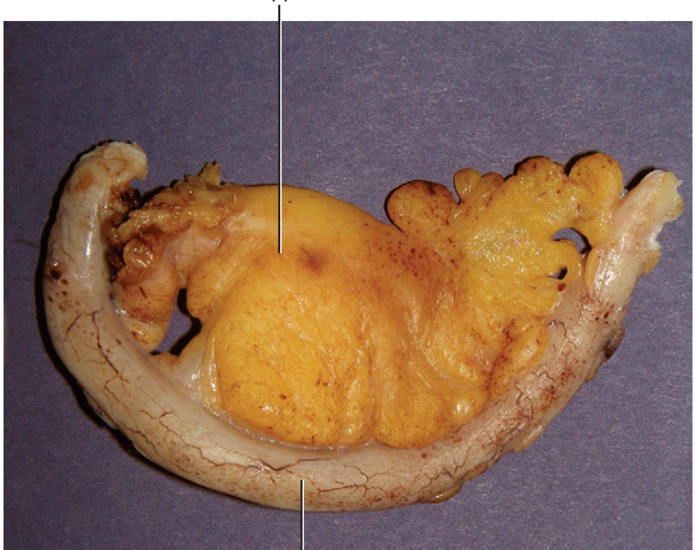

FIGURE 6-30. Normal appendix, with mesentery. *(Image courtesy of Xueli Hao, M.D.)*

ileum from the **cecum** to the **cecal mesentery**, creating the **superior ileocecal recess**. The **ileocecal fold**, the bloodless fold of Treves, crosses to the ileum from the cecum near the base of the appendix or from the mesoappendix to cover the **inferior ileocecal recess**. The histologic features of a normal appendix are shown in Fig. 6-31.

Blood Supply to the Ileocecal Region and Appendix

The more proximal part of the **ileum** is supplied by a system of **ileal arcades** terminating in long **straight arteries** that supply the entire circumference. In contrast, the

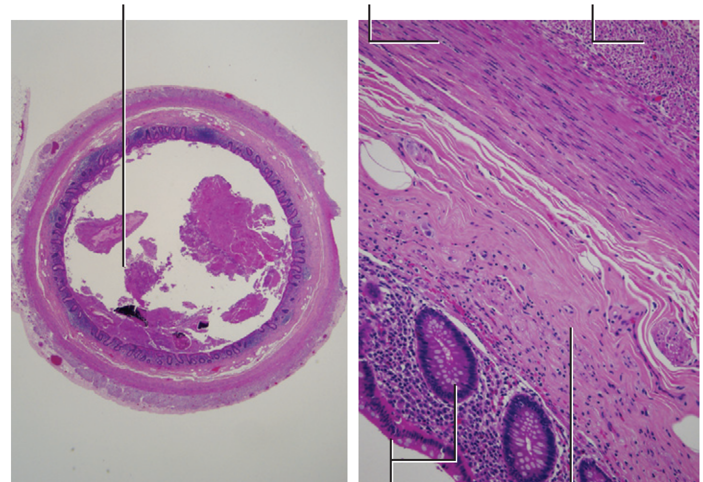

FIGURE 6-31. Appendix. On the left, the lumen contains amorphous debris. On the right, the lumen and the underlying intestinal glands are lined by a mixture of goblet cells and tall columnar cells. The mucosa typically contains abundant lymphoid cells. The muscularis mucosae is often indistinct, whereas the submucosal tissue is a distinct layer composed of collagen and elastic fibers, fibroblasts, scattered inflammatory cells as well as blood vessels, lymphatic vessels, and neural structures. The muscularis externa is composed of an inner circular layer and an outer longitudinal layer.

terminal ileum has a distinct and highly variable blood supply. It lies at the center of the loop formed between **terminal branches** from the superior mesenteric artery to the ileum and the **ileocolic artery**, a major branch of that artery (Fig. 6-32). The network that branches from this loop provides the opportunity for several forms of distribution. The trunk of the ileocolic artery as it terminates gives off branches in several sequences, one being **ascending colic artery, ileal artery, appendicular artery**, and **anterior** and **posterior cecal arteries**. Alternatively, the ileal artery may be given off before the ascending artery or the ileocolic artery may bifurcate into trunks to terminate as the anterior and posterior cecal arteries after releasing branches to the other structures.

Recurrent arteries may originate near the ileocecal junction from one of the cecal arteries or from the ileocolic arcade. These arteries that run along the antimesenteric border of the ileum can be important for the vascularity of the last 3–5 cm of ileum, where the straight vessels from the ileal arcades not only may be scanty but may be of the short type that can supply only the superior half of the ileal circumference. Contrary to previously held opinion regarding the risk of devascularization of the last few centimeters of ileum during bowel resection, a terminal type of vascularization that could leave the distal segment devascularized is not found. Sufficient straight vessels are present, and these are supplemented by recurrent arteries from the cecal circulation. Only a short segment that lies 1–2 cm from the valve is at risk.

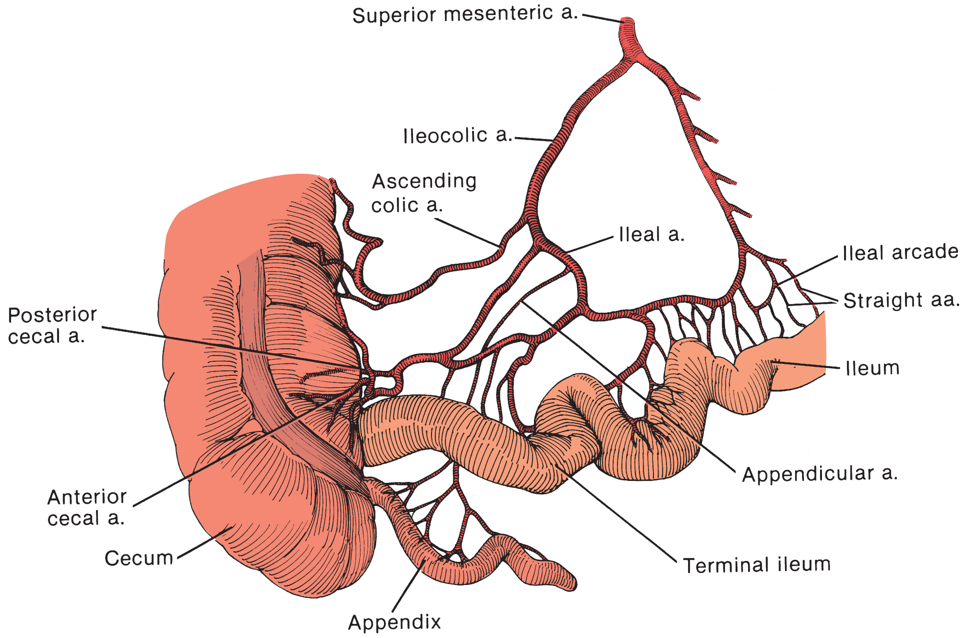

FIGURE 6-32.

The *surgical significance* of these details of arterial supply is that the mesentery must first be examined to see the orientation of the branches of the loop. For ileocecocystoplasty, it is especially important to look for a high bifurcation of the ileocolic artery so the artery itself is ligated, not its branches; this will leave the arcades of the ileal artery and the ascending colic artery intact. Finally, the mesentery must be detached by dividing the terminal arterial branches very close to the ileum to preserve the smaller arcades.

The appendicular artery originates directly from the ileocolic artery (or its ileal branch) or from the cecal artery. There is usually only one artery, but there may be two. The base of the appendix may be supplied by the anterior or posterior cecal arteries. The appendicular vein accompanies the artery to the cecal vein that drains into the ileocolic vein. Chains of lymph channels and nodes along the arteries drain the lymph to the celiac nodes.

The ascending colic artery supplies the first part of the ascending colon. The anterior and posterior cecal arteries run to their respective aspects of the cecum.

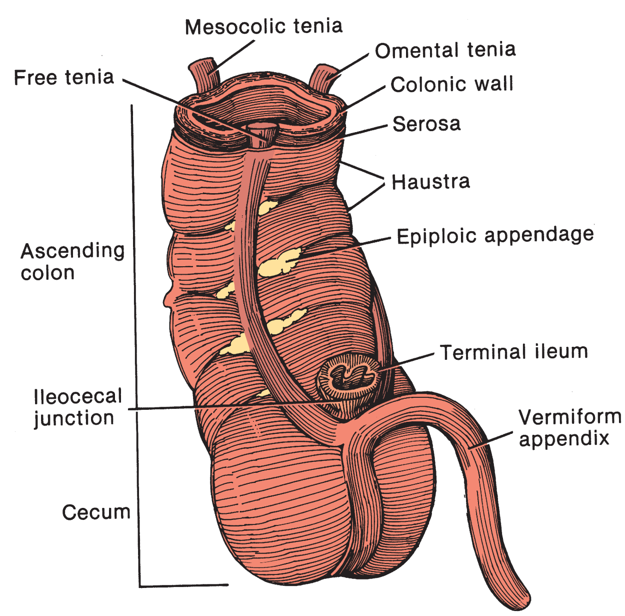

FIGURE 6-33.

Cecum

The **cecum** is defined as that portion of the large bowel proximal to the entrance of the ileum at the **ileocecal junction** (Fig. 6-33). It lies in the right iliac fossa over the iliacus and psoas major but is separated by its covering of peritoneum. The retrocecal recess extends behind it. At birth, the cecum is conical, with the appendix at the apex. Later, the appendix assumes a more medial and cephalad position.

The wall of the cecum and ascending colon possesses the same layers as that of the ileum (serosa, longitudinal muscle, circular muscle, submucosa, muscularis mucosae, lamina propria, and mucosa) but is of heavier construction. In the cecum and the colon, part of the longitudinal muscle fibers are thickened in three strips to form the **teniae coli**: (1) an anteriorly placed **free tenia** (tenia libera); (2) a posteromedial **mesocolic tenia**, where the mesocolon attaches (tenia mesocolica); and (3) an **omental tenia** that is posterolateral (tenia omentalis). The exception is in the transverse colon, where the posterolateral tenia actually lies anterosuperiorly to receive the attachment of the posterior layers of the greater omentum (hence the name tenia omentalis). The three sets of teniae join at the base of the **vermiform appendix**, onto which the outer coat continues. Being shorter than the other portions of the longitudinal coat, the teniae coli produce **haustra**. The mucous membrane is thrown into crescent-shaped folds by haustration. **Epiploic appendages** that are distributed along the colon are pouches of peritoneum containing fat.

Ascending and Transverse Colon; Jejunum and Ileum

Ascending Colon

The ascending colon begins at the ileocecal junction and extends to the right lobe of the liver, where it bends forward and to the left as the **hepatic** or right colic **flexure** (Fig. 6-34). It is surrounded with peritoneum except at that portion of its posterior surface that lies in areolar tissue against the fascia of the posterior abdominal wall and the perirenal (Gerota) fascia.

Transverse Colon

The **transverse colon** begins at the hepatic flexure as a continuation of the ascending colon. It takes a curving course across the abdomen; the center of the arch may even lie in the pelvis. The transverse mesocolon attaches it to the pancreas, beginning at the head. The transverse colon ends at the splenic or left colic flexure, which lies at a higher level than the right flexure. The phrenicocolic ligament attaches the colon to the diaphragm below the lateral end of the spleen.

Blood Supply of the Ascending and Transverse Colon

Arterial blood to this part of the colon, which is a derivative of the midgut, is delivered by the **superior mesenteric artery**. Three branches are involved: (1) the **ileocolic artery**, as the lowest branch of the right-side system; (2) the **right colic artery**; and (3) the middle colic artery as far as the hepatic flexure.

The ileocolic artery divides into a superior and an inferior branch. The **superior branch** joins the **descending branch** of the right colic artery. The **inferior branch** divides into the **ascending colic artery** that supplies the lower part of the ascending colon, the **anterior** and **posterior cecal arteries** that supply the **cecum**, the artery to the appendix, and an **ileal artery** that supplies the **terminal ileum** (see Fig. 6-28).

The right colic artery, which originates from the superior mesenteric artery cephalad to the ileocolic artery, divides into a **descending branch** that joins the ileocolic artery and an **ascending branch** that joins the middle colic artery. They supply the hepatic flexure as well as that part of the ascending colon not supplied by the ileocolic artery.

The middle colic artery, after leaving the superior mesenteric artery below the pancreas, divides into a right and left branch. The **right branch** supplies the right half of the transverse colon and joins the right colic artery. The **left branch** supplies the left half of the transverse colon and joins the inferior mesenteric system through the left colic artery, as shown in Fig. 6-36.

Venous drainage is through the superior mesenteric vein.

Peripheral mobilization of the portion of bowel to be used allows the arteries to be identified so that they may remain intact and be encased in an adequate mesenteric fold.

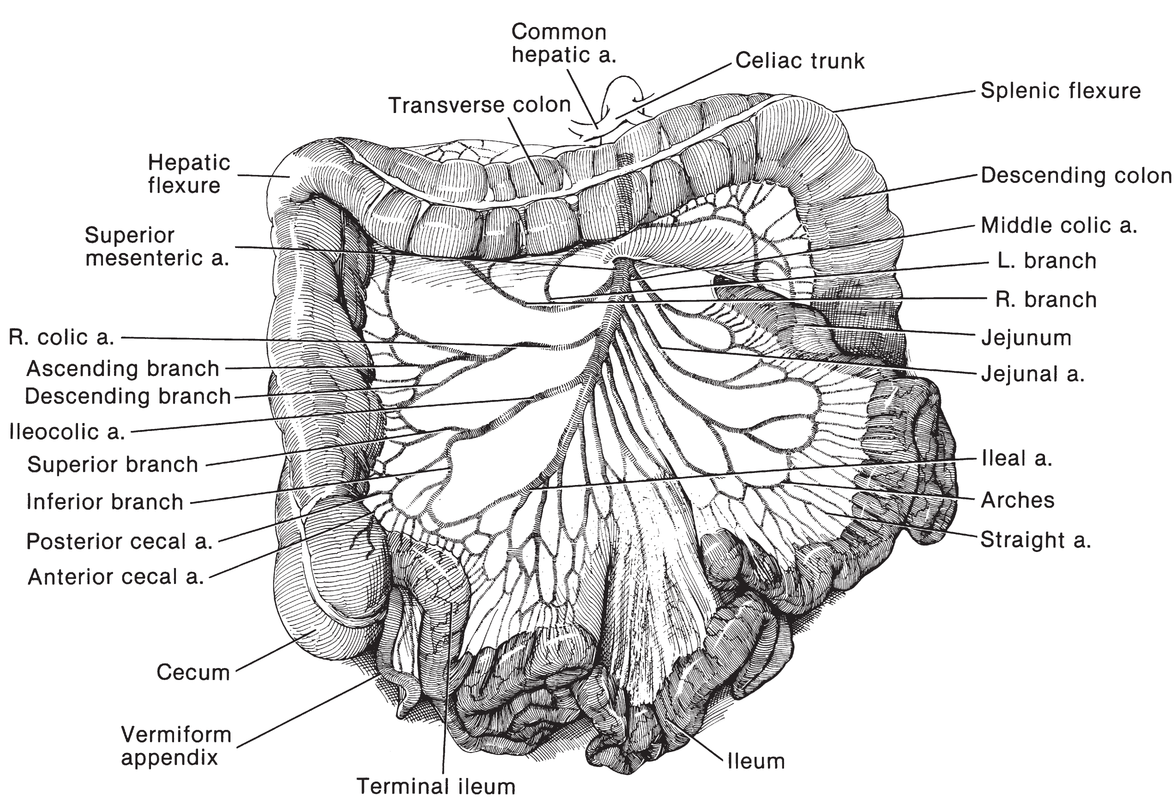

FIGURE 6-34.

The blood supply to the large bowel is more tenuous than that to the ileum and jejunum. There are few anastomoses between the small terminal arteries, and the supply to the mesenteric side is greater than that to the antimesenteric border, especially because the long arteries become appreciably reduced in caliber as they pass under the antimesenteric teniae.

Blood Supply of the Jejunum And Ileum.

As derivatives of the midgut, the **jejunum** and **ileum** are supplied from the superior mesenteric artery. This artery emerges from the aorta a centimeter below the **celiac trunk** and passes ventral to the left renal vein to give off 12–15 **jejunal** and **ileal arteries**. As these arteries divide and each member of the pair joins an adjacent branch, they form **arches**. The divisions continue until, especially in the more distal ileum, as many as five arches are developed to form an arcade. From the arches, short terminal arteries, called **straight arteries**, join the bowel, distributed more or less equally to each side. There they spread between the serous and muscular coats and give off multiple branches to the muscle. Successive vessels usually supply opposite sides of the bowel. After passage through the muscle layer, they join a plexus in the submucosa, which supplies the glands and villi of the mucosa (Fig. 6-35). The veins follow a similar course as the arteries and drain into the superior mesenteric vein. The mucosal lymphatics form a plexus in the mucosa and submucosa that drain the villi and the solitary lymph follicles in the wall.

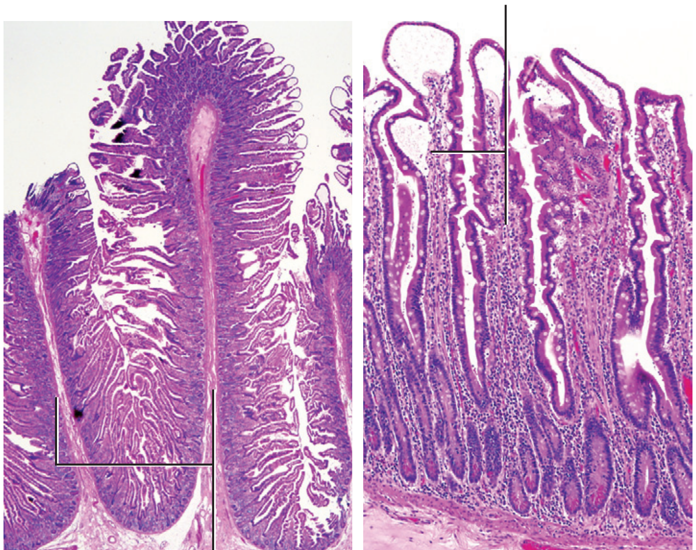

FIGURE 6-35. Jejunum, normal histology. The jejunal portion of the small intestine exhibits taller and more numerous permanent circular folds (plicae circulares), as compared to the ileum. Jejunal villi are tall, slender, and fingerlike, with a villus-to-crypt ratio of 3:1 to 5:1. The epithelium consists of goblet cells and relatively abundant tall columnar absorptive cells.

Lymph vessels (lacteals) drain either the muscle or the mucosa.

Descending and Sigmoid Colon and Rectum

The **descending colon** starts at the left colic flexure and ends by joining the **sigmoid colon** above the lesser pelvis (Fig. 6-36). The posterior surface is free of peritoneum because it is attached to the perirenal fascia and the fascia of the posterior abdominal wall.

The sigmoid colon forms a loop within the lesser pelvis (Fig. 6-37). Three parts may be identified: the first part lies on the posterior abdominal wall, the second runs transversely across the pelvis, and the third turns back to the midline to join the rectum. The colon lies in the sigmoid mesocolon, which is longest in the middle of the loop. In the sigmoid colon, the longitudinal coat becomes more diffusely distributed. Internal to the muscular layer are the usual submucosa and muscularis mucosae layers (Fig. 6-38).

The **rectum** begins where the sigmoid mesentery ends at the level of the body of the third sacral vertebra. It curves in an anteroposterior direction—the **sacral flexure**—before passing through the pelvic floor to join the **anal canal** at the anorectal junction, the site where the anal canal bends backward forming the perineal flexure. The upper part of the rectum is shaped like the sigmoid colon except that it is free of mesentery or epiploic appendixes; the lower part widens to form the rectal ampulla.

Peritoneum loosely covers the anterior and lateral surfaces of the upper portion of the rectum and the anterior surface of the middle portion, forming the rectovesical pouch (the rectouterine pouch in the female). Because the rectum was once an intraperitoneal organ, the remainder is covered by the inner stratum of retroperitoneal connective tissue, the rectal fascia. This layer adjoins the posterior wall of the bladder and prostate (vagina) with the intervening coverings from the intermediate stratum and the fusion-fascia that constitutes the anterior lamella of Denonvilliers' fascia (rectovesical septum in the male; rectovaginal septum in the female). The longitudinal muscle layer, associated with the teniae in the sigmoid colon, spreads out to surround the bowel but remains thicker anteriorly and posteriorly. Some of these anterior fibers in the ampulla join the perineal body, forming the rectourethralis muscle, and some of the posterior fibers attach to the coccyx as the rectococcygeal muscle. The circular layer also becomes thicker around the rectum and especially around the anal canal, where it forms the internal anal sphincter.

The rectum is supported from the sacrum by a band of fascia, the rectosacral (Waldeyer) fascia, and from the posterolateral walls of the pelvis by condensations of the connective tissue associated with the middle rectal vessels that form the lateral ligaments of the rectum. It is held anteriorly behind the prostate and seminal vesicles by the rectovesical fascia.

The **anal canal** begins after the bowel has passed through the levator ani musculature and is surrounded by the external and internal sphincters of the anus. The

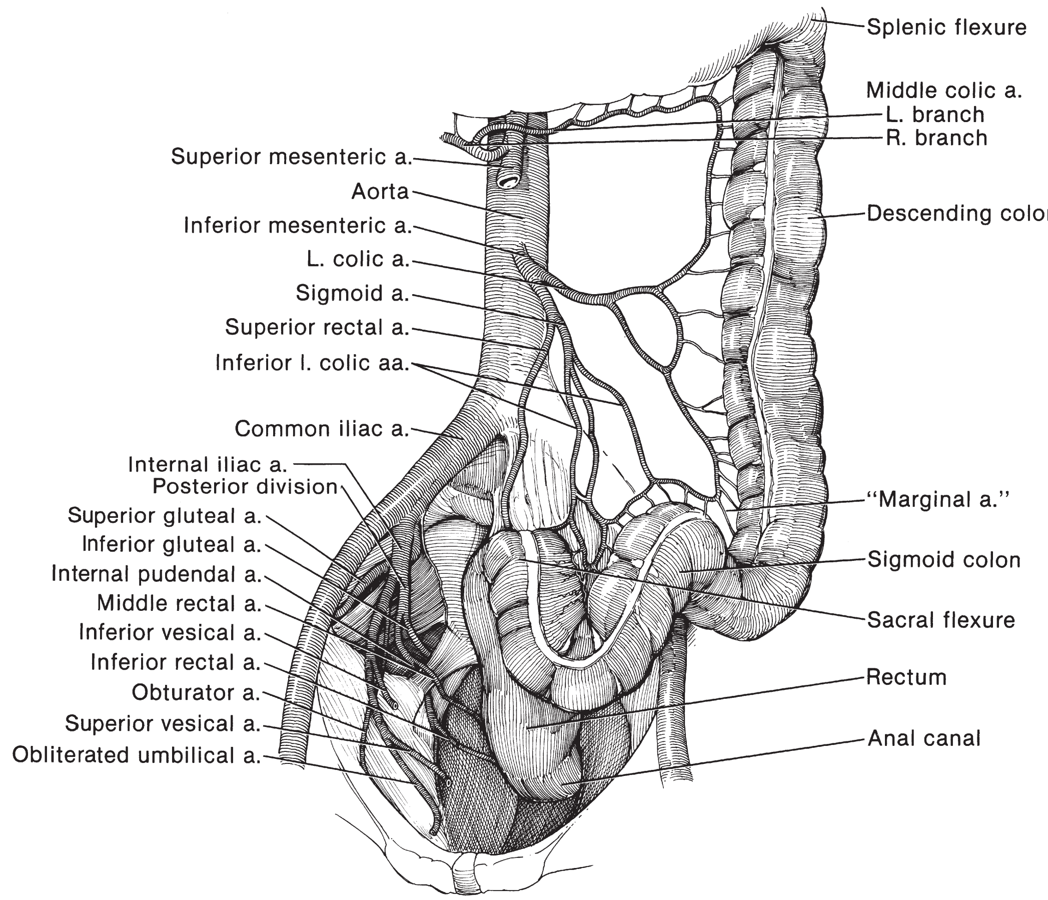

FIGURE 6-36.

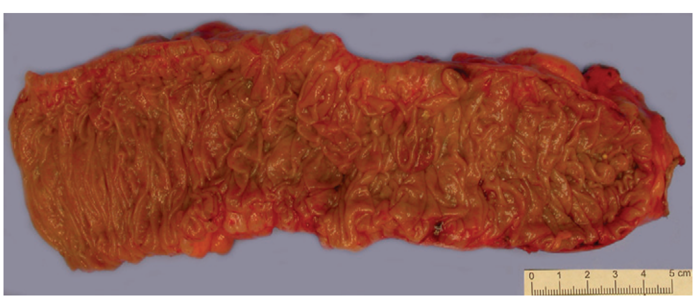

FIGURE 6-37. Sigmoid colon, opened, in fresh state. The specimen was removed for symptomatic diverticulosis and recurrent diverticulitis. The sigmoid colon, when viewed endoscopically, particularly in older adults, often demonstrates luminal narrowing, thickened mucosal folds, and numerous diverticular orifices. *(Image courtesy of Huankai Hu, M.D.)*

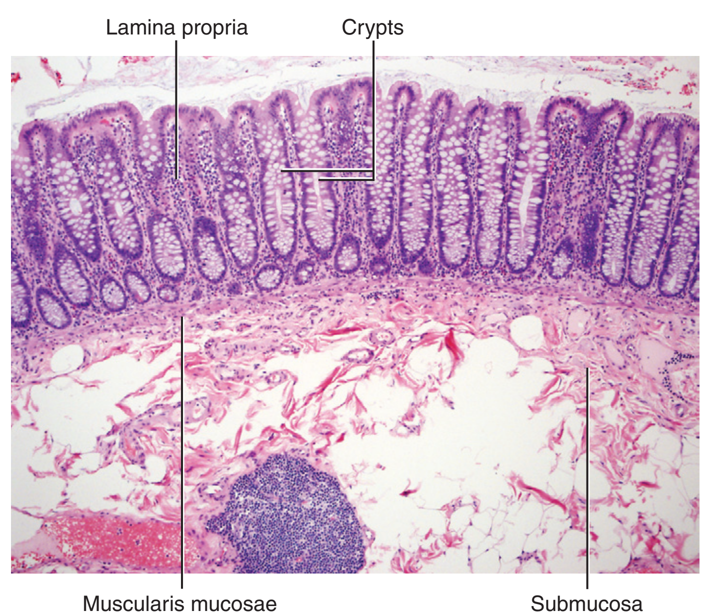

FIGURE 6-38. Colon, normal histology. Mucosal crypts are aligned parallel to one another "like a row of test tubes." Epithelium on the surface and lining the crypts consists of absorptive tall columnar cells and goblet cells. Lamina propria invests the crypts and contains fibroblasts, macrophages, neuroendocrine cells, plasma cells, lymphocytes, eosinophils, and mast cells. A thin but distinct layer of smooth muscle (muscularis mucosae) separates mucosal elements from the submucosal space. The submucosa contains neural plexuses, fat, blood vessels, and lymphatic vessels. The muscularis externa is composed of an inner circular and an outer longitudinal layer of smooth muscle.

function of the internal anal sphincter is supplemented by a dilatable venous pad.

Blood Supply to the Descending and Sigmoid Colon and Rectum (See Fig. 6-36)

Descending and Sigmoid Colon

The **inferior mesenteric artery** supplies the remainder of the large bowel that is not supplied by the superior mesenteric artery. Its first branch, the **left colic artery**, supplies a limited part of the transverse colon near the **splenic flexure** and the first part of the **descending colon**. The next branch, the **sigmoid artery**, after giving off the **superior rectal artery**, splits into two or three **inferior left colic arteries** that supply the **sigmoid colon**. The anastomoses between these arteries appear to form a **"marginal artery"** near the mesenteric margin of the colon. During resection of the right colon, because the anastomosis between the left colic artery and the left branch of the middle colic artery may be highly variable, the main trunk of the middle colic artery should be left to supply the transverse colon up to the left colic flexure. By dividing a major vessel close to its origin, circulation through the arcades formed by the "marginal artery" can be exploited.

Venous drainage follows the arteries to the inferior mesenteric vein.

Rectum

The rectum and upper half of the anal canal receive blood from the most distal branch of the inferior mesenteric artery, the **superior rectal** (hemorrhoidal) **artery**. These structures are also supplied by the **middle rectal** (hemorrhoidal) **artery**, a branch of the **posterior division** of the **internal iliac artery**, and the **inferior rectal artery**, a branch of the **internal pudendal artery**. Venous drainage accompanies the arteries; that going with the superior rectal artery drains into the portal system. The lymphatics from the rectum accompany the superior rectal and inferior mesenteric arteries to the aortic nodes, while those from the anus drain to the superficial inguinal nodes.

Nerve Supply to the Bowel (See Figs 4-11 and 4-12)

Both the sympathetic and the parasympathetic systems supply the large and small bowel.

Jejunum, Ileum, and Ascending and Transverse Colon

That portion of the intestinal tract originating from the midgut and supplied by the superior mesenteric artery receives sympathetic innervation from the celiac and superior mesenteric ganglia, and parasympathetic innervation from the vagus and splanchnic nerves.

The neurons innervate the myenteric plexus composed of nerves and ganglia that lie between the outer and inner layers of the muscular coat of the bowel. From this plexus, nerves pass to a submucous plexus to supply the muscularis mucosae and the mucosa. Both sympathetic (inhibitory to peristalsis and stimulatory to the sphincters) and parasympathetic (with an opposite action, plus stimulatory for secretion) are present in the ileal wall.

Transverse Colon and Descending and Sigmoid Colon

The portion derived from the hindgut and supplied by the inferior mesenteric artery is supplied by sympathetic nerves from the lumbar part of the sympathetic trunk and from the inferior mesenteric plexus via the hypogastric plexus. It is also supplied by parasympathetic nerves from the pelvic splanchnic nerves—the nervi erigentes—through the inferior and superior hypogastric plexuses and along the inferior mesenteric artery to the left colon.

Rectum

The rectum is innervated from aganglionic autonomic nerve plexuses (rectal plexus via the inferior mesenteric plexus) that run in the areolar tissue. They are connected to the myenteric plexus, which has ganglia situated between the two muscle layers. In addition, a submucous plexus is present. The external sphincter has a rich somatic nerve supply.

Section II

BODY WALL

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Chapter 7

Anterolateral Body Wall

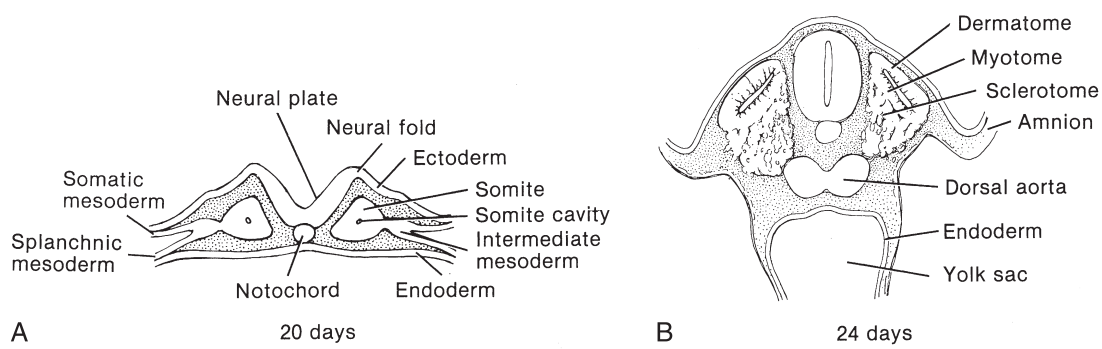

FIGURE 7-1.

There bee tenne muscles which couer the nether Belly, on either side fiue, called the muscles of the Abdomen.

CROOKE
Body of Man, 796, 1615

DEVELOPMENT OF THE ABDOMINAL WALL MUSCLES

The extraembryonic mesoderm divides longitudinally into a paraxial part, from which the dorsal muscles will develop, and a lateral plate, the precursor of the muscles of the abdominal wall.

Somites

The paraxial mesoderm becomes segmented transversely into **somites,** each of which appears as a mass of mesodermal cells arranged around a central **somite cavity,** in continuity with the **intermediate mesoderm** (Fig. 7-1A).

Except for the cervical and cranial ones, the somites differentiate into three portions: (1) a **dermatome** from the outer wall, to form the skin; (2) a **myotome** from the dorsal part of the inner wall, to form the muscles of the body wall and limbs; and (3) a **sclerotome** from the ventral part of the inner wall, which forms the skeleton (Fig. 7-1B).

Myotomes

Around 5 weeks, the **myotomes** divide into a **ventral division** and a smaller **dorsal division,** each of which will be supplied by an anterior or posterior branch of the corresponding spinal nerve (Fig. 7-2). The individual myotomes formed by the dorsal division remain arranged segmentally, but those formed by the anterior division (on the lateral plate) lose their segmentation before the age of 3 weeks.

Trunk Muscles

From the anterior myotomes, precursor cells separate in the thoracic area as discrete buds and emigrate to staging areas in the flank to form large premuscle masses. Primitive myotubes from the myoblasts in these masses assume the orientation that the muscle fibers will later take. As differentiation progresses, these premuscle masses split longitudinally or tangentially into the primordia of individual muscles and fuse with mesodermal material from adjacent myotomes.

As the ribs develop, the ventral extension of the myotomes in the thoracic area moves anteriorly to form the muscles of the anterior abdominal wall. Those in the lumbar area form the psoas and quadratus lumborum, which are involved in flexing the vertebral column, and those in the sacral area form the musculature of the pelvic diaphragm. The dorsal myotomes develop into the extensor muscles of the back. The lumbodorsal fascia forms over them and separates them from the **latissimus dorsi** and parts of the **serratus,** which are migratory muscles of the anterior division (see Fig. 8-2).

Development proceeds, through final shifting and growth, to reach the fully differentiated state (Fig. 7-3). The **rectus abdominis** is formed by longitudinal splitting of the ventral end of the fused myotomes. The **external oblique** and the serratus posterior superior and inferior arise

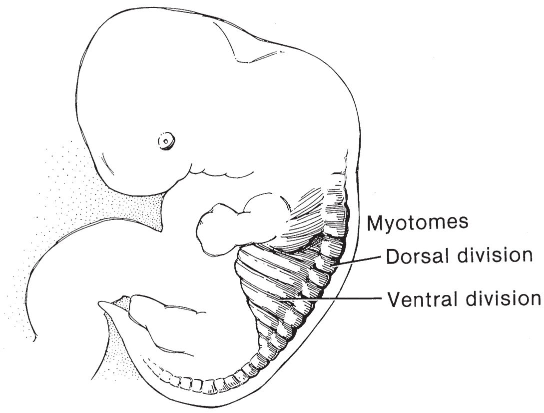

FIGURE 7-2.

through a tangential split of the lateral sheet, and the internal oblique and **transversus** arise from the medial sheet; the remaining part of the myotomal processes form the internal and external intercostals. At 6 weeks, the muscles are differentiated, although in a more lateral position than in the adult. In fact, the recti are still widely separated at 10 weeks, a condition that, if persistent, would result in diastasis recti. Some of the myotomal material degenerates and disappears entirely or remains as vestigial fibrous structures to form the aponeuroses of the anterior trunk muscles, or as the nonmuscular sacrotuberous ligament. In contrast, the tendons do not originate from the muscles but develop from the local connective tissue to become secondarily attached to the muscles.

The number of muscle fibers is established in the neonatal period, but the fibers may grow by the addition of sarcomeres at either end or by an increase in diameter. Satellite cells are added to the muscle fiber syncytium as the fibers grow. It is from these cells that muscle fibers may regenerate after surgical or other injury.

The mesenchyme underlying the rectus abdominis and transversus abdominis is continuous with that covering the levator ani. The transversalis fascia will develop from this portion of the retroperitoneal tissue, a layer that is separate from the epimysium of the muscles of the body wall.

ANOMALIES

Prune Belly Syndrome

Although several theories have been championed, the embryogenesis of this anomaly (absence or hypoplasia of the abdominal muscles, distention of the bladder, ureters, and renal pelves, and cryptorchidism) is not understood. Muscular change secondary to distention of the urinary tract, with or without ascites, is a doubtful cause; an obstructive lesion is not found and known obstructive lesions such as urethral valves do not result in the syndrome. A primary mesodermal defect may be at fault, because both of the involved systems—the urinary tract and the abdominal wall—arise from the mesoderm of the paraxial intermediate and lateral plates.

The defect starts before the seventh week, when the several muscles differentiate from the somatic mesoderm of the anterior division of the myotomes (see Fig. 7-3). The first lumbar segment has been implicated in the dysgenesis because normally much of the oblique and transverse muscles develop from this location; the hypoplasia is maximum here and is less pronounced above and below. However, defects of the lower limbs indicate that the dysgenesis may extend to the lower lumbar and sacral segments and absence of the upper portion of the rectus suggest involvement of the lower thoracic region.

The effects of the anomaly vary from minimal hypoplasia to complete absence of muscle fiber, but the medial and lower portions of the abdomen are uniformly involved. A sheet of fibrous tissue, which is firmly attached to the peritoneum, takes the place of the muscles (Fig. 7-4). Occasionally, congenital megalourethra is found. The bladder is large and thick walled, often with a pseudodiverticulum on the dome, and is attached to the umbilicus (Fig. 7-5). The trigone is

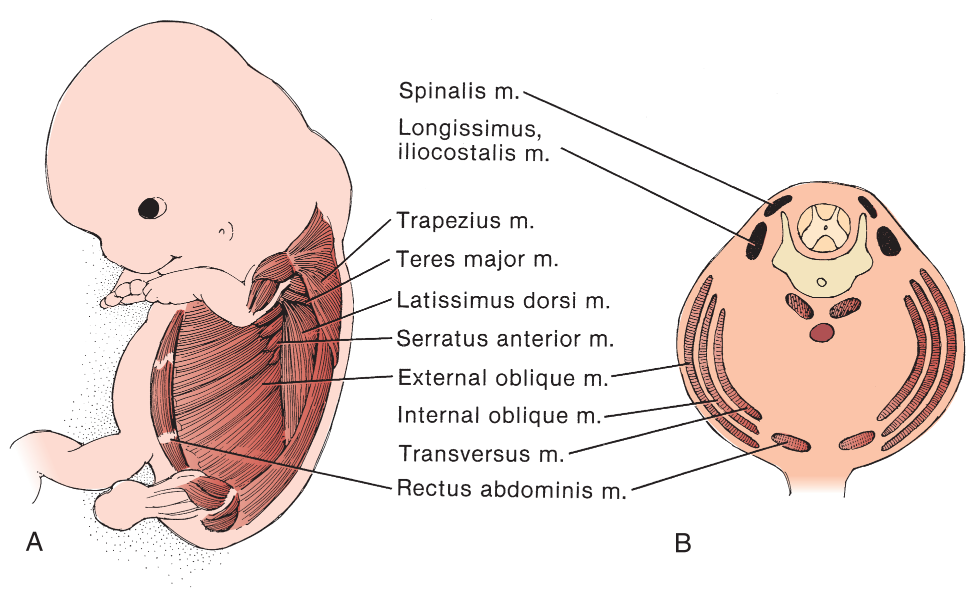

FIGURE 7-3. A, Oblique view. **B,** Transverse cut at the level of the 1st lumbar vertebra.

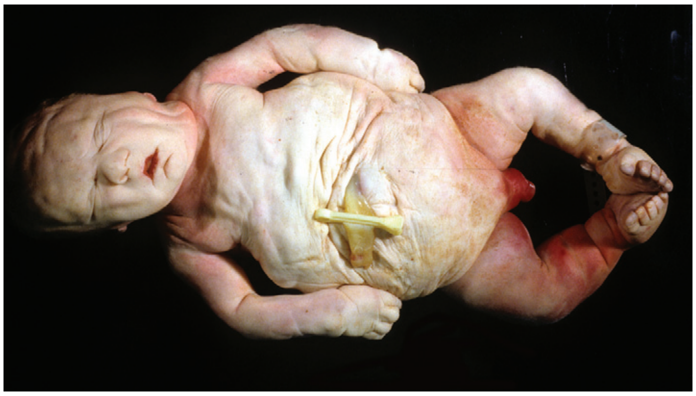

FIGURE 7-4. Abdominal distension and prominent wrinkling of the abdominal skin are characteristic of prune belly syndrome. Although the underlying pathophysiology is enigmatic, distension of the abdomen associated with distension of the urinary bladder is present in all cases. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. London, Springer-Verlag, 2011.)*

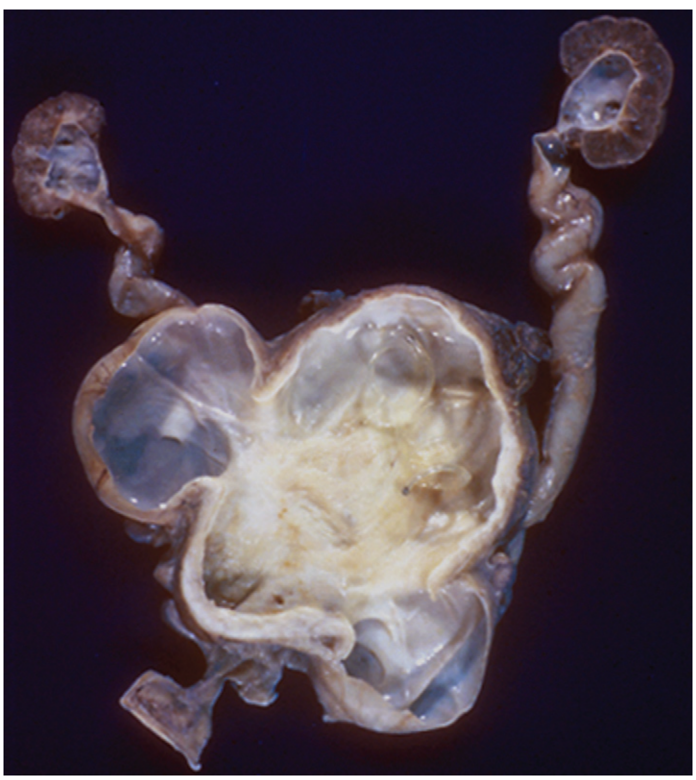

FIGURE 7-5. In the classic form of prune belly syndrome, the bladder appears distended, and there is bilateral hydroureteronephrosis. It is unclear whether failure of bladder emptying is a mechanical or a physiologic problem. Mechanical obstructions may include posterior urethral valves, urethral diaphragm, urethral stenosis, atresia or multiple lumina; or the bladder neck may be incompetent, forming a flap-like valve. When seen at autopsy, the bladder is not always massively distended and thin-walled. After decompression, it may be small or normal-sized but markedly thick-walled; in such cases, bilateral upper tract distension and renal abnormalities are readily apparent nonetheless. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. London, Springer-Verlag, 2011.)*

large, and reflux is common. The bladder neck is widely dilated far down into the prostatic urethra. The prostate itself is poorly developed, usually consisting of only a shell. The upper tracts are dilated, and renal dysplasia and hydronephrosis are not uncommon findings. Cryptorchidism, accompanied by short spermatic vessels, is the rule.

ANTEROLATERAL AND LOWER ABDOMINAL BODY WALL: STRUCTURE AND FUNCTION

Surgical access to the contents of the abdomen and pelvis is through the abdominal wall and requires incisions that gain the greatest exposure with the least disturbance of muscular and fascial layers and the nerve and blood supply to them.

The body wall has three major layers—skin, musculofascial, and peritoneal—to be traversed during surgery (Table 7-1).

The external oblique is the most powerful muscle of the body wall and the internal oblique, only a little less so. In contrast, the transversus abdominis is the thinnest and contributes least structurally but is important surgically because the principal vessels and nerves lie on the surface of its investing fascia as they run in the direction of its fibers. Thus, when one is opening the transversus, injury to a nerve is possible and incorporation in a suture can occur when closing.

Although the intrinsic fascial layer that intimately covers the external surface of each of these muscles is not well developed, it is strong enough to hold sutures spaced 1 cm apart and 1 cm deep even if little or no muscle is included in them.

The muscles and their relationships can be most clearly comprehended by first topographically viewing the surface of the body wall, then removing successive muscle layers until the deepest structures of the body wall, the transversalis fascia and the muscles of the posterior body wall, are reached.

Topography

From the surface, the more superficial muscular layers of the anterolateral body wall can be seen (Fig. 7-6). The oblique course of the **external oblique** is clear, especially in its upper portion. Note the insertion of slips from the external oblique between similar slips from the **serratus anterior inferior** and the passage of slips of the external oblique beneath the **latissimus dorsi**. The **pectoralis major** inserts above the serratus muscles. The belly of the external oblique joins its aponeurosis, which, in turn, is incorporated into the anterior rectus sheath beginning at the **semilunar line.** The **tendinous intersections** of the **rectus abdominis** have a role as fixation points for contraction of the muscle in its upper portion.

The *skin* is described in Chapter 5.

Fascial Layers

One thin but definite layer, the superficial fascia, lies under varying thicknesses of superficial fat over most of the abdomen, the bulk being in the lower abdominal wall. Near the

LAYERS OF THE BODY WALL

TABLE 7-1

SKIN AND SUPERFICIAL FASCIA

Dermis: Supports the epidermis

Subcutaneous fascia: superficial (dartos); deep (Scarpa's, Buck's, Colles')

Deep muscular fascia: external investment of body wall muscles (external oblique, internal oblique, transversus abdominis)

MUSCLES OF BODY WALL RETROPERITONEAL TISSUE

Outer stratum: investment of body wall muscles (transversalis fascia and its pelvic extensions)

Intermediate stratum: investment of urinary tract organs (Gerota's fascia, prostatic sheath, lateral vesical pedicle, broad ligament)

Inner stratum: investment of intestinal tract (supporting connective tissue of the peritoneum)

PERITONEUM

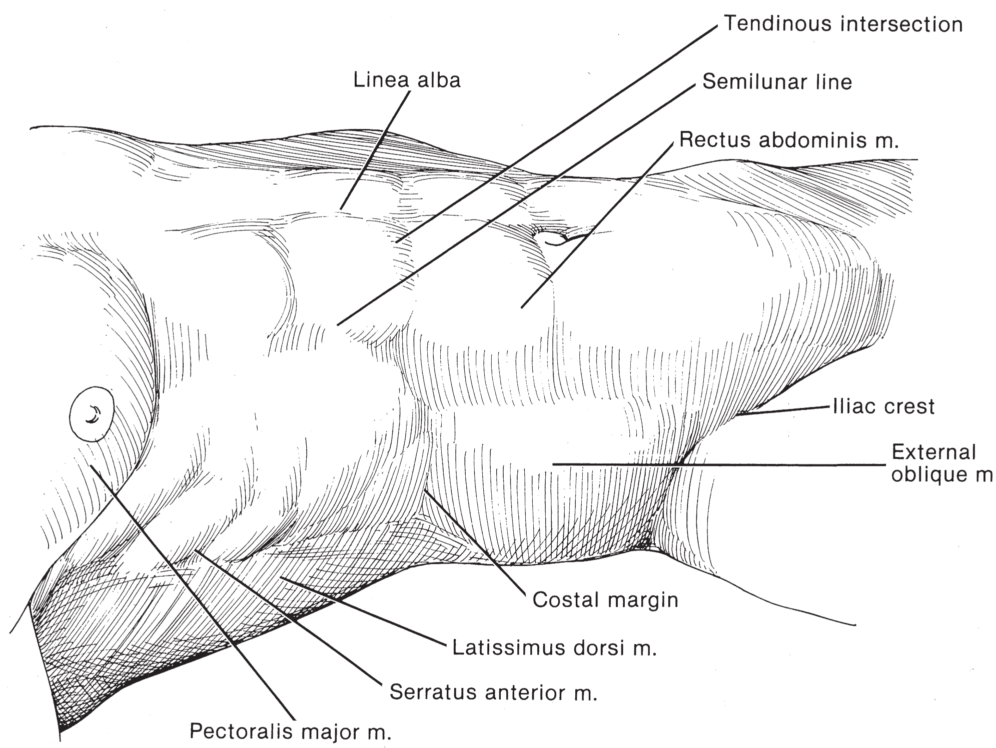

FIGURE 7-6.

groin, the fascia separates into two layers: (1) a superficial layer (Camper's fascia) and (2) a deep or membranous layer (Scarpa's fascia) (see Chapter 9 for details of the inguinal area). The deep layer, sutured during wound closure, brings the fatty layers together, which is especially desirable in obese patients.

External Oblique and its Attachments

The **external oblique,** the most superficial of the anterior muscles, after rising as narrow fleshy slips from **ribs 5** to **12,** runs obliquely forward and downward (Fig. 7-7A). The upper slips fit between similar slips of the **serratus anterior inferior** near their attachment to the upper ribs; the lower, deeper ones arise among similar slips from the **latissimus dorsi** that are attached to the lower ribs (Fig. 7-7B). The external oblique inserts in part on the anterior half of the **iliac crest** and in part in a broad **external oblique aponeurosis** that extends to the midline after participating in the formation of the **anterior rectus sheath,** of which it forms the most superficial part. It fuses with the opposite aponeurosis as part of the **linea alba.** This layer of the sheath can be separated from the underlying layer derived from the internal oblique usually to the mid-belly of the rectus abdominis. The free inferior border of the external oblique forms the **inguinal ligament** that extends from the **anterior superior iliac spine** to the pubic tubercle and attaches to the **symphysis** and the **pubic crest**. Laterally, it is attached to the iliopsoas fascia and medially to the pectineus fascia. An opening occurs above the medial end of the ligament, the **superficial**

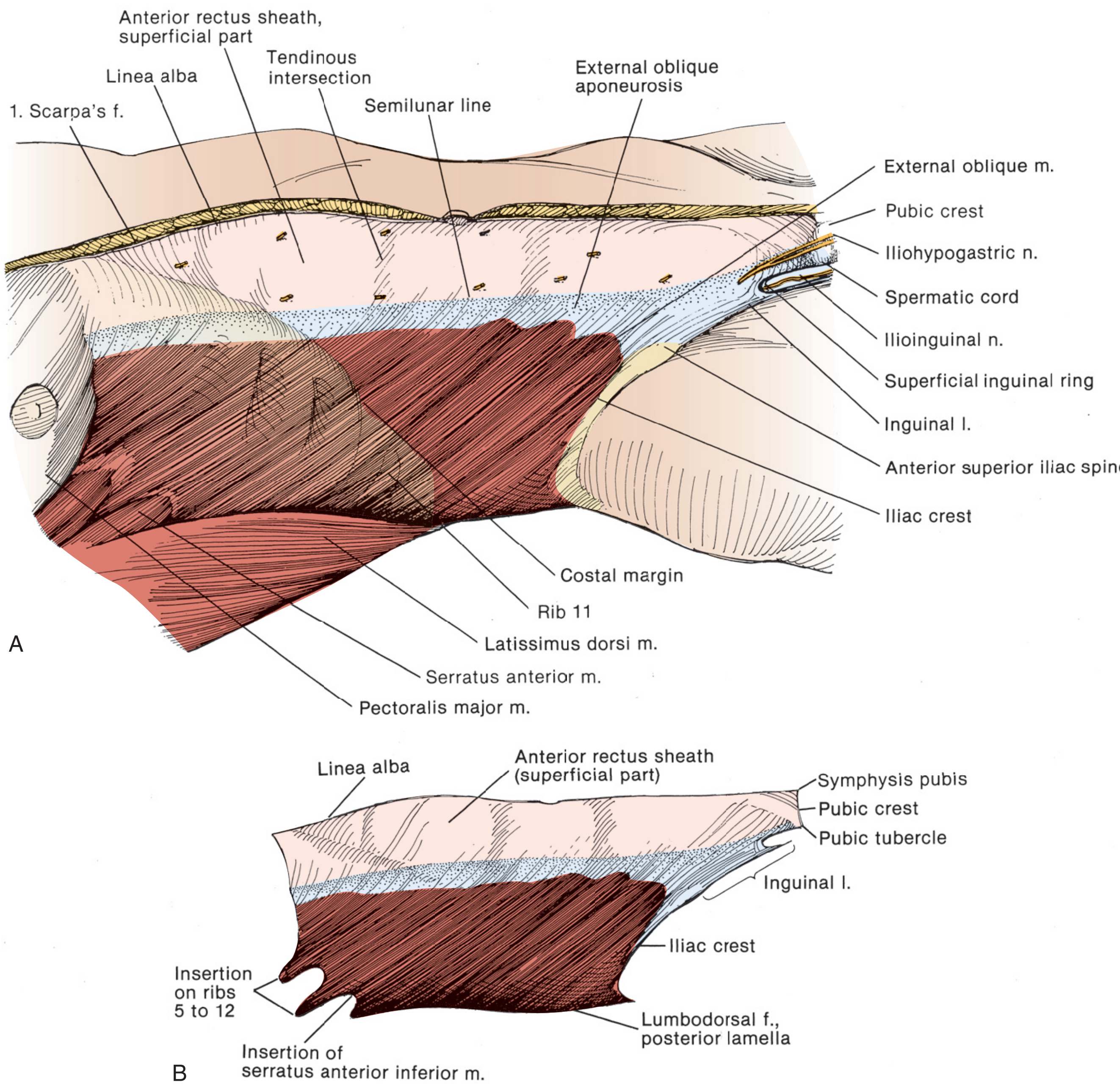

FIGURE 7-7.

inguinal ring from which the ilioinguinal nerve emerges (see Chapter 9 for details of the inguinal area). Dorsally, the external oblique joins the posterior lamella of the lumbodorsal fascia. Innervation is from the ventral (motor) rami of the lower six spinal nerves.

The deep fascia covering the external oblique, the innominate fascia of Gallaudet, is a distinct layer separable not only from the muscle but also from its aponeurosis. Below the inguinal ligament, the innominate fascia continues as the fascia lata of the thigh.

Internal Oblique and its Attachments

A smaller, thinner muscle than the overlying external oblique, the **internal oblique** has a fan shape, with the convergence lying posteriorly. It arises from three sites: (1) the lateral half of the upper surface of the **inguinal ligament** (or from the iliopsoas fascia), in association with the transversus abdominis; (2) the anterior two-thirds of the **middle lip** of the **iliac crest;** and (3) the **posterior lamella** of the **lumbodorsal fascia** (Fig. 7-8A). The lumbodorsal fascia, in turn, covering the erector spinae, connects the internal oblique indirectly to the spines of the lumbar vertebrae. The internal oblique also attaches to the **costal margin** extending from the 9th to the 12th ribs. Anteriorly, the muscle continues as the **internal oblique aponeurosis**. Part of the aponeurosis passes anterior to the rectus abdominis to form the **middle part** of the **anterior rectus sheath** (Fig. 7-8B). Another part passes posterior to form part of the posterior layer of the rectus sheath. After forming the sheaths, the aponeurosis attaches to the **linea alba** and merges with its contralateral counterpart. The lowest fibers of the aponeurosis curve medially and downward to form part of the roof of the **inguinal canal** and join with the dominant fibers from the transversus abdominis to form the **conjoined tendon** running to the **pubis** on the pectineal line. The **iliohypogastric nerve** emerges from beneath the internal

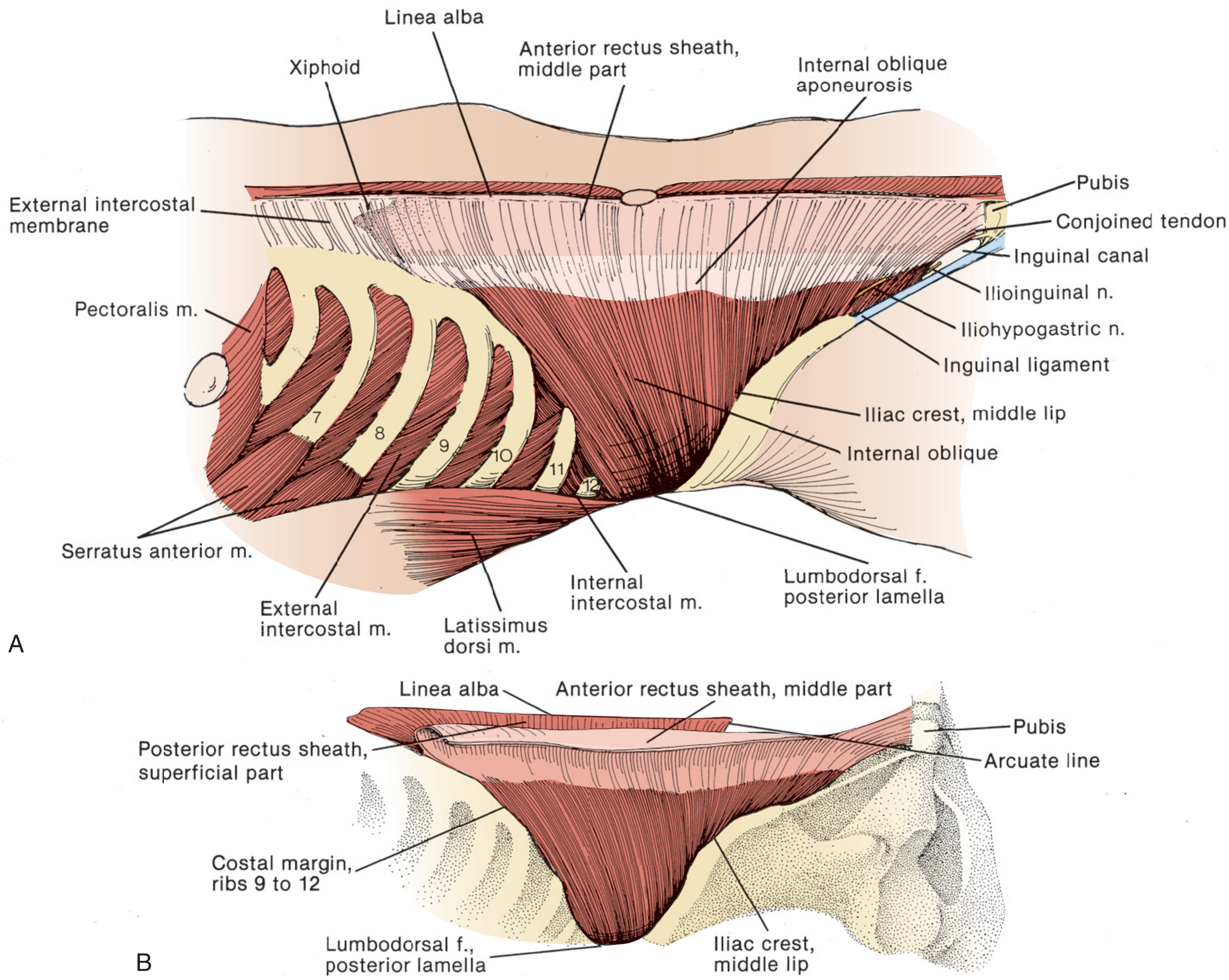

FIGURE 7-8.

oblique proximal to the inguinal canal; the **ilioinguinal nerve** exits distal to the margin of the canal.

The nerve supply to the internal oblique is the same as that to the external oblique but, in addition, includes some innervation from the first lumbar nerve.

Intercostal Muscles

The 11 **external intercostals** are actually of the same layer as the external oblique, and like its fibers, they run downward and forward as they connect the lower and upper borders of the ribs. Over the cartilages and extending to the sternum, an aponeurosis, the external intercostal membrane, substitutes for the muscle. Similarly, the **internal intercostals** beneath, like the internal oblique, run upward and forward. Posterior to the costal angle, an internal intercostal membrane substitutes for this muscle.

Transversus Abdominis and its Attachments

Lying under the internal oblique muscle, the transversus abdominis runs in a transverse direction, as its name implies. It arises from three areas. The upper part arises from the inner surface of the lower six **costal cartilages,** the middle part from fusion with the posterior and middle lamella of the **lumbodorsal fascia,** and the lower part from the lateral third of the **inguinal ligament** and the anterior two-thirds of the inner lip of the **iliac crest** (Fig. 7-9A). It interdigitates with slips from the diaphragm on the costal cartilages. The fleshy fibers run horizontally forward to become the transversus abdominis aponeurosis near the lateral border of the **rectus abdominis** (Fig. 7-9B). The lower fibers of the aponeurosis curve downward and fuse with fibers from the aponeurosis of the internal oblique as they insert into the **crest of the pubis** and pectineal line as the **conjoined tendon**. The upper part of this broad aponeurosis fuses with the posterior layer of the aponeurosis fuses with the posterior layer of the aponeurosis of the internal oblique muscle to form the **posterior rectus sheath**. Caudal to the arcuate line, the aponeurosis passes over the rectus abdominis to form the deep part of the **anterior rectus sheath**. Although in the illustration it is represented as a separate layer, the transversus abdominis is actually fused with the overlying part of the sheath that is derived from the internal oblique. The lowest fibers of the aponeurosis attach to the lateral part of the inguinal ligament, arch over the inguinal ligament and the inguinal canal, and in combination with the internal oblique, make up a portion of the conjoined tendon.

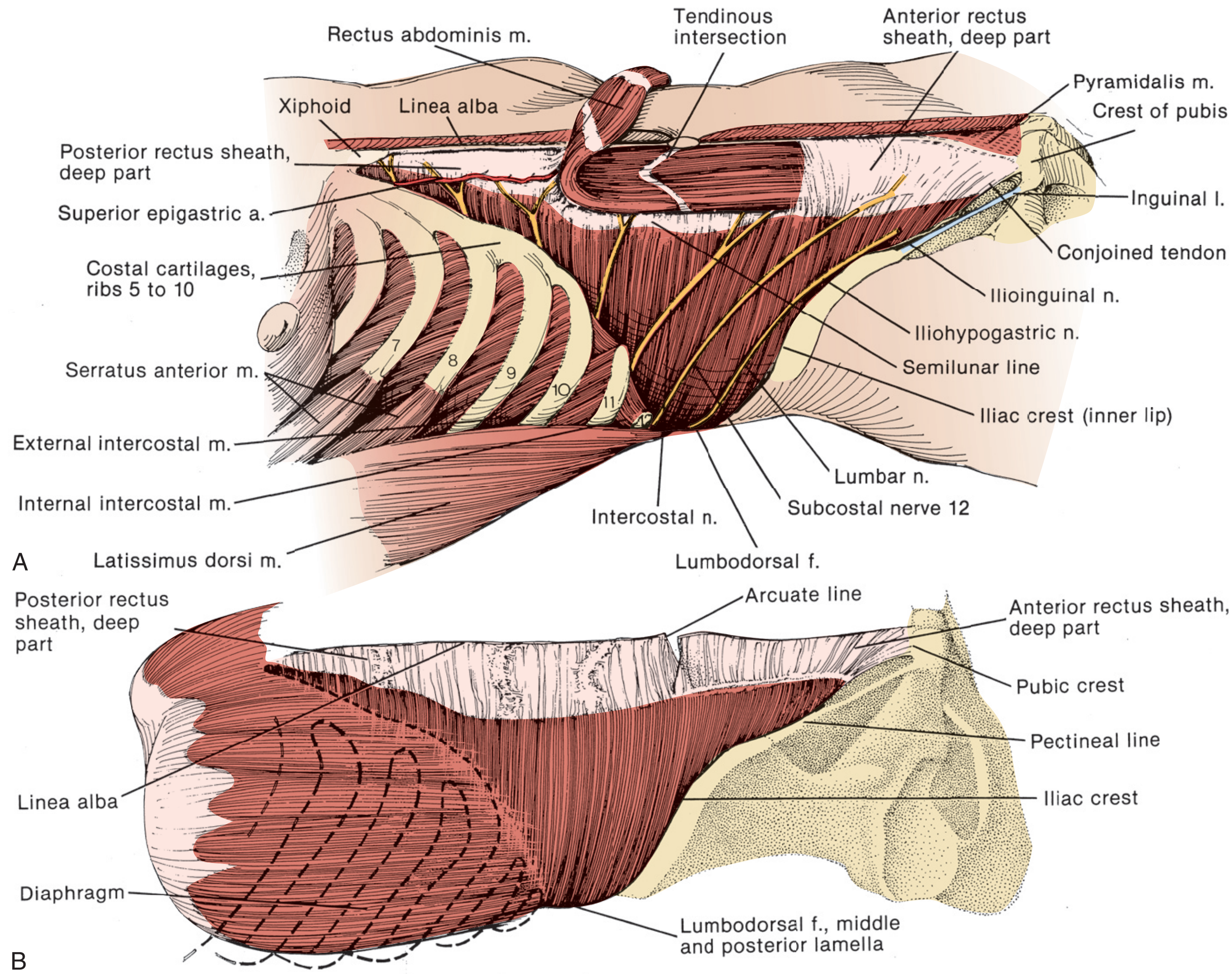

FIGURE 7-9.

Conjoined Tendon

The conjoined tendon of the internal oblique and transversus, composed principally of the aponeurosis of the latter muscle, inserts into the **crest** and usually to the ridge of the pubis. Medially it joins the **rectus sheath**.

Serratus Anterior

The serratus anterior inferior inserts on ribs 7 and 8 after emerging from beneath the **latissimus dorsi.**

Blood Supply

Besides that from the lower intercostal vessels, blood is supplied by the **superior epigastric artery** that lies on the posterior rectus sheath and goes to the rectus and part of the transversus abdominis.

Nerve Supply

The ventral rami of the lower six thoracic and the first **lumbar nerves** innervate the skin, muscles, and peritoneum over the anterior abdomen. **Intercostal nerves 7 to 11** exit from the intercostal space to enter the neurovascular plane, lying between the internal oblique and transversus abdominis. Intercostal nerves 7 and 8 slope upward, the 9th courses horizontally, and the 10th and 11th run obliquely downward. They terminate medially as anterior cutaneous branches in the skin after passing through the rectus abdominis and anterior rectus sheath. The 12th or **subcostal nerve** runs forward under the 12th rib, then enters the neurovascular plane over the transversus abdominis. The six lowest intercostal nerves give off lateral cutaneous nerves that separate into an anterior branch to supply the skin up to the lateral edge of the rectus abdominis and a posterior branch to innervate the skin over the latissimus dorsi.

The ventral ramus of the first lumbar nerve forms two branches. The upper branch is the **iliohypogastric nerve,** which divides just above the iliac crest to form the lateral cutaneous branch to the buttock and the anterior cutaneous branch to the suprapubic region. The lower branch, the **ilioinguinal nerve,** after running in the neurovascular plane, goes through the internal oblique above the iliac crest to reach the spermatic cord (or the round ligament of the uterus) in the inguinal canal. Its final distribution is to the skin of the medial side of the upper thigh, of the proximal portion of the penis and of the top of the scrotum (or, in the female, the mons pubis and anterior part of the labia majora).

Surgeons: Note that the intercostal nerves and accompanying vessels lie on the surface of the investing fascia of the transversus abdominis, as does the iliohypogastric nerve and the terminal part of the ilioinguinal nerve. These nerves run at an angle downward in the lower part of the abdomen but in the upper portion their course is obliquely upward, making denervation of the rectus possible with chevron-type incisions.

Rectus Abdominis

The two long muscles of the **rectus abdominis** run vertically on either side of the **linea alba,** which is a dense midline interlacing of the several aponeuroses, particularly condensed around the umbilicus (Fig. 7-10). Attachment of the rectus abdominis superiorly is by three unequal slips to the anterior surfaces of the **costal cartilages 5, 6,** and **7.** Occasional connections occur with the 4th or 3rd rib above and with the **costoxiphoid ligaments.** The attachment inferiorly is by two tendons: a smaller medial one attaches to the anterior aspect of the **symphysis pubis** and a larger lateral tendon attaches to the pubis often as far laterally as the **pubic crest**. The **semilunar line** marks its lateral margin. Several **tendinous intersections,** one of which is usually at the level of the umbilicus with a second midway to the xiphoid and another at the level of the xiphoid (rarely are they found below the umbilicus), zigzag incompletely across the muscle to divide it transversely. They are densely adherent to the anterior rectus sheath.

The paired **pyramidalis muscles,** arising from the anterior surface of the symphysis pubis, insert in the linea alba inside the rectus sheath. They are supplied by the 12th intercostal nerve.

Rectus Sheath

The sheath containing each **rectus abdominis** is formed from combined aponeuroses of the anterior abdominal wall muscles (Fig. 7-11).

The **anterior rectus sheath** covers the muscle for its full length and is firmly attached to it at the tendinous intersections. Above the costal margin, the anterior sheath is comprised solely of the external oblique aponeurosis. From the costal margin to the **arcuate line** (linea semicircularis, Douglas), it is composed of the **aponeuroses of the external oblique** and that of the anterior half of the **aponeurosis of the internal oblique**. Below the arcuate line, the **aponeurosis of the transversus abdominis** contributes a deep part to the anterior sheath. However, considerable variation may be found in the contributions of the aponeuroses to the sheaths and in the level of the arcuate line.

The **posterior rectus sheath** is composed of the deep part of the aponeuroses of the internal oblique and the aponeurosis of the transversus abdominis. Superiorly, the sheath ends at the costal margin to permit attachment of the rectus abdominis directly to the costal cartilages. Inferiorly, the posterior sheath stops just below the level of the umbilicus, forming the arcuate line, although the level may vary. This leaves the investing fascia of the lower third of the muscle in

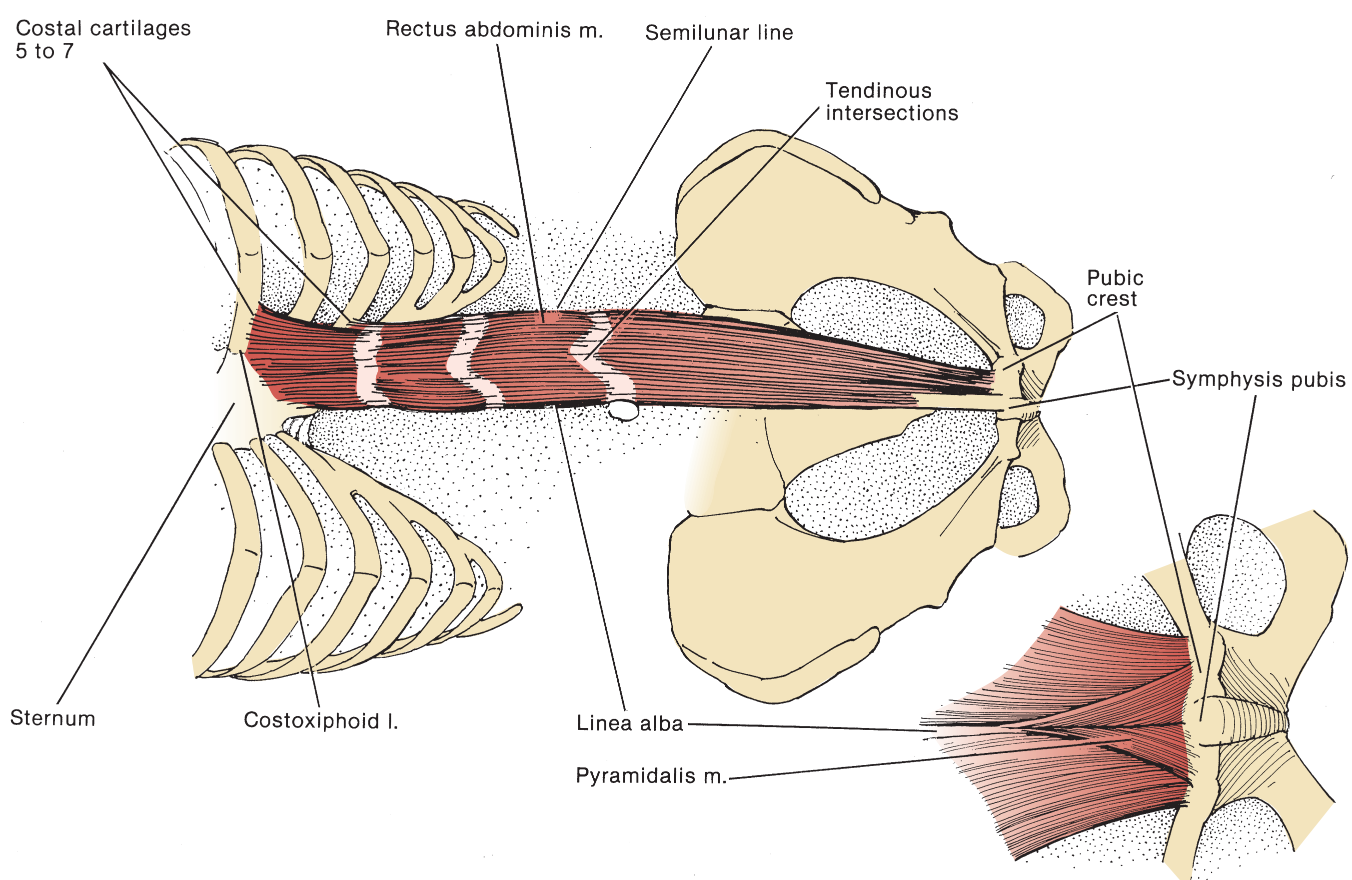

FIGURE 7-10.

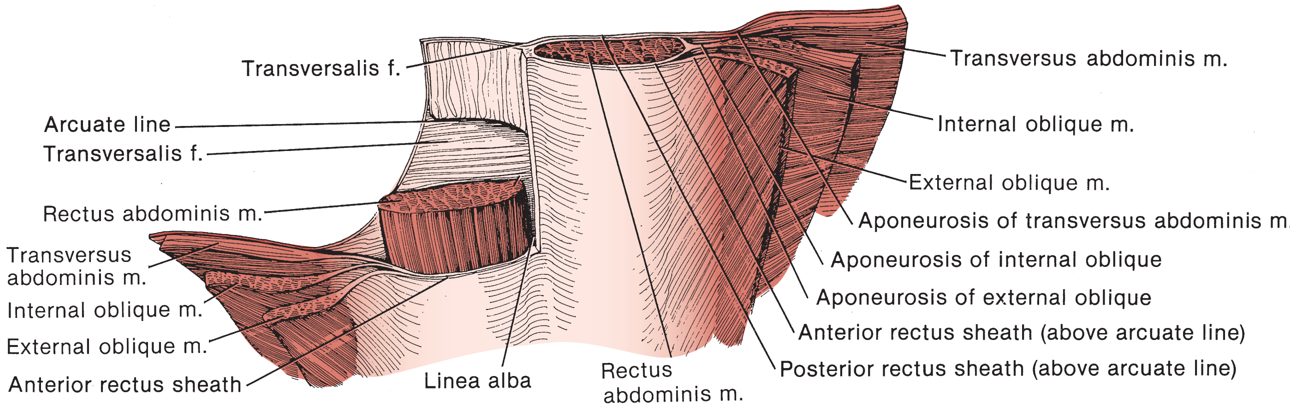

FIGURE 7-11.

contact with the intermediate stratum of the retroperitoneal connective tissue.

Inside the sheath under the muscle are the superior and inferior epigastric vessels and the ends of the lower six intercostal nerves that supply the muscle and the overlying skin. About halfway between symphysis and umbilicus, perforating vessels from the inferior epigastric arteries run into the rectus muscle, vessels that may be used to form the pedicle for rectus flaps.

Linea Alba

The **linea alba** lies between the rectus muscles and extends from the xiphoid to the symphysis. It is composed of interlacing fibers from the aponeuroses of the three major abdominal muscles. The structure is narrower below the umbilicus than above, because the rectus muscles diverge in the epigastrium to leave a relatively weak area for the generation of midline hernias (Fig. 7-12). Its superficial fibers attach to the symphysis anteriorly; its deeper fibers form a triangular layer that adheres to the posterior surface of the pubic crest. The linea alba is especially dense where it is penetrated by the umbilicus.

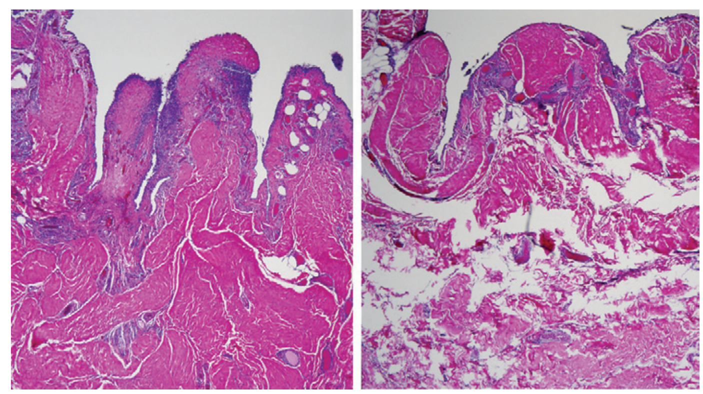

FIGURE 7-12. These sections are from the linea alba in a case of umbilical hernia. The open area at top is the peritoneal cavity. On the left are bundles of dense fibroconnective tissue composed of the interlacing fibers of the aponeuroses of the three major abdominal muscles, most likely from a region above the umbilicus. On the right, the fibroconnective tissue bundles appear less dense; this tissue may be from an area below the umbilicus that was structurally weaker and therefore prone to hernia formation.

Transversalis Fascia, Extraperitoneal Tissues, and Peritoneum

The three layers of the retroperitoneal fascias develop: (1) an inner stratum, (2) an intermediate stratum, and (3) an outer stratum (see Chapter 12, Retroperitoneal Fascias and Spaces section). Anteriorly, only the inner stratum and outer stratum are present.

Inner Stratum

The inner stratum envelops the intestinal tract. The origin and distribution of these fascias are described in detail in Chapter 12.

Outer Stratum

The outer stratum of retroperitoneal connective tissue as the **transversalis fascia** covers the muscle surfaces within the body cavity (Fig. 7-13). Deep to this fascial layer lies the pararenal fat layer, continuous anteriorly with the **properitoneal fat**.

A thin layer of fascia, the transversalis fascia, is intimately associated with the investing layer (epimysium) of the internal surface of the muscles of the abdominal wall. It is continuous with the iliac and pelvic fascias inferiorly and the anterior lamella of the lumbodorsal fascia posteriorly. Beneath it in this area lies the intermediate stratum of the extraperitoneal connective tissue. Above the middle of the inguinal ligament, the transversalis fascia is dense and is supplemented by the aponeurosis of the transversus abdominis. It has an opening that forms the lateral margin of the inguinal canal at the deep inguinal ring (see Fig. 9-8). It attaches posteriorly to the **iliac crest** between the origins of the iliacus and the transversus, continues along the posterior margin of the inguinal ligament past the femoral artery and vein to become continuous with the iliac fascia.

Fibroareolar tissue associated with the outer stratum of retroperitoneal connective tissue covers the internal surface of the transversalis fascia, forming the posterior pararenal space that lies between it and the posterior lamina of the renal (Gerota's) fascia. Laterally, with a greater content of fat, it constitutes the properitoneal fat layer. The fat layer is

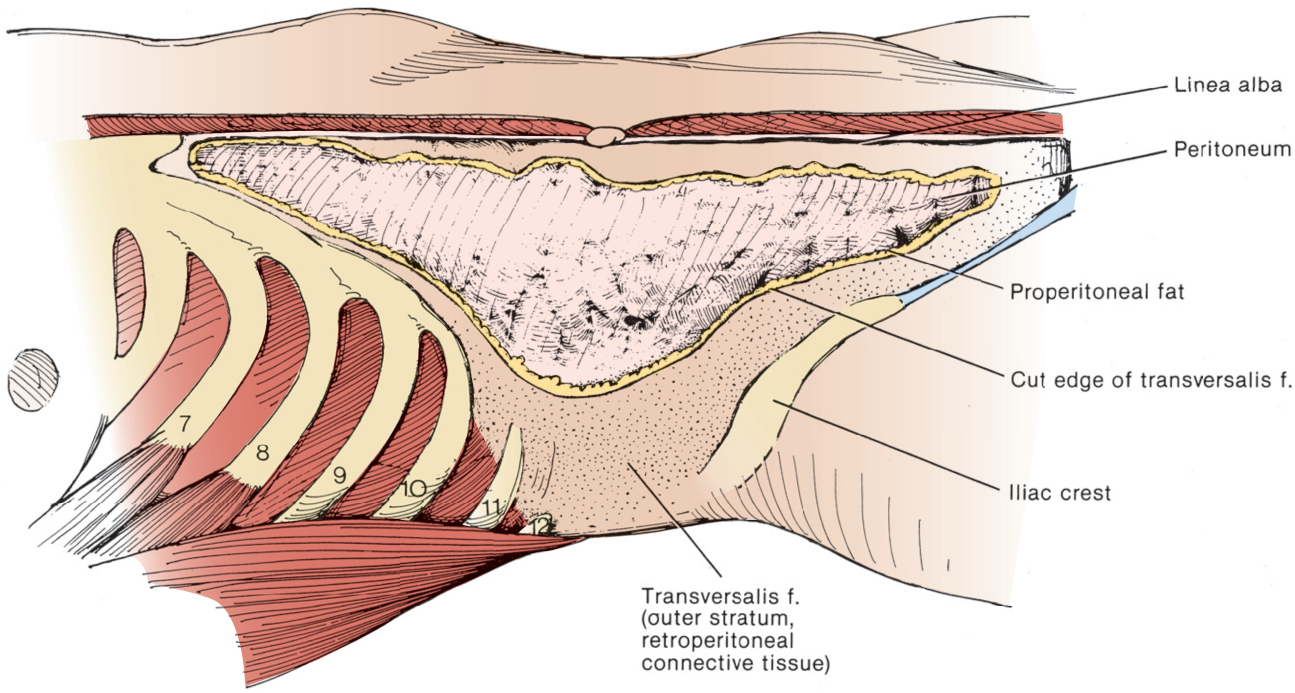

FIGURE 7-13.

thickest in the renal area superficial to the posterior layer of the renal fascia and in the pelvis; it is thinnest beneath the transversalis fascia anteriorly above the umbilicus. Superiorly, it surrounds the round ligament of the liver (ligamentum teres), the remnant of the umbilical vein. Below, the urachus (urachal ligament or median umbilical ligament), a remnant of the allantois, is imbedded in it in the midline. On either side, the obliterated umbilical arteries (medial umbilical ligaments) lie within it.

Peritoneum

The **peritoneum** is more than a layer of mesothelial cells. It includes a basement membrane and some of the closely adherent connective tissue that contains the vessels and nerves that end in the peritoneum proper (Fig. 7-14). It is distinct anatomically and surgically from the intermediate stratum of the extraperitoneal connective tissue. It encases the viscera and forms the adventitia of the gastrointestinal organs. The portion of the peritoneum associated with the body wall, the parietal peritoneum, covers the properitoneal fat and encloses the abdominal contents by lining the cavities of the abdomen and pelvis. Its somatic sensory nerves that register pain are found in greater numbers on the anterior portion. It receives its blood supply from the terminal branches of the vessels supplying the abdominal wall. The visceral peritoneum, in contrast, has no sensory nerves; the autonomic nerves respond to distention. It takes its blood supply from the organ that it encloses, through the celiac trunk and the superior and inferior mesenteric arteries.

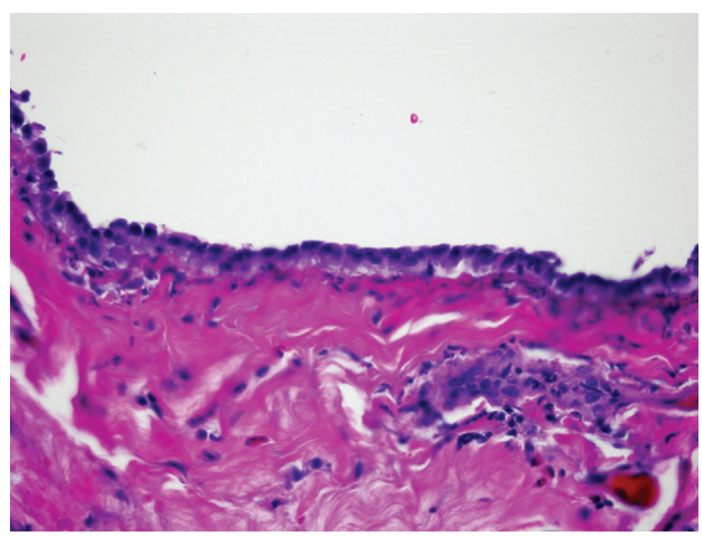

FIGURE 7-14. This image is from the umbilical hernia case illustrated in Figure 7-12. Peritoneum overlies the dense fibroconnective tissue. The only component of the peritoneum that is clearly visible is a single layer of mesothelial cells. The mesothelial cells in this image are reactive and readily seen; frequently, mesothelial cells are flat and inconspicuous in tissue sections.

Blood Supply to the Anterior Abdominal Wall

The **superior epigastric artery** supplying the upper portion of the **rectus abdominis** originates from the **internal mammary artery** (internal thoracic artery) that runs anterior to the upper margin of the transversus abdominis to pass through the rectus sheath behind the rectus abdominis near its lateral border. As it runs caudad on the anterior surface of the **posterior rectus sheath**, it penetrates the muscle to supply it and then passes through the anterior rectus sheath to supply the overlying skin (Fig. 7-15). The falciform ligament supporting the liver contains vessels from a branch of the **superior epigastric artery** that are destined to reach the hepatic artery, thus requiring ligation after division.

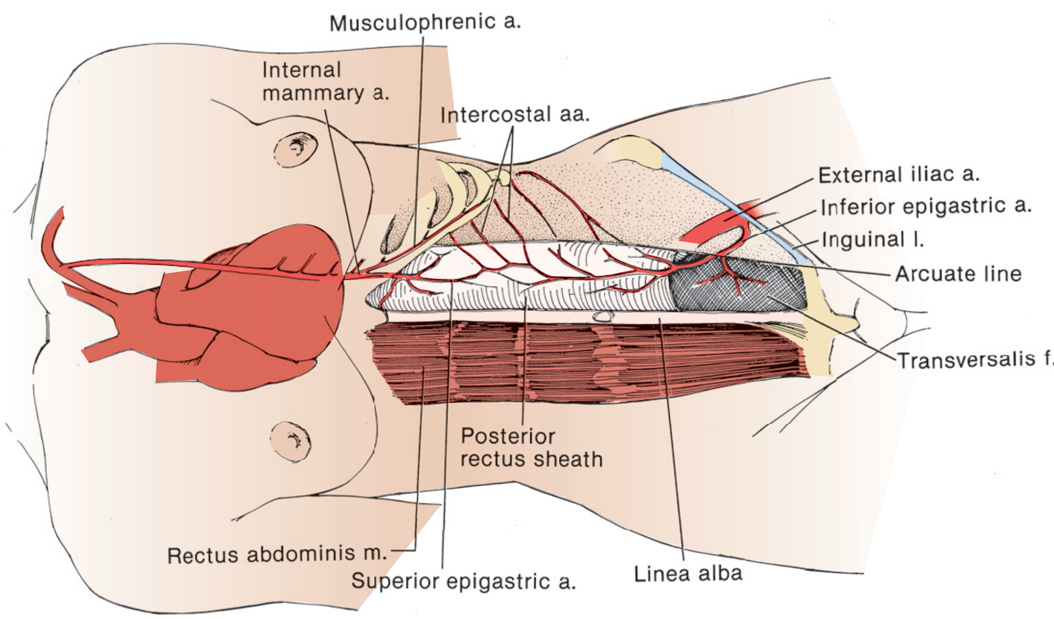

FIGURE 7-15.

The **inferior epigastric artery** arises from the **external iliac artery** just above the **inguinal ligament** in the subperitoneal connective tissue and rises medial to the deep inguinal ring. There, it lies deep to the spermatic cord, with **transversalis fascia** intervening. It then passes through the fascia behind the **rectus abdominis** to enter the space between the muscle and the **posterior rectus sheath** at the **arcuate line**. In addition, **intercostal arteries** from the lower two or three intercostal spaces come forward in the neurovascular plane over the transversus abdominis to provide important blood supply to the rectus. The veins run with the respective arteries.

Although the kidneys lie against the posterior body wall, almost within the chest, their vascular supply arises near the midline, making an anterior or anterolateral approach appropriate when vascular control is important, as with neoplasms and trauma.

Within the abdominal muscles, few of the vessels are of large caliber; they may be divided with the electrocautery without the clamping and tying they would require if divided with a scalpel.

Lymphatic Drainage

Above the umbilicus, the lymphatics from the skin and superficial fascia drain into the pectoral and subscapular groups of axillary nodes, whereas those from the upper abdominal muscles drain into the deeper internal thoracic (parasternal) nodes, following the course of the superior epigastric artery. A lymphatic vessel also follows the abdominal branch of the internal mammary artery to end in the internal mammary nodes. Below the umbilicus, the superficial lymphatics drain into the superoexternal and superointernal superficial inguinal nodes, and the deep tissues drain along the inferior epigastric artery or the deep circumflex iliac artery into the circumflex iliac or inferior epigastric nodes and thence to the external iliac nodes.

The umbilicus is drained by three groups of lymphatics. The cutaneous lymphatics arise from the skin over the umbilicus and run very superficially under the skin to the superointernal and superoexternal groups of superficial inguinal nodes. The lymphatics from the residual nucleus of the umbilicus pass through the rectus sheath and drain into the channels running with the inferior epigastric artery along with lymphatics from the posterior sheath itself. From the area of attachment of the umbilicus to the rectus sheath, anterior channels join those from the nucleus, and posterior channels form a periumbilical network deep to the rectus sheath, which then either pass through the transversalis to run on that surface or run inferiorly along the inferior epigastric artery to end in external and internal retrocrural nodes.

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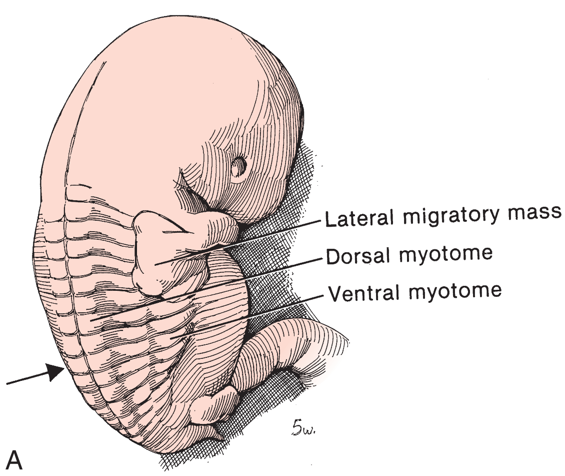
Chapter 8

Posterolateral and Posterior Body Wall



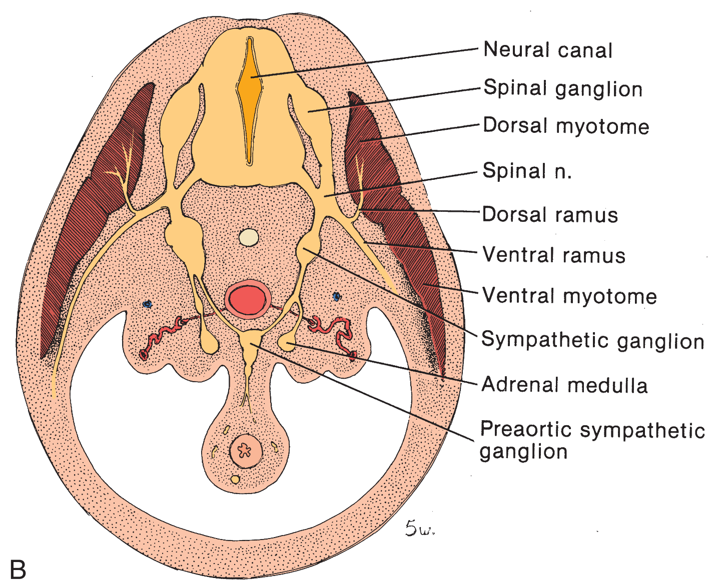


FIGURE 8-1.

You muste ordeyne . . . fastnygis tofore & bihinde & in his flankis.
LANFRANC'S CIRURG,
269, c.1400

DEVELOPMENT OF THE POSTERIOR BODY WALL

The primitive mesenchyme, as the mesoderm, is differentiated into three layers of the body (Table 8-1). The primitive subcutaneous layer becomes the dermis and the superficial and deep fascias. The body layer forms the skeleton and its support, and the retroperitoneal layer forms three strata involved with the peritoneum and intestines, the urinary organs, and the internal body wall.

BODY WALL MUSCULATURE

Dorsal and Ventral Division of Myotomes

The epaxial, **dorsal myotomes** form a dorsal division, supplied by a posterior branch of the corresponding spinal nerve (Fig. 8-1A). The individual myotomes maintain their segmental positions. They do not migrate but remain in the myotomal region of the developing somite, which is destined to form the extensor muscles of the vertebral column and the lumbar extensor musculature. Moreover, the dorsal myotomes fuse so that by the sixth week, almost all evidence of segmentation is gone. The more distant vertebral levels are connected by the fusion of the fibers from adjacent vertebrae to form longer slips of muscle. An exception is in the deep areas, where the muscles retain their metameric arrangement, connecting one vertebra to the next.

The hypaxial, **ventral myotomes** form an anterior division, in which each myotome is innervated by the corresponding ventral ramus, as described in Figures 7-2 and 7-3.

The **lateral migratory mass** will form the shoulder muscles, including the latissimus dorsi.

The dorsal myotomes lie dorsolateral to the vertebral column and are innervated segmentally by the **dorsal ramus** of a **spinal nerve**. The **ventral ramus** innervates the **ventral myotomes** (Fig. 8-1B). The **sympathetic ganglion** has connections with the **adrenal medulla** and the **preaortic sympathetic ganglion**.

Dorsal Muscles of Ventral Origin

Not all the dorsally situated muscles arise from the posterior myotomes. Before the sixth week, muscles from the anterior myotomes migrate posteriorly to cover the dorsal muscles.

TABLE 8-1 DIFFERENTIATION OF MESENCHYME

Primitive	Late Fetal	Adult
Subcutaneous layer	Dermis	Same
	Superficial fascia	Camper's fascia
		Scarpa's fascia
	Deep fascia	Same
Body layer	Muscles, ligaments, and bones	Same
Retroperitoneal layer	Outer stratum	Transversalis fascia
	Intermediate stratum (urogenital embedding)	Gerota's fascia
	Inner stratum (intestinal embedding)	Intestinal fascia

The ventral **trapezius, deltoid, teres major** (Fig. 8-2A), and **serratus posterior inferior** muscles (Fig. 8-2B), innervated by anterior rami, cover the dorsal **sacrospinalis muscles** as they attach to the vertebral spines. Similarly, muscles may migrate in a longitudinal direction, an example of caudal migration being the **latissimus dorsi** that is innervated by cervical nerves.

LUMBODORSAL FASCIA

The lumbodorsal fascia separates the original deep muscles from those that migrate over them. As it develops with the dorsal muscles, it covers them with sheaths. The sacrospinalis is enclosed between the posterior and middle lamellae of the lumbodorsal fascia, the middle lamella separates the

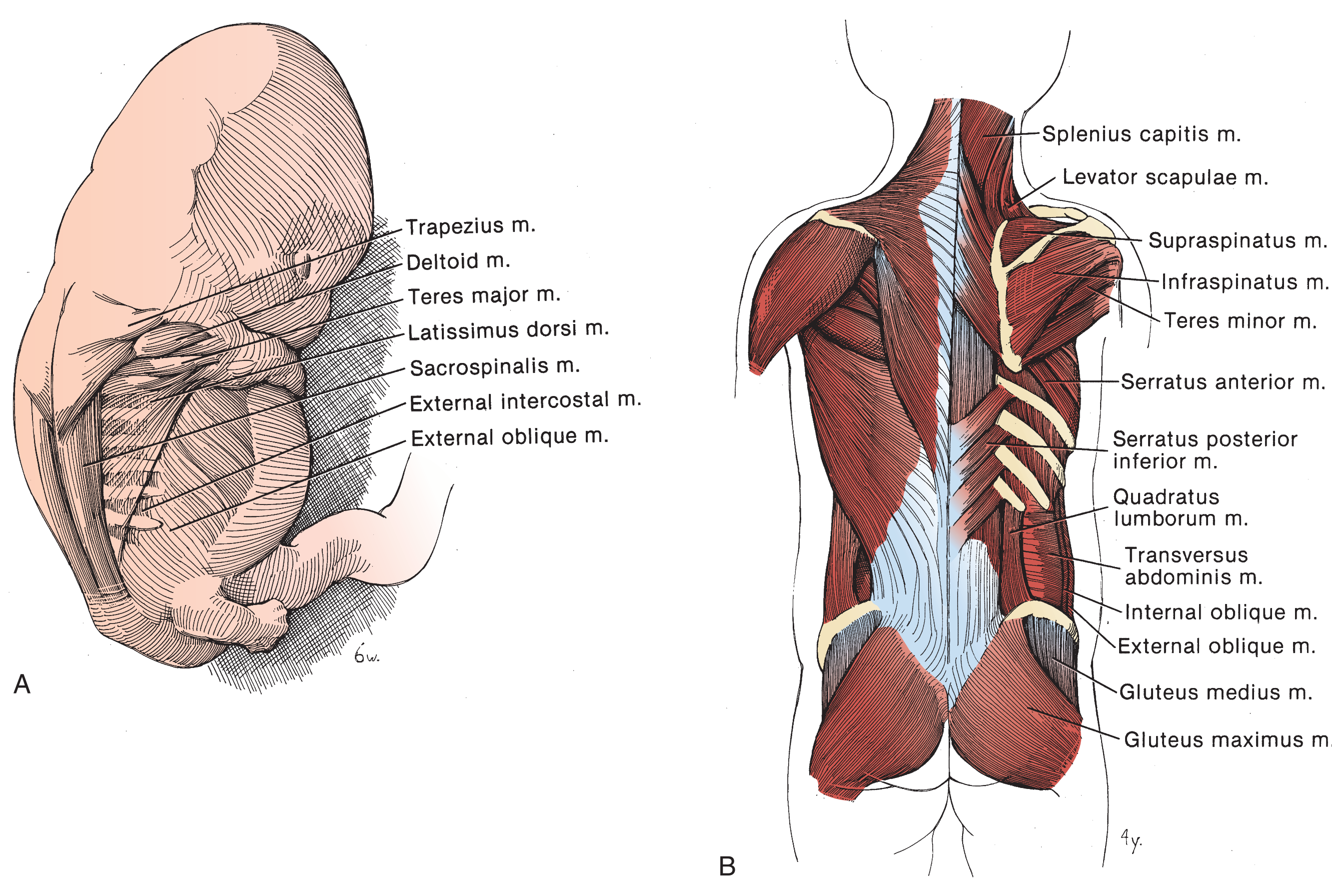


FIGURE 8-2. A, At 6 weeks of gestation. **B,** At 4 years of age.

erector spinae from the quadratus lumborum, and the anterior lamella covers the ventral surface of the quadratus lumborum.

RETROPERITONEAL FASCIAS

The retroperitoneal fascias are not related to the fascias of the dorsal myotomes. The outer stratum is associated with ventral myotomal derivatives. The dorsally and ventrally derived fascias meet at the lateral border of the psoas major, where the muscles developed from the dorsal myotomes (psoas major and quadratus lumborum) and ventral myotomes (transversus abdominis) overlap to form a dense connection.

Retroperitoneal Fascial Development

The abdominopelvic fascias evolve from one continuous layer of **retroperitoneal connective tissue.** From this tissue, three fundamental embryonic tissues develop as three strata. One is the mesenchyme, which develops interior to the intrinsic fascia (epimysium) of the **body wall musculature.** This layer, the **outer stratum,** forms the abdominal and pelvic fascia, and is represented by the transversalis fascia (Fig. 8-3). A second layer is the loose mesenchyme lying between the outer stratum and the celomic epithelium. This layer is destined to become the **intermediate stratum** and will form the fascia that encloses the urinary tract. The third layer, the **inner stratum,** is the connective tissue associated with the celomic epithelium (peritoneum) itself. It will become the fascia involved with the intestinal tract.

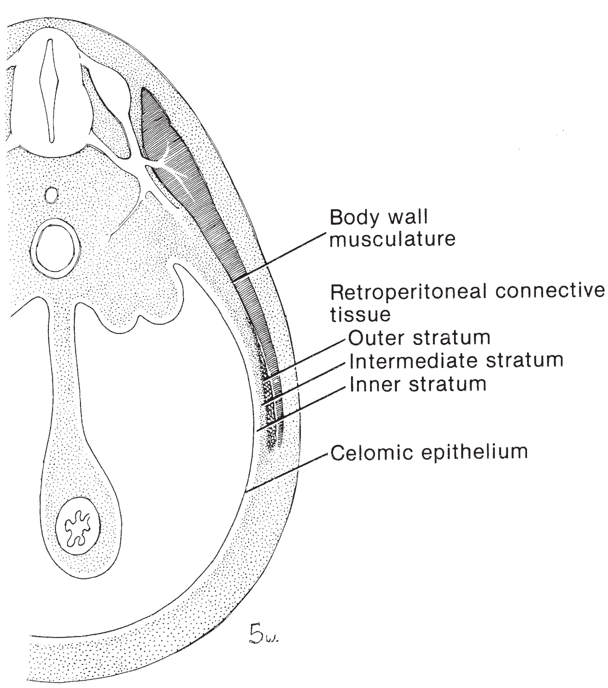


FIGURE 8-3.

Distribution of Retroperitoneal Fascias

Outer Stratum

The outer layer forms the **transversalis fascia** that lies over the transversus abdominis, quadratus lumborum, and psoas muscles and covers their intrinsic fascia (epimysium) (Fig. 8-4). Fusion takes place between the transversalis fascia associated with the ventral myotomes and the inner lamella of the lumbodorsal fascia, derived with the dorsal myotomes at the lateral border of the psoas muscle. This junction accounts for the difficulty in separating the transversalis fascia from the posterolateral body wall during retroperitoneal mobilization.

Intermediate Stratum

Early in development (4½ weeks), the loose mesenchyme in the subserosal layer of retroperitoneal tissue appears, which is the precursor of the extraperitoneal connective tissue that will surround the kidneys and adrenals as well as the aorta, renal vessels, and ureter into the pelvis. At 11 weeks, the mesenchyme differentiates as the intermediate stratum into a laminated covering of the **kidney** and adrenal that melds with the connective tissue about the **aorta** and **vena cava**. As the kidney grows, the fascia becomes more pronounced and splits into two layers, a thicker dorsal layer and a thinner ventral layer. These layers form the **posterior lamina** and the **anterior lamina** of the **renal fascia** (Gerota's fascia). Between the two layers is the **perirenal space** that encloses the kidney, ureter, and adrenal. Without development of a kidney, this process does not occur.

Inner Stratum

The inner stratum closely invests the gastrointestinal tract beneath the **peritoneum.** It also constitutes part of the **fusion-fascia** that forms when an intraperitoneal organ (pancreas, duodenum, or ascending or descending colon) makes contact with the undersurface of the primitive celomic epithelium.

POSTEROLATERAL BODY WALL: STRUCTURE AND FUNCTION

The kidney and adjacent retroperitoneal structures lie close to the posterolateral body wall. An approach from that direction causes less interference with nerves, blood vessels, and abdominal organs than an anterior approach.

Conforming to their embryologic origin, two groups of muscles are found. Muscles derived from the *dorsal divisions* of the myotomes develop into the back muscles proper, the sacrospinalis group of muscles. Those derived from the *ventral divisions* form the muscles of the anterior body wall, most of which extend around to the posterior portion of the trunk. These are the external and internal oblique and transversus abdominis muscles. Thus, the muscles of the ventral division are encountered in operations through the flank. The muscles of the anterior body wall have been described

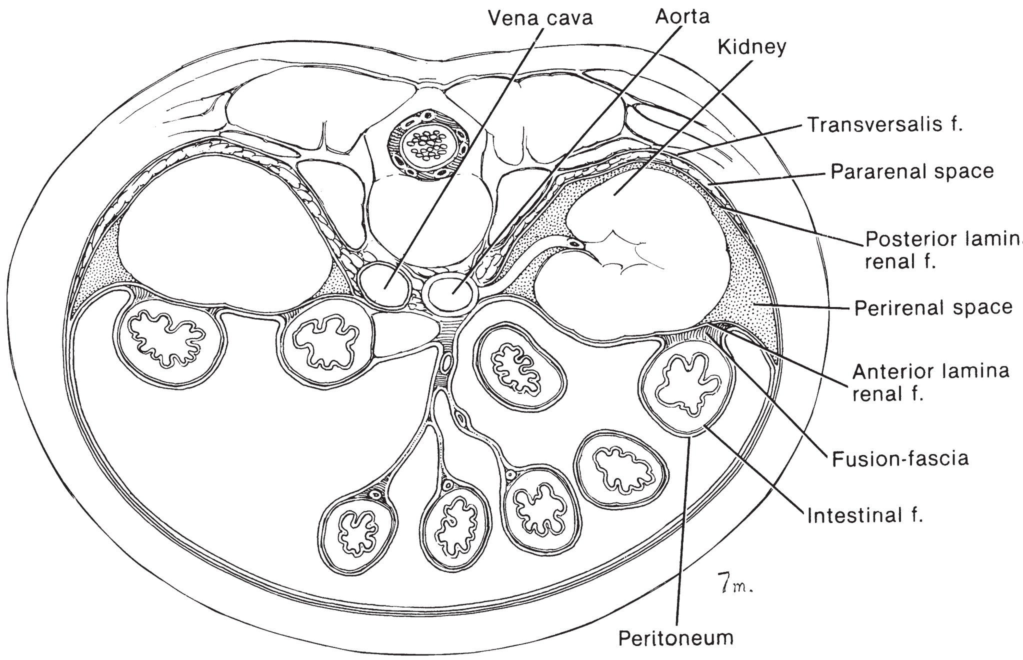


FIGURE 8-4.

in Chapter 7; here, the focus is on their posterior extensions exposed through a posterolateral or posterior incision.

FOUR LAYERS OF MUSCULATURE

The muscles may be divided for purposes of description into four layers: (1) an *outer layer*, composed of the latissimus dorsi along with the posterior extension of the external oblique and the serratus posterior inferior; (2) a *middle layer*, made up of the sacrospinalis and the posterior portion of the internal oblique; (3) an *inner layer*, formed from the quadratus lumborum and iliacus, with a contribution from the transversus abdominis; and (4) an *innermost layer*, made up of the psoas muscles and the diaphragm.

OUTER LAYER

Structures of the Outer Muscle Layer

The outer layer is composed of the latissimus dorsi, the external oblique, the serratus posterior inferior, the external intercostals, and the posterior lamella of the lumbodorsal fascia. Figure 8-5A is a posterior view; line **X-X** indicates the plane of the transverse section shown in Figure 8-5B.

Latissimus Dorsi

Covering most of the lumbar surface of the trunk, this flat, triangular muscle is properly part of the shoulder mechanism; it is attached by a tendon to the humerus and its nerve supply, the thoracodorsal nerve, arises from the brachial plexus. It originates from the spinous processes of the **lower six thoracic vertebrae** and from the **posterior lamella** of the **lumbodorsal fascia,** through which it is ultimately attached to the spines of the lumbar and sacral vertebrae as well as to part of the **iliac crest.** It is also attached by muscular slips to the **lower four ribs** that fit between similar slips of the external oblique. The latissimus functions to extend, adduct, and medially rotate the arm as well as retract the shoulder.

External Oblique

This muscle arises as seven or eight muscular slips from the outer surface of the eight lower ribs, interdigitating with similar slips of the serratus anterior and the latissimus dorsi. It inserts as a muscle on the anterior half of the iliac crest, contributes one layer to the anterior rectus sheath as an aponeurosis, and inserts on the linea alba, where it fuses with the aponeurosis from the other side. It inserts on the upper border of the symphysis pubis and in the pubic crest. By folding inward, it forms the inguinal ligament (see Figure 9-8A).

Serratus Posterior Inferior

This relatively small muscle is partly thoracic and partly lumbar because it arises by an aponeurosis that is fused to the lumbodorsal fascia in an obliquely upward course and from the **spinous processes** of the two lower thoracic vertebrae and of the two upper lumbar vertebrae. The muscle itself attaches to the lower and outer surfaces of the four lower **ribs** near their angles, acting to pull the lower ribs outward and downward.

External Intercostals

These 11 muscles between 12 ribs cross from the upper border of one rib to the lower border of the next in an oblique direction, running downward and laterally, their insertion being farther forward around the thorax than their origin. They extend from the posterior fibers of the superior costotransverse ligaments at the tubercles to the costal cartilages anteriorly (Fig. 8-6A), where they become

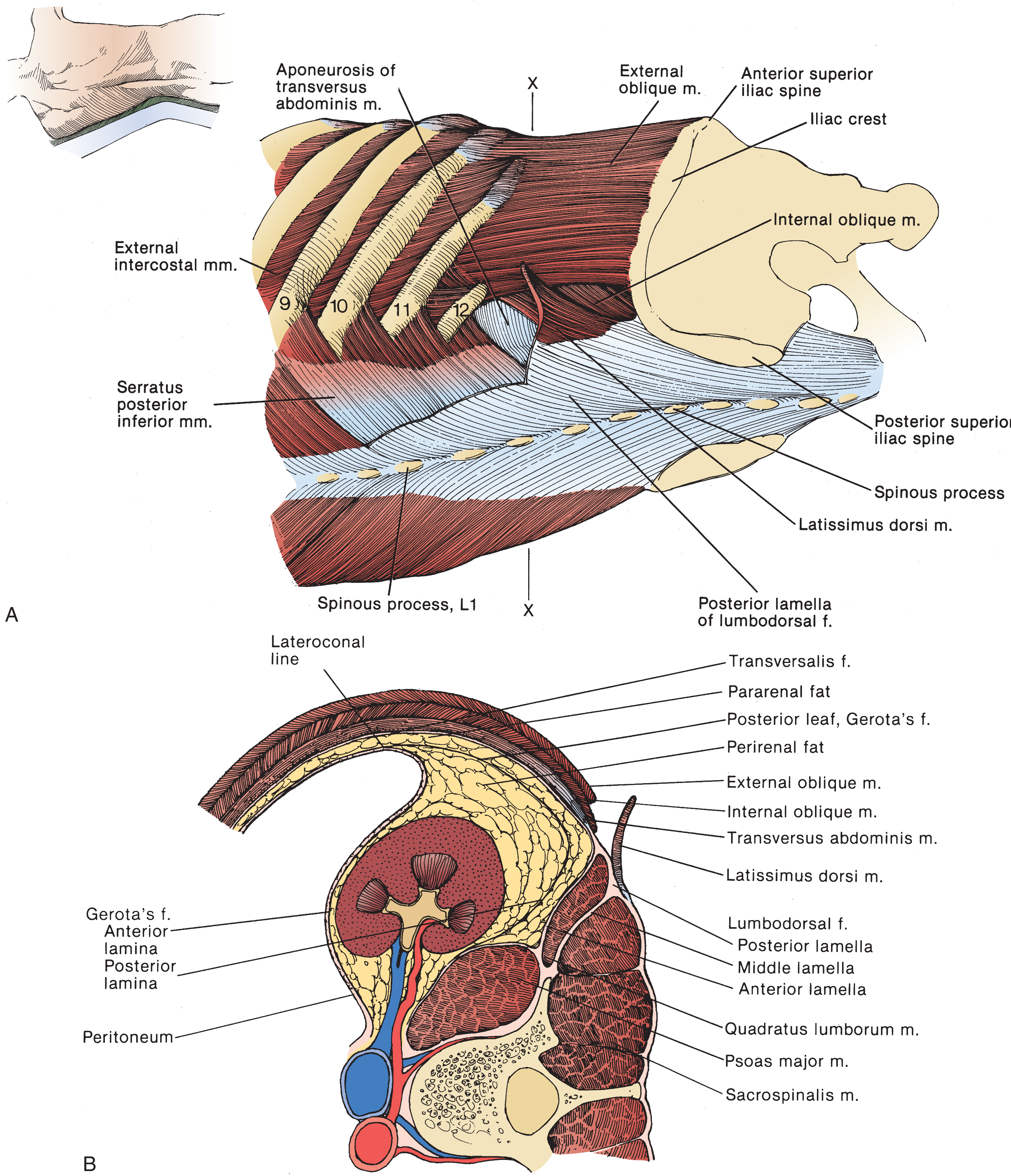


FIGURE 8-5.

the external intercostal membrane. They act to approximate the ribs during exhalation and coughing.

Posterior Lamella of the Lumbodorsal Fascia

The posterior lamella of the lumbodorsal fascia, the most superficial of the three lamellae, lies over the sacrospinalis. It is attached to the **spinous processes** and provides a site of origin for the latissimus dorsi.

MIDDLE LAYER

Structures in the Middle Layer

This layer is made up of the sacrospinalis, internal oblique, internal intercostals, and the middle lamella of the lumbodorsal fascia. Figure 8-6A is a posterolateral view; the plane of the transverse section in Figure 8-6B is line **X-X**.

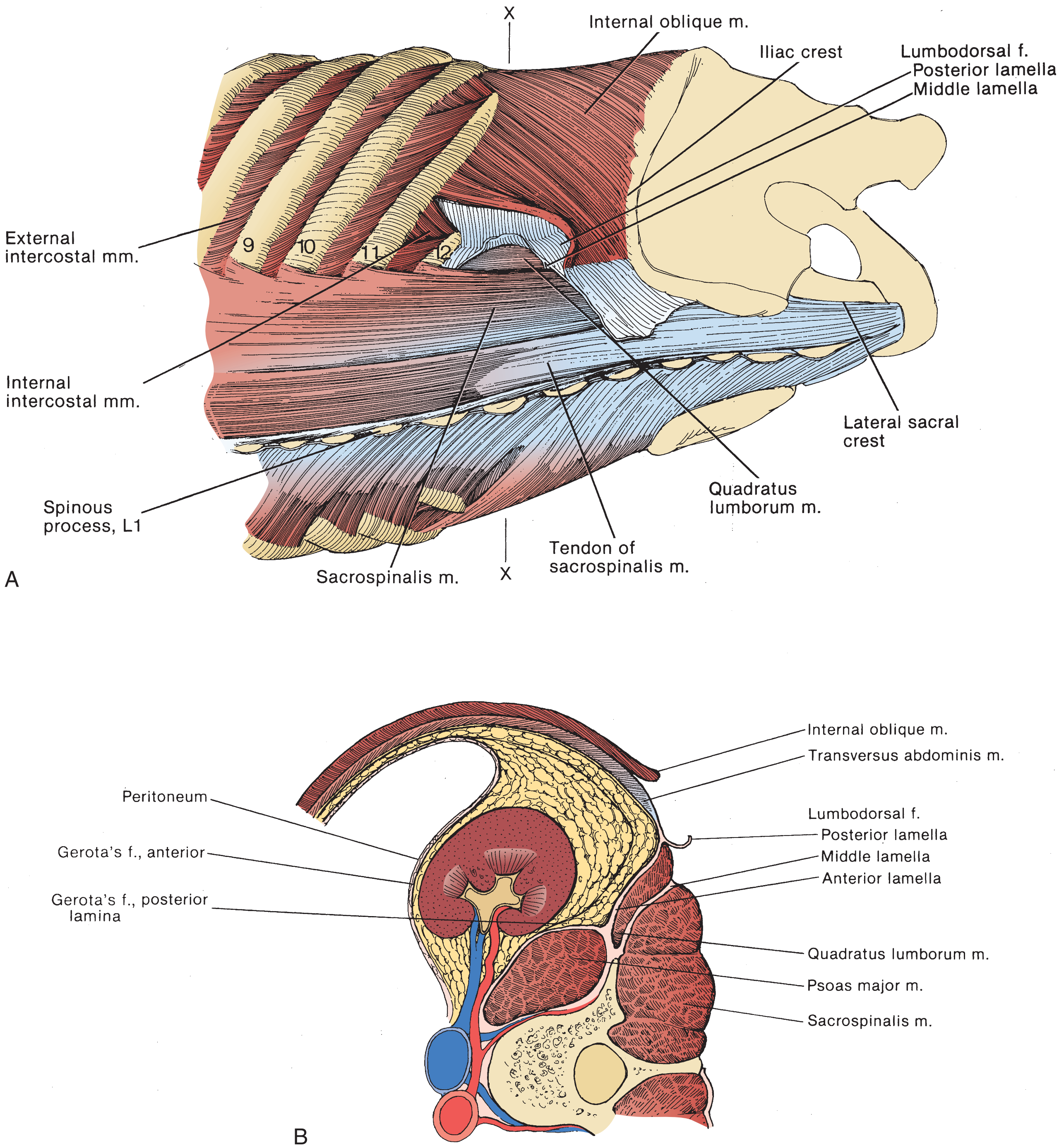


FIGURE 8-6.

Sacrospinalis (Erector Spinae)

This tube-shaped muscle fills the groove between the **spinous processes** and the transverse processes of the lumbar, thoracic, and cervical vertebrae. It is enclosed between the **middle** and **posterior lamellae** of the **lumbodorsal fascia**. It originates as a muscle from a heavy tendon attached to the medial portion of the sacral crest and to the **spinous processes** of the lumbar vertebrae and the two lower thoracic vertebrae along with their supraspinous ligaments. This tendon is also attached to the posterior portion of the **iliac crest** and to the lateral sacral crest. The region of the muscle exposed in posterolateral operations separates to form the spinalis (more medial), the longissimus, and the iliocostalis; a portion of the last is attached to the upper borders of the last six ribs at the angles. This collection of muscles extends the spine.

Internal Oblique

This muscle arises from the iliac crest, from the lateral portion of the **inguinal ligament** and from the **lumbodorsal fascia.** Starting at these sites, fibers slope diagonally forward and upward to attach to the **costal margins** of the lowest three **ribs** (see Fig. 7-8). It is these paracostal bundles that are encountered in a posterolateral incision.

Internal Intercostals

The 11 **internal intercostals** are distributed between the ribs extending from the sternum to the costal angles. At the angles, they become aponeurotic to blend with the internal intercostal membrane, which is continuous with the anterior fibers of the superior costotransverse ligament (see Fig. 8-6A). These muscles are not as heavy as the external group and their fibers run at a right angle to that group, taking an oblique downward and backward course. They act together with the external set. The intercostal nerve and vessels lie beneath the internal intercostal, superficial to the innermost intercostals (see Fig. 8-8).

Middle Lamella of the Lumbodorsal Fascia

The **middle lamella** separates the **sacrospinalis** from the **quadratus lumborum**. It extends from the **12th rib** to the **iliac crest** and is attached medially to the tips of the transverse processes.

INNER LAYER

Structures in the Inner Layer

This layer is formed by the quadratus lumborum, psoas major and minor, and the innermost intercostals, with a contribution from the transversus abdominis. It includes the anterior lamella of the lumbodorsal fascia. Figure 8-7A is a sagittal cut at the level of the right kidney. Figure 8-7B is a cut in the transverse plane at **X**.

Quadratus Lumborum

Originating from the lower border of the **12th rib** and the transverse processes of the **L1** to **L5 vertebrae**, this muscle inserts on the **iliac crest** and the **iliolumbar ligament**. This important ligament is attached to the tip and front part of the **L5 vertebra** and runs as two bands. One is the lumbosacral ligament, which passes to the lateral part of the **sacrum**. The other forms part of the origin of the quadratus lumborum and attaches to the **iliac crest** in front of the sacroiliac joint and joins the **lumbodorsal fascia**. The quadratus lumborum moves the lowest rib toward the pelvic bone and flexes the spine in the lumbar region.

Transversus Abdominis

This muscle, the upper portion of which is encountered in flank incisions, originates from the inner surface of the lower six costal cartilages and the **lumbodorsal fascia**; it inserts anteriorly in an aponeurosis. The fibers in the posterior portion run in an almost exactly transverse direction.

Innermost Intercostals

A thin layer of muscles attached to the inner surface of the lower ribs lies deep to the internal intercostals as part of the transversus abdominis system. On the inner side, they are covered by the endothoracic fascia, over which lies the pleura. The innermost intercostals act with the other intercostals.

Costal Levators

The 12 short **costal levators** arise from the ends of the **transverse processes** of all but the 12th thoracic vertebra and attach to the next lower **rib**. The four lowermost muscles divide into a long costal levator that passes downward and laterally to attach to the upper edge of the second lower rib between the tubercle and the posterior angle. These levators raise the ribs during inspiration and also extend and laterally rotate the thoracic vertebra.

Anterior Lamella of the Lumbodorsal Fascia

The **anterior lamella** of the lumbodorsal fascia covers the ventral surface of the quadratus lumborum and sacrospinalis. It is attached medially to the anterior surface of the **transverse processes**, and inferiorly it connects with the **iliolumbar ligament**.

Attachment of the Intercostal Muscles, Viewed Anteriorly

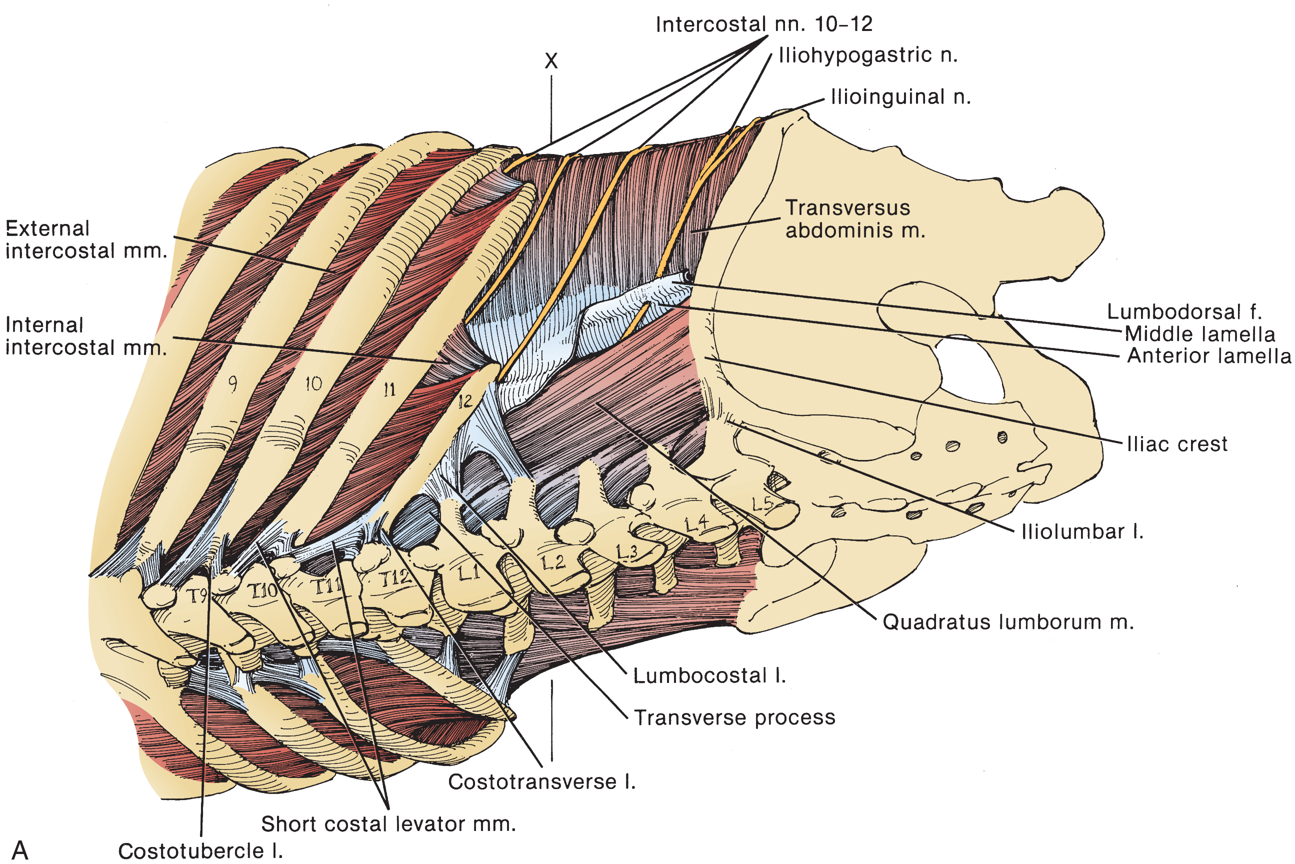
The lower **ribs** are covered by the latissimus dorsi and the serratus posterior inferior. Beneath, the **external intercostals** extend from the outer edge of one rib to that below. Under them lie the **inner intercostals**, which attach to the outer portion of the floor of the **costal groove** of the rib above and to the midportion of the upper margin of the rib below (Fig. 8-8). The **innermost intercostals** are attached to the inner margin of the costal groove, such that the **intercostal nerve, artery, and vein** lie between the innermost and internal intercostals. On the inner side they are covered by the endothoracic fascia, over which lies the pleura.

Intercostal Nerves

The 9th to 11th intercostal nerves, as the ventral rami of the corresponding thoracic nerves, lie caudal to the intercostal vessels between the internal and innermost intercostals in the subcostal groove on the lower inner surface of each rib (Fig. 8-8). They go under slips of diaphragm to pass between the transversus abdominis and the internal oblique before they penetrate the posterior layer of the internal oblique aponeurosis to supply the rectus abdominis and the overlying skin. The larger 12th intercostal nerve, as the subcostal nerve, communicates with the first lumbar nerve and passes behind the lateral arcuate ligament to run also between the transversus and internal oblique.

Sympathetic Nerves

The **sympathetic chain** with its **ganglia** and **splanchnic nerve** lies at the junction of rib and vertebra (Fig. 8-8).


Intercostal nn. 10–12
X
Iliohypogastric n.
Ilioinguinal n.
External intercostal mm.
Transversus abdominis m.
Internal intercostal mm.
Lumbodorsal f.
Middle lamella
Anterior lamella
9
10
11
12
Iliac crest
Iliolumbar l.
T9
T10
T11
T12
L1
L2
L3
L4
L5
Quadratus lumborum m.
Lumbocostal l.
Transverse process
Costotransverse l.
Short costal levator mm.
A
Costotubercle l.

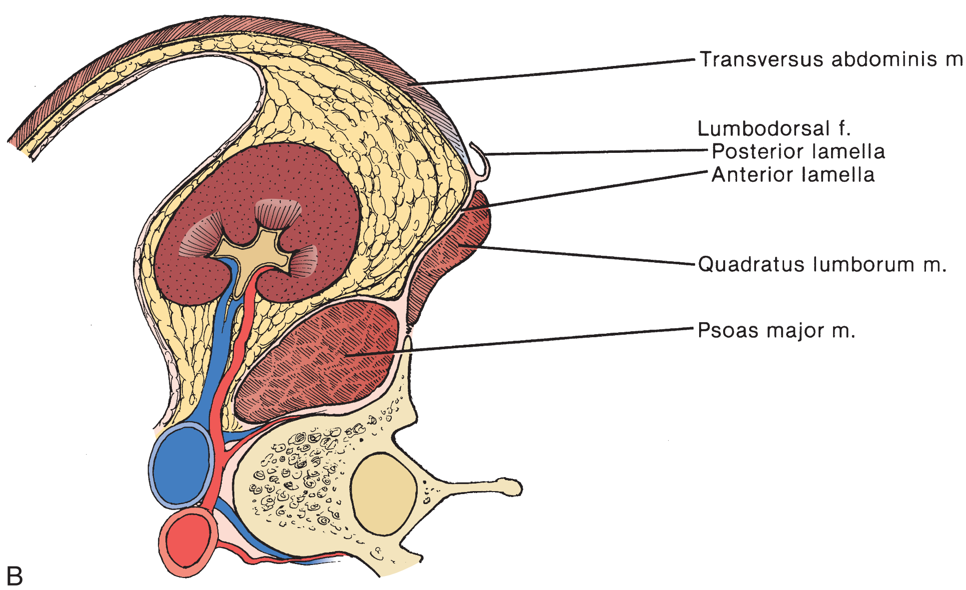

Transversus abdominis m.
Lumbodorsal f.
Posterior lamella
Anterior lamella
Quadratus lumborum m.
Psoas major m.
B

FIGURE 8-7.

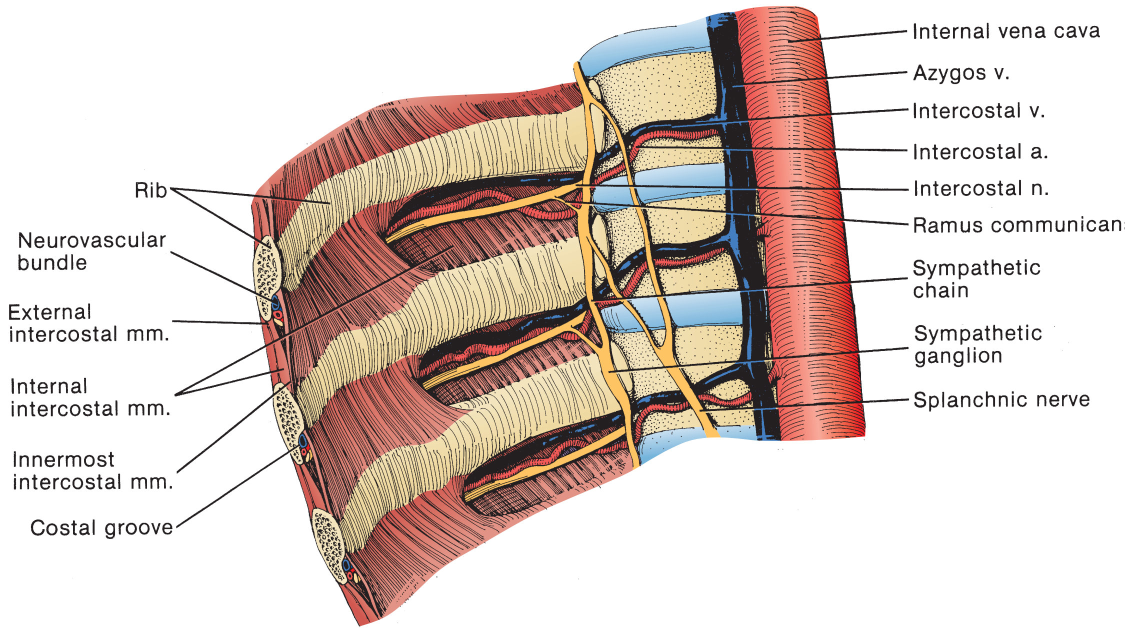


FIGURE 8-8.

INNERMOST LAYER

Structures in the Innermost Layer

This layer is composed of the psoas major and minor and the diaphragm. Figure 8-9A is a posterior view; Figure 8-9B is a transverse section at line **X-X**.

Psoas Major

This muscle originates from the sides and disks of all five **lumbar vertebrae** as well as from their transverse processes. It passes down behind the inguinal ligament to attach to the lesser trochanter of the femur, in company with the iliacus. Its covering fascia, the **psoas fascia**, fuses above with the inferior surface of the **diaphragm** and laterally with the **transversalis fascia**. The psoas major acts with the iliacus to flex the thigh on the pelvis.

Psoas Minor

The psoas minor lies in front of the major muscle, arising from the lateral surfaces of the 12th thoracic and first lumbar vertebrae. Its long tendon attaches to the pectineal line and to the iliopubic eminence of the ilium and laterally to the iliac fascia. This muscle flexes and medially rotates the thigh; it also acts in concert with the quadratus lumborum to flex the lumbar spine.

Radiographically, the psoas muscle can be visualized in all but emaciated individuals by the different density of the overlying fat, the perirenal fat over the kidney and the pararenal fat posterior to it. Thus perirenal fluid collections tend to obliterate the upper margin of the psoas muscle, whereas collections in the pararenal space obliterate the lower portions or the entire margin.

The tendinous portion of the psoas minor lies behind the upper margin of the bladder and so forms an anchor site for extending the bladder wall in the psoas hitch procedure.

Diaphragm

The centripetal fibers of the diaphragm merge to form the aponeurotic **central tendon** (Fig. 8-10). These fibers are attached to the xiphisternum by two slips and to the inner surface of the **lower six ribs** and their costal cartilages by slips that interdigitate with those of the transversus abdominis. The diaphragm is attached to the vertebral column by two **crura**, between which the great vessels run (see Chapter 12). These are each attached to the bodies of the upper two lumbar vertebrae and are joined anteriorly as the median arcuate ligament. Laterally, the diaphragm is attached on the medial side to the **transverse process** of the **L1 vertebra** by the **medial arcuate ligament**, or lumbocostal arch, and to **rib 12** by the **lateral arcuate ligament**. The diaphragm lies almost parallel with the inner side of the thoracic wall at its attachment, resulting in a narrow gutter—the costodiaphragmatic recess—where the pleura covering the diaphragm and that covering the chest wall come in contact.

Viewed from the flank, the **pleural line** of attachment of the diaphragm to the 12th rib and to the underlying pleural gutter is seen to slope caudad as the rib angles cephalad. This means that the farther back along the rib the incision is carried, the more the underlying pleura will be exposed.

Phrenic Nerves

The two phrenic nerves are important surgically because one of them may be injured during incision of the diaphragm in a thoracoabdominal approach. The left phrenic nerve passes through the diaphragm just anterior to the central tendon, and the right phrenic nerve passes through

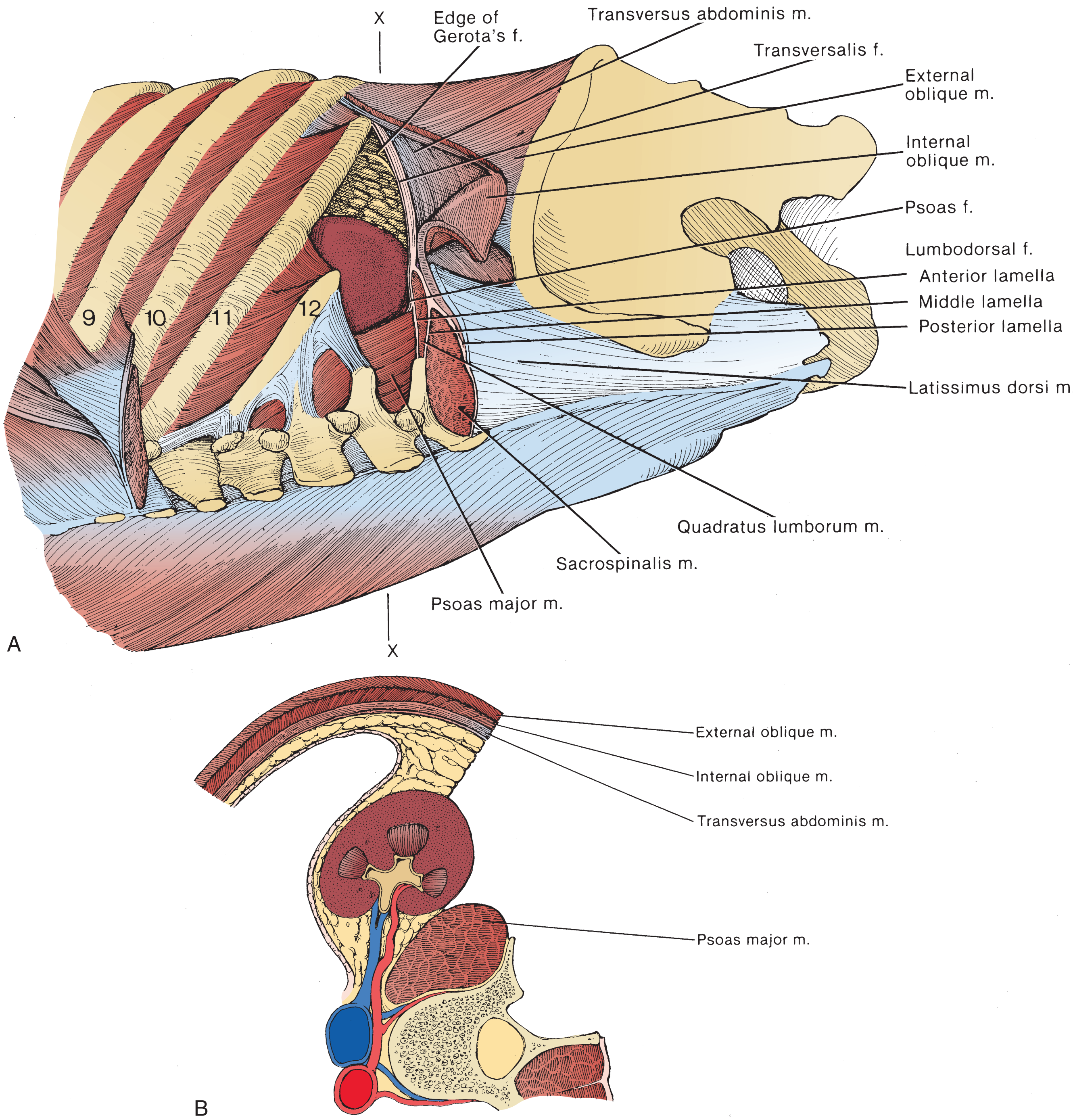


FIGURE 8-9.

the central tendon where the inferior vena cava enters. They each divide into three branches: (1) an anterior branch running toward the sternum, (2) an anterolateral branch that passes lateral to the lateral leaflet of the central tendon, and (3) short posterior branches running behind the lateral leaflet of the central tendon as well as to the crural area. They usually cannot be seen during intrapleural surgery because they lie within the diaphragmatic muscle itself.

The function of the diaphragm is respiration, but it also acts as the divider between the abdomen and the chest, maintaining appropriate pressures on both sides.

Posterior Approach to the Kidney Through the Lamella of the Lumbodorsal Fascia

The **posterior lamella** is divided first, exposing the **sacrospinalis.** This is followed by opening the **middle lamella** to the **quadratus lumborum**, followed by the **anterior lamella** and the underlying **transversalis fascia**. The **posterior lamina** of the **renal** (Gerota's) **fascia** may then be entered (Fig. 8-11). During puncture for percutaneous access to the kidney, the lumbodorsal fascia is felt as resistance to the trocar.

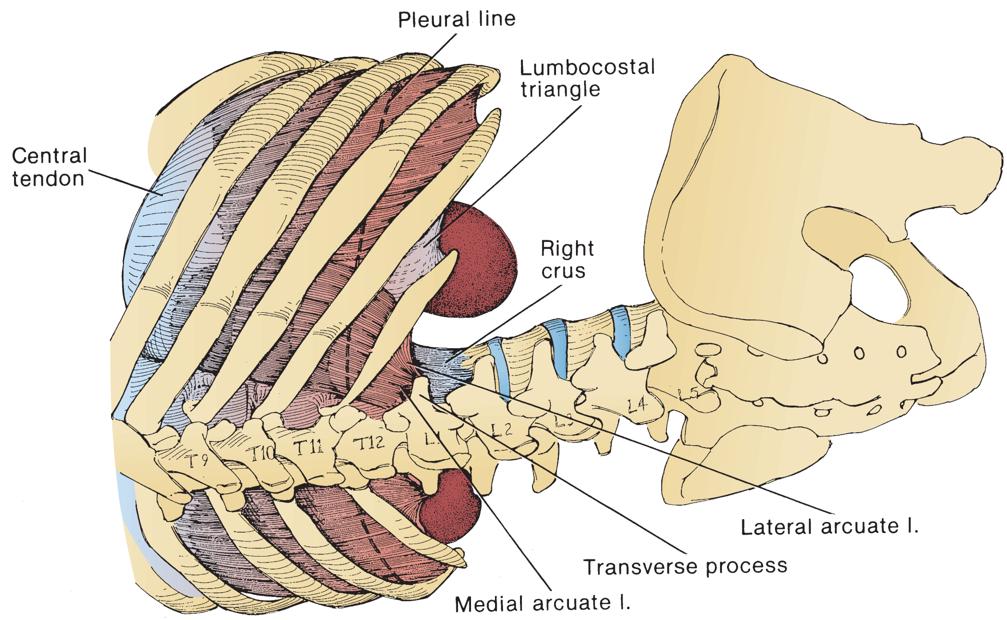


FIGURE 8-10.

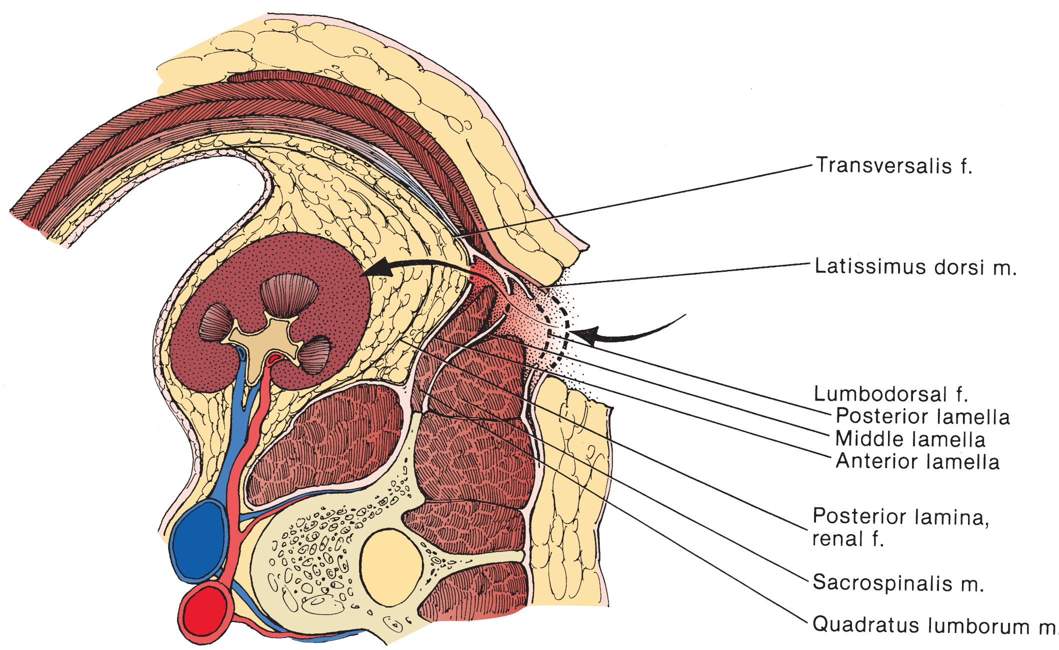


FIGURE 8-11.

THORACOLUMBAR STRUCTURES

Costovertebral Joints and Articulation

A description of a typical rib and its attachment to the vertebral body is given to facilitate the mobilization of the ribs and division of the ligamentous attachments.

The transverse process of the vertebra has two sets of paired facets, the **superior articular facets** for connection with the next higher transverse process and the **facets for the tubercle of the rib**. The body of the vertebra also has two sets of facets, the **superior** and **inferior costal demifacets,** to which the head of the rib attaches (Fig. 8-12).

The posterior portion of the **10th rib** consists of a head, a neck, and a tubercle, shown in this image displaced and viewed from below, in region B. The **head,** through two facets, articulates with the body of the vertebra over the intervertebral disk in the superior and inferior demicostal facets. The **neck** connects these surfaces of attachment with a **tubercle.** There, the rib joins the transverse process at the **articular facet of the tubercle.** The distal part of the tubercle is nonarticular. Beyond the tubercle, the rib appears less curved on its posterior surface until it reaches the **posterior angle,** where it resumes the smooth curved contour of the chest wall.

The vertebrae are connected by **superior** and **inferior articular facets** on symmetric **superior** and **inferior articular processes** and by the **intervertebral disks.**

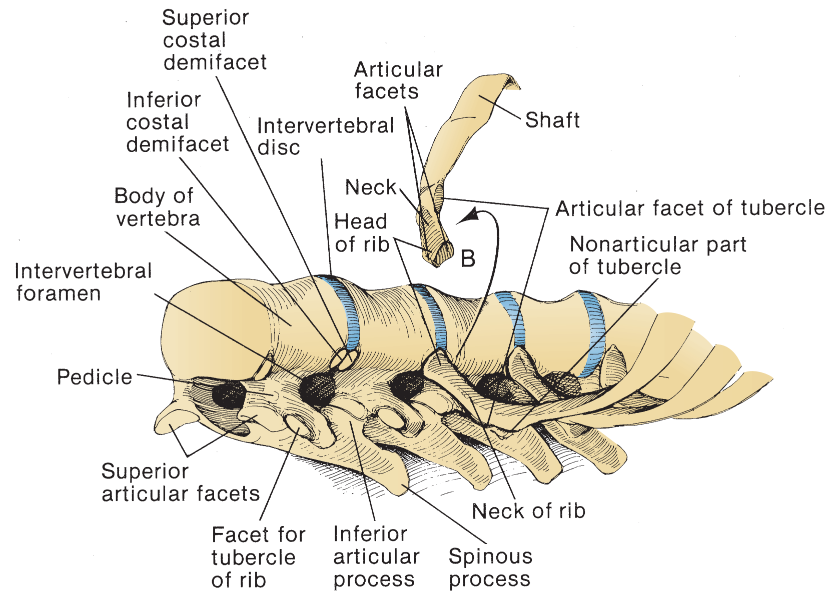


FIGURE 8-12.

Articulation of Lower Three Ribs

The last three thoracic vertebrae represent a transition between the thoracic and lumbar regions. The **10th thoracic vertebra** has only one set of facets on the body; it does not connect with the rib below (Fig. 8-13). Moreover, it may or may not have a facet on the transverse process for connection with the tenth rib. The **11th vertebra** does not have facets on the small transverse processes. On the **12th vertebra,** the facets on the body are lower and the transverse processes smaller. The **11th** and **12th ribs** have no neck or tubercle. Instead, they have a single large facet on the head. The angle of the 11th rib is less pronounced than that of the ribs above, and the 12th rib is short and has no angle.

The lumbar vertebrae are larger than their thoracic counterparts and have no facets for ribs; their transverse processes are thinner and longer. The spinous processes run horizontally rather than sloping obliquely as they do above.

Costovertebral Ligaments

The ribs are held by several sets of ligaments (Fig. 8-14). The **superior costotransverse ligaments** (the so-called costovertebral ligaments) have two layers, corresponding to the external and internal intercostal muscles. The **posterior layer** is more superficial and runs upward and medially at a right angle to the anterior layer; it joins the posterior surface of the **neck** of the rib to the **transverse process** above. It is continuous laterally with the **external intercostal membrane** and the external intercostal muscles. The **anterior layer** connects the upper edge of the **neck** with the lower edge of the **transverse process** lying just above it. It joins the **internal intercostal membrane** in the plane of the internal intercostal muscles.

Rib 12 lacks a superior costotransverse ligament, having instead a **lumbocostal ligament** that attaches its shaft to the transverse process of the **L1** vertebra.

Less important surgically are the shorter ligaments, the costotransverse ligaments that lie between the neck of the rib and the transverse process.

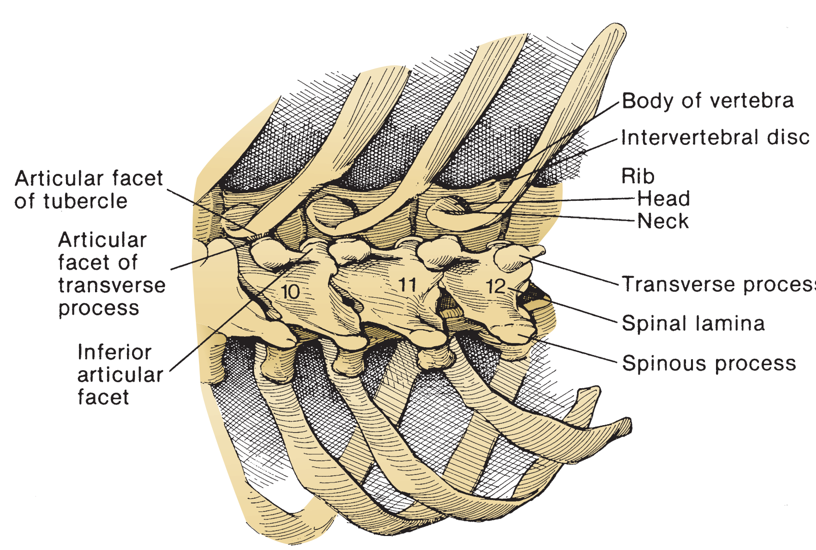


FIGURE 8-13.

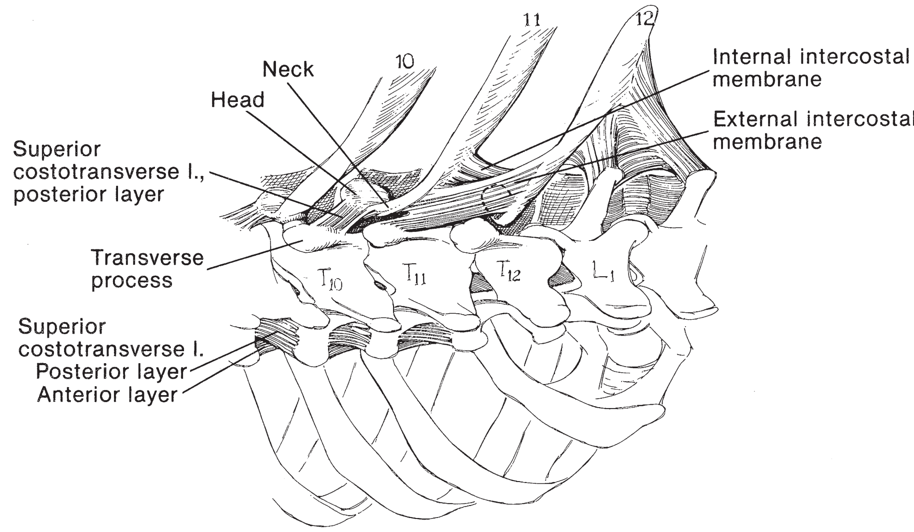


FIGURE 8-14.

PERITONEUM AND RETROPERITONEAL LAYERS

Posterior Parietal Peritoneum

The **peritoneum,** as the term is used here, is composed of a layer of mesothelial cells over a basement membrane and underlying connective tissue that contains terminal vessels and nerves to the peritoneum. It is freely separable from the retroperitoneal connective tissue proper.

The **parietal peritoneum** covers the musculature and those organs related to the posterior body wall (Fig. 8-15). Folds from it form the mesenteries of the small intestine, arising from the **root of the mesentery**, and form the mesocolons of the ascending, transverse, descending, and sigmoid colon. The free portion of the **ascending** and **descending mesocolons** is short, such that the bowel is in virtual contact with the kidneys, separated only by the inner stratum of the retroperitoneal fascia and representations from the peritoneum (fusion-fascia) and the anterior lamina of Gerota's fascia. The attachment of the **transverse mesocolon** to the parietal peritoneum is somewhat narrower, and the mesocolon is more developed as it crosses the body wall above the duodenum. The **root of the transverse mesocolon** is shown, fused to the **posterior layer** of the **greater omentum.** (For details of the mesenteries, see Chapter 6.)

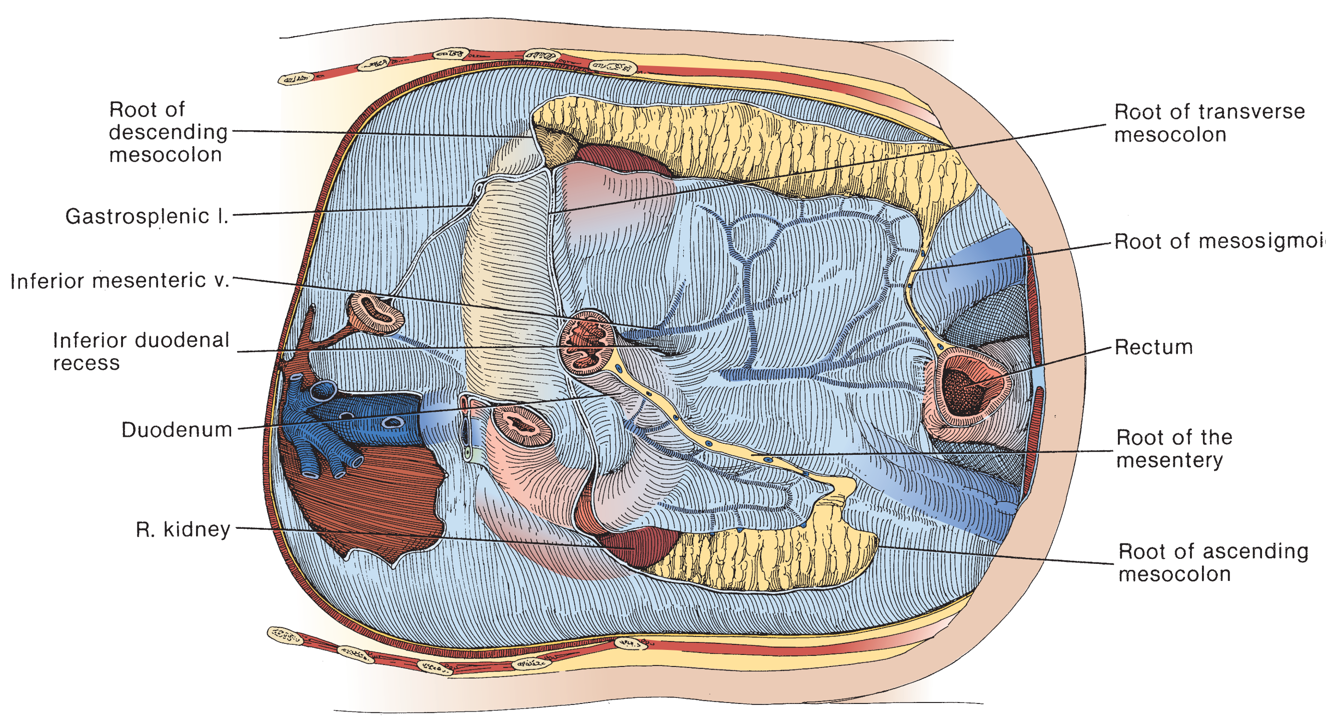


FIGURE 8-15.

Retroperitoneal Connective Tissue

Although the retroperitoneal connective tissue originally consisted of one layer, it subsequently differentiates into three layers called strata. The layer immediately beneath the peritoneum is the inner stratum that covers the gastrointestinal viscera and their blood supply. The intermediate stratum encloses the adrenals, kidneys, and ureters as well as the larger vessels and nerves. The outer stratum forms the fascia of the body wall.

The *inner stratum* is a thin layer of areolar tissue that lies directly beneath the basement membrane of the peritoneum. It encases the intestinal tract within the abdomen and pelvis, constituting its adventitia. It also holds the mesenteric vessels and nerves. This stratum is continuous from the emergence of the esophagus from the diaphragm above to the pelvic diaphragm, where it fuses with the outer stratum.

The *intermediate stratum* has a varied composition, ranging from fibrous in areas where the organs are fixed, to fatty about more mobile organs and in subjects with generous body fat. Across the posterior body wall, this stratum encloses the great vessels; the blood vessels to the intestines and to the body wall are covered as they pass through it. It is divided into two layers in the region of the kidney. The posterior one composes the pararenal fat layer. The anterior layer is split to form the anterior and posterior lamina of the renal fascia of Gerota enclosing the perirenal space (see Chapter 12). In the midline over the great vessels, the anterior and posterior laminae fuse. They also fuse with the outer stratum on the ventral surface of the diaphragm, although the fusion is not complete because gas infused into the perirenal space can spread to the mediastinum. The two layers enclose the ureters as they extend caudally and portions of the layers are continuous with the vesical connective tissue. They fuse laterally to contribute to the lateroconal fascia (see Chapter 12).

The *outer stratum* forms the transversalis fascia that covers the investing fascia (epimysium) of the transversus abdominis muscle as a layer of dense, collagenous-elastic connective tissue. It fuses with the subdiaphragmatic fascia. It also fuses with the psoas fascia at its lateral border and with the fascia of the quadratus lumborum that forms the anterior lamella of the lumbodorsal fascia. It is attached to the lateral and ventral surfaces of the vertebral bodies and is continuous with the iliac fascia and the fascia of the pelvic diaphragm. Fascial collars are formed from the transversalis fascia at the sites of exit of the urinary and digestive tracts, and of the reproductive tract in the female. The term *endopelvic fascia* is appropriate for these special arrangements of the transversalis fascia, although the term has also been used to denote all of the transversalis fascia in the pelvis.

Fascial and Peritoneal Layers

The **transversalis fascia,** from the outer stratum of retroperitoneal connective tissue, lines the inner aspect of the muscles of the abdominal wall (Fig. 8-16). Beneath it is the **pararenal space** that is covered by the two layers of the intermediate strata, the **anterior** and **posterior lamella** of the **renal** (Gerota's) **fascia.** The **perirenal space** lies between the two lamellae. The **fusion-fascia,** derived from adherence of the peritoneum of the colonic mesentery with the primary posterior peritoneum, lies anterior to the anterior lamella of the renal fascia.

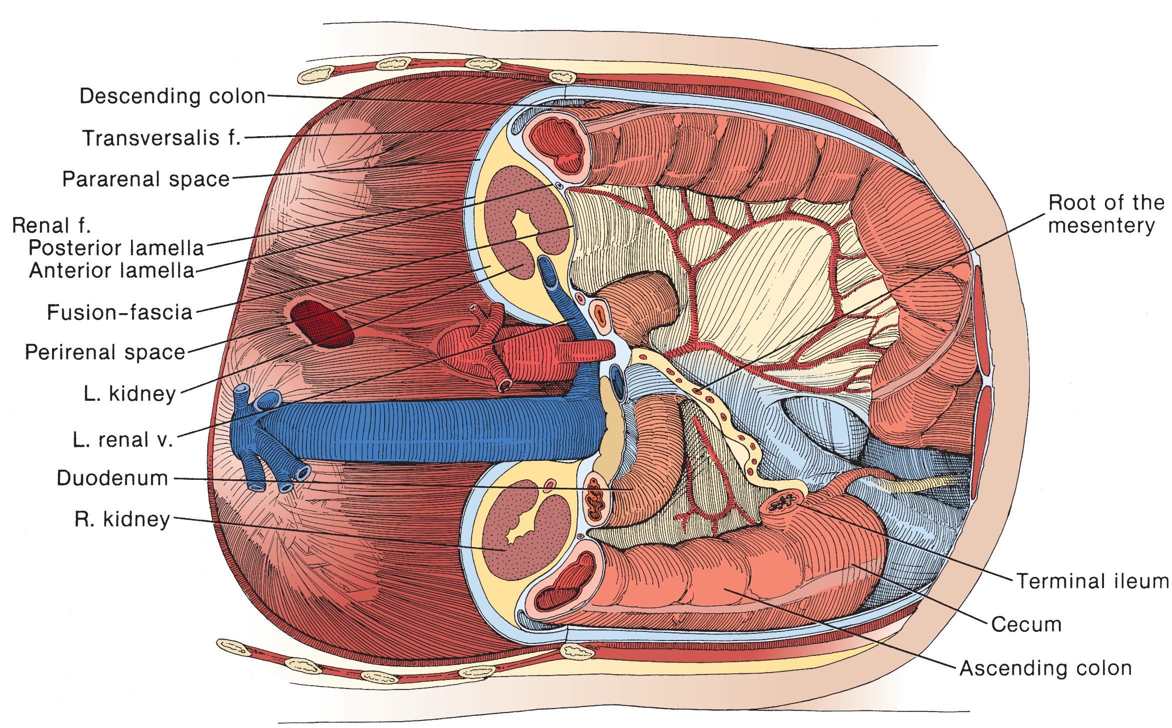


FIGURE 8-16.

Retroperitoneal Structures

The **inferior vena cava** exits from the retroperitoneum through the vena caval opening in the diaphragm between the **right leaf** of the diaphragm and the anterior leaf of the **central tendon** (Fig. 8-17). The aorta enters beneath the **median arcuate ligament** and gives off the **celiac trunk** and the **superior mesenteric artery**. The **esophagus** enters through the muscular medial fibers of the right crus. The **pancreas** and **duodenum** overlie the **aorta** and **inferior vena cava** and the **kidneys** and **adrenals** laterally. The junction of the diaphragm with the posterior abdominal wall is marked by the **lateral** and **medial arcuate ligaments** over the **quadratus lumborum** and **psoas major**, respectively.

Anterior Aspect of the Innermost Layer and Diaphragm

Removal of the peritoneum and transversalis fascia that overlie the diaphragm and the muscles of the posterior body wall exposes the internal surface of the posterior body wall.

The posterior portion of the **diaphragm** arises from part of the lower six ribs and from the 2nd and 3rd lumbar vertebrae by two **crura,** which pass on either side to provide an opening for the aorta and esophagus (with the vagal trunks) as well as for the thoracic splanchnic nerves that go to the celiac plexus (Fig. 8-18). The diaphragm is attached to the body of the 1st and 2nd lumbar vertebrae and to the transverse process of the 1st lumbar vertebra by thickened bands of fascia, the **medial arcuate ligament** over the **psoas major.** It is also attached to the midpoint of the 12th rib and the transverse process of the 1st lumbar vertebra by the **lateral arcuate ligament** spanning the quadratus lumborum. The muscle fibers attach to the **central tendon,** which has an opening for the passage of the inferior vena cava accompanied by the right phrenic nerve. The tendinous right crus is separated from the left crus by the short **median arcuate ligament** at the site of exit of the **aorta,** and both are attached to the body of the 1st and 2nd lumbar vertebrae, with the right also attaching to the 3rd lumbar vertebra.

The **quadratus lumborum,** arising from the 12th rib and the transverse processes of the 1st to 4th lumbar vertebrae, inserts in the iliac crest and the iliolumbar ligament. The psoas major takes origin from the sides and disks of all five lumbar vertebrae, as well as from their transverse processes, and attaches to the lesser trochanter of the femur along with the iliacus. The **psoas minor** originates from the lateral surfaces of the 12th thoracic and 1st lumbar vertebrae and attaches to the pectineal line and to the iliopubic eminence of the ilium and laterally to the iliac fascia. It also attaches to the femur. The **iliacus** arises in the iliac fossa and the inner lip of the iliac crest and part of the sacrum and inserts in the lateral side of the psoas tendon and into the lesser trochanter of the femur.

Attachments of the Deep Musculature

The **psoas major** passes under the **medial arcuate ligament** to attach to the anterior surface and lower margin of the **lumbar transverse processes** and by five muscular slips to the **vertebral bodies** of the 12th thoracic and all of the **lumbar vertebrae** (Fig. 8-19). It terminates with the iliacus on the **lesser trochanter of the femur**. The **psoas minor**, lying over the psoas major, has a narrow tendon that attaches to the pecten pubis and the iliopectineal eminence. It is absent about 40% of the time. The **quadratus lumborum** extends cephalad beneath the **lateral arcuate ligament**

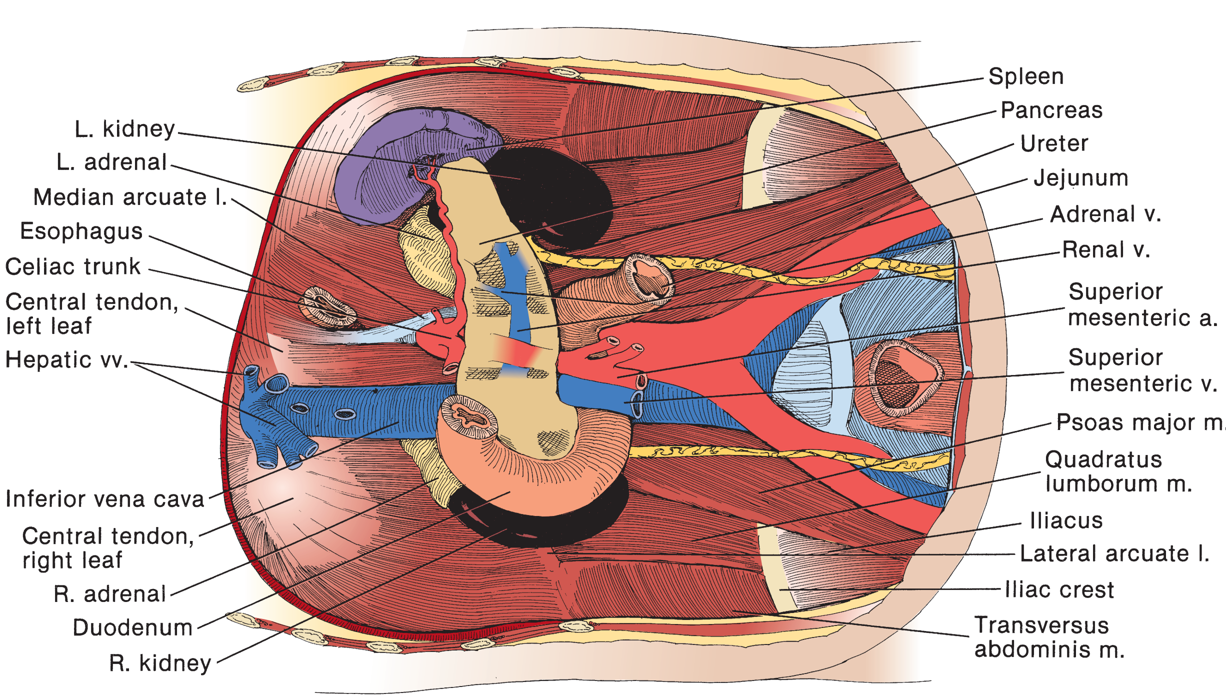


FIGURE 8-17.

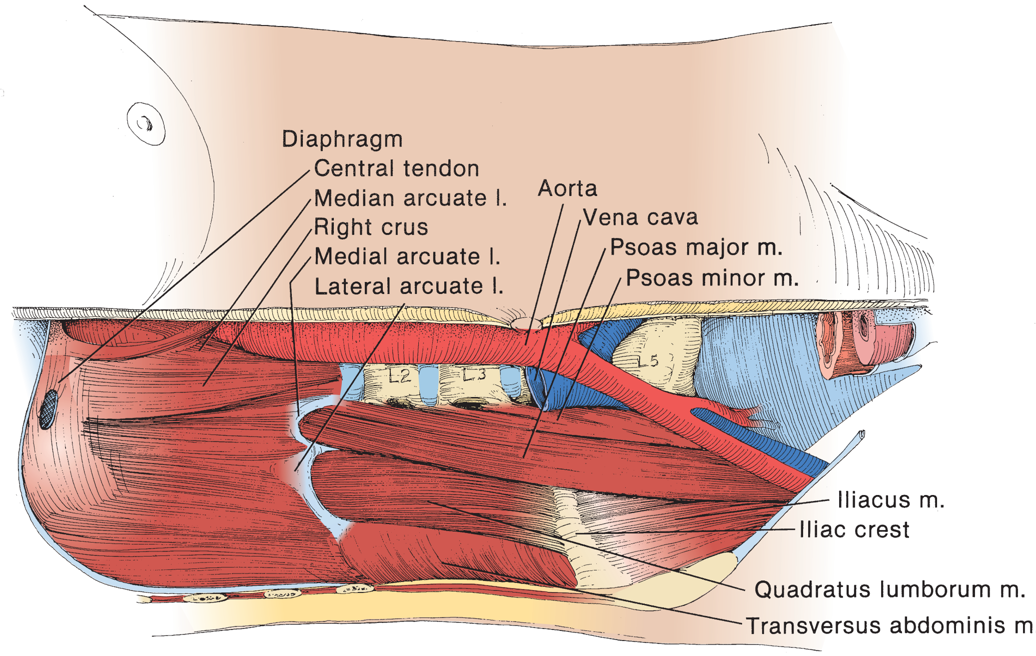


FIGURE 8-18.

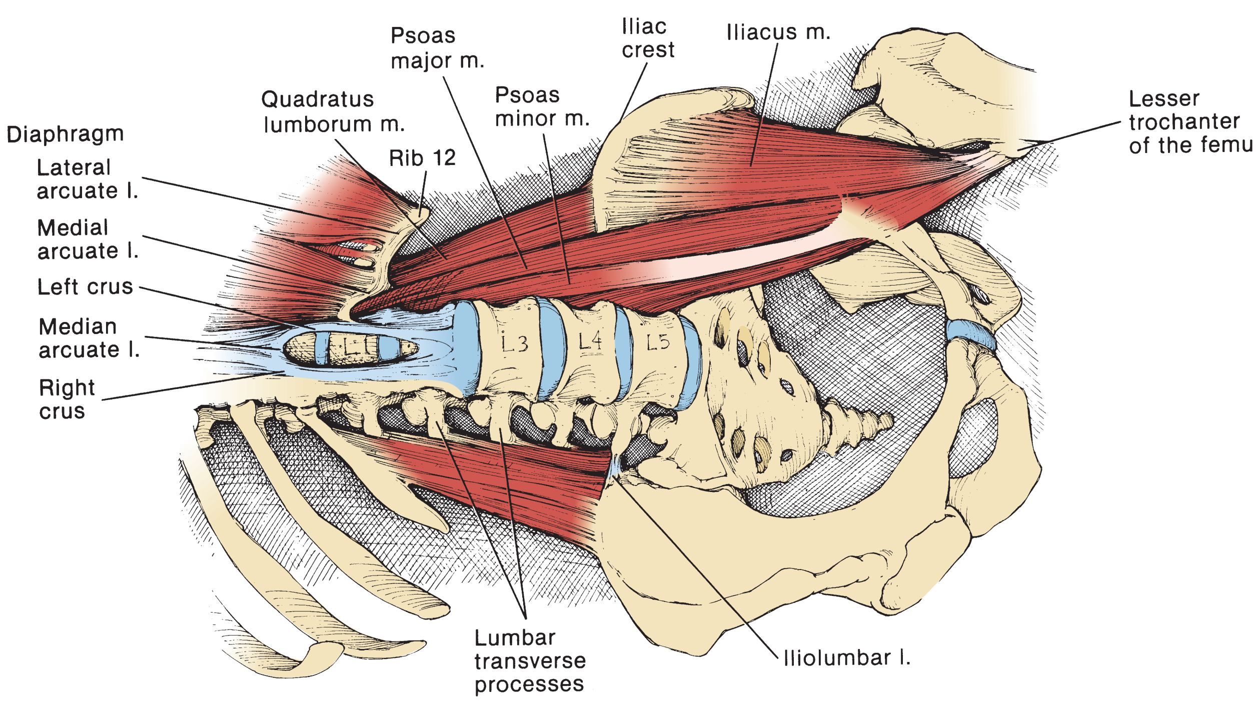


FIGURE 8-19.

to reach the lower border of rib 12 and the transverse processes of the first four lumbar vertebrae. Caudally, it attaches to the iliolumbar ligament and the **medial part of the iliac crest.** The **iliacus** is attached above to the inner surface of the ilium and sacrum and ends joined with the tendon of the psoas major on the femur.

Lymphatics

The superficial lymphatics of the posterior body wall join those of the back and gluteal regions to form several collectors that pass over the iliac crest to end in the superoexternal group of superficial inguinal nodes. The deep lymphatics, originating in the muscles and aponeuroses of the flank, form lumbar collectors that run with the lumbar vessels to the para-aortic nodes.

Innervation of the Body Wall

The junction of the dorsal and ventral spinal roots form a **spinal nerve**, which divides into a dorsal and ventral ramus that innervate the muscles of the body wall and the overlying skin.

The segmentally arranged **dorsal rami** run dorsally, then split into medial and lateral branches supplying the muscles on either side of the spine and the overlying skin.

The **ventral rami** are also segmentally arranged in the thoracic region, but in the lumbar and sacral regions they form plexuses after emerging from the cord. In the thoracic region, the ventral rami are larger than the dorsal ones. Of urologic concern are the ventral rami of the 7th to 12th thoracic (intercostal) nerves because they innervate the subcostal, intercostal, and abdominal muscles and the peritoneum, and supply the skin with **lateral** and **anterior cutaneous branches** (Fig. 8-20). Around the abdomen, they are found between the **internal oblique** and **transversus**. In the thorax, they run below the ribs in the intercostal space between the posterior intercostal membrane and its continuation, the internal intercostal muscle, and the innermost intercostal muscle to reach the anterior abdominal wall (see Fig. 8-8).

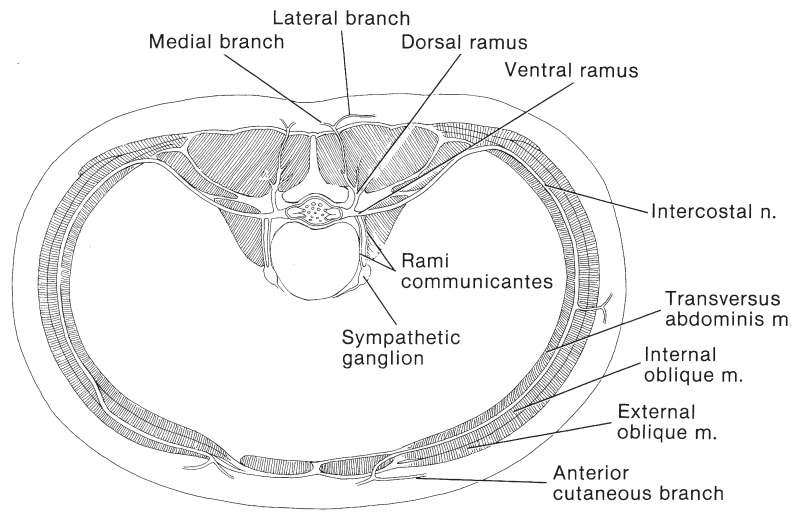


FIGURE 8-20.

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Chapter 9

Inguinal Region

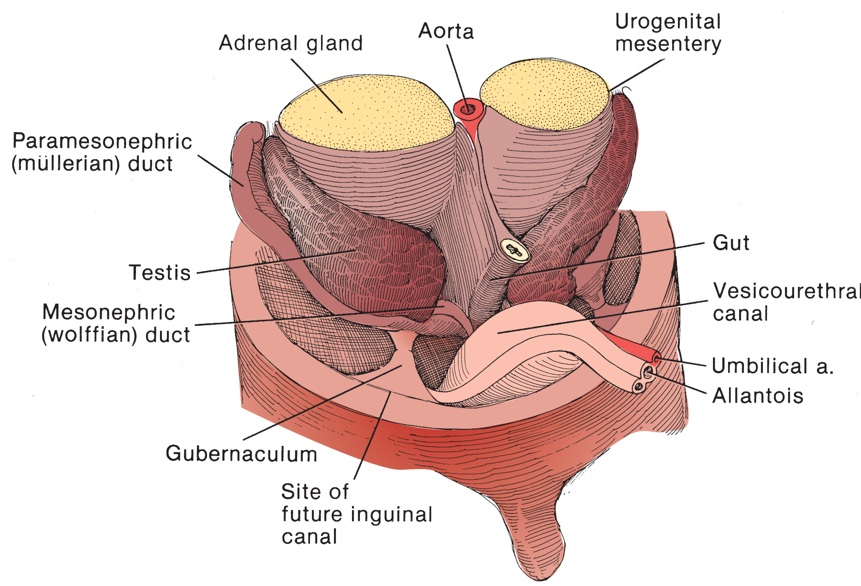

FIGURE 9-1.

Inguinal, belonging to the groin.

WILLIS' REM. MED. WKS., *Vocab. 1681*

DEVELOPMENT OF THE STRUCTURES AROUND THE GROIN

Some of the tissue of the primitive myotome does not persist as muscle but degenerates into fibrous structures that form the aponeuroses of the muscles. The inferomedial aponeurotic attachments of three abdominal muscles, the external and internal obliques and the transversus abdominis, form the inguinal canal about the gubernaculum.

DIFFERENTIATION OF THE INGUINAL CANAL

The development of the inguinal canal is not dependent on that of the testis, because it is similar in both sexes and virtually complete at 22 weeks, the time testicular descent begins in the male.

Development of the Gubernaculum

At about 8 weeks, the **testis** is suspended from the posterior body wall by the **urogenital mesentery** that runs medial to the **paramesonephric** (müllerian) **duct** (Fig. 9-1).

The **gubernaculum** is formed as mesenchymal cells condense and reinforce the more caudal portion of the mesentery. This structure extends as a short stalk from the lower pole of the testis and epididymis to the anterior abdominal wall at the site of the future inguinal canal. The **mesonephric** (wolffian) **duct** runs dorsal to the testis. (See also Chapter 17.)

Opening of the Inguinal Ring

Between the sixth and tenth weeks, the **peritoneum** partially surrounds the **gubernaculum**, covering it on the anterior and lateral sides (Fig. 9-2A). Enlargement of the abdominal cavity by accumulation of the intestines displaces the anterior abdominal wall, which effectively pulls the **testis** and **epididymis** away from the posterior wall. As the gubernaculum tightens, it rotates the testis into a horizontal position with the epididymis below and holds it adjacent to the future canal.

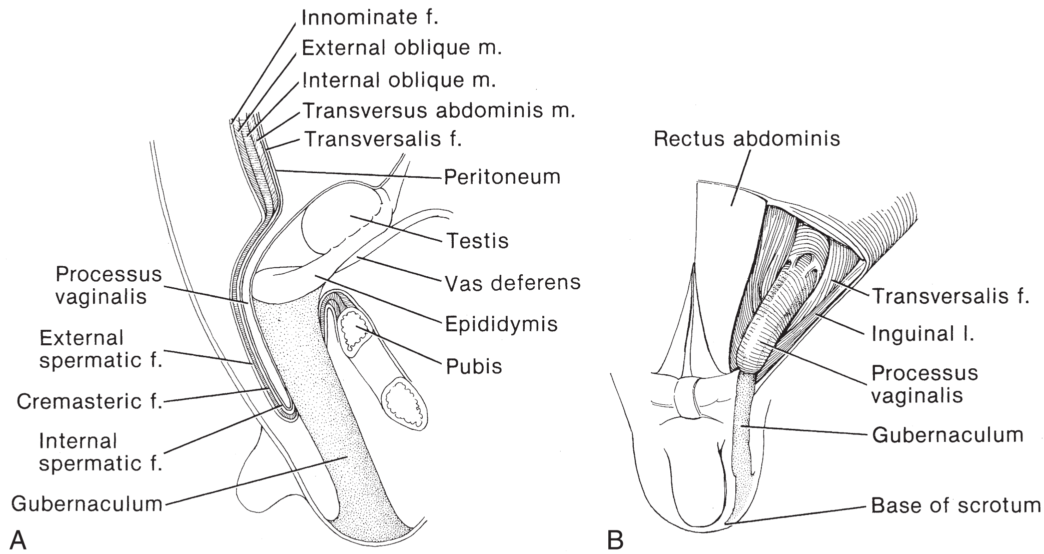

FIGURE 9-2.

The peritoneum evaginates as a pouch to form the **processus vaginalis**.

Because the **head** of the **epididymis** lies distal to the **testis** and is attached to the gubernaculum, it enters the **internal ring** of the new inguinal canal ahead of the testis. The **epididymis** follows the lead of the **gubernaculum** along with the processus vaginalis to the base of the scrotum.

The **transversalis fascia** that continues as the **internal spermatic fascia** about the **gubernaculum** thickens and forms an inverted U-shaped structure, the **internal inguinal ring**. The ring is at its greatest development around the 28th week, when the diameter of the gubernaculum is larger than that of the testis itself and testicular descent is imminent.

Evagination of the peritoneum occurs anterior and lateral to the spermatic cord (Fig. 9-2B). When an indirect hernia occurs, the sac exits through the deep inguinal ring in the same relationship to the cord.

Testicular Descent

The peritoneal evagination forming the **processus vaginalis** progresses anterolateral to the **gubernaculum** until it has reached the base of the scrotum (Fig. 9-3A).

After the testis is in the scrotum, the tissues of the ring contract on the cord, leaving the oblique **inguinal canal** that is found in the adult. The peritoneal lining of the processus becomes obliterated (Fig. 9-3B).

The inguinal region in infants differs somewhat from that in the adult, and the differences are important for surgery at this age. With time, the initially thick superficial fascia resembling the aponeurosis of the external oblique assumes its normal thickness. The canal subsequently runs more obliquely, and the previously well-developed cremaster becomes thinned.

Cryptorchidism is the most common congenital abnormality of the testis. Approximately one-tenth of cryptorchid testes are intra-abdominal and the same proportion are ectopic, a fifth are prescrotal, two-fifths are inguinal, as many as a fifth are bilateral, and 3% or 4% are absent.

COVERINGS OF THE SPERMATIC CORD

(See also Chapter 17.)

The four coverings of the spermatic cord arise from undifferentiated mesenchyme lying between the tissue destined to be the epithelium of the skin and that destined to

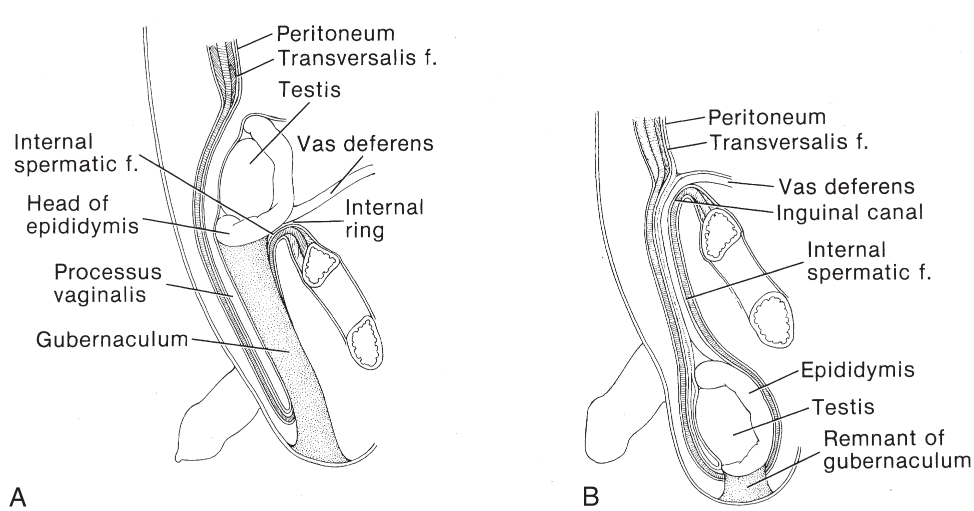

FIGURE 9-3.

be the mesothelium of the peritoneum. The mesenchyme develops three layers: (1) a subcutaneous layer, (2) a middle layer that becomes the body wall itself, and (3) a retroperitoneal layer. Late in fetal life, the subcutaneous layer differentiates into dermis, superficial fascia (eventually to become Camper's and Scarpa's fascias and the dartos), and deep investing fascia of the body wall (see Table 8-1).

During passage of the testis through the inguinal canal, the testis within the tunica vaginalis pulls with it a succession of layers from the anterior body wall (see Fig. 9-2). The exception is the cremaster, which probably forms from local mesenchyme.

The internal spermatic fascia is derived from the same layer of retroperitoneal connective tissue that forms the transversalis fascia. The cremasteric fascia and cremasteric muscle are continuations of the internal oblique and transversus abdominis; the external spermatic fascia is continuous with the innominate fascia over the external oblique (see Fig. 9-10).

INGUINAL AND FEMORAL REGIONS: STRUCTURE AND FUNCTION

The anatomy of the inguinal region is complex because of adaptation to testicular descent and erect posture. The surgeon, by viewing the groin region from inside the pelvis as well as from the exterior and then mentally combining both views, can create a three-dimensional picture of the area to apply during an operation, whether for node dissection or for orchiopexy and hernia repair.

EXTERNAL APPROACH TO THE INGUINAL REGION

Skin and Fascia

The skin, in combination with two layers of superficial fascia, encloses the superficial vessels and nerves and the superficial inguinal lymph nodes.

The *skin* of the groin area is thick and relatively inelastic but because it is accessible and relatively hairless, it can be used for skin grafts during genital repair. The surface over a lower abdominal quadrant is suitable for excising full-thickness grafts or dermal grafts, and the anterolateral surface of the thigh can be flattened for cutting a split-thickness graft with a dermatome. In infants and obese adults, a fold of skin runs transversely above the skin crease at the bend of the thigh. This marks the lower border of the thickest part of the abdominal panniculus and is a useful crevice in which to hide an incision. In fact, the lines of skin tension run transversely and should be followed to favor healing of the wound, because the surrounding skin flaps can always be moved to allow surgical exposure of all parts of the groin.

The *superficial fascia* in the groin is a continuation of adjacent layers. Although an attempt is made to divide the superficial fascia into a superficial layer and a deep or membranous layer, the continuities are not precise, because some layers become attenuated and others acquire local importance. Buck's fascia is a case in point. Although it is defined as being part of the membranous layer of the superficial fascia, it is covered by the dartos, which is an extension of Colles' fascia, also part of the membranous layer of the superficial fascia. Table 9-1 defines the layers.

The **superficial layer** of the **superficial fascia (Camper)** is areolar tissue with its contained fat (Fig. 9-4). This layer passes over the inguinal ligament to continue as the superficial fascia of the thigh. It is also continuous with the **superficial fascia** of the **penis** (often called the dartos layer). It descends into the scrotum with that of the areolar outer covering of the spermatic cord, the dartos proper, where the areolar tissue picks up nonstriated muscle fibers to become the **dartos muscle**. The layer then passes posteriorly to join the superficial layer of the superficial fascia of the perineum. The superficial epigastric vein and artery arise from the anterior surface of the femoral vein and artery 1 cm below the inguinal ligament and run across the line of an inguinal incision beneath the superficial layer to the level of the umbilicus. An incision through the neck of the scrotum may encounter the superficial external pudendal vessels as they cross from the fossa ovalis to supply the penis and scrotum.

The deep or **membranous layer** of the **superficial fascia** (Scarpa) is found in the groin as a distinct compact layer, but it becomes less identifiable over the upper portions of the flank and abdomen and may not be found in obese individuals. It should not be mistaken for the external oblique aponeurosis, especially because Scarpa's fascia does not have parallel collagenous fibers. Also, traction on it

TABLE 9-1 CONTINUITY OF FASCIAL LAYERS

Inguinal Region	External Genitalia	Thigh
Camper's fascia		Subcutaneous fat
Scarpa's fascia	Dartos, Buck's, Colles' fascia	Cribriform fascia
Innominate fascia	External spermatic fascia	Fascia lata
Internal oblique	Cremasteric fascia and muscle	
Transversalis fascia	Internal spermatic fascia	Anterior, medial walls, femoral sheath
Peritoneum	Tunica vaginalis	

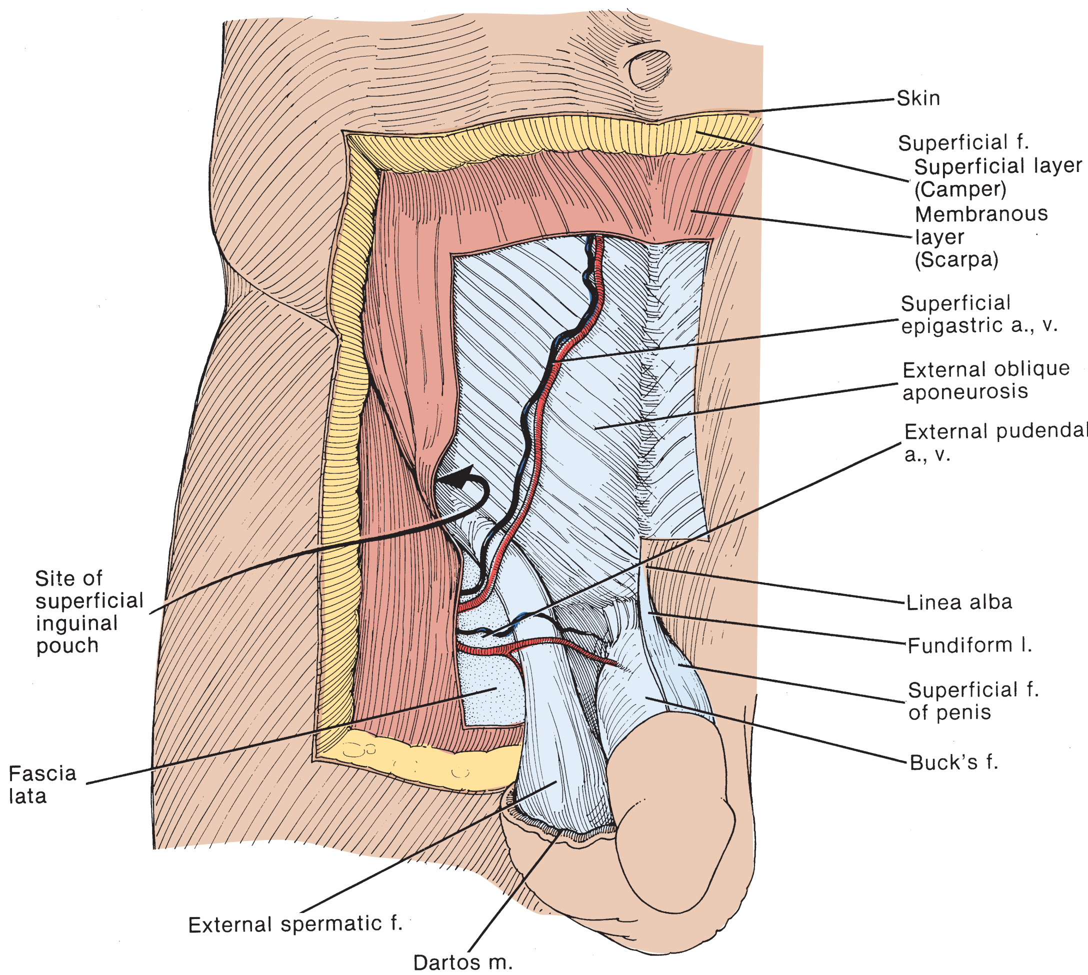

FIGURE 9-4.

moves with the skin to which it is attached. It is loosely connected to the innominate fascia of Gallaudet, which is the investing fascia overlying the **external oblique aponeurosis**. The membranous layer is firmly connected to the **linea alba** and to the symphysis pubis, contributing to the **fundiform ligament**.

The **superficial inguinal pouch** (Denis Browne) is a potential space between the membranous layer and the innominate fascia. The pouch lies lateral to the external ring and provides a space in which a cryptorchid testis may be found.

Between the pubic symphysis and the pubic tubercle, the membranous layer of the superficial fascia or Scarpa's fascia is unattached, leaving an opening for the spermatic cord—the so-called abdominoscrotal passage that is felt as a ring around the examining finger. This ring is not to be confused with the external inguinal ring, which lies higher and is rarely palpable in the absence of a hernia. Scarpa's fascia passes over the inguinal ligament, where it is attached only to the middle third, and blends with the superficial fascia of the thigh (over the superficial inguinal lymph nodes) and over the fossa ovalis and the **fascia lata**. It is continuous over the penis as the **superficial fascia of the penis**, the dartos layer, and it follows the spermatic cord into the scrotum as the membranous layer of the superficial fascia (dartos tunic). In the perineum it joins Colles' fascia representing the membranous layer of the superficial fascia in that region.

Bony Pelvis

Before describing the soft tissues, the bony surfaces and landmarks of the public portion of the pelvis are presented as a framework for attachment of the fascial structures about the inguinal canal. The pubis constitutes the lower medial third of the innominate bone (Fig. 9-5).

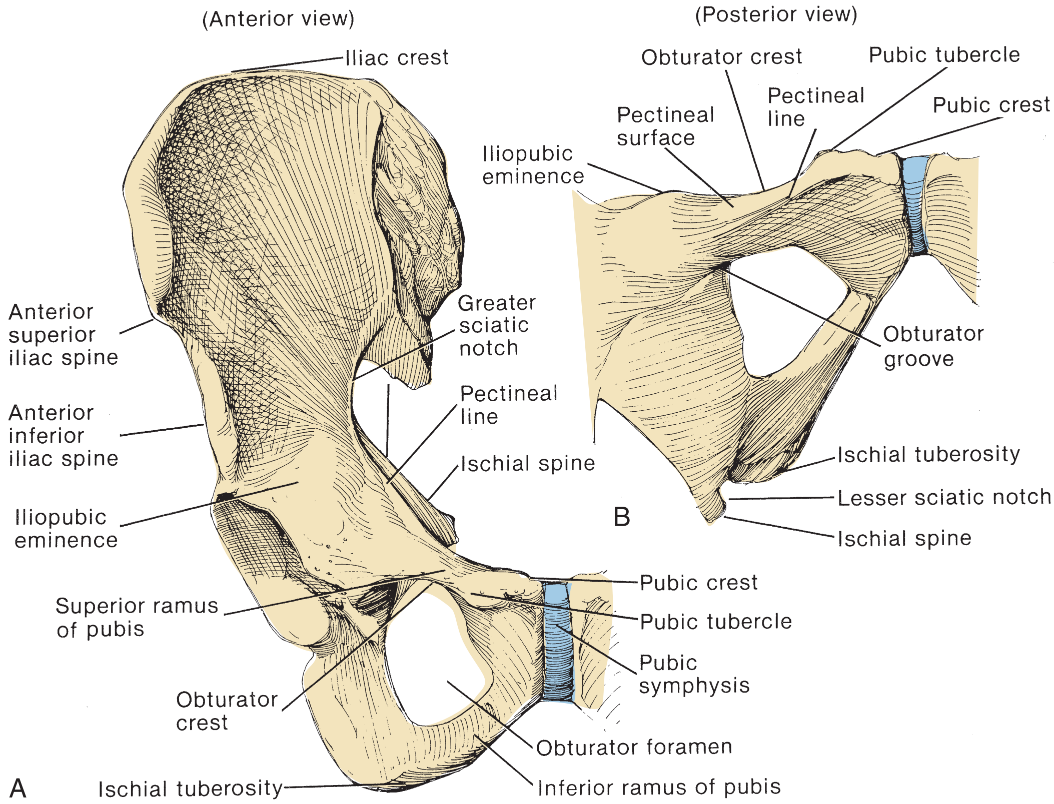

FIGURE 9-5. A, Anterior view. **B,** Posterior view.

The sites of attachment of inguinal structures are outlined in Table 9-2.

The **pectineal surface** (see Figs. 9-18 and 9-19) on the **superior ramus of the pubis** has a triangular shape that is oriented forward and slightly upward. This surface extends from the **pubic tubercle** (also see Figs. 9-9A, 9-10, 9-11A, and 9-19) to the **iliopubic eminence** (see Figs. 9-17 and 9-18) that marks the junction of the ilium and the pubis. In front is the **obturator crest** (also see Fig. 9-19) and behind is a sharp edge, the **pectineal line** (pecten pubis) (also see Figs. 9-7, 9-11B, and 9-19).

The **pubic crest** (also see Figs. 9-9A and 9-19) is the free upper border of the body of the pubis medial to the obturator crest. The lateral head of the rectus abdominis arises from its lateral part; the medial part of the rectus crosses its medial part before attaching to the symphysis and adjacent pubis. The pubic tubercle lies near the medial end of the pubis and is an important landmark in surgery of the groin because it indicates the medial attachment of the inguinal ligament. The tubercle provides part of the floor of the external inguinal ring.

The joint between the pubic bones, the **pubic symphysis**, has a thickness of 2 to 3 mm and is composed of hyaline and fibrous cartilage. It has an oval shape and commonly has a primitive cavity. It is connected by a heavy anterior pubic ligament and a smaller posterior pubic ligament, structures that are more likely to pull off from the bone rather than rupture.

External Oblique Layer

Each of the three muscles of the anterior abdominal wall is covered on both sides with investing fascia. The layer covering the external surface of the external oblique, the innominate fascia of Gallaudet, is the thickest and becomes the fascia lata in the thigh. The internal surface of the muscle has a thinner fascial coat and both the inner and outer fascias fuse at the inferior, free border, where the external oblique forms the inguinal ligament.

The fibers of the **external oblique aponeurosis,** following the direction of the fibers of the **muscle,** run downward and medially to end in and form part of the **linea alba**

TABLE 9-2

SITES OF ATTACHMENT OF INGUINAL STRUCTURES

BONES	
Pectineal line	Lacunar ligament
	Fascial lacunar ligament
	Pectineal ligament
	Falx inguinalis
	Lowest fibers of internal oblique
	Conjoined tendon
	Lowermost portion of the transversus
Pubic tubercle	Medial end of inguinal ligament
	Lacunar ligament
	Cremaster
Pubic crest	Lateral head of rectus abdominis
	Aponeurosis of external oblique
	Conjoined tendon
Symphysis	Membranous layer of superficial fascia
	Aponeurosis of external oblique
	Medial head of rectus abdominis
Anterior superior iliac spine	Lateral end of inguinal ligament
	Transversalis fascia (deep crural arch)
LIGAMENTS	
Superior pubic ligament (Cooper)	Transversus abdominis
Iliopsoas fascia	Inguinal portion of internal oblique
	Inguinal portion of transverses

(Fig. 9-6A). The aponeurosis is also attached medially to the upper border of the **pubic symphysis** and to the **pubic crest** as far as the **pubic tubercle**. It forms the anterior wall of the inguinal canal, supplemented laterally by fibers of the internal oblique aponeurosis that attach to the lateral part of the inguinal ligament.

The **external spermatic fascia** results from fusion of the innominate fascia and the fascia associated with the internal surface of the external oblique and its aponeurosis (Fig. 9-6B). It forms the outer tubular sheath surrounding the spermatic cord and testis. It is important surgically during exposure of the spermatic cord: If this fascia is incised along with the underlying external oblique aponeurosis to the point where its sheath widens near the upper pole of the testis, the scrotal contents, even if enlarged, may be drawn into the wound. It covers the **cremasteric fascia** and **internal spermatic fascia**.

Aponeurosis, fascia, and ligament are defined in Table 9-3.

The **superficial inguinal ring** is the most medial of the three inguinal rings (superficial, external, and internal) that provide passage for the spermatic cord while preventing herniation of the peritoneum and its contents (see Fig. 9-10). It is a triangular opening based on the pubic crest. Its sides are the medial and lateral crura formed by the edges of the external oblique aponeurosis as that structure splits to join the crest. The lateral edge, as the inferior or **lateral crus**, is the inguinal ligament itself reinforced by the **intercrural fibers** that come from the innominate fascia. The intercrural fibers run at right angles to the fibers of the aponeurosis and may arch over the superficial ring. The medial edge of the superficial inguinal ring, the superior or **medial crus**, is a thin extension of the external oblique aponeurosis that is attached to the front of the pubis and also to the linea

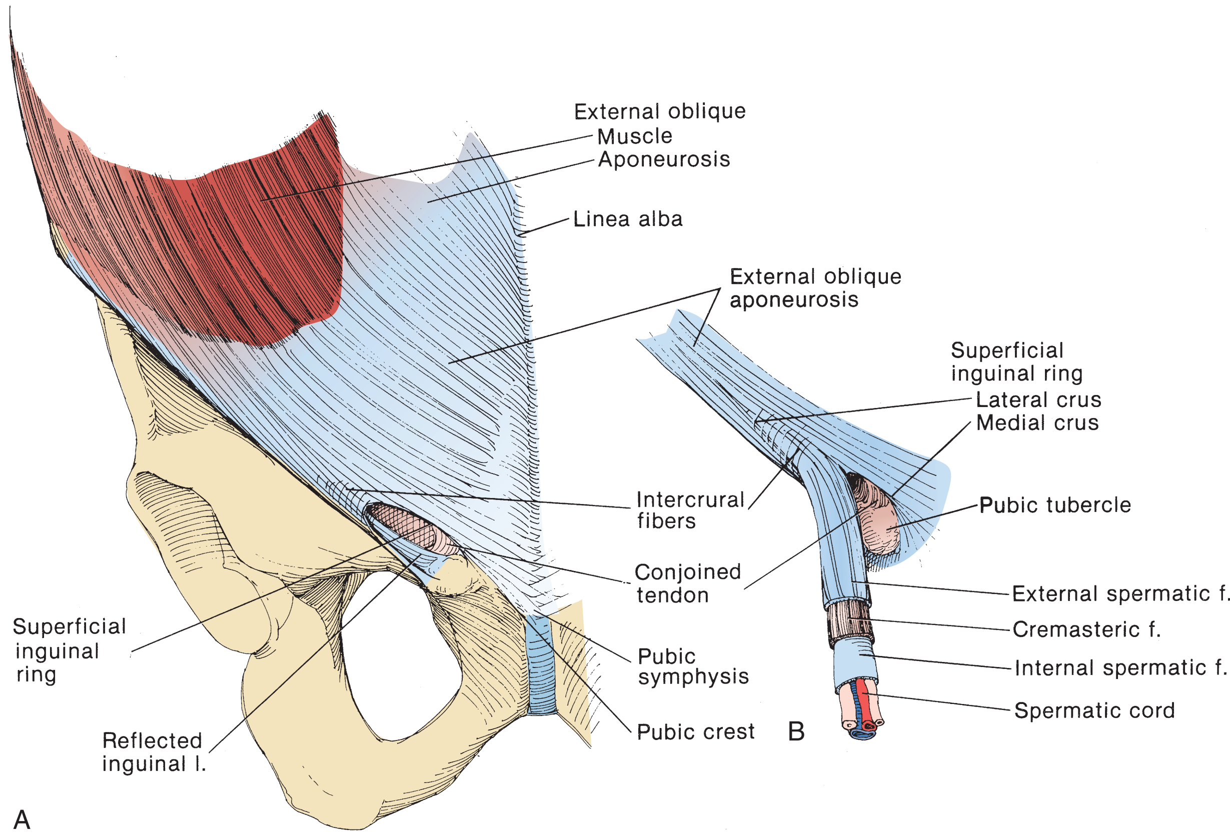

FIGURE 9-6.

TABLE 9-3

DEFINITIONS IN INGUINAL SURGERY

Aponeurosis: A flat, dense structure composed of strong collagenous parallel fibers that form a white tendon of insertion of the external oblique, the internal oblique, and the transversus abdominis into the sheath of the rectus abdominis muscle and into the pubis

Fascia: Layers formed from condensations of connective tissue covering muscles or derived from the retroperitoneal connective tissue

Ligaments: Condensations of connective tissue distributed between structures

alba, where its fibers interlace with those from the opposite side.

Inguinal Ligament

The inferior margin of the aponeurosis of the external oblique extends between the **anterior superior iliac spine**, where it is attached to the iliopsoas fascia, and the pectineus fascia at the **pectineal line** on the inner aspect of the pubis (Fig. 9-7A). The aponeurosis becomes somewhat thicker as it arches over the femoral nerve, vessels, and canal and folds internally on itself before ending as a free edge. This inward fold forms a shelf along its inner aspect, the **inguinal ligament** (Poupart). The ligament is rounder laterally but becomes flatter medially as it joins the **pubic tubercle**. The fibers of the external oblique aponeurosis change their oblique course to a more transverse direction to follow the line of the ligament. The deeper fibers posteromedially spread out to join the pectineal line. The ligament itself forms the floor of the inguinal canal.

The **reflected inguinal ligament** (Colles' or triangular ligament) (also see Figs. 9-7B, 9-11A, 9-16, 9-17, and 9-18) arises from the aponeurotic fibers of the lateral (inferior) crus of the inguinal ligament as the fibers expand and pass upward and medially behind the medial end of the superficial inguinal ring, then run behind the **external oblique aponeurosis** and in front of the arch of the transversus abdominis that, with some contribution from the internal oblique, constitutes the **conjoined tendon** (also see Figs. 9-9A, 9-11A, 9-16, and 9-20A). The reflected inguinal ligament is usually poorly developed, if it is present at all, and is not of use in hernia repair. However, the right and left inguinal ligaments interlace at the **linea alba**.

The **lacunar ligament** (Fig. 9-7C) (Gimbernat) viewed from inside the pelvis (also see Figs. 9-8C, 9-16, 9-17, and 9-18) is a subregion of the inguinal ligament, constituting its

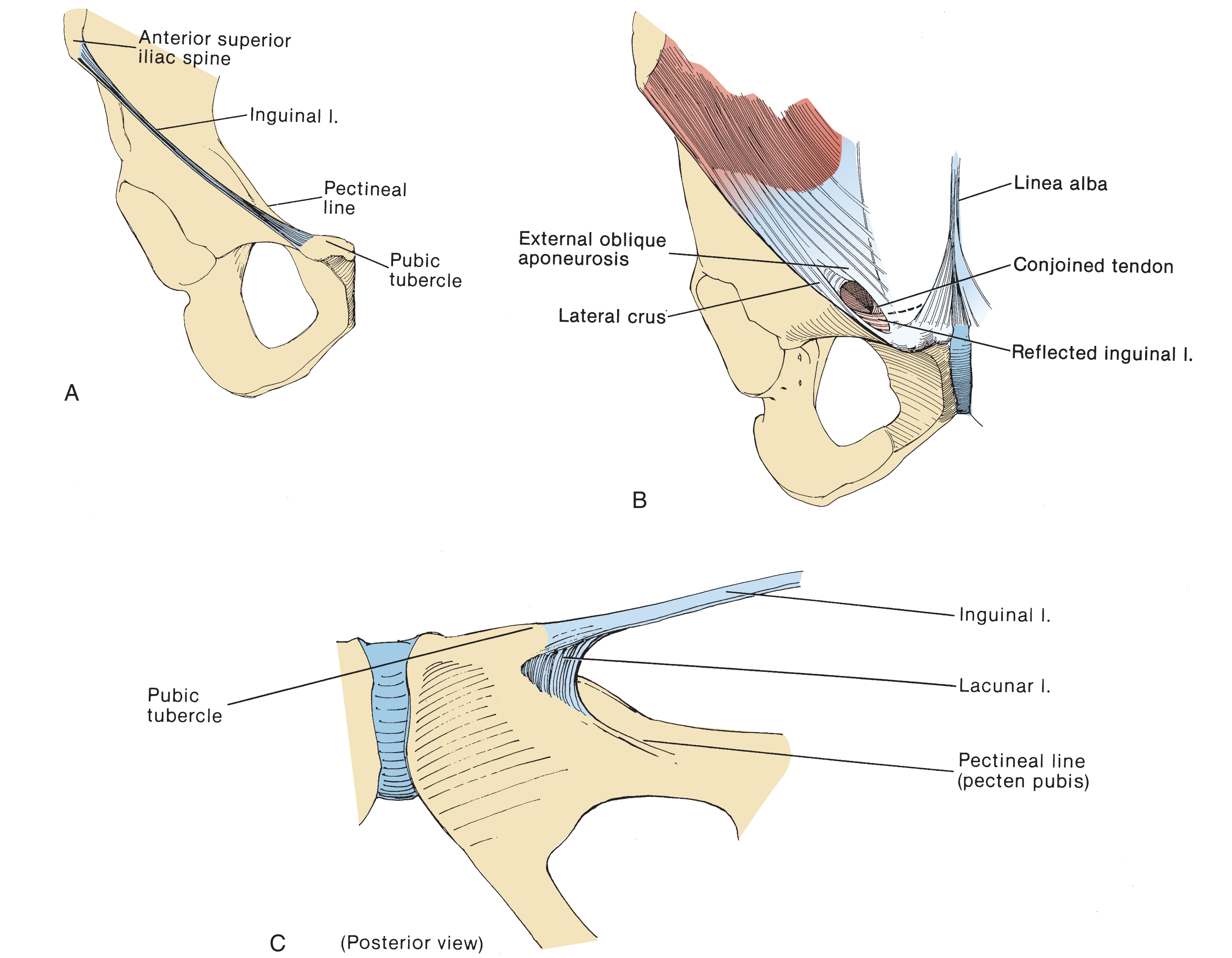

FIGURE 9-7.

pectineal part. It is a triangular continuation of the external oblique aponeurosis, extending from the medial part of the **inguinal ligament** to the medial end of the **pectineal line** (also see Figs. 9-11B, 9-19, and 9-20B), where it is joined by the pectineal fascia. Its base is concave and thin, and usually does not take part in the formation of the femoral sheath (see Figs. 9-8A and B and 9-20). Its anterior margin is a continuation of the inguinal ligament proper. The lacunar ligament serves to broaden the area of insertion of the inguinal ligament (also see Figs. 9-16 and 9-18). As a result of this configuration, the external oblique aponeurosis covers the anterior, the inferior, and part of the posterior portions of the cord.

Relations of the Inguinal and Femoral Canals

The femoral triangle (Scarpa) is bounded laterally by the medial margin of the sartorius. Its medial boundary is the adductor longus and the inguinal ligament is anterior. The floor is composed laterally of the fascia of the iliacus and psoas major and medially of the fascia of the pectineus and adductor longus.

When the inguinal canal is sagittally sectioned at midpoint, the relationships among the external oblique, the inguinal ligament and its reflected portion, and their relation to the femoral canal are demonstrated.

The inferior margin of the **external oblique aponeurosis** folds dorsally to form the **inguinal ligament** (Fig. 9-8A). The reflected inguinal ligament is in continuity with it (see Figs. 9-7B, 9-11A, 9-16, 9-17, and 9-18). The **inguinal canal** containing the spermatic cord lies in the fold.

The **femoral** (crural) **sheath** is composed anteriorly of a layer from the **transversalis fascia** as it extends caudal to the inguinal ligament and posteriorly from slips from the iliopsoas and pectineus fascia as the sheath passes behind the inguinal ligament (Fig. 9-8B). It is covered by the fascia lata, which has an opening, the fossa ovalis, which, in turn, is covered by the cribriform fascia, to accommodate the superficial vessels and saphenous vein. The **femoral canal** containing lymphatics, including Cloquet's node, passes through the sheath at its medial border. More laterally, a vascular compartment holds the iliac artery and vein. A third, neuromuscular compartment, containing the femoral nerve and the iliopsoas, lies laterally, outside the sheath.

In section, the space between the **inguinal ligament** and **iliopsoas fascia** and the bony pelvis may be seen to contain three compartments (Fig. 9-8C). Starting laterally, the *neuromuscular compartment* occupies the lateral portion of the space. It contains the **iliopsoas,** formed from fusion of the iliac and psoas muscles, and the **femoral nerve**. The **iliopectineal ligament** separates this compartment from the vascular compartment.

More medially, the **femoral artery** and **femoral vein** pass through the *vascular compartment,* which is surrounded by loose fibrofatty tissue that is continuous with that of the outer stratum of the retroperitoneal connective tissue. The femoral branch of the **genitofemoral nerve** enters the vertical lateral wall, and the **lymphatics** leave the medial wall.

The third compartment, the **femoral canal,** lies next to the iliopubic tract, medial to the other two. It is the residual space beneath the inguinal ligament. It is funnel-shaped, with the wide end at the inguinal ligament, tapering to obliteration about 4 cm below the ligament, where it fuses with the fascial coverings of the femoral vessels. It contains the femoral septum in which lie lymph channels that connect the deep inguinal to the external iliac lymph nodes. Cloquet's node usually lies at the upper end.

The inlet of the femoral canal is the femoral ring, which is bounded medially and anteriorly by the **iliopubic tract,** posteriorly by the **pectineal ligament,** and laterally by the iliopectineal arch. The boundaries of the femoral canal are in front, the **inguinal ligament;** behind, the **pectineus** and its fascia; medially, the edge of either the iliopubic tract or the

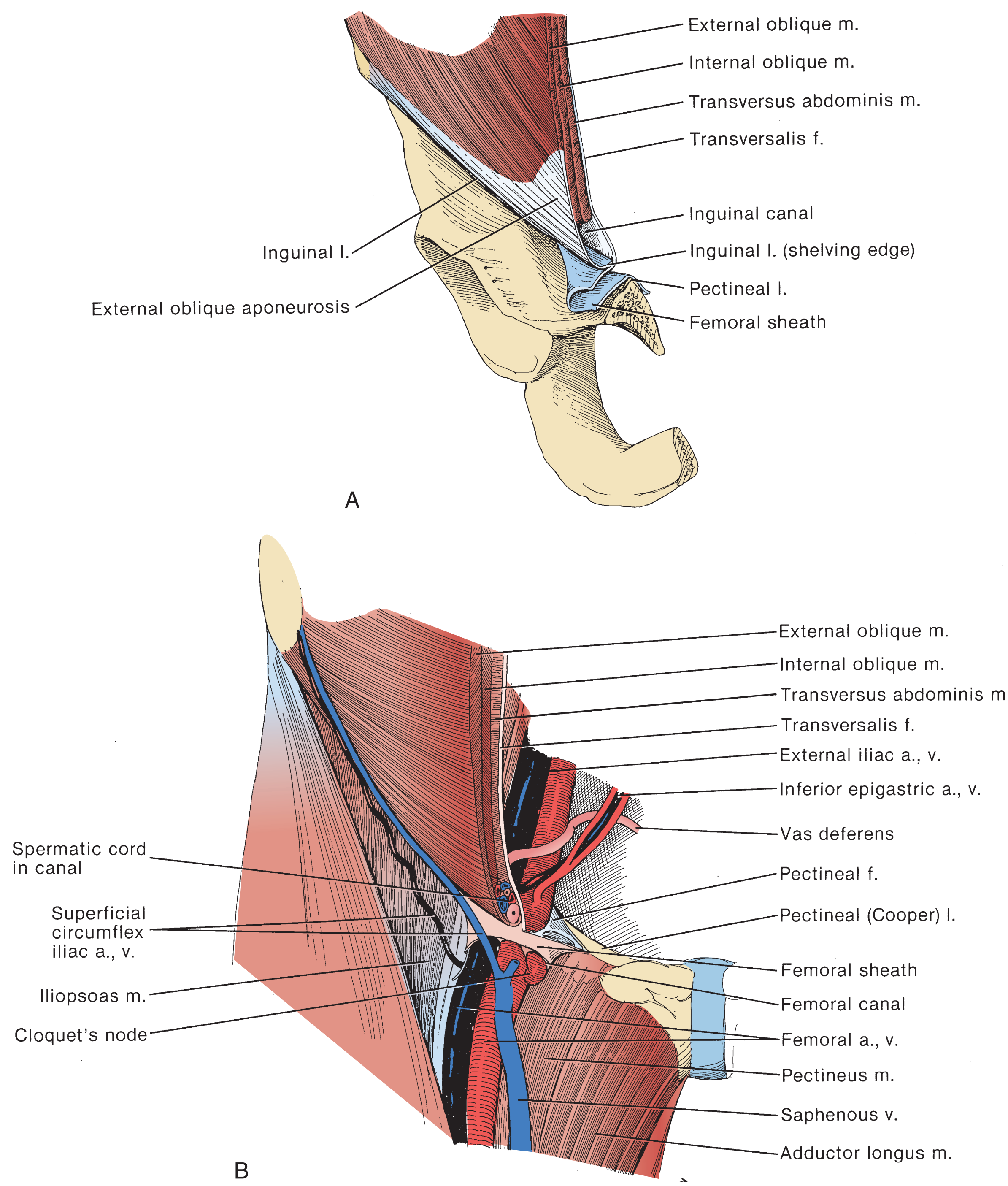

FIGURE 9-8.

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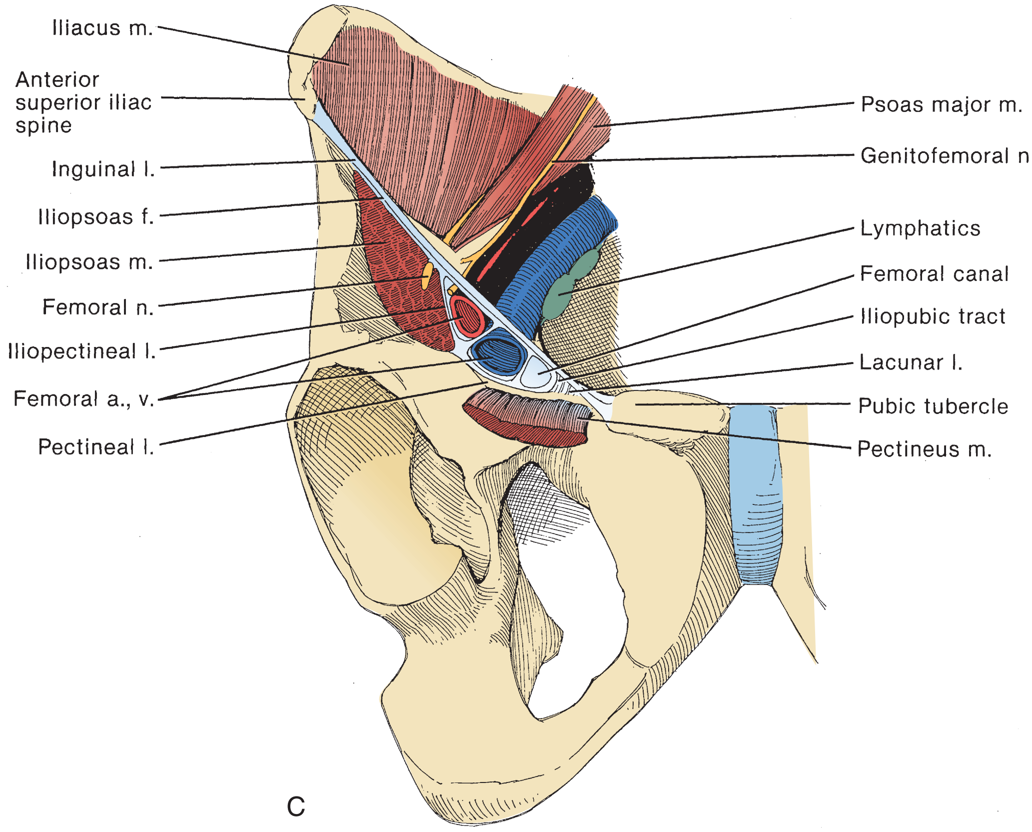

FIGURE 9-8. cont'd

aponeurosis of the transversus abdominis; and laterally, the femoral vein. Femoral hernias follow the canal.

Internal Oblique and Conjoined Tendon

Although arising from the lateral portion of the inguinal ligament, the **internal oblique** along much of its inguinal course is firmly attached to the underlying transversus abdominis, which is aponeurotic in this region (Fig. 9-9A). These layers fuse along the lower border to form the **conjoined tendon** (actually an aponeurosis) (see Figs. 9-7B, 9-9A, 9-11A, 9-16, and 9-20A). The conjoined tendon is principally an arch of the aponeurosis of the transversus, the **transversus arch,** although the lowest fibers of the internal oblique take part. Thus both of the terms *conjoined* and *tendon* may be misleading. The portion of the transversus abdominis that forms the conjoined tendon appears to arise from the lateral part of the **inguinal ligament,** but an origin from the neighboring iliopsoas fascia is more accurate, the tendon having only loose connections with the ligament itself. From the ligament, the fibers curve over the inguinal canal to form its roof and fasten to the **pubic crest** and the pectineal line, where they form the medial margin of the femoral ring.

The conjoined tendon is the principal line of defense against hernia, acting as a protective shutter on exertion. The edge of the conjoined tendon, called the transversus arch, is the most important structure in repair. Because the curve of the conjoined tendon is maintained by the ultimate attachment of the transversus muscle to the linea alba, vertical division of the rectus sheath eliminates the curve to allow the tendon to lie along the inguinal ligament for hernia repair.

The **cremaster** is a continuation of the **internal oblique** onto the **spermatic cord** anteriorly as the fibers curve over the cord. Above, other fibers come from the conjoined tendon as far as the pectineal line and pubic tubercle and, below, fibers come from the inner surface of the inguinal ligament (Fig. 9-9B). Both of these sets fan out over the cord to join the anterior fibers, effectively encasing the cord and testis so that mobilization of the cord requires division of the upper and lower fibers.

Cremasteric Fascia and Cremaster

The **cremasteric fascia** is a continuation of the **internal oblique aponeurosis** attached to the iliopsoas fascia. It encloses loops of loosely arranged bundles of striated muscle fibers held together by areolar tissues, which constitute the **cremaster** itself (Fig. 9-10). The fibers start at the midportion of the inguinal ligament on the anterolateral surface of the **spermatic cord,** pass through the superficial inguinal ring, and run on the posterolateral aspect of the cord to reach the medial portion of the cremaster that arises from the **pubic tubercle.** The loops so formed cover the **internal spermatic fascia** (see Fig. 9-6B) overlying the cord and tunica vaginalis. The muscle is under reflex control and functions to elevate the testis for protection during attack or sexual intercourse and in the regulation of testicular temperature. It is supplied by the genital branch of the genitofemoral nerve.

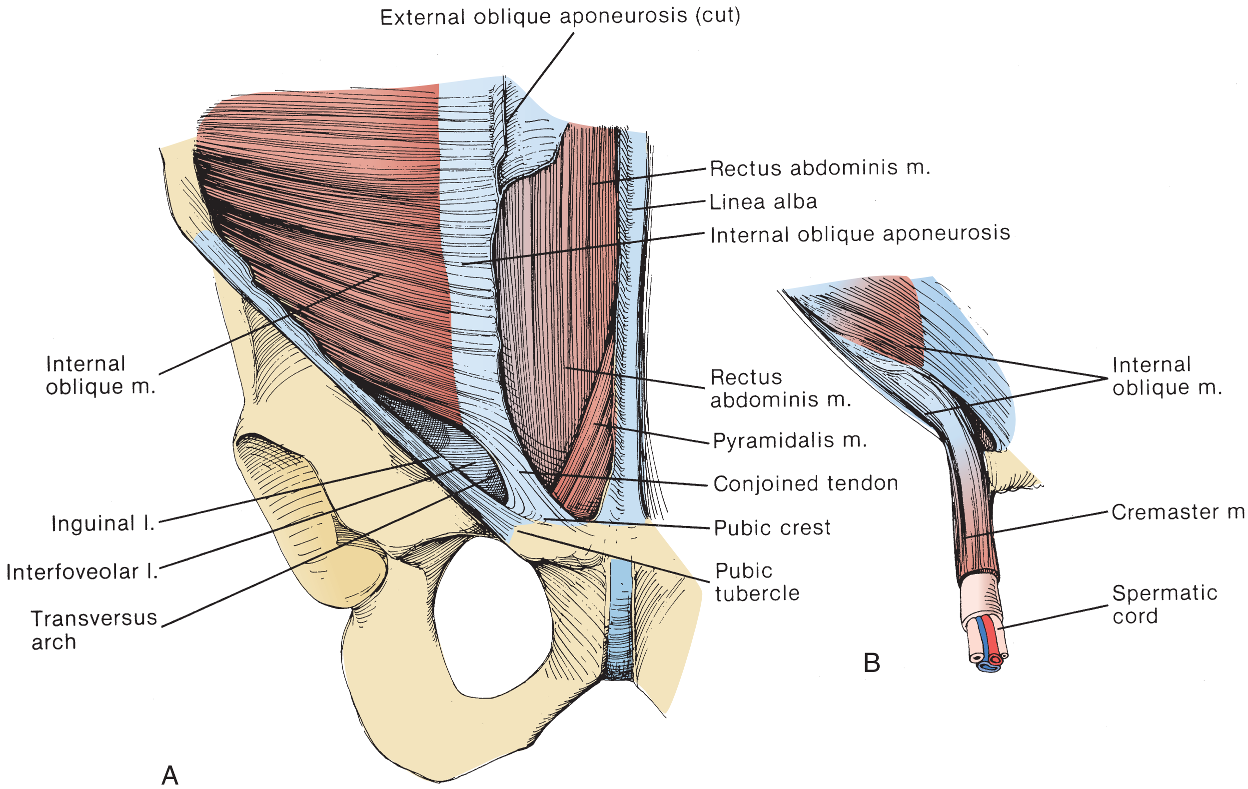

FIGURE 9-9.

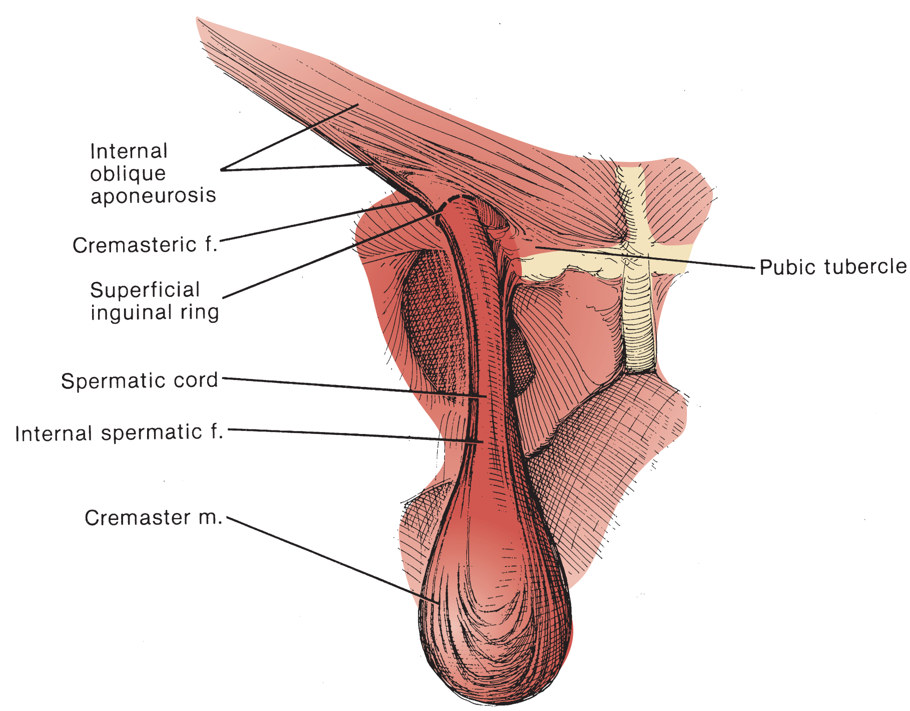

FIGURE 9-10.

Incision with displacement, or excision of the cremasteric fascia during inguinal hernia repair, exposes the floor of the inguinal canal and allows ready identification of the internal ring preliminary to repair.

Transversus Abdominis and Transversalis Fascia

Transversus Abdominis

The **transversus abdominis** in the inguinal area is principally aponeurotic. The fibers can be traced proximally to the iliopsoas fascia in common with those from the internal oblique. They extend distally beyond the level of the inguinal ligament where they join the femoral sheath. The transversus abdominis inserts in the pubis from the **pubic symphysis** to the **pubic tubercle** and then attaches along the pectineal line to the femoral ring.

Transversalis Fascia

The **transversalis fascia** represents the outer stratum of retroperitoneal connective tissue in this area. It lies beneath the transversus abdominis and is covered by the properitoneal fat layer. It is continuous with the obturator, iliac and psoas fascias, and also with the endopelvic fascia at the exit site of the pelvic organs and the anterior lamella of the lumbar fascia. In the inguinal region, it is thickened where it is supplemented by the **transversus abdominis aponeurosis** (Fig. 9-11A). It forms the posterior wall of the inguinal canal

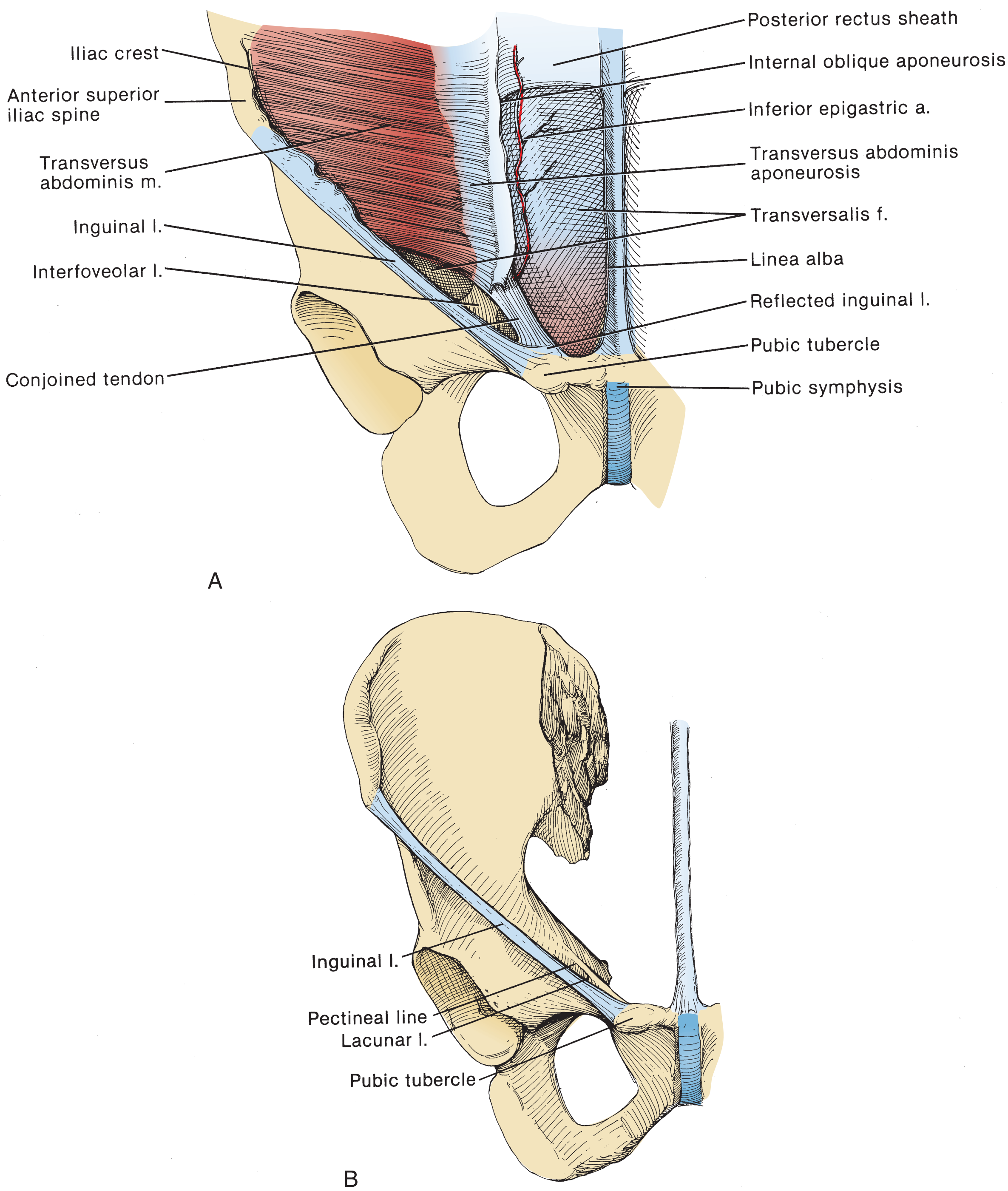

FIGURE 9-11.

and is reinforced medially by the **conjoined tendon.** It attaches to the whole length of the **iliac crest** between the origins of the transversus and iliacus and to the posterior margin of the **inguinal ligament** between the **anterior superior iliac spine** and the femoral vessels, and is then continuous with the iliac fascia. It is a weak layer, and even though it is reinforced by other fascias in the region of the inguinal canal, it will not of itself support sutures for hernia repair.

The transversalis fascia is thin medial to the iliac vessels. It is attached to the pectineal line (see Figs. 9-5, 9-7, 9-11B, 9-19, and 9-20B) and to the falx inguinalis (see Figs. 9-16 and 9-17). It then descends in front of the femoral vessels to make up the anterior wall of the femoral sheath. The internal spermatic fascia (see Figs. 9-6B and 9-10) is a continuation of the transversalis fascia onto the cord, where it may contain muscle fibers, and blends with the loose tissue around the parietal layer of the tunica vaginalis.

The transversalis fascia continues around the vessels in the femoral region to form a ventral sheath with the deep crural arch at the rim and a dorsal sheath that is attached to the superior pubic ramus and the pubic crest.

The peritoneum in the groin is separated from the transversalis fascia by adipose tissue, leaving it poorly supported. During hernia repair, the redundant portion must be excised, leaving only enough for a tension-free closure (Fig. 9-12).

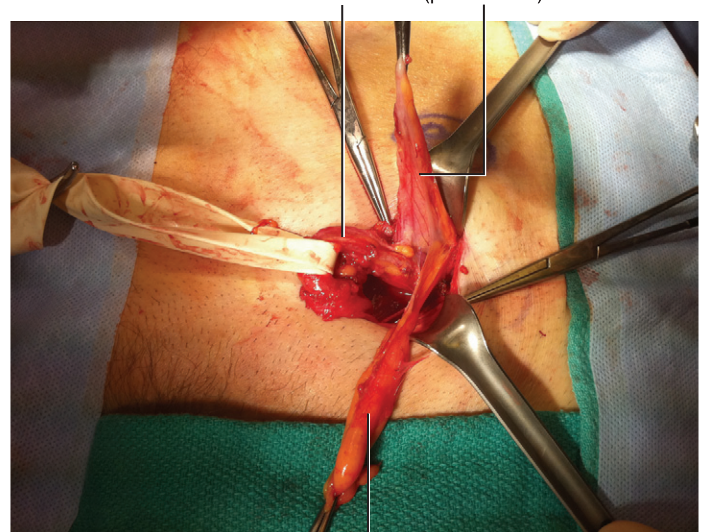

FIGURE 9-12. Operative photograph of an open left indirect inguinal hernia repair in an adult. A portion of peritoneum has been separated from the cord structures; it will be excised and closed at its base. A small cord lipoma is also present. *(Image courtesy of Raymond Onders, MD.)*

Internal Inguinal Ring

Above the middle of the inguinal ligament, where the transversalis fascia is dense and supplemented by the aponeurosis of the transversus, is an opening that forms the lateral margin of the inguinal canal at the internal inguinal ring. This ring is not visible externally because it is hidden by the transversalis fascia as it forms the internal spermatic fascia. On the medial aspect of the internal ring, the transversalis fascia forms the transversalis fascial sling, which has two crura, a longer superior crus and a shorter inferior crus that follows the iliopubic tract. It is this arrangement on either side of the internal ring that during abdominal straining can act like a shutter.

The **interfoveolar ligament** (Hesselbach) is not a true ligament but a thickening of the transversalis fascia at the medial side of the inguinal ring and is described with the interior approach (see Fig. 9-13). It appears like a lateral condensation

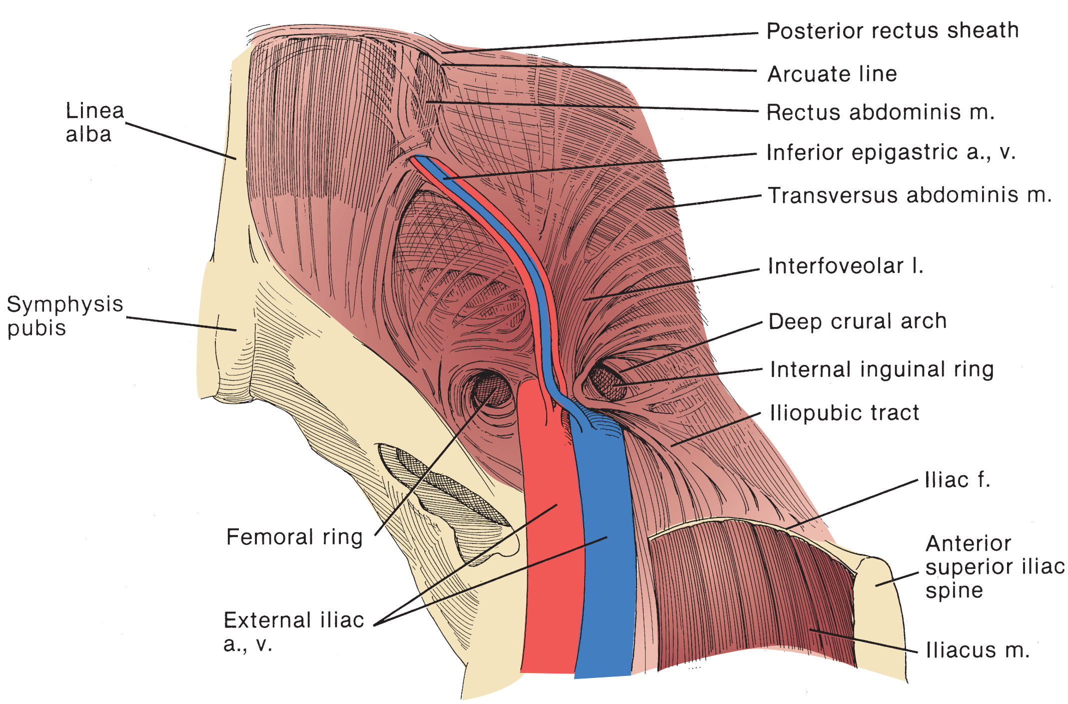

FIGURE 9-13.

of the falx inguinalis (see Fig. 9-16). It provides some reinforcement at the medial margin of the internal ring.

The structures in the *female groin* are less complex than in the male because only the round ligament requires passage through the body wall. The coats of the round ligament are similar to those of the spermatic cord: external spermatic fascia, cremasteric fascia and muscle, and internal spermatic fascia.

INTERNAL APPROACH TO THE INGUINAL REGION

Because the structures appear to be different when approached from inside the body, this section will first show the more superficial layers and progress to exposure of the pelvic bone, repeating descriptions of many structures described previously. Figure 9-5 may be reviewed for sites of attachment of structures to the bones of the pelvis.

Transversalis Fascia and Related Ligaments

The **transversalis fascia** is exposed after removal of the peritoneum and the properitoneal fat. It is firmly attached to the **linea alba** over the **rectus abdominis**. In the pelvis, the transversalis fascia is continuous with the endopelvic fascia, the portion that surrounds the exit sites of pelvic viscera, and the **iliac fascia,** all covering the epimysium of the underlying muscles (Fig. 9-13). The transversalis fascia attaches posteriorly to that part of the iliac crest that lies between the origins of the **iliacus** and **transversus abdominis** and also attaches to the posterior margin of the inguinal ligament from the anterior superior iliac spine and over the iliac vessels. Medial to these vessels, the transversalis fascia attaches to the pectineal line (see Figs. 9-5, 9-7, 9-19, and 9-20B). As it continues, it attaches to the falx inguinalis (see Figs. 9-16 and 9-17). The **posterior rectus sheath** ends at the **arcuate line,** so the lower part of the muscle is covered only with transversalis fascia. The **external iliac artery** and **vein,** before they exit through the **femoral sheath** beneath the inguinal ligament (see Figs. 9-8B and C, 9-16, and 9-20B), give off the **inferior epigastric artery** and **vein,** which enter the transversalis fascia to course cephalad under its cover before passing beneath the posterior rectus sheath (Figs. 9-14 and 9-15).

The thickened transversalis fascia is supplemented inferiorly by contributions from the transversus abdominis aponeurosis. This combined structure forms the posterior wall of the inguinal canal.

The **internal** (deep) **inguinal ring** is an opening in the transversalis fascia, strengthened on the inferomedial portion by transversely arched fibers of the transversus abdominis that run laterally toward the anterior superior iliac spine, forming the anterior crus of the **deep crural arch.** The posterior crus is composed from elements of the **iliopubic tract** (see Figs. 9-8C, 9-16, and 9-20B) and transversalis fascia.

The **interfoveolar ligament** (Hesselbach) (also see Figs. 9-9A and 9-11A) is a condensation of the transversalis fascia along the medial border of the internal inguinal ring lateral to the medial portion of the conjoined tendon.

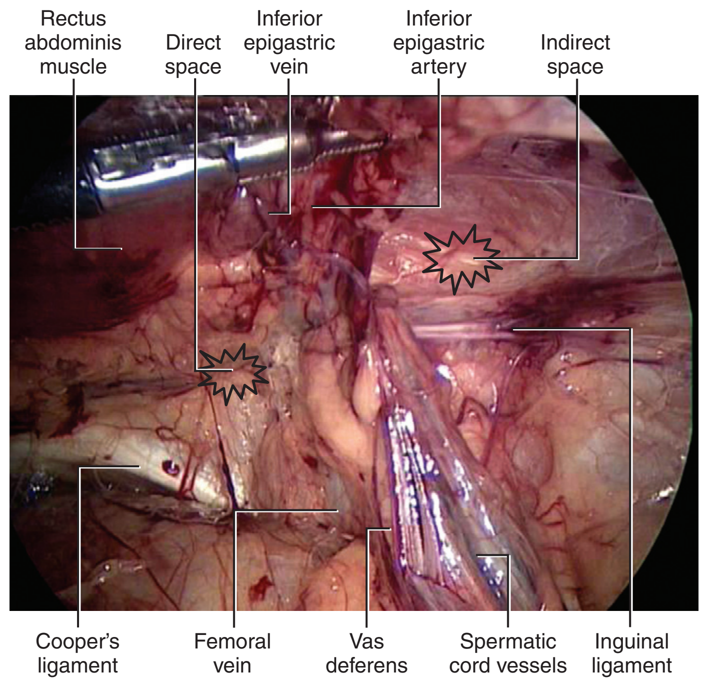

FIGURE 9-14. Laparoscopic view of lower abdomen in a patient with an indirect inguinal hernia. Bowel that had prolapsed into the hernia has been retracted back into the peritoneal cavity. Hernias that develop medial to the inferior epigastric vessels, in the area designated "direct space," are designated direct inguinal hernias. Those that develop lateral to the inferior epigastric vessels, in the area designated "indirect space," are designated indirect inguinal hernias. *(Image courtesy of Raymond Onders, MD.)*

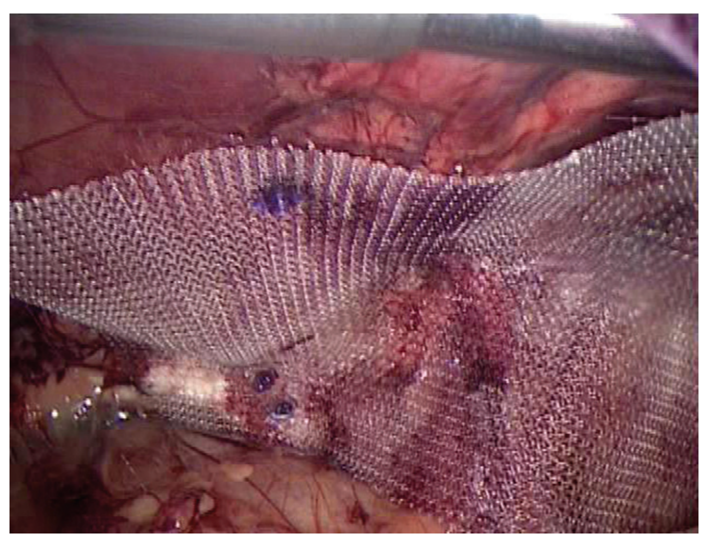

FIGURE 9-15. Mesh has been placed over the hernia site. The mesh is designed to cover the sites where direct, indirect, and femoral hernias might develop. *(Image courtesy of Raymond Onders, MD.)*

Transversus and Internal Oblique

Removal of the transversalis fascia exposes the rectus abdominis and transversus abdominis muscles, along with the several important ligaments that support the inguinal and femoral canals (Fig. 9-16). The transversus abdominis is

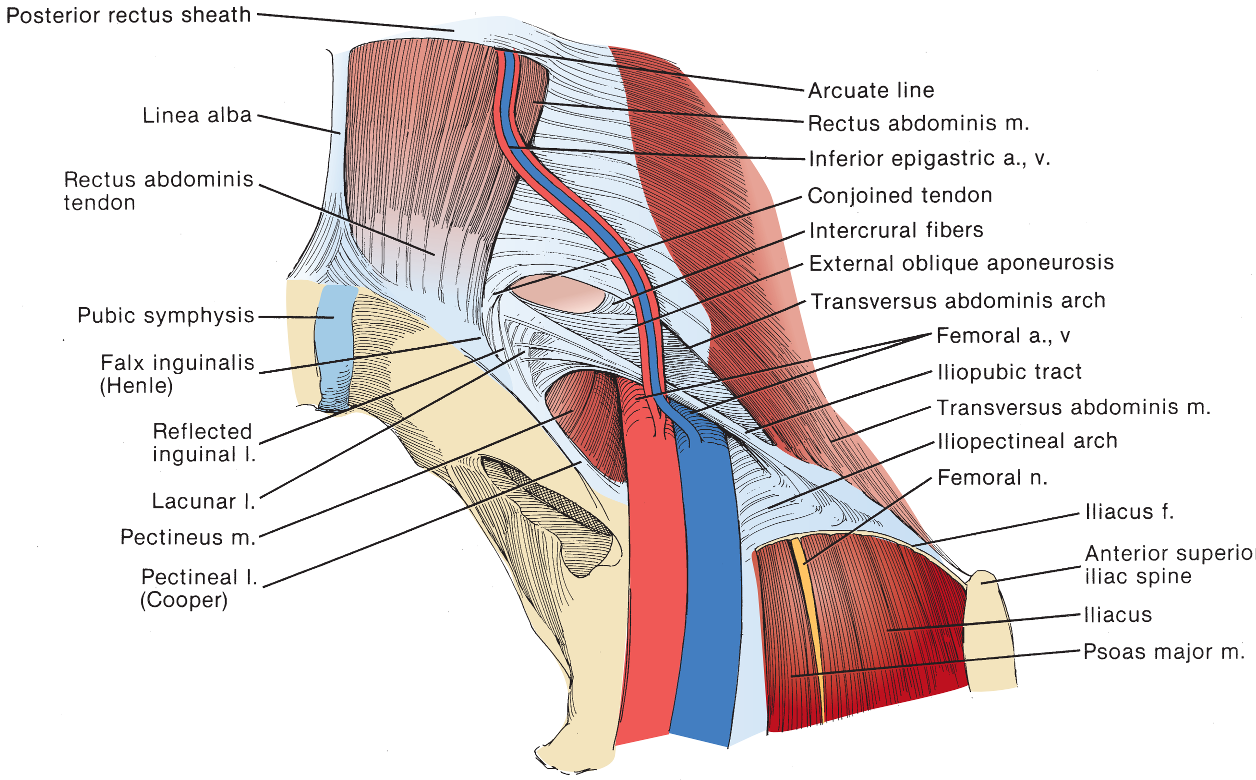

FIGURE 9-16.

the layer involved in the formation and repair of inguinal hernias.

Surgically, the most important structure is the **conjoined tendon** (see Figs 9-7B, 9-9A, 9-11A, and 9-20A), which is formed from fusion of the lowest fibers of the transversus abdominis aponeurosis with some from the internal oblique. It arises from the lateral part of the inguinal ligament so that the tendon becomes the roof of the inguinal canal as it arches over it as the **transversus abdominis arch** to attach to the pubic crest and the **pectineal line**. It is in this medial and inferior area, the posterior wall of the inguinal canal, that the fibers of the transversus aponeurosis splay out, exposing the thinner transversalis fascia between them. Such an arrangement fosters direct hernias (see Fig. 9-14).

The **rectus abdominis tendon** at its insertion along the pubic crest and tubercle displays a 2-cm extension of its investing fascia on the pectineal line that forms the true **falx inguinalis** (Henle). Alternatively, the falx inguinalis is described as a dense portion of the transversus aponeurosis that inserts into the superior pubic ramus, a part of the conjoined tendon. It is most likely that fibers from the aponeurosis join with Henle's ligament, so that both origins are congruous.

Hesselbach's Triangle

The inguinal triangle, an important area for hernia formation, is bounded by the rectus sheath and falx inguinalis, the inferior epigastric vessels, and the pectineal ligament; the inguinal ligament is also often described as a boundary.

Lacunar Ligament

The **lacunar ligament** (see Figs. 9-8B and C, 9-17, and 9-18) is derived from the fascia lata as it joins the posterior border of the inguinal ligament, supplemented by some fascia from the external oblique. It fuses with the pectineal fascia before reaching the pectineal line. Its lateral border fits around the medial wall of the femoral sheath to lie 1 cm below and anterior to the pectineal line.

Pectineal Ligament

The **pectineal ligament** (Cooper) (also see Figs. 9-8A and B, 9-17, 9-18, and 9-20B) is a fibrous accretion that may be several millimeters thick involving the periosteum of the superior ramus of the pubis along the pectineal line. It extends laterally from the base of the lacunar ligament along the pectineal line with additions from the pectineal fascia. The aponeurosis of the transversus abdominis and the iliopubic tract insert along the pectineal line next to the medial half of the pectineal ligament; through the pectineal ligament the transversalis fascia is provided a line of insertion into the superior ramus of the pubis. Laterally, the pectineal ligament diverges more caudally than the insertions of the muscles of the anterior body wall.

Iliopubic Tract

The **iliopubic tract** (sometimes called the anterior femoral sheath) appears as the thickened fibrous lower border of the transversalis fascia that runs caudal to and parallel with the inguinal ligament (see Figs. 9-8C, 9-13, 9-16, and

9-20B). It marks the junction of the abdominal part of the transversalis fascia from that of the thigh. It is derived from the fascia of the outer stratum on the posterior aspect of the anterior abdominal wall and from the same stratum in the iliopsoas area (iliacus fascia). Whether it also contains fibers from the transversus abdominis aponeurosis has not been agreed on.

Although the iliopubic tract lies very close to the inguinal ligament in its midportion, it is an entirely separate structure. The inguinal ligament is a superficial structure as part of the external oblique layer of the groin, whereas the iliopubic tract is part of the deep, transversalis layer. From within the pelvis, only the iliopubic tract is visible.

The iliopubic tract is attached laterally along the iliac crest and to the **anterior superior iliac spine,** where the iliacus and lowest fibers of the **transversus abdominis** join it. It then curves over the **psoas major** and the **femoral artery** and **vein**, making up part of the anterior femoral sheath. In this way, the transversalis fascia is supplemented by transversely arched fibers that run laterally toward the anterior superior iliac spine and medially behind the **rectus abdominis**. Its fibers pass medially to insert into the superior ramus of the pubis and into the pectineal ligament. Other, more inferior fibers curve down to insert in the more lateral part of the pectineal ligament, thus defining the medial border of the femoral canal. They serve to strengthen the inferomedial portion of the rim of the internal inguinal ring and are an important element in hernia repair.

Although a double layer of investing fascia, called interparietal fascia, separates the transversus abdominis from the internal oblique over most of their extent, near the inguinal canal and the conjoined tendon, the two muscles are firmly attached to each other.

Internal Oblique

Removal of the transversus abdominis exposes the superficial portion of the **conjoined tendon** and shows the relation of the **external oblique aponeurosis** to the **inguinal ligament** (Fig. 9-17). A double layer of interparietal fascia separates the internal and external oblique. In this area the internal oblique is mainly muscular, with its fibers running transversely. The lower portion of the internal oblique that originates laterally from the iliac fascia forms an arch over the spermatic cord between the internal and external rings. A truly conjoined tendon may not form because this arch from the internal oblique may terminate in the linea alba or rectus sheath without curving downward in company with the transversus to the pubic crest.

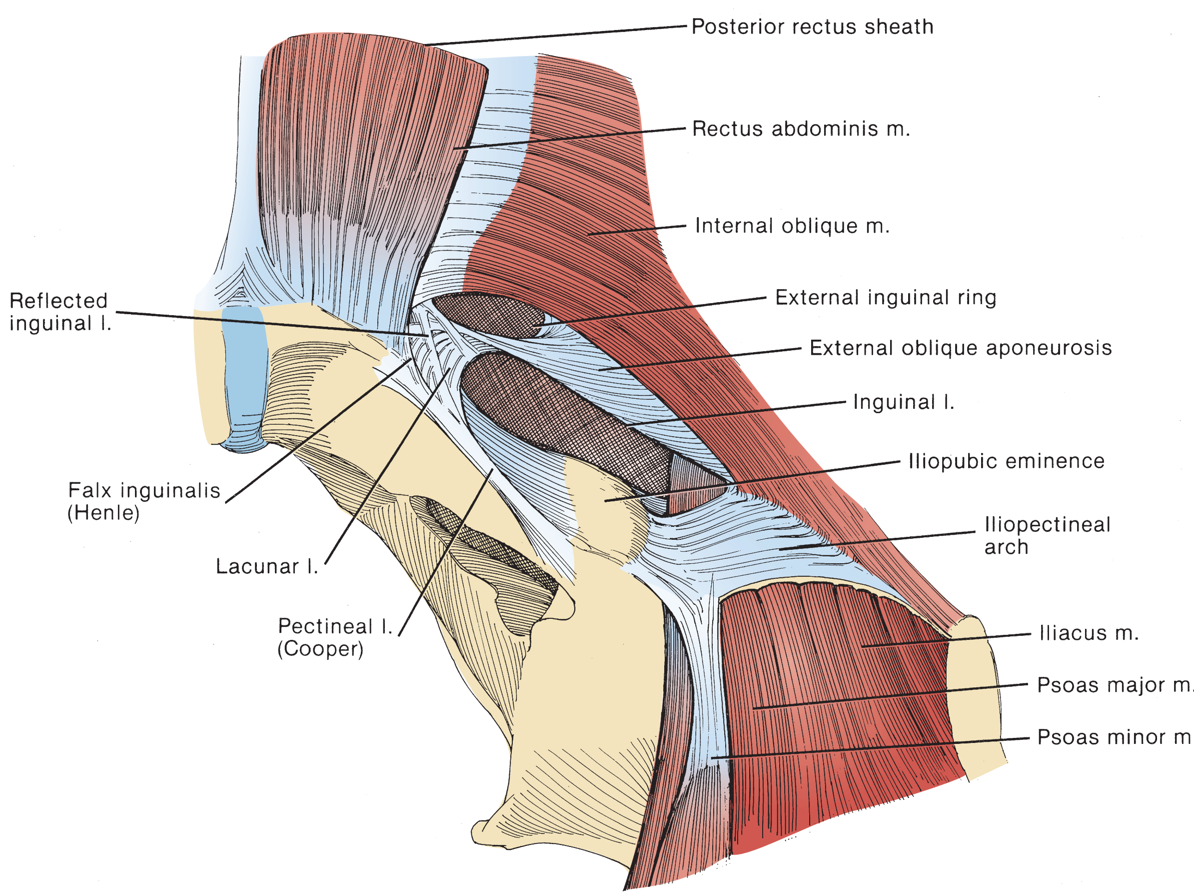

FIGURE 9-17.

External Oblique

The anterior wall of the inguinal canal is formed from the **external oblique aponeurosis**, the fibers of which are attached to the upper border of the symphysis and to the pubic crest as far as the pubic tubercle (Fig. 9-18). It also forms the **inguinal ligament** (see Figs. 9-8A and B, 9-9A, 9-11A and B, 9-17, 9-18, and 9-19), including that portion that forms the floor of the canal.

The **reflected inguinal ligament** is an attenuated group of fibers resulting from an expansion of the lateral crus of the inguinal ligament that passes behind the medial end of the superficial inguinal ring (see Figs. 9-7B, 9-11A, 9-16, 9-17, and 9-18). It has little importance in hernia repair.

The **lacunar ligament**, part of the inguinal ligament (also shown in Figs. 9-8B and C, 9-16, 9-17, and 9-18), is attached anteriorly to the medial end of the inguinal ligament and to the pubic tubercle as far as the medial end of the **pectineal line**. Because this ligament cannot be seen from an anterior approach, it may be confused with the combined insertion of the rectus and transversus into the pectineal line. The lacunar ligament has three sides: (1) its base is attached to the pubic tubercle, (2) its inferior concave portion bounds the femoral canal medially, and (3) its deep margin connects with the pectineal fascia.

Landmarks on the Pubis

The **pectineal line** (Fig. 9-19) is the site of juncture of the pectineal ligament (Cooper) (see Figs. 9-5, 9-7, 9-11B, 9-19, and 9-20) and the lacunar ligament (see Figs. 9-8C, 9-16, and 9-18). It marks the sharp posterior edge of the **pectineal surface** (pectin), a triangular surface that lies on the superior ramus of the pubis from the **pubic tubercle** to the **iliopubic eminence** (see Figs. 9-5, 9-17, and 9-18). The bone is rounded anteriorly forming the **obturator crest** (see Figs. 9-5A and 9-18). The **inguinal ligament** attaches to the **anterior superior iliac spine** at the end of the **iliac crest**.

Boundaries of the Inguinal Canal

In a frontal view, the inguinal canal is seen as a potential triangular opening between the inferior margins of the external oblique and transversus abdominis aponeuroses, about 4 cm in length, beginning at the lateral margin of the internal inguinal ring (see Fig. 9-13) and ending at the medial margin of the external inguinal ring (see Fig. 9-18). The spermatic cord passes through it from its preperitoneal position to a subcutaneous one, carrying the layers of the abdominal wall with it (Fig. 9-20A).

The inferior wall (floor) is formed from the **inguinal ligament** as it turns inward, and it is composed medially of the lacunar ligament (see Figs. 9-8C, 9-16, 9-17, and 9-18). The roof consists of the lowermost fibers of the **internal oblique** and **transversus abdominis** as they arch over the canal to join together as the **conjoined tendon** (see Figs. 9-5, 9-7B, 9-9, 9-11A, 9-16, and 9-20A). The anterior wall is made up of the external oblique aponeurosis with some fibers of the internal oblique, which attach to the lateral part of the inguinal ligament. The posterior wall is formed from the **transversalis fascia**, except medially, where the **conjoined tendon** from the transversus abdominis intervenes.

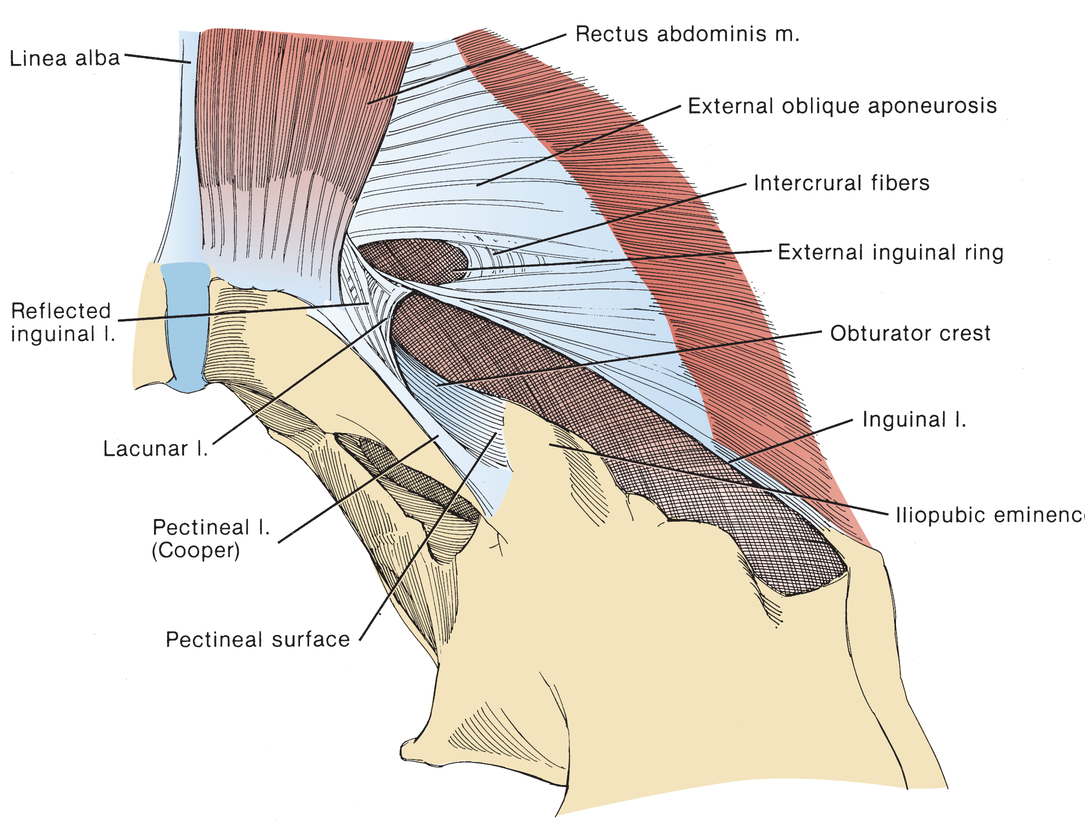

FIGURE 9-18.

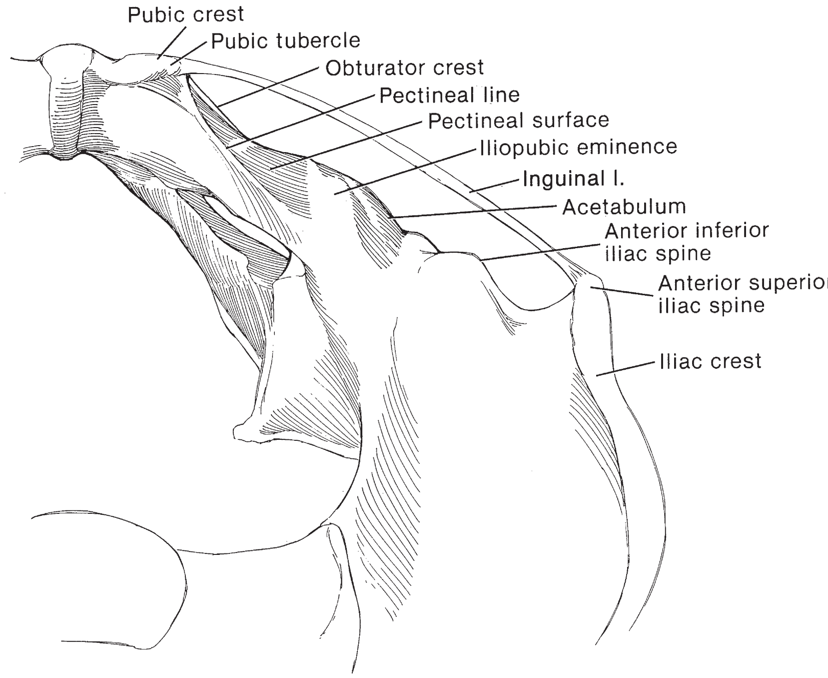

FIGURE 9-19.

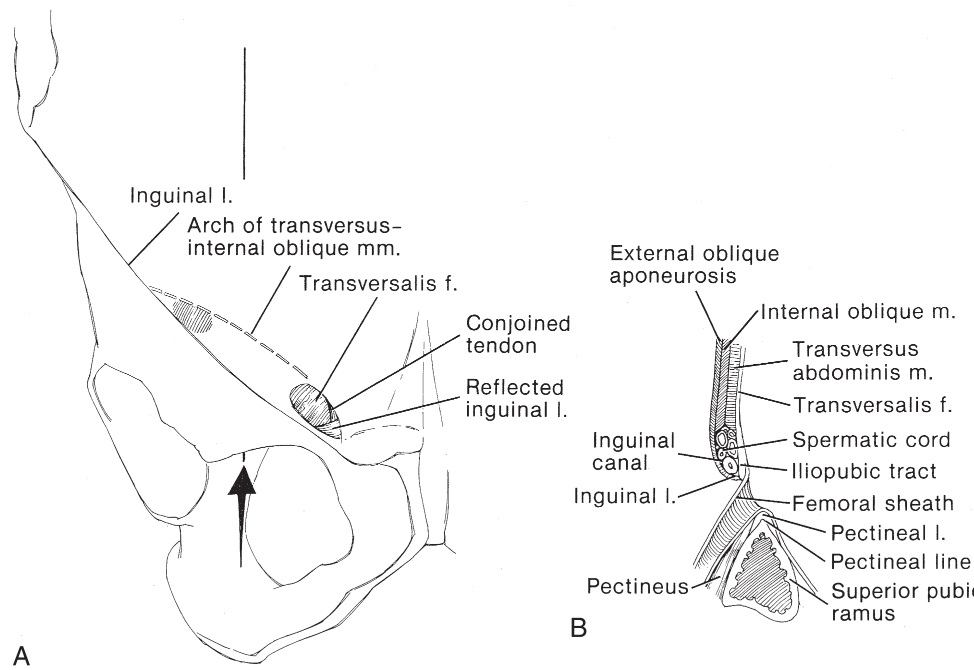

FIGURE 9-20.

In the sagittal section, the transversalis fascia thickens as it forms the **iliopubic tract** before continuing as the anterior part of the **femoral sheath** (Fig. 9-20B). The **external oblique aponeurosis** forms the **inguinal ligament** as it curves inward to provide the floor for the **inguinal canal.** The **pectineal ligament** (Cooper) (see Figs. 9-8A and B, 9-16, 9-17, 9-18, and 9-20B) rides on the **pectineal line** (see Figs. 9-5, 9-7, 9-11B, 9-19, and 9-20B) of the **superior pubic ramus** (see Fig. 9-5A).

The *contents of inguinal canal* are the **spermatic cord** in the male and the round ligament in the female. The ilioinguinal nerve runs medially in the anterior wall of the canal below the cord to exit through the superficial ring. The genital branch of the genitofemoral nerve, the external spermatic (cremasteric) artery and veins, the sympathetic testicular plexus, and some filaments from the pelvic plexus accompanying the deferential artery pass with the cord into the scrotum.

BLOOD SUPPLY, LYMPHATIC DRAINAGE, AND INNERVATION

Arterial and Venous Supply

The superficial layer of the *lower anterior abdominal wall* has three sources of blood supply from vessels that emerge from the fossa ovalis: (1) the superficial circumflex iliac, (2) the superficial inferior epigastric, and (3) the superficial internal pudendal vessels.

The structures about the *inguinal canal* are supplied by distal branches of the external iliac artery, the inferior epigastric artery, and the deep circumflex iliac artery (see Fig. 10.14).

The inferior epigastric artery ascends in the preperitoneal space between the transversalis fascia (outer stratum of the retroperitoneal connective tissue) and the intermediate strata around the pelvic organs and the inner strata associated with the peritoneum to supply the rectus abdominis (see Fig. 9-14). Usually, double inferior epigastric veins, which are separated by the artery and fuse before entering the external iliac vein, are found.

The inferior epigastric artery has two small branches. The first is a small pubic branch that takes off near the origin of the inferior epigastric artery and runs caudally along the iliopubic tract to cross the pectineal ligament, where it provides a small (corona mortis) branch that follows medially on the ligament. The main channel continues caudally to join the obturator artery. In fact, if it is large, it appears as an accessory obturator artery. The veins that accompany these arteries are appreciably larger and contribute to hemorrhage during groin operations. The second branch of the inferior epigastric, the external spermatic (cremasteric) artery, takes a course on the medial aspect of the deep ring before penetrating the transversalis fascia and joining the elements of the cord.

Another branch of the external iliac artery is the deep circumflex iliac artery that penetrates the transversalis fascia and runs laterally along the iliopectineal arch to reach the region of the anterior superior iliac spine where ascending branches go through the transversus abdominis to terminate beneath the internal oblique medial to the iliac crest.

LYMPHATIC DRAINAGE

The inguinal region contains superficial nodes as well as deep nodes beneath the deep fascia. The **superficial inguinal nodes** form two groups, an upper and a lower. The more medial nodes of the upper group, lying about the great saphenous vein, are important urologically because they drain the external genitalia as well as the perianal region, whereas the lower group receives drainage from the leg.

The **deep inguinal nodes** lie about the iliac artery and vein. Both superficial and deep nodes may be approached through a low inguinal incision.

Superficial Lymph Drainage System

The **skin** drains into the superficial inguinal lymph nodes, which are variable both in number and in position. They are found in the superficial fascia of the thigh, lying in the fatty tissue of the **membranous layer** of the **superficial fascia** overlying the **fascia lata** (Fig. 9-21). These nodes are also the primary drainage system for the glans penis and the penile urethra. They are found within a region that starts slightly above the **inguinal ligament** and runs onto the upper inner thigh. The boundary line of this area runs from the pubic tubercle caudally for 15 cm, then laterally for 10 cm, and finally cephalad for 20 cm to join the outer end of the inguinal ligament. The area may contain as few as 4 and as many as 25 nodes, but the average is 8. Rouviere described five zones within the larger region, two of which drain the penis. The superomedial zone, the area surrounding the **superficial epigastric** and **superficial external pudendal veins**, drains the penile skin. The central zone, lying at the junction of the **long saphenous vein** with the **femoral vein**, drains the penis, including the glans.

Deep Inguinal Drainage System

The **fascia lata** separates the deep inguinal from the superficial nodes.

The deep inguinal nodes lie beneath the superficial nodes and receive their drainage. They form a chain along

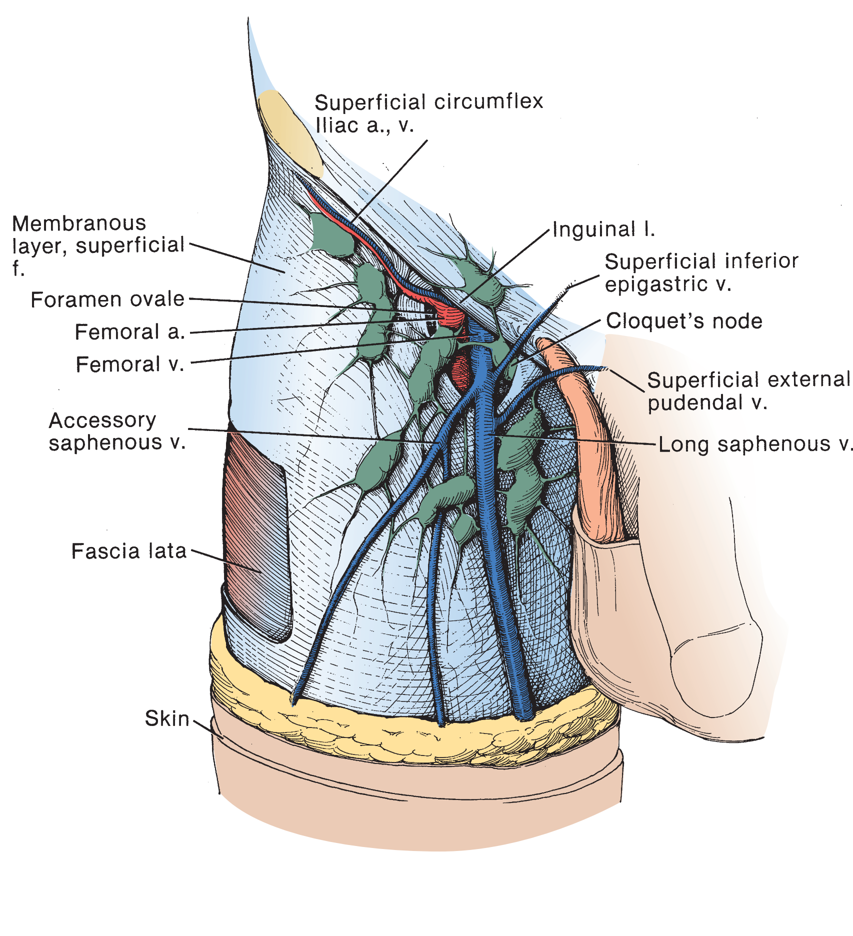

FIGURE 9-21.

the **femoral artery** and **femoral vein** in the femoral triangle under the **fascia lata** and run under the **inguinal ligament** via the **femoral canal** through the femoral **septum** to join nodes about the **external iliac vessels** (Fig. 9-22). The drainage then continues through the chain into the retroperitoneal space to reach the **pelvic nodes** situated in the subserous tissue that lies between the peritoneum and the transversalis (endopelvic) fascia over the pelvic musculature. These nodes lie along the sides of the **external, internal, and common iliac vessels** and are continuous above with the aortic nodes.

INNERVATION

Innervation of the Inguinal Region

The groin structures are innervated principally by the **iliohypogastric** and **ilioinguinal nerves** from spinal nerve **L1** via the **lumbar plexus** (Fig. 9-23). These two nerves run obliquely, like their subcostal counterparts, about 8 to 10 cm apart through the **psoas major** to lie on the surface of the **quadratus lumborum** just under the endopelvic fascia and peritoneum. Above the middle of the **iliac crest,** the nerves pass through the **transversus abdominis** to lie between it and the **internal oblique,** a site where either nerve may be divided inadvertently during a muscle-splitting incision and lead to abdominal weakness and direct inguinal hernia.

The **iliohypogastric nerve** divides into iliac and hypogastric branches in the passage through the transversus abdominis. The hypogastric branch runs forward and downward to supply the abdominal muscles. At a point above and medial to the anterior superior iliac spine, the nerve lies under the aponeurosis of the **external oblique** and then passes under the **anterior rectus sheath,** which it pierces to provide cutaneous supply to the lower abdomen.

The **ilioinguinal nerve** takes a similar but somewhat more medial course to that of the iliohypogastric nerve, coming to lie under the external oblique aponeurosis about 2 cm medial to the anterior superior iliac spine. It passes through the **inguinal canal** in front of the **spermatic cord** and then at the superficial inguinal ring, it divides into branches to the skin of the pubic region and the upper part of the scrotum and labia majora. Small motor branches are given off to the abdominal muscles. The ilioinguinal nerve is smaller than the iliohypogastric nerve; in fact, it may be absent when a branch of the iliohypogastric takes its place.

The **genitofemoral nerve** (the genital part from the L1 spinal nerve and the femoral part from L2 via the lumbar plexus) runs through the **psoas major** and then follows along its surface to the internal inguinal ring, above which

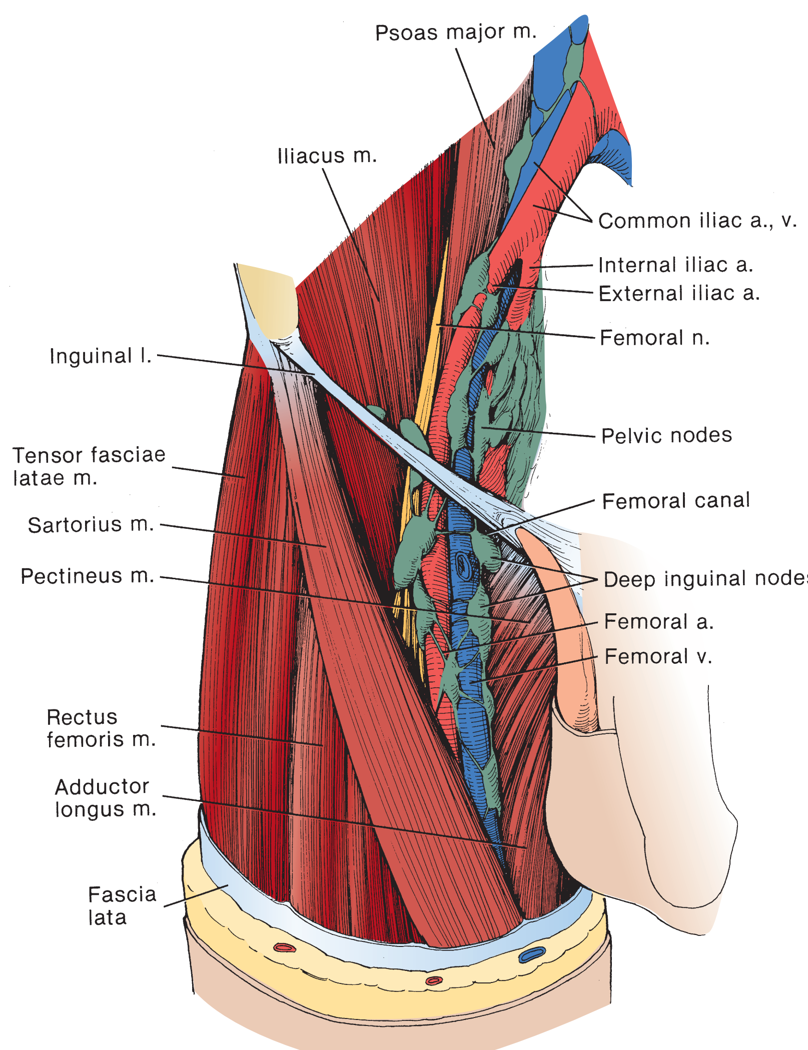

FIGURE 9-22.

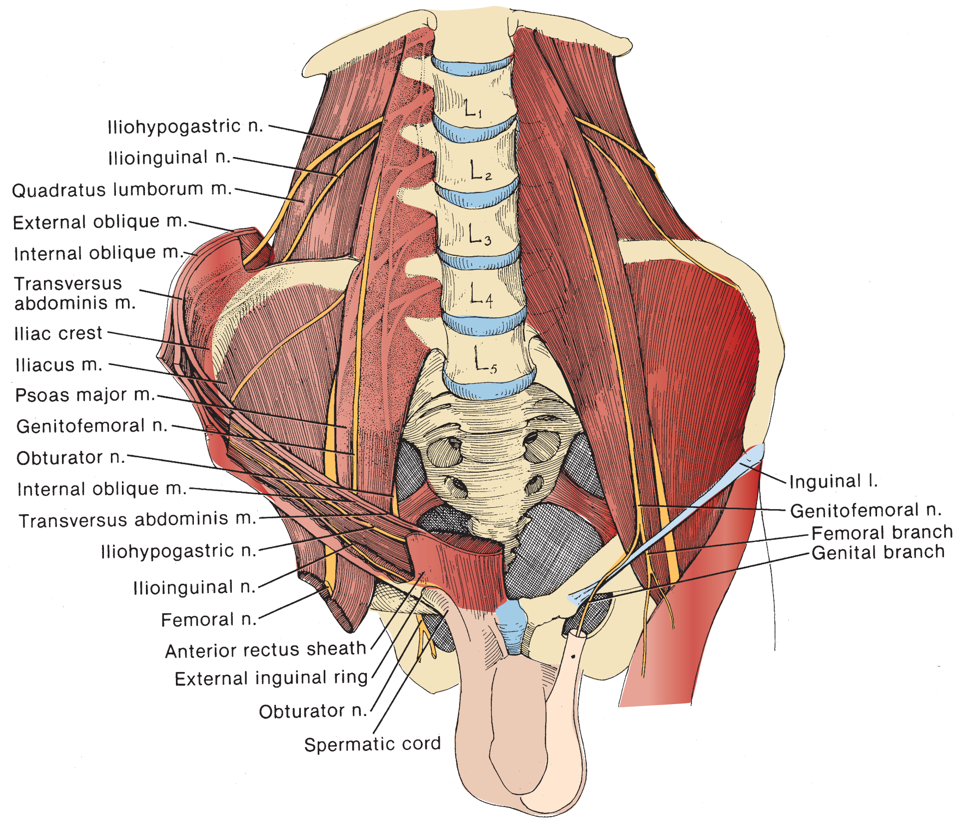

FIGURE 9-23.

it divides into genital and femoral branches. The **genital branch** enters lateral to the internal inguinal ring through the iliopubic tract after crossing the lower end of the iliac artery. It joins the spermatic cord on its posterior aspect to pass through the external ring and supply motor nerves to the cremasteric muscle and sensation to some of the scrotal skin and the medial aspect of the thigh. The **femoral branch** passes along the psoas muscle under the inguinal ligament into the leg, supplying the anterior thigh.

The lateral cutaneous nerve of the thigh arises from the ventral rami of the L2 and L3 spinal nerves. After emerging from the psoas major, it runs obliquely across the iliacus and behind the inguinal ligament, and divides into an anterior and posterior branch in the thigh, supplying the skin of the anterior and lateral surfaces of the thigh. It may be compressed by retractors against the inguinal ligament during surgery, causing pain in the area of its distribution.

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Chapter 10

Pelvis

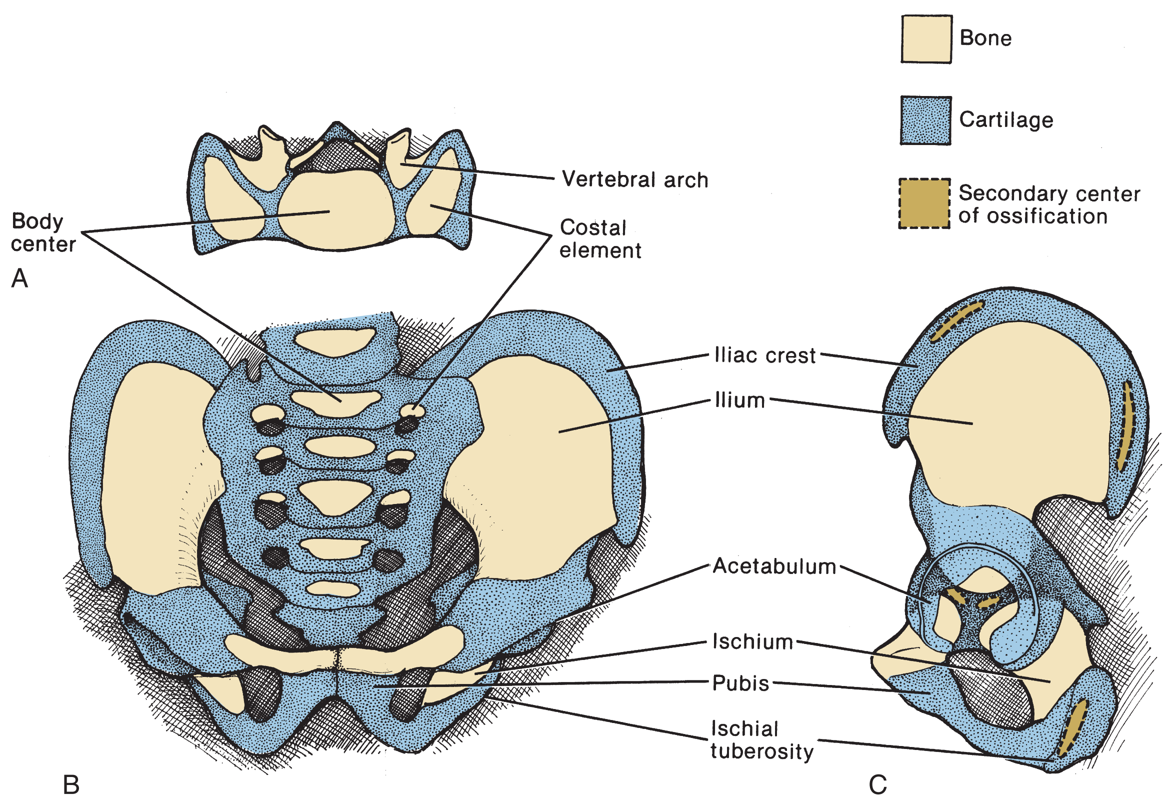

FIGURE 10-1. Development of innominate bone and sacrum. **A,** Transverse view. **B,** Frontal view. **C,** Lateral view.

These bones together with the holy-bone, make that pelvis or Dish which containeth part of the guts, the bladder and the womb.

CROOKE
Body of Man, 118, 1615

DEVELOPMENT OF THE PELVIS

Skeletal Pelvis

Development of the Innominate Bone and Sacrum

Innominate bone

Hyaline cartilage is first laid down as the model for the several elements of the pelvic bone that will form the **ilium, ischium**, and **pubis** (Figs. 10-1B, C). The first ossification center to appear is that of the ilium in the second month; the last center, that of the pubis, appears in the fourth or fifth months. Eventually, the whole mass of cartilage turns into bone. The appearance and fusion of the centers proceeds with considerable individual variation in addition to differences because of gender. The process occurs earlier in the female than in the male, especially with the onset of adolescence. For example, the ischium and pubis fuse to form the pubic ramus in the seventh to eighth year of life, whereas secondary centers in the **iliac crest, acetabulum,** and **ischial tuberosity** do not appear until puberty and fuse with the other ossified parts between the 15th and 25th years. At birth, large remnants of cartilage persist in each part. Secondary sites of ossification are indicated with dashed lines; these will appear at puberty and be united by the 25th year.

Sacrum

Up to the fifth week, the neural tube and gut extend into the tail bud, from which the sacrum and coccyx develop; however, by the eighth week, the bud, tube, and gut have regressed, leaving the bony structures behind.

The five elements of the sacrum are similar to those of the other vertebrae. Ossification centers for the **body center** and each half of the **vertebral arch** appear between the 10th and 20th weeks, whereas those for the **costal elements** appear much later, in the sixth to eighth months of gestation (Fig. 10-1A). Fusion of the sacral bodies begins in the sixth week, with the middle intervertebral disk fusing first and the first intervertebral disk fusing last.

Gender Differences

The shape of the original cartilages of the pelvic bones is different in males and females. Even in fetal life, the subpubic angle or arch is wider in females than in males. After birth, male infants have larger pelves overall, but in female infants, the pelvic cavity is larger, the difference being greatest at 22 months and decreasing in subsequent years.

Gender differences in the pelvis in adults are influenced by the functions of locomotion in the male and childbearing in the female. In general, the male pelvis resembles a cone, whereas the female pelvis resembles a cylinder. The male pelvis is more heavily muscled, so that even though the cavity within the bony pelvis is larger, the net space is smaller. The various zones for muscular attachments are more clearly demarcated. Moreover, the bones themselves are heavier, especially the iliac crest, which curves more medially at its anterior projection. In the female, the blades of the ilia are oriented more vertically but are shorter, resulting in a smaller iliac fossa.

Pelvic Cavity

The musculature and fascia of the pelvic floor are derived from the tissues of the lumbar body wall and are supplied by nerves from the lumbar cord. The levator ani arises from the primitive tail musculature and thus has sacral innervation.

The development of the pelvic contents is described under the headings of the organ systems.

Anomalies

Individual variations in pelvic form are the rule and are, in part, influenced by abnormal hormonal environment during development. Some investigators feel that sacral anomalies fall into three definite patterns: (1) absent vertebra (the "agenetic" group, corresponding to "caudal regression syndrome") (Figs. 10-2 and 10-3); (2) hemivertebrae (the "dysgenetic" group); and (3) deficiencies of the neural arch (the "dysraphic" group) (Fig. 10-4). Patients in group 1 have relative neurologic sparing and a relatively low incidence of visceral congenital anomalies. Those in group 2 have a high incidence of visceral abnormalities, but the neurologic deficit is minimal and usually only the bladder is denervated. Individuals in group 3 are prone to have sacral spina bifida with meningocele or myelomeningocele at the sacral level, with denervation of the lower urinary tract. Sacral and coccygeal anomalies

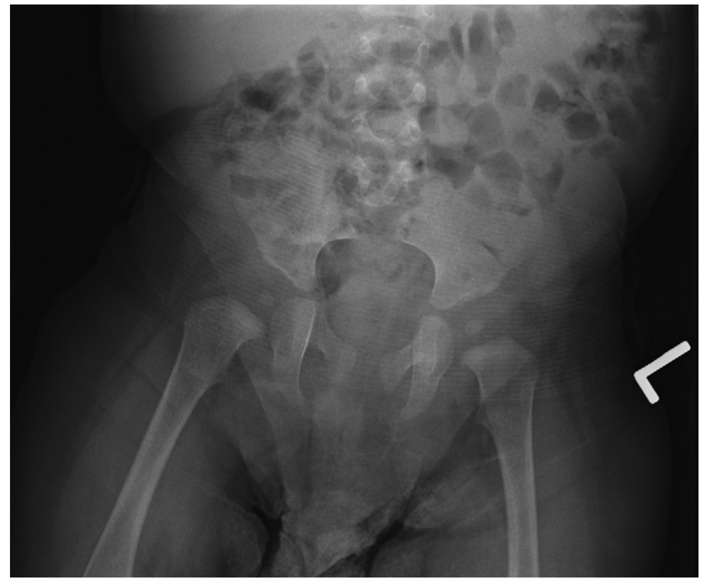

FIGURE 10-2. Sacral agenesis. Plain radiograph shows complete agenesis of the sacrum. *(Image courtesy of Vikram Dogra, M.D.)*

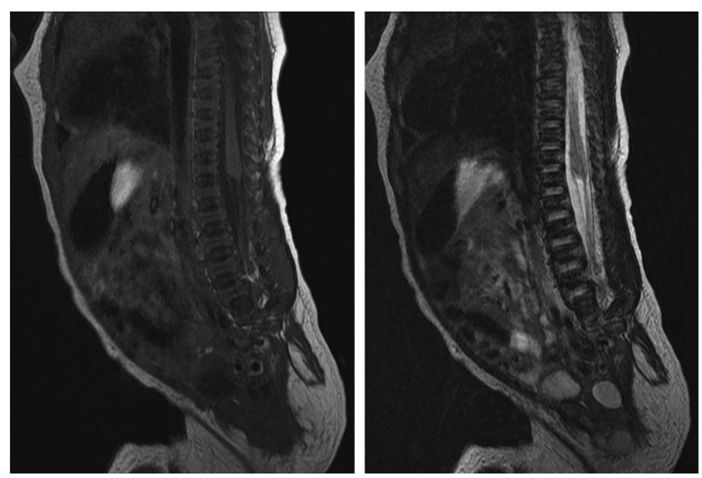

FIGURE 10-3. Sacral agenesis. Magnetic resonance imaging scan T1- and T2-weighted confirms complete agenesis of sacrum below S1 segment. Spinal cord is truncated and cone-shaped, with a thick filum terminale and an abnormal cyst posterior to the bladder. *(Image courtesy of Vikram Dogra, M.D.)*

are common with malformations of the distal lumbar spine. Regression of the tail bud may be asymmetric, leaving the pelvis tilted. The fifth lumbar vertebra may become assimilated into the sacrum, resulting in another promontory at a higher level. Bladder exstrophy is regularly accompanied by a variety of defects, including absence of the pubic symphysis with externally rotated pelvic girdle (Fig. 10-5).

STRUCTURE OF THE PELVIS

The surgical approach to the pelvis is different from the approach to the perineum. Even though the two spaces are contiguous, they will be considered separately.

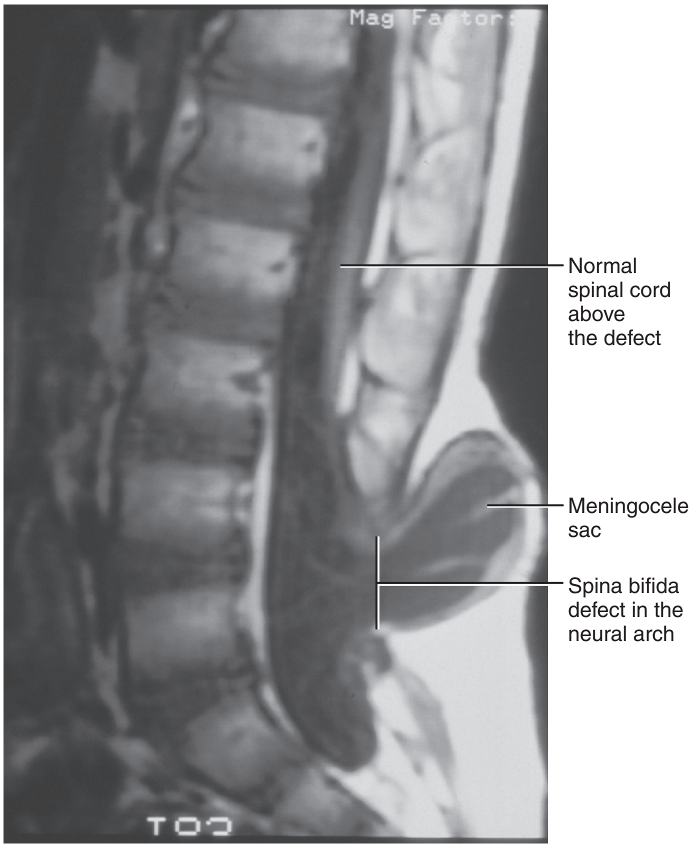

FIGURE 10-4. Meningocele. T1-weighted magnetic resonance imaging scan showing a defect in the neural arch in the lumbar region, with herniation of thecal sac; no neural elements are in the sac. The normal spinal cord ends above the level of the bony defect. *(Image courtesy of Raj Paspulati, M.D.)*

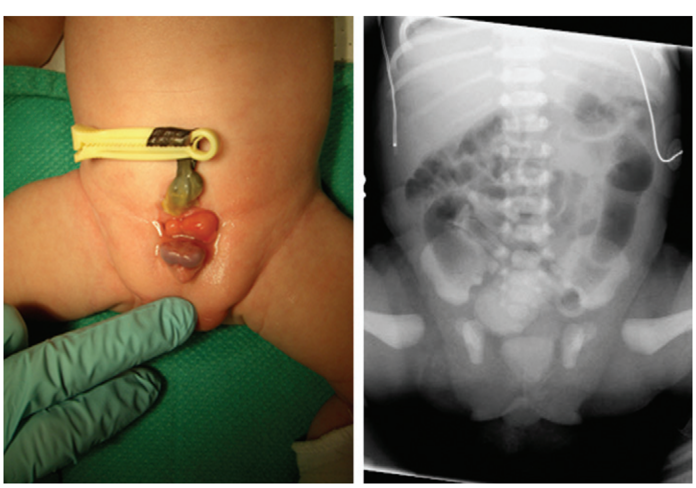

FIGURE 10-5. Bladder exstrophy, accompanied by epispadias. Radiograph demonstrates absence of the symphysis pubis, and external rotation of the pelvic girdle. *(Clinical photo courtesy of Jonathan Ross, M.D.; radiologic image courtesy of Raj Paspulati, M.D.)*

Pelvic Cavity

Pelvic surgery means surgery within the lesser or true pelvis, the cylindric cavity within the bony pelvis. It is distinguished from the bowl-shaped greater or false pelvis, which is actually a region of the abdomen.

The pelvic cavity proper begins at the pelvic inlet, marked by a line drawn anteriorly from the upper border of the pubic bone and the pectineal line. The arcuate line of the ilium marks it laterally, and the promontory of the sacrum marks it behind. The boundary below is the pelvic outlet (inferior pelvic aperture), which is rimmed by the inferior surfaces of the ischiopubic arch, the sciatic notches, and the greater and lesser sciatic foramina.

Bony Pelvis

Paired innominate bones make up the anterior and lateral parts of the bony pelvis, and the sacrum forms the posterior wall. Each innominate bone has three parts: (1) ilium, (2) ischium, and (3) pubis (Fig. 10-6).

The **ilium** has the shape of a wedge. The wider part of the wedge begins near the **anterior inferior iliac spine**, first running anteriorly and upward to the **anterior superior iliac spine**, then making a wide sweep over the **iliac crest**, tapering to the posterior superior and posterior inferior iliac spines and the greater sciatic notch.

The **ischium** and **pubis**, as parts of the innominate bones, are described in the sections on the inguinal region (see Fig. 9-5) and the perineum (see Fig. 11-3), respectively. Together, these heavy bones provide the framework for support of the body and a base of action for the muscles of locomotion.

Female pelvis

In the female, the false pelvis is wider than in the male because of the spread of the ilium at the anterior superior spine. The pelvic outlet is also wider and more circular because it is encroached on less by the ischial tuberosities and ischial spines.

Pelvis, Posterior Aspect

For a surgical approach to the dorsal and ventral spinal nerve roots, the anatomy of the posterior aspect of the pelvis is important.

The **median sacral crest** runs down the center of the sacrum and is surmounted by four **spinous tubercles**. Four **dorsal sacral foramina** form a row on either side of the median crest; each of these provides egress for the dorsal ramus of a spinal nerve (Fig. 10-7). An **intermediate sacral crest** composed of four vestigial articular tubercles runs medial to the foramina. A **lateral sacral crest**, a remnant of fused transverse processes, lies lateral to the foramina. The **sacral hiatus** opens caudal to the lower tubercle and communicates with the spinal canal. The **coccygeal cornua** are vestiges of the fifth articular tubercles.

The cauda equina and filum terminale lie within the sacral canal (see Fig. 4-4). The meninges that define the subdural and subarachnoid spaces are fused in the middle

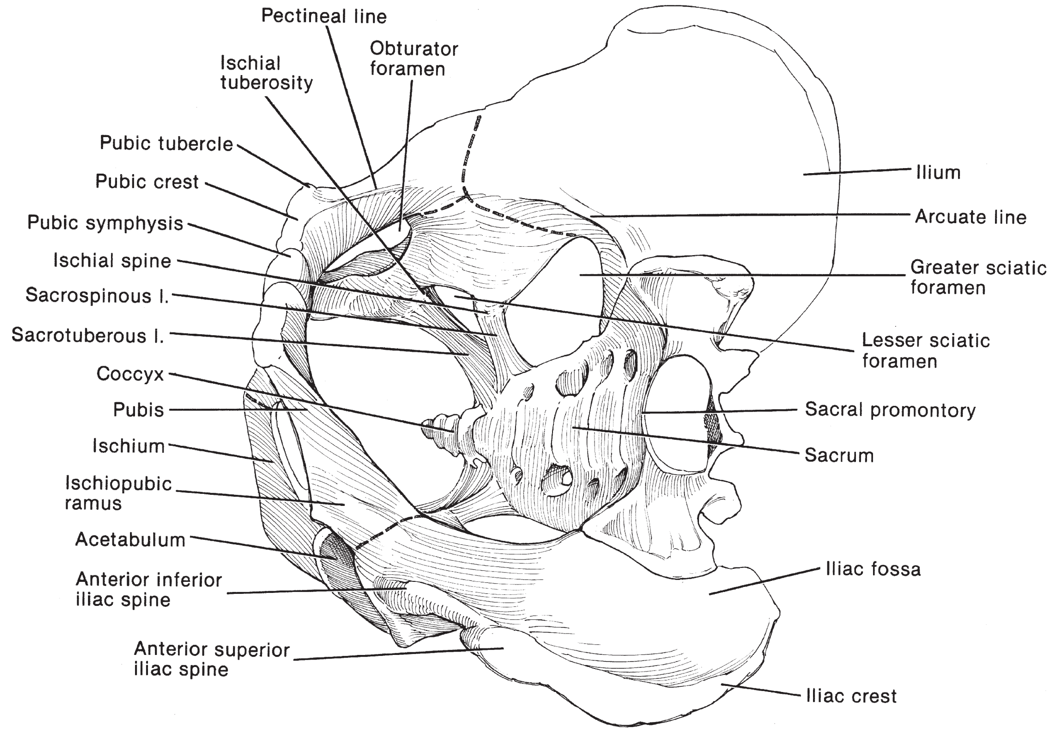

FIGURE 10-6.

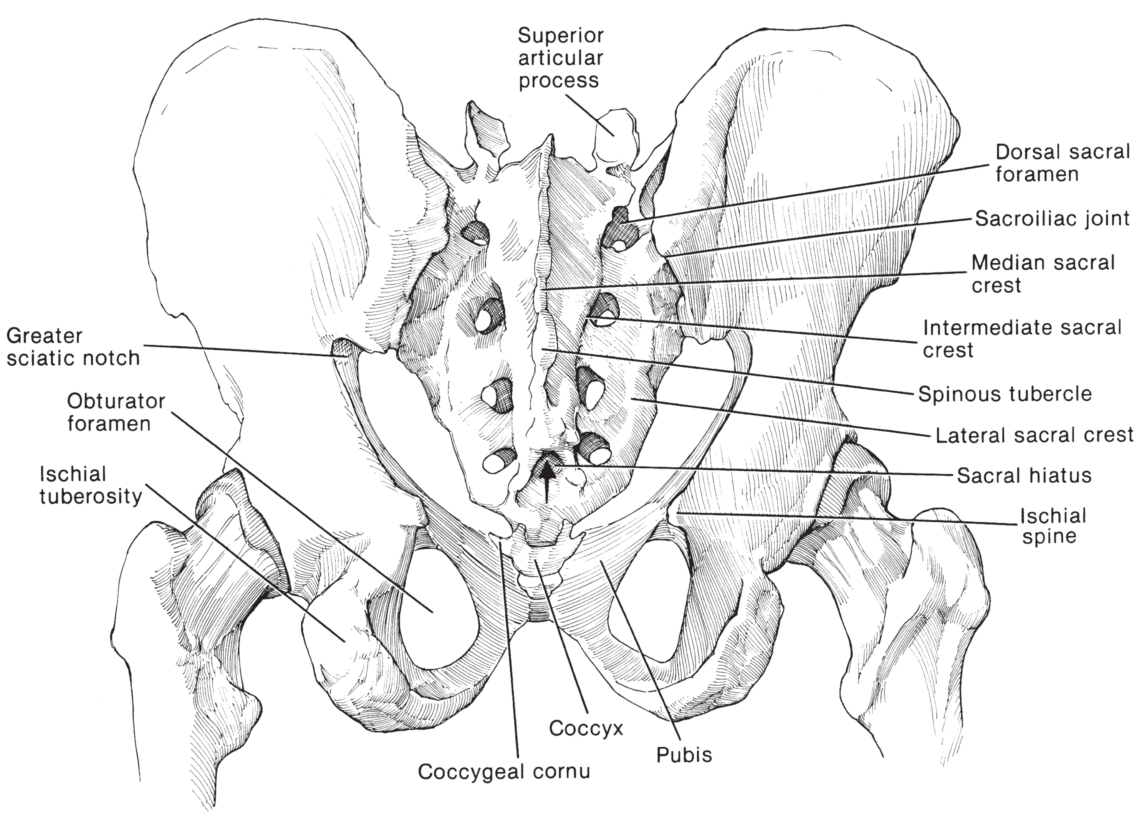

FIGURE 10-7.

of the sacrum so that the lower sacral nerves and filum terminale must traverse their walls to reach the foramina. The fifth sacral spinal nerve and the filum leave the canal through the sacral hiatus.

Pelvic Ligaments, Posterior View

Because of their relation to structures encountered during pelvic surgery, two pelvic ligaments are of urologic concern. The long **sacrotuberous ligament** attaches the ilium to the sacrum and joins the sacrum with the ischium. It runs as a thick, narrow band from the **posterior iliac spine** to the lower sacral tubercles and the adjacent lateral sacral border and ends on the medial margin of the **ischial tuberosity** (Fig. 10-8). It continues along the ischial ramus as the **falciform process**. The thinner **sacrospinous ligament** attaches the **ischial spine** to the lateral sacral border, crossing in front of the sacrotuberous ligament. The **greater sciatic foramen** opens above the two ligaments as they cross the pelvis; the **lesser sciatic foramen** lies below.

The **iliolumbar ligament** connects the ilium to the fifth lumbar vertebra. **Short dorsal sacroiliac ligaments** run upward obliquely to connect the upper portions of the sacrum to the ilium; the **long dorsal sacroiliac ligament** has similar connections for the lower portions. The **sacrospinous ligament** joins the lateral margins of the sacrum to the **spinous tubercle** of the ilium over the medial spinous process of the sacrum in continuity with the **sacrococcygeal ligament**.

The uppermost ligament within the pelvis is the ventral sacroiliac ligament, a thickening of the fibrous capsule of the sacroiliac joint, most developed at the level of the arcuate line and the level of the posterior inferior iliac spine. The dominant ligament, however, is the interosseous sacroiliac ligament that bonds the sacrum and ilium firmly about the sacroiliac joint.

Peritoneal Relationships in the Male

The upper surfaces of the pelvic organs are covered with peritoneum, which also lines the **rectovesical pouch** (cul-de-sac) lying between the **bladder** and upper ends of the **seminal vesicles** and the **rectum** (Fig. 10-9). Extending caudally from the pouch is a fused double fold of the inner stratum of the extraperitoneal connective tissue that was left behind after the absorption of the overlying peritoneum. This forms the anterior layer of **Denonvilliers' fascia** (see Fig. 14-19).

Vesical Ligaments

Fibroareolar ligaments support the bladder and prostate (Table 10-1). They are called true ligaments, in contrast to the peritoneal folds that also connect the bladder to the pelvic walls. The lateral true ligaments of the bladder, derived from the transversalis (endopelvic) fascia over the levators (see Fig. 10-12), connect it to the tendinous arch of the endopelvic fascia (not to be confused with the tendinous arch, which serves as site of attachment of the levator ani). The lateral puboprostatic ligaments do the same for the prostate. The medial puboprostatic ligaments (the familiar puboprostatic ligaments) attach the prostate to the back of the pubis and constitute the floor of the retropubic space. The posterior ligaments are condensations of the vesical venous plexus that run to the internal iliac veins posterolaterally.

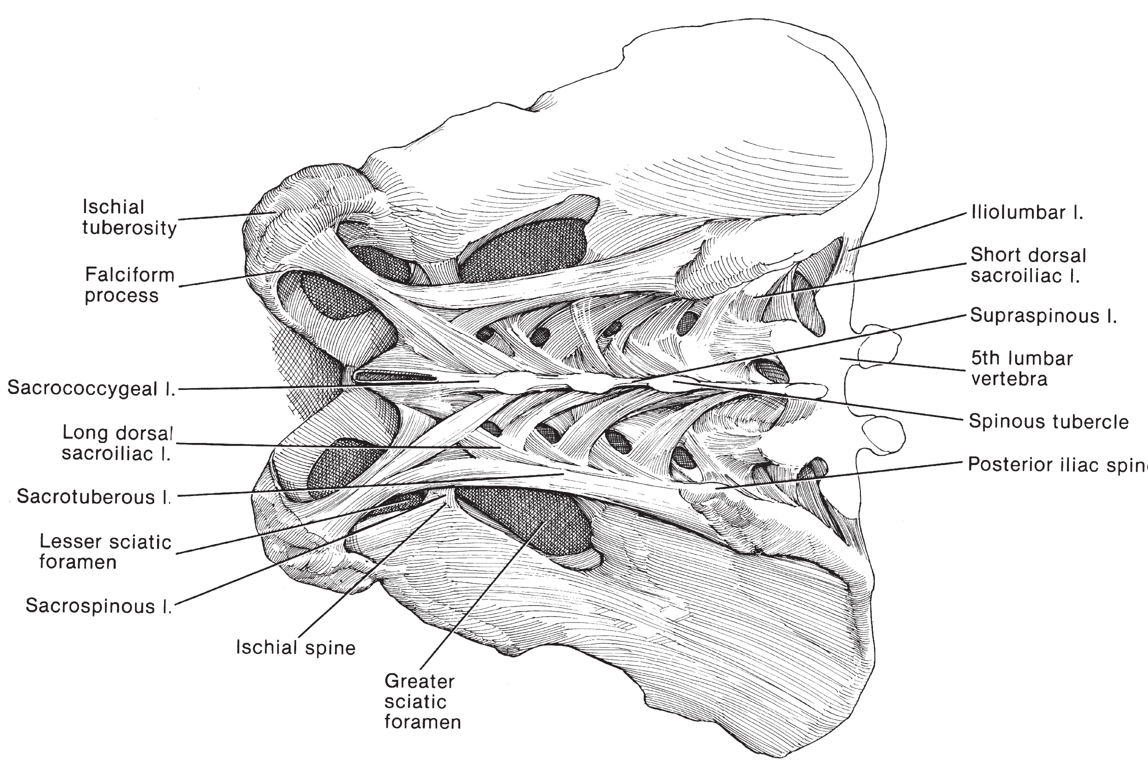

FIGURE 10-8.

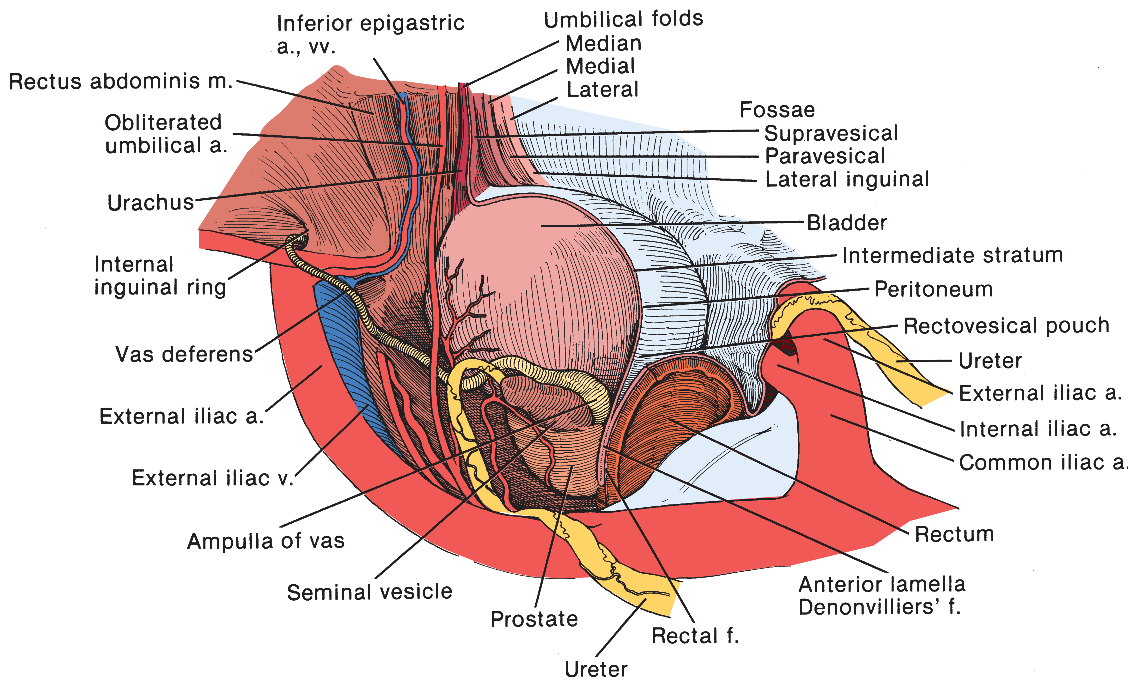

FIGURE 10-9.

TABLE 10-1 PELVIC LIGAMENTS

Ligament	Origin	Terminus	Resulting Anatomic Feature
FIBROAREOLAR (TRUE) LIGAMENTS			
Lateral true ligaments of the bladder	Bladder	Tendinous arch of the pelvic fascia	—
Lateral puboprostatic ligament	Prostatic sheath	Tendinous arch	Medial inguinal fossa
Medial puboprostatic ligament (pubovesical) ligament	Prostatic sheath	Back of pubic bone	Floor of retropubic space
Posterior ligaments	Lateral border of bladder base with vesical venous plexus	Internal iliac veins	—
PERITONEAL FOLDS			
Median umbilical fold (contains urachus)	Bladder	Umbilicus	Supravesical fossae
Medial umbilical folds (contain obliterated umbilical arteries)	Bladder	Umbilicus	Paravesical fossae
Lateral umbilical folds (contain inferior epigastric arteries)	Bladder	Pelvic sidewalls	Lateral inguinal fossae
Sacrogenital folds	Bladder	Sacrum	Pararectal fossae

Peritoneal folds

The peritoneum extends over the tips of the seminal vesicles and then covers the dome of the bladder. On the anterior abdominal wall, it forms three sets of folds that are clearly seen laparoscopically. In the midline is the **median umbilical fold** covering the **urachus** within the intermediate stratum of the retroperitoneal connective tissue as the median umbilical ligament. The **supravesical fossa** lies on either side of it. Slightly laterally is the **medial umbilical fold** covering a ligament derived from the **obliterated umbilical artery**. It extends from the **internal iliac artery** to the umbilicus and defines the medial margin of the **paravesical** or medial umbilical **fossa**. This fossa is delimited posteriorly by the ridge of peritoneum created by the underlying vas deferens. Next are the **lateral umbilical folds** covering the **epigastric vessels** before they reach and enter the rectus sheath. The **lateral inguinal fossa** lies between the lateral umbilical and the sacrogenital folds that delimit the rectovesical pouch.

Rectovesical Pouch and Pararectal Fossa

The folds of peritoneum extending from the bladder to the sacrum, called the sacrogenital folds, close the rectovesical pouch laterally. Posterior to a sacrogenital fold and lateral to the rectum is a peritoneal depression, the pararectal fossa.

Peritoneal Relationships in the Female

The **uterus** is interposed between the **rectum** and **bladder** so that the peritoneum forms a deep **recto-uterine pouch** (pouch of Douglas) behind the uterus that extends almost to the anus (Fig. 10-10). Anterior to the uterus, a more shallow depression is formed between the bladder and the body of the uterus, the **vesicouterine pouch**, that terminates at the junction of **uterine body** and **cervix**. The **broad ligament** is formed by lateral extensions of peritoneum from the anterior and posterior surfaces of the uterus and serves to separate the two pouches. It encloses the **uterine tube** at the upper free border. The **ovary** lies on its posterior surface. The **round ligament** crosses the **external iliac artery** to exit through the **internal inguinal ring**. The pararectal and paravesical fossae are similar to those in the male, with the peritoneum forming the **uterosacral fold** (see Fig. 15-12). The pubovesical ligaments extend from the pelvic fascia and the back of the pubic bone to the vesicourethral junction, similar to the puboprostatic ligaments in the male.

Pelvic Fascias

The fascias of the pelvis are continuous with those lining the abdominal cavity as described in Fig. 12-44. The fascias are derived from the fatty-areolar retroperitoneal connective tissue that lines the body wall and intervenes among the internal organs. As the tissue matures, it becomes distributed more or less into three strata: (1) an *inner stratum*, the subperitoneal layer about the gastrointestinal organs; (2) an *intermediate stratum* accompanying the kidneys and ureters and covering portions of the bladder and prostate (this layer is termed the **renal fascia** [Gerota] in the kidney region); (3) and an *outer stratum* investing the muscles of the body wall, the most prominent part of this outer stratum being the **transversalis fascia** that extends caudally to form the **internal spermatic fascia** (Fig. 10-11).

The named fascias derived from the retroperitoneal connective tissue are outlined in Table 10-2.

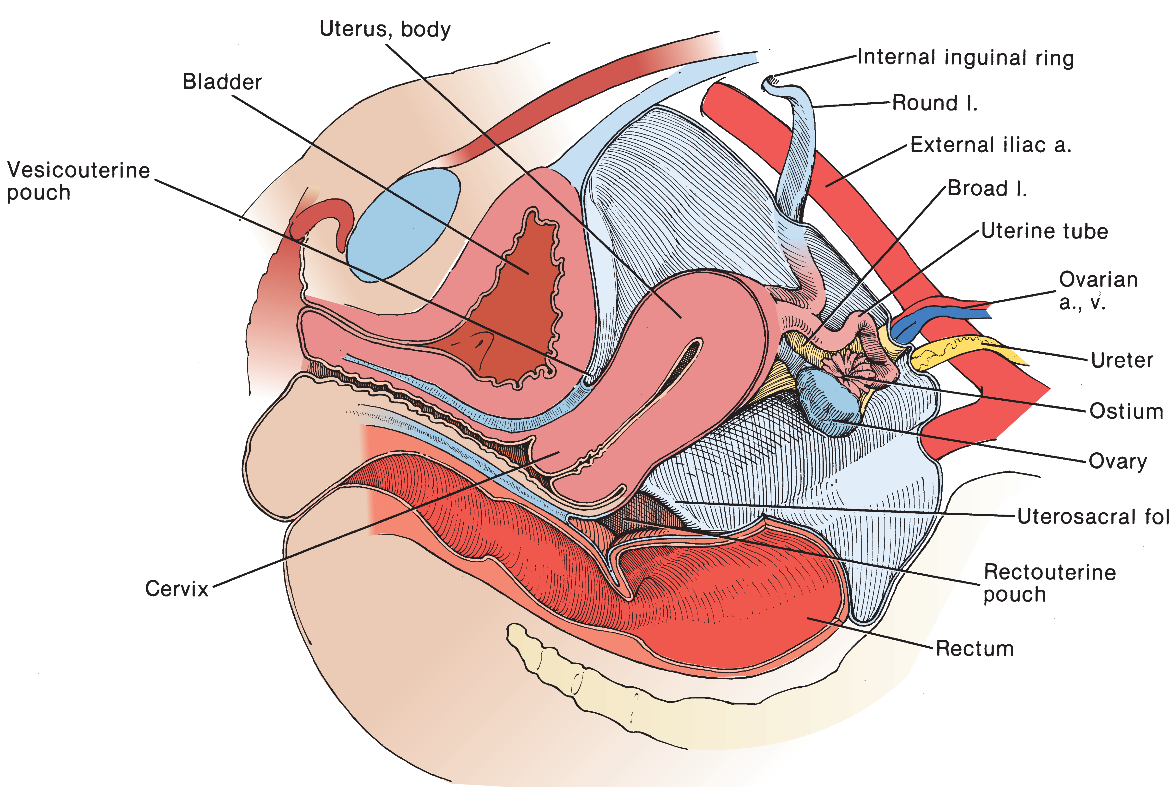

FIGURE 10-10.

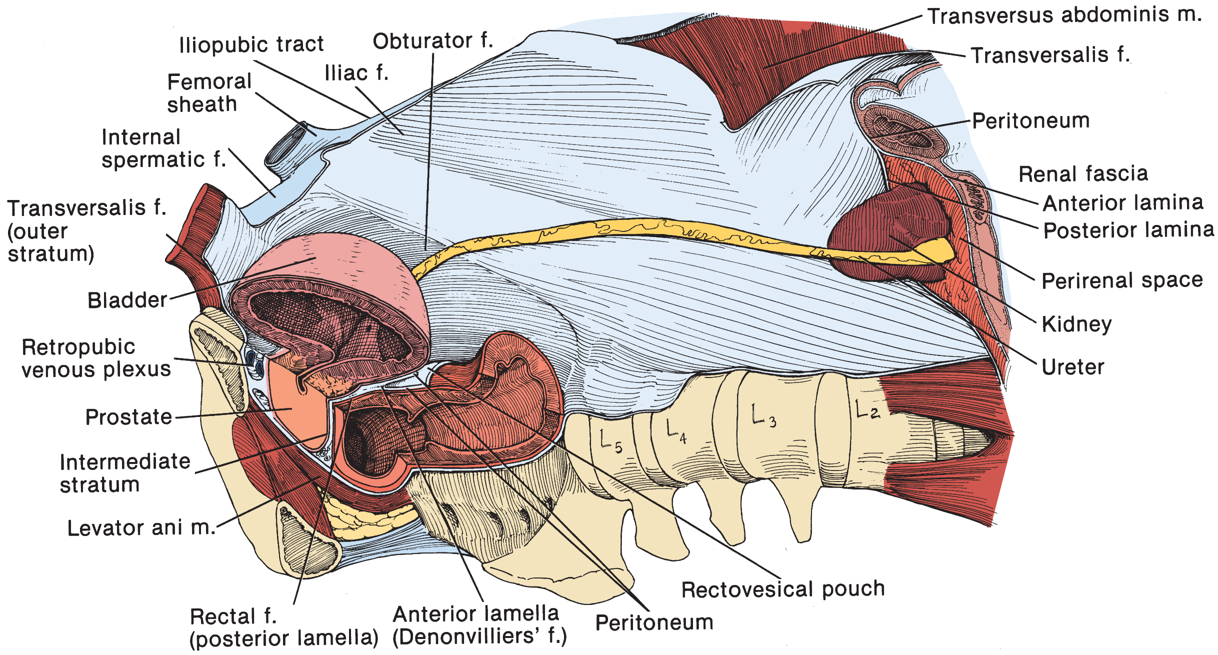

FIGURE 10-11.

TABLE 10-2 NAMED FASCIAS DERIVED FROM RETROPERITONEAL CONNECTIVE TISSUE

Inner stratum	Rectal fascia
Intermediate stratum	Anterior lamina, renal fascia, perirenal fat
	Posterior lamina, renal fascia, pararenal fat
	Ureteral sheath
	Vesical, prostatic fascia
Outer stratum	Transversalis fascia
	Iliacus fascia
	Psoas fascia
	Obturator fascia
	Superior fascia of pelvic diaphragm
	Endopelvic (lateral pelvic) fascia
	Lumbocostal arches
	Diaphragmatic fascia

Inner stratum

The **rectal fascia** is one portion of the **inner stratum** of urologic importance because it forms the posterior lamella of **Denonvilliers' fascia** that covers the anterior and lateral walls of the rectum and the rectal vessels and nerves. The anterior lamella of this fascia is formed from the fused mesoderm of extraperitoneal connective tissue of the anterior and posterior walls of the **rectovesical pouch**.

Intermediate stratum

This stratum encases the prostate (as the prostatic sheath) and the bladder. In the female, it covers the uterus and the vessels supplying the female genital structures. It also provides support for the pelvic viscera, where it lies beneath the peritoneal folds and along the blood vessels, often combined with strands from the outer stratum.

Outer Stratum

The **transversalis fascia** represents the outer stratum and its continuations, the iliac and obturator fascias. Endopelvic fascia and lateral pelvic fascia are terms in common use in descriptions of retropubic prostatectomy and vesical suspension, but strictly speaking, these fascias are merely portions of the transversalis fascia. They form collars of endopelvic fascia around exiting structures by fusion with the extensions of the intermediate and inner strata.

The outer stratum can be subdivided into several somewhat distinct areas in addition to the portion directly associated with the transversus abdominis muscle. The **iliac fascia** is that part covering the iliacus and psoas muscles in the iliac fossa. It is thin above the site of adherence to the iliac crests and the brim of the true pelvis but becomes thicker as it runs down to the **tendinous arch of the levator ani** (the white line), where the obturator fascia, the fascia of the levator ani, and the residual tissue of the levator aponeurosis meet. It is continuous with the posterior margin of the inguinal ligament, where it merges as part of the transversalis fascia. It becomes the pectineal fascia as it passes behind the femoral vessels to form the posterior wall of the femoral sheath. It is continuous with the **obturator fascia** that covers the pelvic surface of the obturator internus and piriformis muscles (see Fig. 10-12). Distally, it forms the lateral wall of the ischiorectal fossa. The superior fascia of the pelvic diaphragm covers the upper surface of the levator ani.

A band of fascia running from the symphysis pubis to the ischial spine forms the tendinous arch of the pelvic fascia. This is recognized as a white strip to which the lateral true ligament of the bladder attaches. The tendinous arch of the levator ani should not be confused with it; that arch is the result of thickening of the obturator fascia.

Muscles and Fascia of the Pelvis and Perineum, Frontal View

The walls of the pelvis are lined by the iliacus, the psoas major and minor, the piriformis, and the obturator internus, as well as the iliococcygeus and pubococcygeus as part of the levator ani system and the coccygeus (Fig. 10-12). The levator ani and coccygeus form the pelvic diaphragm that separates the pelvis from the perineum. However, these two regions share muscles and muscular attachments. The pelvic diaphragm closes the outlet of the pelvis except for the sites of exit of the rectum and urethra, and of the vagina in the female.

Muscles of the Pelvic Diaphragm

The levators ani, making up the larger portion of the diaphragm, are large flat quadrilateral-shaped muscles that are attached to each other, to the inner rim of the pelvic outlet, and to the tendinous arch of the levator ani. Each may be divided into two parts: (1) an anterior part, the **pubococcygeus**, which includes the puboprostatic and puborectalis muscles, and (2) a posterior part, the **iliococcygeus**. Two other paired muscles that line the pelvis lie deep to the pelvic diaphragm are the **piriformis** and the **obturator internus** muscles that are associated with movement of the leg. The piriforms act with the levators to close the posterior part of the pelvic outlet and are overlain by the sacral plexus.

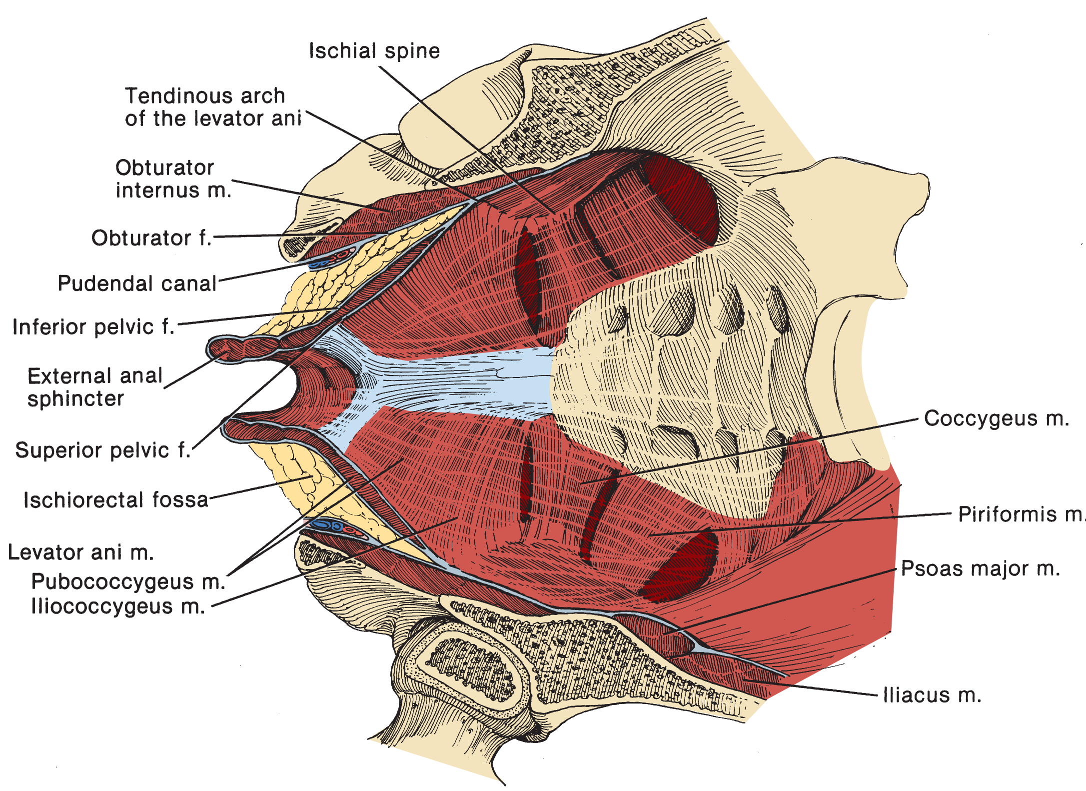

FIGURE 10-12.

Fascias of the Pelvic Diaphragm

Fascia covers the levator ani on both its superior and inferior surfaces, forming the superior and inferior pelvic fascias.

The **superior pelvic fascia** (outer stratum) arises from the **obturator fascia** and attaches to the back of the symphysis pubis, where it runs laterally to attach to the **ischial spine**. The lateral true ligament of the bladder and the lateral puboprostatic ligaments arise from the superior fascia to form the vesical and puboprostatic ligaments (the pubovesical ligaments in the female) anteriorly (see Figs. 10-9 and 13-52).

The superior fascia is very thin compared with that covering the pelvic sidewalls, being little more than loose connective tissue over the epimysium of the muscles. This characteristic allows mobility of the levators, because the thickness of the fascia over a muscle or organ appears to be inversely related to the freedom of motion of the structure. Not only is the pelvic diaphragm covered with a very thin fascial layer, but so are the domes of the bladder and the rectum, whereas the immobile prostate has a thicker coat.

The **tendinous arch of the levator ani** is a whitish thickening of the superior layer of the pelvic fascia that extends from the **ischial spine** to a point near the middle of the posterior aspect of the pubic bone. It forms the origin for portions of the **levator ani** and **coccygeus muscles** and marks the site where the **obturator fascia** splits to form the superior and inferior pelvic diaphragmatic fascias.

The **inferior pelvic fascia** is a thin layer covering the inferior surface of the levator ani. Its continuities are with the fascia of the **pudendal canal** and **obturator fascia** at the junction with the levator ani and it forms the margins of the **ischiorectal fossa**.

Supporting ligaments form about distensible organs that are surrounded by poorly supportive loose areolar tissue that provides the dead space needed for their movement. Some pelvic ligaments appear as connective tissue condenses in the intermediate stratum along the branches of the internal and external iliac vessels and nerves running to the bladder and uterus, forming the lateral ligaments. Other ligaments are formed independently from the superior fascia of the pelvic diaphragm (outer stratum); the puboprostatic and pubovesical ligaments and the uterosacral ligaments are derivations of the intermediate stratum. Smooth muscle is incorporated into these ligaments and provides the tension and flexibility needed to maintain position yet allow distention of the suspended organ.

The great vessels, along with the urinary organs, are imbedded in the intermediate stratum of the retroperitoneal fascia but near the pelvic wall they lose that coating and are covered only by the outer stratum, the transversalis (endopelvic) fascia.

Pelvic Musculature, Oblique View

The pelvic floor is composed of three muscles. Two, the pubococcygeus and iliococcygeus, form the levator ani; the third is the coccygeus. The piriformis is a partial contributor to the pelvic floor (Fig. 10-13).

Pubococcygeus

The **pubococcygeus** arises from the posterior surface of the inferior pubic ramus and from the anterior part of the **tendinous arch of the levator ani** (the white line) that extends

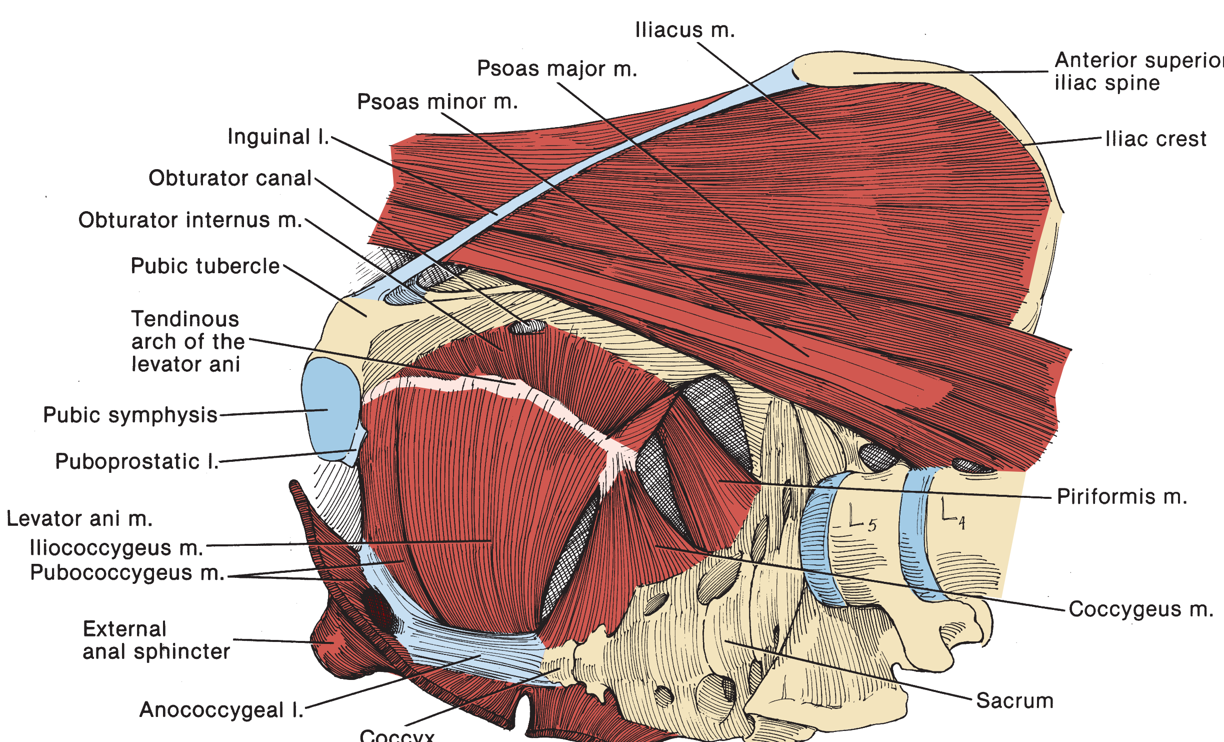

FIGURE 10-13.

laterally to the **obturator canal**. Its fibers run posteriorly and downward as they angle medially to end as a sling about the prostate or the urethra and vagina in the female, forming the puboprostatic or pubovaginal muscles, and about the rectum as the puborectalis, a muscle that holds the rectum forward. The more medial fibers of the anterior part of the pubococcygeus enter into the prostatic sheath and insert into the perineal body. The muscle fibers of the pubococcygeus, some of which are nonstriated, join with the rectal musculature above the **external sphincter** and insert in the last two segments of the **coccyx**. The gap between the levators anteriorly is occupied by the **puboprostatic ligaments** in the male and the pubovesical ligaments in the female.

The prostatic levators are those portions of the levator ani that pass alongside the prostate to attach to the perineal body.

Iliococcygeus

The **iliococcygeus** portions of the levators originate from a condensation of the obturator fascia and from the ischial spine. The two portions meet in the midline deep to the rectococcygeus to form the musculotendinous **anococcygeal ligament** (or raphe), which has contributions from the pubococcygeus. The paired iliococcygeus muscles join the rectum and serve as an attachment for the external anal sphincter as they pass by to insert in the coccyx. The *rectourethralis muscle* is an extension of the longitudinal musculature of the rectum. It lies on the superior surface of the levators and attaches to the perineal body in the male or to the vaginal wall in the female.

Coccygeus

The **coccygeus** is not part of the levator system but lies more caudally. It arises from the ischial spine and inserts in the anococcygeal ligament and into the coccyx and sacrum.

Both the iliococcygeus and the coccygeus are supplied by divisions of the pudendal nerve arising from the second to fourth sacral nerves, principally by branches from the inferior rectal nerve and, farther anteriorly, by the deep branch of the perineal nerve.

Part of the **piriformis** lies in the pelvis as it arises from the sacrum. Over it lie the rectum and the sacral plexus.

The function of the *pelvic diaphragm* is the tonic support of the viscera when at rest. With increased intra-abdominal pressure, as from coughing and straining, the pelvic diaphragm is reflexly contracted to augment the holding power of the several sphincters. In addition, selective contraction or relaxation of elements of the diaphragm, in concert with the perineal musculature, coordinates defecation or micturition.

Arteries of the Pelvis

In addition to the single middle sacral artery, three pairs of arteries supply the structures of the pelvis: (1) the common iliacs, (2) the inferior mesenteric, and (3) the gonadal arteries (Fig. 10-14).

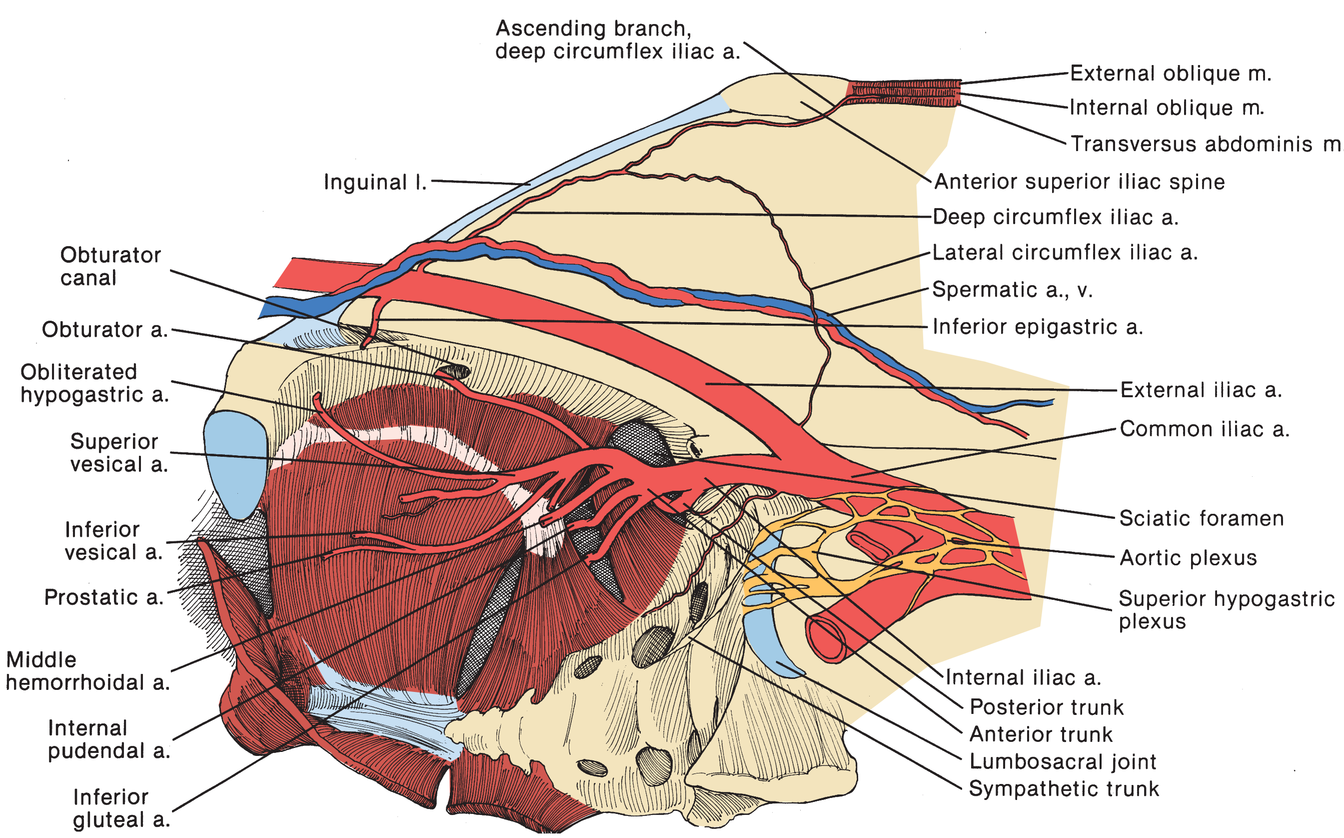

FIGURE 10-14.

Common Iliac Artery

The **common iliac arteries** branch from the **abdominal aorta** to the left of the fourth lumbar vertebral body at the level of the iliac crests. The **right common iliac artery**, 5 cm in length, crosses the fifth lumbar vertebra underneath the **superior hypogastric plexus** and the ureter. The **sympathetic trunk** lies behind it, along with the proximal ends of the common iliac veins and the first part of the inferior vena cava. The **left common iliac artery** is shorter by a centimeter than the right and runs under the sympathetic nerves supplying the superior hypogastric plexus and the ureter, but overlies the sympathetic and lumbosacral trunks and the obturator nerve.

External Iliac Artery

Each **external iliac artery** leaves the common trunk at the level of the **lumbosacral joint** and follows the medial border of the psoas muscle to end beneath the **inguinal ligament** as the femoral artery (Fig. 10-15). At the lower end, it is crossed by the **spermatic artery** and **vein** as well as the genital branch of the genitofemoral nerve, the deep circumflex iliac vein, and the vas deferens.

The two branches of the external iliac artery within the pelvis are the inferior epigastric and the deep circumflex iliac artery.

The **inferior epigastric artery** arises from the external iliac artery immediately above the inguinal ligament to run along the medial aspect of the internal inguinal ring and pass through the transversalis fascia before diving under the posterior rectus sheath at the arcuate line. It can be located laparoscopically within the lateral umbilical fold. It gives off a public branch and a cremasteric branch.

Not only does the inferior epigastric artery provide an important collateral between the internal thoracic and the iliac arteries should the external or common iliac be occluded above the site of its takeoff, but it is useful surgically for procedures involving a rectus abdominis flap or penile or testicular revascularization.

The **deep circumflex iliac artery** arises from the lateral side of the external iliac artery almost opposite the origin of the inferior epigastric artery. It anastomoses with the lateral ascending branch of the **lateral circumflex iliac artery** near the **anterior superior iliac spine**, where it provides an **ascending branch** between the **internal oblique** and **transversus abdominis**. Alternatively, it anastomoses with the iliolumbar artery, a derivation of the posterior division of the internal iliac artery. The main artery then continues posteromedially to join the iliolumbar and superior gluteal arteries.

Internal Iliac Artery

The **internal iliac artery** (hypogastric artery), in half the cases after leaving the bifurcation, branches at the **greater sciatic foramen** into an anterior and a posterior trunk. The **posterior trunk** provides the gluteal supply via the superior gluteal artery and also branches into the iliolumbar and lateral sacral arteries. In the control pelvic hemorrhage, the internal iliac artery must be ligated distal to the takeoff of the posterior branch to preserve that portion of the circulation.

The **anterior trunk** has seven branches, which may be variable in their connections.

The first branch is the **superior vesical artery,** supplying the upper portion of the bladder through the paravesical fascia (Fig. 10-16). Branches extend to the vas deferens as the artery to the vas deferens and then connect with the

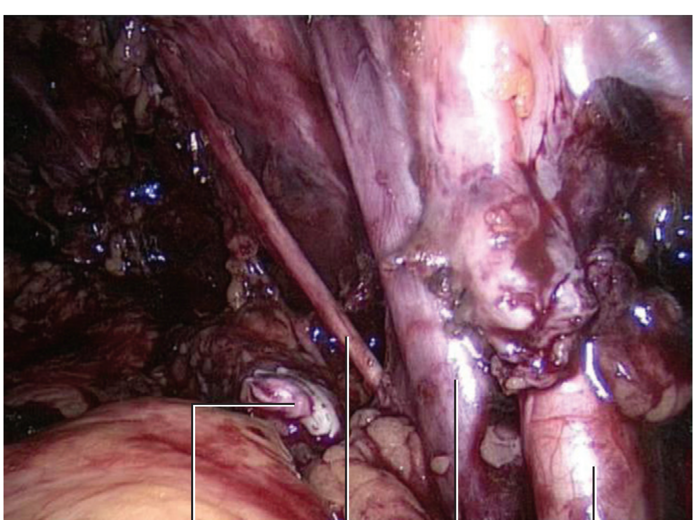

FIGURE 10-15. Pelvic structures, intraoperatively. Image from laparoscopic cystoprostatectomy showing the external iliac artery and vein, the obturator nerve, and the divided remnant of the superior vesical artery. *(Image courtesy of Lee Ponsky, M.D.)*

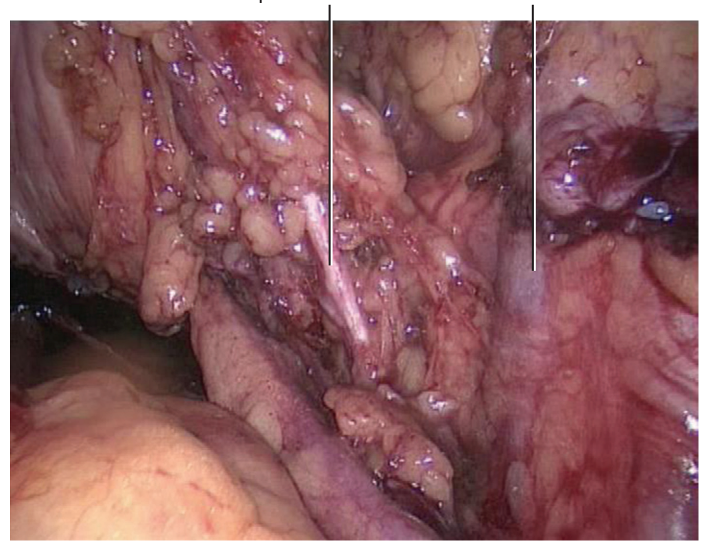

FIGURE 10-16. Pelvic structures, intraoperatively. Iliac vein is visible at right. The superior vesical artery has been exposed prior to division (as illustrated in Fig. 10-15). *(Image courtesy of Lee Ponsky, M.D.)*

spermatic artery. Branches supply portions of the inguinal canal and distal ureter as well. The first part of the superior vesical artery is the patent portion of the fetal umbilical artery remaining after closure of the fetal circulation. The more distal part becomes the **obliterated hypogastric artery** that provides an important surgical guide to locate the superior vesical pedicle (see Fig. 13-66). This structure forms the medial umbilical ligament and is covered by the medial umbilical fold ending at the umbilicus.

The **inferior vesical artery** arises slightly more distally, near or in common with the **middle rectal artery,** and supplies the lower part of the bladder as well as the prostate and seminal vesicles, with branches to the ureter.

In the female, the uterine artery enters the base of the broad ligament of the uterus, the cardinal ligament to the cervix, where it branches into a descending limb to the cervix and vagina and an ascending limb anastomosing with the vessels of the ovary and uterine tubes (see Fig. 15-13).

The **obturator artery** is subject to considerable variation in origin. It may arise directly from the posterior trunk or from the inferior epigastric artery or even from the inferior gluteal artery. It lies on the obturator fascia over the obturator internus between the obturator nerve anteriorly and the obturator vein posteriorly. It runs to the **obturator foramen,** first giving off iliac branches, then a vesical branch supplying a portion of the bladder, and finally, a pubic branch that runs behind the pubis to join the pubic branch of the inferior epigastric artery.

Distal to the origin of the inferior vesical artery, the anterior division branches into the inferior gluteal and internal pudendal arteries. The **internal pudendal artery** supplies the external genitalia. One branch, the inferior rectal artery, goes to the rectum and anal canal, anastomosing with the middle and superior rectal arteries. The internal pudendal, in turn, branches into the perineal artery, artery of the bulb, urethral artery, and the deep and dorsal arteries of the penis (see Fig. 16-30 and 16-31). The inferior gluteal artery, which may arise as a branch of the posterior trunk, gives off branches to the muscles of the deep pelvis and those of the buttocks and upper thigh.

Veins of the Female Pelvis

The course of the veins of the pelvis generally parallels that of the arteries with the same name. But, in contrast to arteries, the veins are multiple and are highly interconnected through venous plexuses: uterine and vaginal, retropubic, vesical, and rectal (Fig. 10-17).

Common Iliac Veins

Each **common iliac vein** arises from where the external and internal iliac veins merge and ends on the right side of the fifth lumbar vertebra, where it joins the **inferior vena cava** that runs on the right side of the aorta. An additional vein, the **middle sacral vein,** usually joins the left common iliac vein.

External Iliac Vein

The **external iliac vein,** a continuation of the femoral vein at the inguinal ligament, joins the common iliac vein over the sacroiliac joint. It drains three systems: the (1) inferior epigastric, (2) deep circumflex iliac, and (3) pubic. The **inferior epigastric vein** enters about 1 cm from the inguinal ligament and collects from the area supplied by the corresponding artery. The **deep circumflex iliac vein** enters 1 cm higher. The pubic vein forms a connection with the obturator vein and then ascends behind the pubis in company with the pubic branch of the inferior epigastric artery.

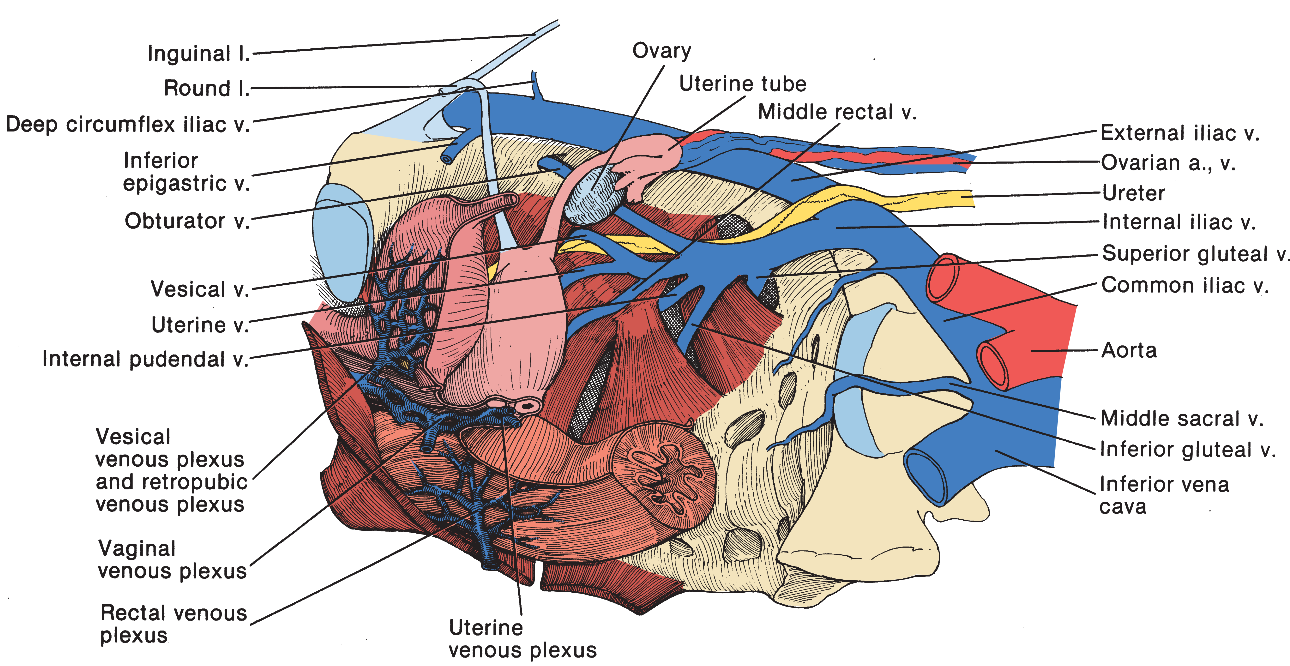

FIGURE 10-17.

Internal Iliac Vein

The **internal iliac vein** is the major collector from the veins in the pelvis. It runs behind and slightly medial to the companion artery. The contributing veins match the arteries that come from the internal iliac artery. These veins enter the internal iliac veins:

The **superior** and **inferior gluteal veins** drain from the buttock and the back of the thigh.

The **internal pudendal vein** receives blood from the areas supplied by the internal pudendal artery and drains into the internal iliac vein as a single vessel.

The **obturator vein** runs in front of the sacroiliac joint from the adductor compartment of the thigh via the obturator fossa and continues beneath the obturator artery and the ureter to join the internal iliac vein.

Other branches contributing to the internal iliac vein are the lateral sacral veins, the middle rectal vein, and the rectal venous plexus.

Venous Plexuses

The plexuses are subject to stasis in conditions of high pressure and low flow when the subject is standing, factors that contribute to the frequency of thrombosis.

The **uterine** and **vaginal plexuses** intercommunicate and also have connections with the other plexuses. They drain into the internal iliac vein. The blood from the external genitalia and rectum returns through bulbar veins, vulvar and inferior rectal veins, and the deep dorsal vein of the clitoris by way of a **retropubic plexus.** The dorsal veins of the clitoris as well as smaller veins from the **vesical plexus** also drain into the internal pudendal vein. The vesical plexus lies over the lower anterior part of the bladder and is in continuity with the uterine plexus and also drains into the internal iliac vein, as does the **rectal plexus.** A **retropubic plexus** drains the clitoris, its small size contrasting with the large prostatic plexus (Santorini) that lies in front of and to the sides of the prostate and receives the deep dorsal vein of the penis. The retropubic plexus drains through the vesical plexus into the internal iliac vein.

Male Venous Drainage

Pelvic veins in the male are described and illustrated in Fig. 14-42). The blood drains from the bulbar, scrotal, and inferior rectal veins, and the deep dorsal vein of the penis by way of the prostatic plexus. The veins follow the path of the internal pudendal artery, finally draining into the internal iliac vein as a single vessel. The prostatic venous plexus overlies the prostate and the part of the bladder that lies behind the lower part of the symphysis pubis (see Fig. 14-21). The dorsal veins of the penis as well as smaller veins from the prostate and bladder drain into it (see Fig. 16-35). It has connections with the vesical plexus and with the internal pudendal vein, and empties into the internal iliac veins.

Pelvic Lymphatics

In general, the lymphatics from pelvic organs surround the arteries and the groups of nodes are named for the accompanying arteries: internal iliac, external iliac, and common iliac (Fig. 10-18).

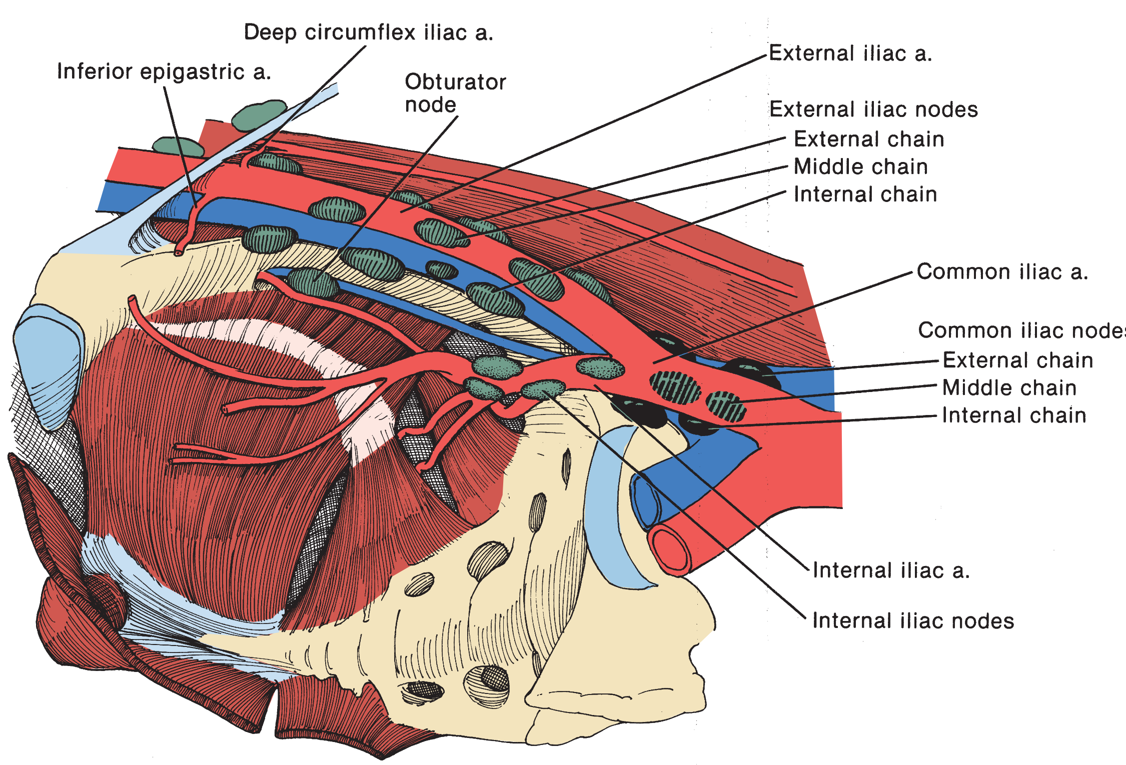

FIGURE 10-18.

Internal Iliac Nodes

The **internal iliac nodes** lie near the origins of the several branches of the **internal iliac artery**: the prostatic or uterine artery, and the pudendal and middle hemorrhoidal arteries. In the male, the internal iliac nodes receive lymph from the prostate, seminal vesicles and membranous urethra, the bladder, and rectum as well as from part of the perineum and penile urethra. In the female, these nodes drain the bladder, vagina, uterus and rectum, and parts of the perineum. These nodes drain into the **middle chain** of the **common iliac nodes** that lie under the vessels in the fossa of the lumbosacral nerve.

External Iliac Nodes

These nodes can be viewed as composed of three chains: (1) external, (2) middle, and (3) internal.

Lymph drains into the **external chain** from the superficial and deep inguinal nodes, from the glans penis or clitoris, and from the lower abdominal wall but not from organs within the pelvis. The external chain has three or four nodes between the **external iliac artery** and the internal border of the psoas muscle. The lowest node, into which most of the afferent vessels terminate, lies over the takeoff of the **deep circumflex iliac arteries,** adjacent to the division of the genitofemoral nerve into its two branches. The efferents from these nodes empty into the inferior node of the chain.

Lymph from the bladder and prostate or parts of the uterus and vagina drains into the **middle chain,** made up of two or three nodes overlying the external iliac artery. Its efferents join those of either the external or internal chain.

The **internal chain** drains the superficial and deep inguinal nodes, the glans penis or clitoris by way of the deep drainage system, portions of the lower abdominal wall, and the bladder neck, prostate, and membranous urethra. This chain consists of three or four nodes that lie on the pelvic wall below the external iliac vein and above the obturator nerve. The middle node of this chain is commonly called the **obturator node**. The efferents join with those of the internal iliac system to empty into the middle chain of the common iliac nodes.

Common Iliac Nodes

The **common iliac nodes** are found in three chains. The **external chain,** usually composed of two nodes, lies on the surface of the common iliac artery and is continuous with the external chain of external iliac nodes distally (afferents) and the para-aortic nodes proximally (efferents). The **middle chain** lies in a fossa deep to the vessels. The **internal chain**, situated over the sacral promontory, is more important because it receives drainage from the prostate and bladder neck or the uterus and vagina. All these systems drain into the lateral aortic system of para-aortic nodes on their respective sides (see Fig. 3-5).

Somatic Nerves of the Pelvis

The sacral plexus lies on the piriformis muscle and is formed from the **ventral rami** of the spinal nerves **L4, L5, S1, S2**, and **S3**. Caudal to it is the **ventral ramus** of **S4**.

The nerve supply to the pelvic floor muscles is from the 2nd, 3rd, and 4th sacral nerves. The **levator ani** is innervated by branches from the 4th sacral nerve and from the pudendal nerve. The **coccygeus** is supplied by branches from the 4th and 5th sacral nerves through the coccygeal nerve. The other important branches, the **pudendal nerve**, posterior femoral cutaneous nerve, inferior hemorrhoidal nerve, perineal nerve, and dorsal nerve of the penis, are described in pertinent chapters.

Autonomic Nerves

The autonomic nerves arise from the **aortic plexus** and from the **ventral rami** of sacral nerves **S2, S3**, and **S4** (see Figs. 4-11 and 4-12). The sympathetic **superior hypogastric plexus** (the presacral nerve) lies below the aortic bifurcation in the outer stratum of the extraperitoneal connective tissue over L5 and the **sacral promontory**.

From each side of the centrally located superior hypogastric plexus, the right and left **hypogastric nerves** descend on the pelvic sidewall medial to the internal iliac artery. They are joined by the **pelvic splanchnic nerves** before proceeding to their respective plexuses, the right and left **pelvic** (or inferior hypogastric) **plexuses** near the bladder base, the prostate, and the seminal vesicles. The anterior part of each pelvic plexus constitutes the **vesical plexus**; the nerves run with the arteries to the bladder at its base. The more distal part makes up the **prostatic plexus**, whose nerves supply the prostate and ejaculatory ducts, seminal vesicles, membranous and penile urethra, and the bulbourethral glands. Branches go to the ureteric and testicular plexuses and to the middle hemorrhoidal plexus. In the female, the uterovaginal plexus substitutes for the prostatic plexus and sends nerve fibers through the broad ligament.

The autonomic nerves of the pelvis lie in several layers. The sacral and lumbar plexuses are beneath the outer stratum of the retroperitoneal connective tissue (transversalis or endopelvic fascia). The parietal nerves also course in this deep fascia, giving off visceral branches that travel more superficially. The vesical, prostatic, and rectal plexuses lie in the intermediate stratum, within the thin areolar tissue that accompanies the vas deferens and ureter. In general, the parasympathetic fibers travel in the deeper part of the intermediate stratum of the connective tissue, whereas the sympathetic fibers lie just beneath the peritoneal surface.

The plexuses may lie at a distance from the innervated organ, sending postganglionic rami to it. The distribution of the autonomic nerves is such that damage to them is limited in operations on the bladder or prostate, although with pelvic node dissection, the nerves lying in the areolar tissue between the peritoneum and the lymph nodes may be damaged.

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Chapter 11

Perineum

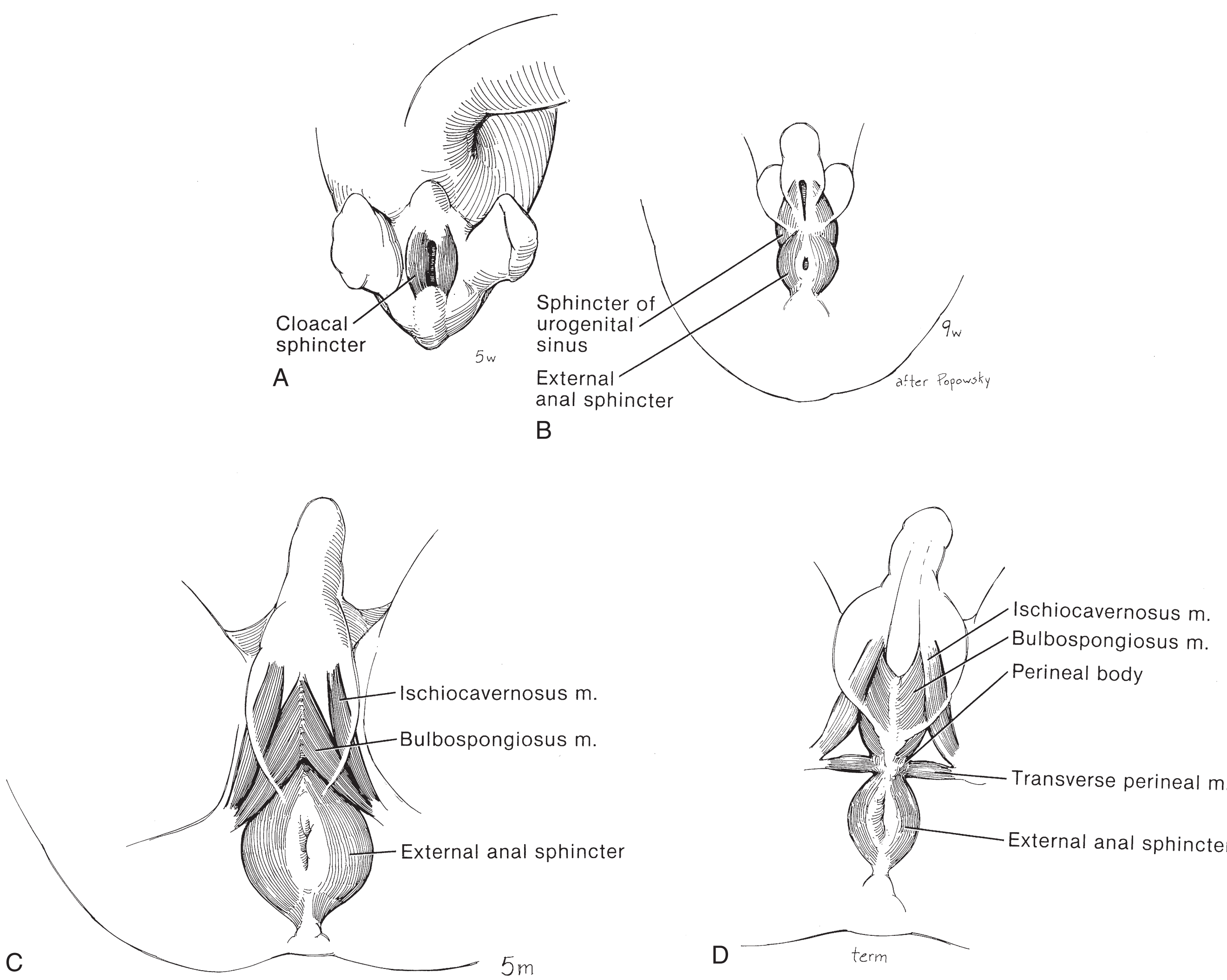


FIGURE 11-1.

Perinaeum, the Ligamentous Seam betwixt the Cod and the Fundament.

Blancard's
Phys. Dict. (ed. 2), 1693

DEVELOPMENT OF THE PERINEUM

By the end of the third week of gestation, the mesoderm has raised swellings around the cloacal membrane as the initial development of the *primary perineum* (see Fig. 16-1). The swellings, in turn, become divided transversely by the perineal spur into anterior genital and posterior anal swellings. A primitive cloacal sphincter develops around the cloacal membrane.

The *secondary perineum* is a late development that accompanies regression of the tail. It arises as the distal part of the urorectal septum divides the cloaca transversely into urogenital and rectal portions (see Fig. 13-8). The point of contact of the septum with the membrane forms the central tendon of the perineum.

Anterior perineal differentiation is dependent on the development of the external genitalia, as described in

Figures 16-3 to 16-14. In brief, the genital tubercle develops into a phallus from its origin at the cranial end of the cloacal membrane. The urethral plate of endoderm, covered on its lower surface with ectoderm from the primary urethral groove, extends onto the phallus. The edges of the groove are elevated to form genital folds that pass around the urogenital membrane reaching almost to the anus. When the membrane breaks down, both the urinary and genital passages open at the base of the phallus. The urethral groove deepens and the stage is set for male and female differentiation. In the male, the genital folds join to create a urethra.

DEVELOPMENT OF THE PERINEAL MUSCULATURE

The **cloacal sphincter muscle**, rather than the internal muscles that form the pelvic floor, is the source of the perineal musculature proper. This muscle develops around the cloacal membrane at 8 weeks and is innervated by the pudendal nerve, as are its subsequent divisions (Fig. 11-1A). It becomes stratified into two planes. The deep plane forms the external anal sphincter, the striated urethral musculature, and the deep transverse perineal muscles. From the superficial plane, the bulbospongiosus muscle, the superficial transverse perineal muscles, and a superficial portion of the external anal sphincter are derived.

By the 12th week, the sphincter is divided into an **external anal sphincter** and the **sphincter of the urogenital sinus** at the same time that the common cloacal opening becomes divided (Fig. 11-1B).

In the male, by the 20th week, the sphincter of the urogenital sinus has formed the **ischiocavernosus** and **bulbospongiosus** muscles and also the striated urethral sphincter (Fig. 11-1C). Finally, the transverse perineal muscles are formed in association with the bulbospongiosus muscle.

By term, the **ischiocavernosus** and **bulbospongiosus**, as well as the **transverse perineal muscles**, are independent of the striated urethral sphincter (Fig. 11-1D).

The *levator ani*, a muscle of the pelvis, arises from a higher mesodermal source in conjunction with the coccygeus, and later, descends to the level of the bladder and prostate to become secondarily related to the sphincters and perineal musculature.

PERINEAL STRUCTURE

Boundaries of the Perineum

The diamond-shaped perineum lies below the pelvic outlet, which is separated from the pelvis by the pelvic diaphragm (see Fig. 10-11). It is limited anteriorly by the pubic arch and the arcuate pubic ligament that joins the lower borders of the symphysis. Posteriorly, it is restricted by the tip of the coccyx and on either side by the inferior margins of the pubic and ischial rami, the ischial tuberosity, and the sacrotuberous ligament. It includes all of the soft parts that connect the lower portions of the digestive, genital, and urinary tracts to the walls of the true pelvis. A line drawn between the ischial tuberosities divides the perineum into an anterior urogenital triangle that is different in the male and female, and a posterior anal triangle common to both sexes.

Descriptions of the perineum are still handicapped by the tendency of anatomists to tailor the muscular and aponeurotic layers to conform to concepts they have derived from their own dissections and to ascribe original names to selected layers. The whole concept of a urogenital diaphragm has yet to be satisfactorily resolved, mainly because the urethral sphincters penetrate its proposed layers. The present illustrations are based on classic descriptions that incorporate recent findings but do not include all the modifications made by every anatomist.

It should be stressed that the classic concept of a two-layered urogenital diaphragm as described by Henle 138 years ago has not been uniformly identified by subsequent anatomists; the most conspicuous difference has been the inability of more recent observers to locate a superior fascial layer. However, by considering this layer to be composed of the deep perineal muscles and their associated fascia rather than a special anatomic sandwich, its perineal relations can be described and understood.

MALE PERINEUM

Compartments and Fascias of the Perineum

Two compartments can be dissected, a superficial perineal space and a deep perineal space. The *superficial perineal space* contains the superficial urogenital muscles: the bulbospongiosus, both of the ischiocavernosus muscles, and the superficial transverse perineal muscles. The *deep perineal space* encloses the deep urogenital muscles: the striated urethral sphincters and the deep transverse perineal muscles. What has been called the urogenital diaphragm is best defined as the layer of deep urogenital muscles and the fascias that accompany them.

Three fascial layers define the two spaces. The first is the *membranous layer of the superficial fascia* (Colles' fascia) that forms the roof of the superficial perineal space. The intermediate layer is the *perineal membrane* or inferior fascia of the urogenital diaphragm that provides both the floor of the superficial perineal space and the roof of the deep perineal space. The deepest layer is the *inferior fascia of the urogenital diaphragm* that serves as the floor of the deep perineal space. These compartments and layers are defined for anatomic convenience and as such provide convenient points for description and reference. During dissection or surgery, many structures are found not to be strictly bounded by such distinct layers because of the tenuous nature of the tissues of the so-called diaphragm and because of anatomical variations.

Table 11-1 outlines the layers of the perineum.

TABLE 11-1

LAYERS OF THE MALE PERINEUM

Superficial perineal fascia (areolar and membranous layers)
Superficial perineal space
Superficial transverse perineal muscles
Bulbospongiosus
Ischiocavernosus
Inferior fascia of the urogenital diaphragm
Deep perineal space
Deep transverse perineal muscles
Membranous urethral sphincter
Superior fascia of the urogenital diaphragm

Superficial Perineal Fascia

Semisagittal View

The membranous layer of the superficial fascia or **Colles' fascia** has a structure resembling an aponeurosis. It forms a roof over the superficial perineal space that extends anteriorly from the dorsal margin of the perineal membrane (**inferior fascia** of the **urogenital diaphragm**) and the **perineal body**. One portion, as the **major leaf** of Colles' fascia, forms a partition between the superficial perineal space and the scrotum (Fig. 11-2A). More anteriorly, Colles' fascia joins the dartos muscle of the scrotum as the **scrotal dartos** and forms part of the scrotal septum. It is continuous over the penis as the **superficial penile fascia** or penile dartos that covers the penile or **Buck's fascia** over the **corpora cavernosa** and **corpus spongiosum.** A thin connective tissue layer, the tela subfascialis of Eberth, intervenes between the superficial penile fascia and Buck's fascia. The superficial penile fascia also encloses the **ischiocavernosus** and **bulbospongiosus muscles** within individual fascial compartments. As a continuation of Colles' fascia, it joins Scarpa's fascia, the membranous layer of the superficial fascia over the lower abdomen. Laterally, it is attached to the **pubic rami** and **ischia**. These connections limit the spread of extravasated urine.

Coronal View

Colles' fascia covers the superficial perineal space containing the ejaculatory muscles, the **ischiocavernosus** and **bulbospongiosus**. These muscles, in turn, surround **Buck's fascia**, which encloses the **corpus spongiosum** and the **crus** of the **corpus cavernosum** on each side (Fig. 11-2B). The penile dartos, **scrotal dartos**, and **scrotal septum** are continuations of Colles' fascia.

The **perineal membrane** (inferior fascia of the urogenital diaphragm), an extension of Colles' fascia, covers the **deep transverse perineal muscles** and forms the roof of the deep perineal space, through which the **membranous urethra** passes and in which the **pudendal arteries** and **veins** lie. Deep to this space are the **superior fascia** of the **urogenital diaphragm** and the **levator ani** group of muscles.

Superficial Perineal Space

After the covering membranous layer of the superficial fascia (Colles' fascia) is removed, the superficial perineal space is exposed. The floor of the space is the perineal membrane (inferior fascia of the urogenital diaphragm) that extends from the obturator fascia to reach the fascias surrounding the urethral and anal sphincters, effectively lining the medial wall of the ischiorectal fossa. The perineal membrane is continuous with the fascia of the obturator internus, fuses with the superior fascia anteriorly, and joins the fascia of the external sphincter ani and the anococcygeal raphe posteriorly, thus forming the upper limit of the ischiorectal fossa.

The posterior edge of the perineal membrane reaches the perineal body and fuses there with the superior fascia of the urogenital diaphragm beneath the superficial transverse perineal muscles. The perineal membrane is also continuous with Colles' fascia. Anteriorly, the perineal membrane becomes more dense, forming the transverse perineal ligament and terminates to allow passage of the deep dorsal vein and the dorsal nerve of the penis. The rectourethralis muscle is formed from a few strands of the anterior longitudinal layer of the rectum at the rectal ampulla that pass forward to the perineal body. The prostatic levators are those portions of the levator ani that pass alongside the prostate to attach to the perineal body.

Within the superficial perineal space are the superficial urogenital muscles, the bulbospongiosus and both **ischiocavernosus muscles** (Fig. 11-3). This space also contains the paired **superficial transverse perineal muscles** that run across from the anterior and medial parts of the **ischial tuberosities**. They join the **perineal body** in the midline in conjunction with muscle fibers from the superficial part of the **external anal sphincter** and the bulbospongiosus muscle.

The superficial perineal space also contains the transverse perineal artery, a branch of the **internal pudendal artery**, which runs beneath the superficial transverse perineal muscle along with a branch of the **perineal nerve**. The perineal branches of the **posterior femoral cutaneous nerves** and the **scrotal arteries, veins**, and **nerves** pass forward alongside the bulbospongiosus.

Perineal Body

The **perineal body**, composed of fibromuscular tissue, is an important landmark. It lies superficial to the pelvic floor in a central position between the anal and urogenital portions of the perineum. It marks the separation of the two parts of the perineum and provides a central point of fixation for the perineal musculature.

The perineal body is formed by the fusion of the rectal fascia (inner stratum of the retroperitoneal connective tissue) and the prostatic fascia (middle stratum) with the intrinsic fascia of the striated muscles of the urethral and anal

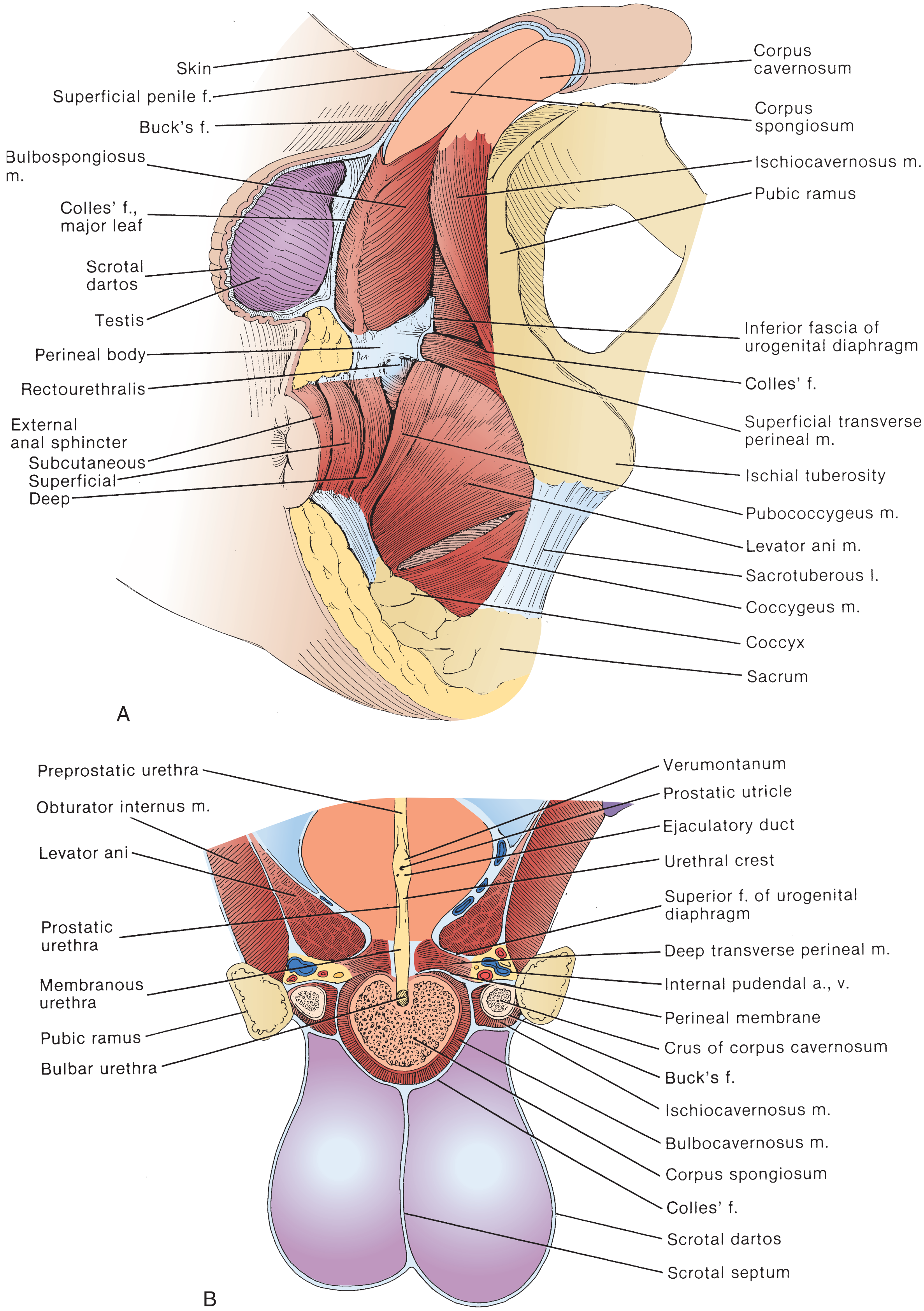

Skin
Superficial penile f.
Buck's f.
Bulbospongiosus m.
Colles' f., major leaf
Scrotal dartos
Testis
Perineal body
Rectourethralis
External anal sphincter
Subcutaneous
Superficial
Deep
Corpus cavernosum
Corpus spongiosum
Ischiocavernosus m.
Pubic ramus
Inferior fascia of urogenital diaphragm
Colles' f.
Superficial transverse perineal m.
Ischial tuberosity
Pubococcygeus m.
Levator ani m.
Sacrotuberous l.
Coccygeus m.
Coccyx
Sacrum
A
Preprostatic urethra
Obturator internus m.
Levator ani
Prostatic urethra
Membranous urethra
Pubic ramus
Bulbar urethra
Verumontanum
Prostatic utricle
Ejaculatory duct
Urethral crest
Superior f. of urogenital diaphragm
Deep transverse perineal m.
Internal pudendal a., v.
Perineal membrane
Crus of corpus cavernosum
Buck's f.
Ischiocavernosus m.
Bulbocavernosus m.
Corpus spongiosum
Colles' f.
Scrotal dartos
Scrotal septum
B

FIGURE 11-2.

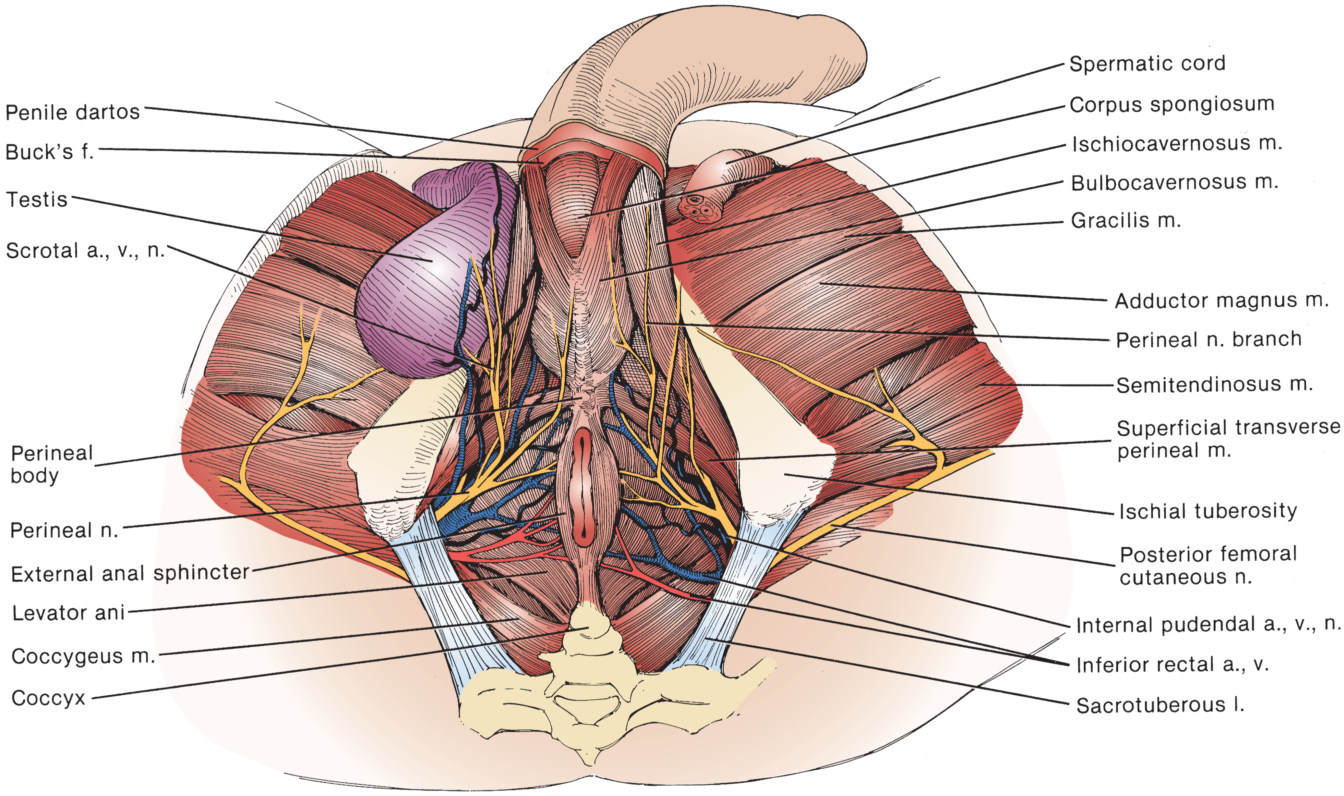


FIGURE 11-3.

striated sphincters. The rectovesical septum makes connections with it above the pelvic floor. Below, it is joined at two levels by fibers from the muscles that arise from the pubis anteriorly, from the ischia laterally and from the coccyx posteriorly. The more superficial attachments of the perineal body come from the bulbospongiosus, the **superficial transverse perineal muscles**, and the more superficial part of the **external anal sphincter**. The deeper connections are with the deep part of the external anal sphincter, the prostatic levators, and the deep transverse perineal muscles (see Fig. 11-4).

The *external anal sphincter*, surrounding the anal canal, is made up of three more or less distinguishable parts (subcutaneous, superficial, and deep) all composed of striated muscle. It is the deep part that is connected to the perineal body by the puborectalis and to the deep transverse perineal muscles. It is also the part of the sphincter that is elevated for a subsphincteric approach to the prostate (see Fig. 11-8; also see Figs. 11-15 and 11-16).

The striated urethral sphincters are described in Figure 14-52 and the periurethral striated sphincter in Figure 14-54 .

Deep Perineal Space and Urogenital Diaphragm

The crura and the bulb have been reflected and mobilized, and the **ischiocavernosus** and **urethra** have been divided in this figure to expose the deeper structures (Fig. 11-4).

The *deep perineal space* or pouch lies between the perineal membrane (inferior fascia of the urogenital diaphragm), which has been removed in the figure, and the ill-defined superior fascia of the urogenital diaphragm. The urogenital diaphragm by definition is the musculofascial content of the deep perineal space: the deep transverse perineal muscles, the membranous urethral sphincter, and their associated fascias.

The **deep transverse perineal muscles** take a course similar to that of their superficial counterparts, running from the ischial ramus to the **perineal body,** where they are joined by the deep part of the **external anal sphincter** and the **membranous urethral sphincter**. The fibers of the membranous urethral sphincter (caudal part of the external urethral sphincter) originate in front of the transverse perineal ligament and virtually encircle the urethra to insert on the perineal body Figure 14-52.

The *rectourethralis*, important in perineal surgery, is formed from fibers that pass to the perineal body from the anterior longitudinal layer of the rectum. Similarly, the *rectococcygeus* arises from the posterior longitudinal muscle to attach to the coccyx.

Besides the muscles, the *deep perineal space* contains the **bulbourethral glands** (Cowper), and through it run the **internal pudendal arteries** and **veins,** the **dorsal nerves of the penis**, and the **bulbourethral arteries** and **veins**.

The so-called *superior fascia of the urogenital diaphragm*, a much more fragile layer than its inferior counterpart, extends across the pubic arch and fuses posteriorly with the perineal membrane and the perineal body, and joins Colles' fascia as well. It lies deep to the anal sphincter, fusing with that structure posteriorly. It is related to the levator ani and is continuous with the outer stratum of the retroperitoneal

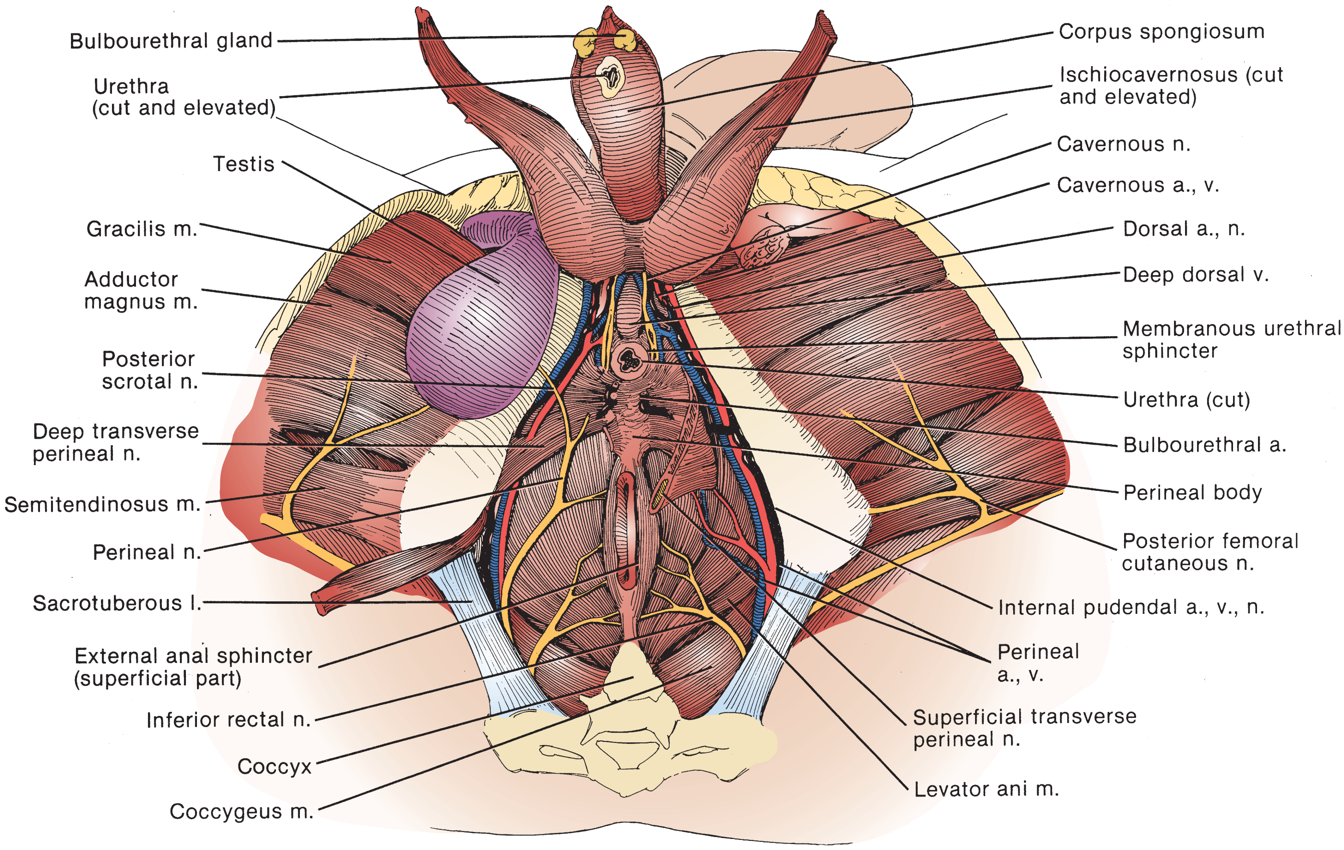


FIGURE 11-4.

connective tissue represented by the obturator fascia and the endopelvic fascia, both parts of the transversalis fascia. Even though it is a poorly defined landmark, the superior fascia of the urogenital diaphragm is, by definition, the upper limit of the perineum.

The **levator ani** and the structures of the pelvis lying above the deep perineal space are described in Chapter 10.

Arterial Blood Supply

The **internal pudendal artery,** after leaving the pudendal canal, bifurcates into the **penile artery** and the **perineal artery**. The perineal artery passes into the **superficial perineal space** over the superficial transverse perineal muscle to which it gives a branch. After passing between the bulbospongiosus and ischiocavernosus it reaches the scrotum as the **posterior scrotal artery**.

Considerable variation can be found. An accessory internal pudendal artery is not uncommon, arising from the obturator artery, the inferior vesical artery, or the contralateral superior vesical artery. It is this alternative, but often principal, blood supply to the corpora that may be injured in radical prostatectomy and cystectomy and result in vasculogenic impotency.

The **bulbourethral artery** is itself subject to several variations in origin, occasionally arising from the cavernous, dorsal, or accessory pudendal arteries. It supplies the bulb of the urethra, the corpus spongiosum, and the glans, structures that not only are anatomically independent from the corpora of the penis but also have a separate blood supply. This first branch of the internal pudendal artery is a short, relatively large-caliber artery that passes medially to traverse the perineal membrane before entering the bulb. It supplies the bulb itself through a posterior group of branches and the proximal quarter of the cavernous tissue of the corpus spongiosum through an anterior group. The **urethral artery**, the second branch, is not always present. It may arise from the artery to the bulb, but more often, it originates directly from the internal pudendal artery, from the cavernous artery, or from the dorsal artery. It runs on the ventral surface of the corpus spongiosum beneath the tunica albuginea. The **cavernous artery** usually arises before the internal pudendal artery terminates as the **dorsal artery**, but it may originate from an accessory pudendal artery, or it may be double, appearing as two vessels running in parallel. For detailed illustrations of the penile vascular supply, as well as the venous drainage and nerve supply, see Chapter 16.

Transition of Perineum to Pelvis Viewed from Below

At the deepest level, the **obturator internus** is seen as it emerges beneath the **sacrotuberous ligament**. The **levator ani** lies superomedially, attached to the arcuate ligament (tendinous arch of the levator ani). The **coccygeus** lies posteriorly in the same plane (Fig. 11-5). The **ischiorectal fossa** occupies the space between the obturator fascia and the inferior fascia of the urogenital diaphragm.

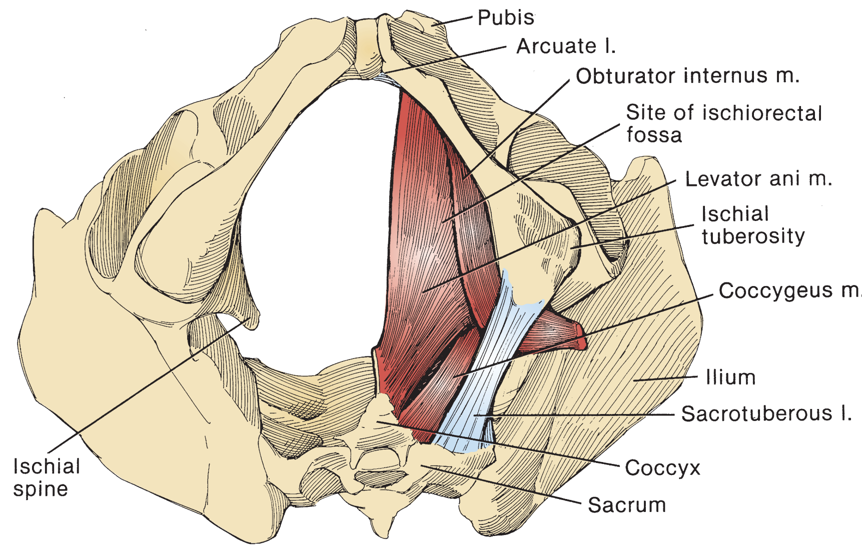


FIGURE 11-5.

Muscles of the Perineum Viewed from the Pelvis

The **perineal body** forms an attachment for the transverse perineal muscles and the **external anal sphincter** (Fig. 11-6). The rectourethralis muscle is formed from fibers of the anterior longitudinal rectal coat that join the perineal body. The **puborectalis** crosses the **deep** and **superficial transverse perineal muscles**. Lying deep to the levator ani, the **obturator internus** exits from the pelvis between the **sacrotuberous** and **sacrospinalis ligaments**. The **anococcygeal ligament** joins the anal musculature to the coccyx. In this figure, the **coccygeus** has been removed on the right side but is shown on the left.

The **inguinal ligament** and the related **lacunar ligament** are seen attached to the **pubic tubercle** and to the **pectineal line**.

Course of the Pudendal Artery in the Male Perineum

The arterial supply to the perineum and external genitalia is from the **internal pudendal artery**, a terminal branch of the anterior trunk of the internal iliac artery. This trunk

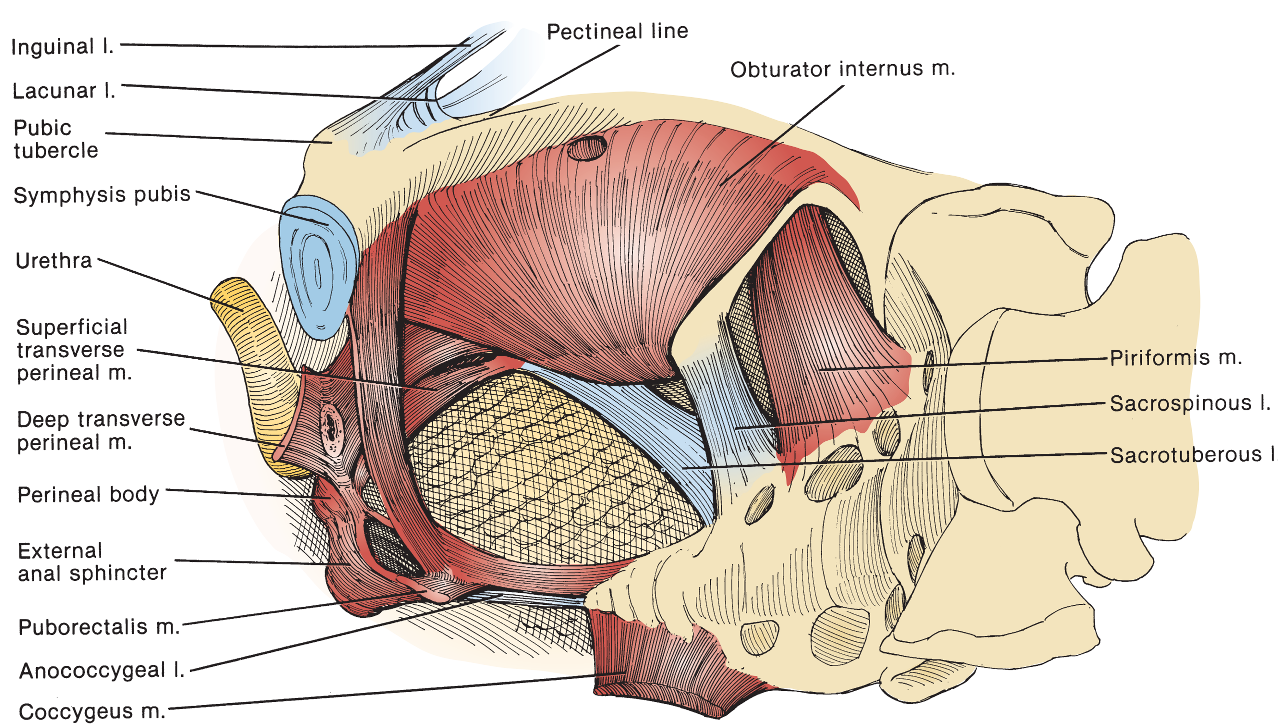


FIGURE 11-6.

shown has already given off the superior and inferior vesical arteries, the middle rectal artery, and the obturator artery (see Fig. 16-30).

The internal pudendal artery passes between the sacrotuberous and sacrospinous ligaments to lie in the **pudendal canal**, a fascial tunnel just lateral to the **levator ani** (Fig. 11-7). While still in the canal, it gives off one branch, the **inferior rectal artery** going to the rectum and anal canal. After leaving the pudendal canal, it bifurcates into the **penile artery** and the **perineal artery**. The perineal artery passes over the superficial transverse perineal muscle to supply the muscles in the superficial perineal space. After running between the bulbospongiosus and ischiocavernosus, it enters the scrotum as the **posterior scrotal artery**.

Distal to the branching of the perineal artery, the internal pudendal artery proceeds as the **penile artery** (artery of the penis) and as the terminal branch of the internal pudendal artery. It pierces the superior fascia of the urogenital diaphragm along the medial margin of the inferior ramus of the ischium. Behind the superficial transverse perineal muscle near the bulb of the urethra, it divides into three branches (see Fig. 16-30). The first branch is the **bulbourethral artery** (artery to the bulb of the penis and urethral artery), followed by the **cavernous artery** (the deep artery of the penis). It then terminates as the **dorsal artery** of the penis.

FEMALE PERINEUM

The female perineum is similar to that of the male except for differences in the degree of development and the placement of the muscles. The superficial fascias are similar, as are the superficial transverse perineal muscles.

Superficial Perineal Space

Colles' Fascia

Near the groin, the membranous layer of the superficial fascia becomes Colles' fascia as it covers the anterior half of the perineum. Over the **labium majus**, smooth muscle fibers, homologous with the dartos muscle layer in the male, are found within it. Colles' fascia is attached laterally to the pubic rami and ischium as far as the **ischial tuberosities**. Posteriorly it joins the perineal membrane (inferior fascia of the urogenital membrane) to enclose the superficial perineal space. Anteriorly, the superficial fascia, the homologue of the penile dartos, covers the **clitoris**.

Contents of the Superficial Perineal Space

The **bulbospongiosus** (bulbocavernosus) is split and surrounds the introitus, covering the bulbs of the vestibule (Fig. 11-8). Anteriorly, it attaches to the corpora cavernosa of the clitoris

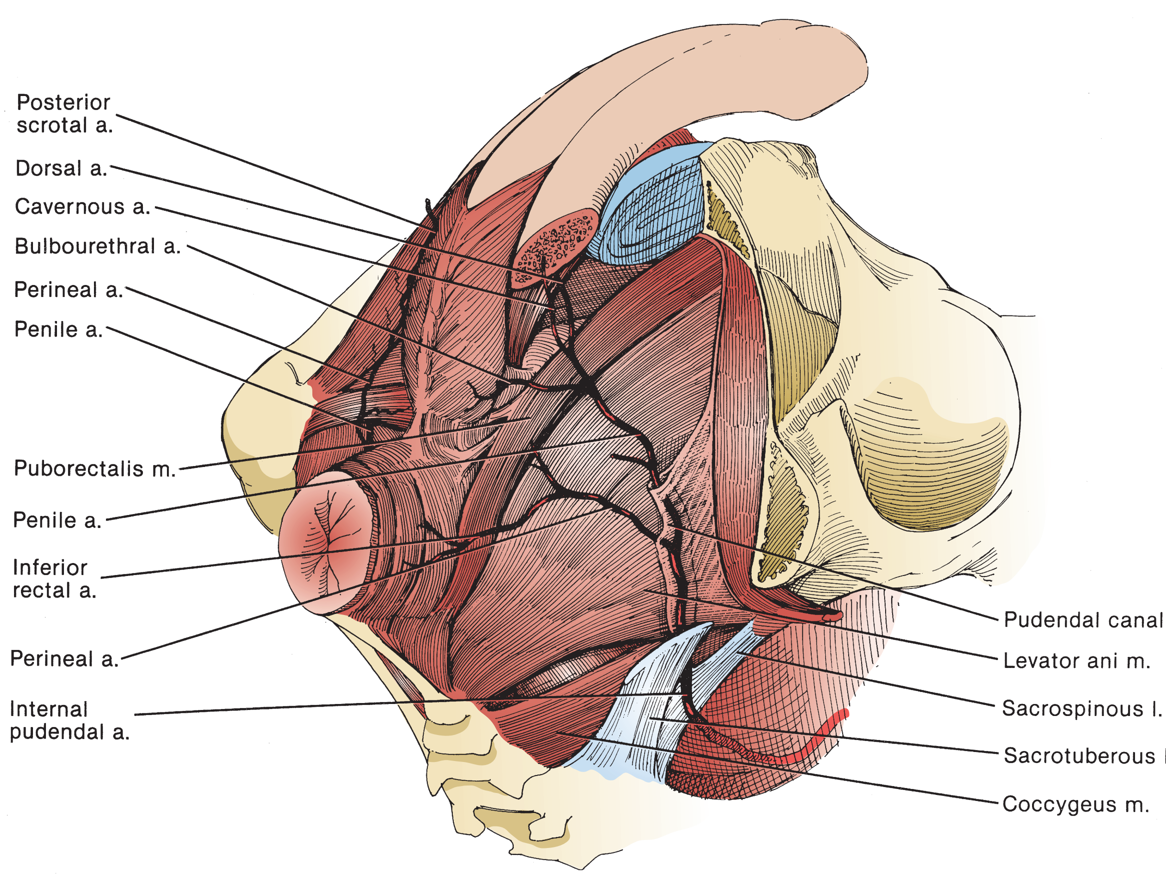


FIGURE 11-7.

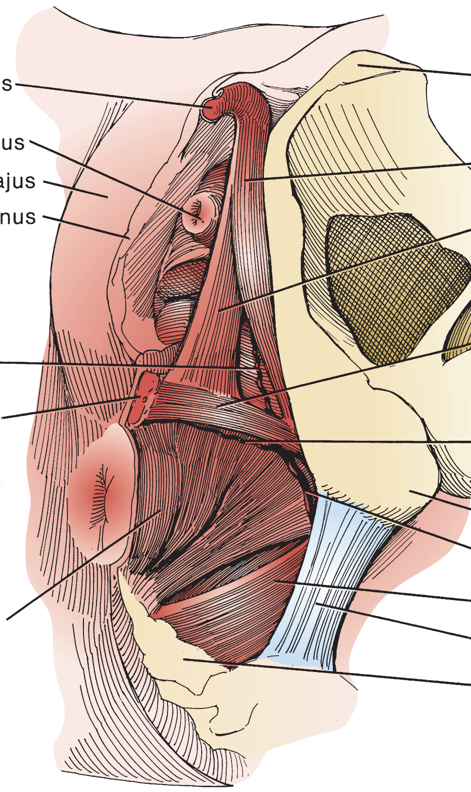


FIGURE 11-8.

and, as in the male, is connected with the **perineal body**. The **ischiocavernosus** is small, has attachments similar to those in the male, and covers the free surface of one crus of the clitoris. The inferior fascia of the urogenital diaphragm (removed in the figure) is even less well developed in the female than in the male, being traversed by the vagina. The **superficial transverse perineal muscles** overlie its posterior border. The posterior labial nerve crosses under the **ischial tuberosity** to terminate in the **labium majus**. The shaft of the clitoris, extending from the crura, turns downward, and then runs posteriorly to terminate in the **glans**. The greater vestibular glands (Bartholin) lie in the superficial space. Although homologous with the bulbourethral glands of Cowper, they lie more superficially so that their ducts do not penetrate the perineal membrane.

Deep Layer of the Female Perineum

The **deep transverse perineal muscles** run from the inner surface of each **ischial ramus** to join the **perineal body** behind the vagina (Fig. 11-9). They are covered by the perineal membrane that constitutes the inferior layer of the urogenital diaphragm. The inferior portion of the external urethral sphincter originates from the perineal membrane on each side and interdigitates between the urethra and vagina. The superior portion of the sphincter embraces the lower part of the urethra.

Colles' fascia covers the **ischiocavernosus** and the **bulbospongiosus**, the latter being called the **vestibular bulb**.

Blood Supply

The **internal pudendal artery** supplying the perineum pierces the **perineal membrane** along the medial margin of the inferior ramus of the ischium behind the superficial transverse perineal muscle to provide posterior labial branches to the labia, the artery of the bulb to the erectile tissue of the vestibular bulbs, the deep artery of the clitoris to the corpus cavernosum, and the dorsal artery to the shaft and glans of the clitoris. The dorsal vein of the clitoris drains into the vesical plexus.

The **inferior hemorrhoidal vessels** course over the **levator ani** to supply the anus and rectum, as does the **inferior rectal nerve**.

Innervation

As the terminal branch of the pudendal nerve, the **perineal nerve** runs with the perineal artery. It divides into a **posterior labial branch** to supply the labium majus and several muscular branches to supply both the **superficial** and the **deep transverse perineal muscles** and the ventral parts of the **external anal sphincter** and **levator ani**. The nerve to the urethral bulb supplies the **bulbospongiosus**. The small **dorsal nerve** of the clitoris runs above the internal pudendal artery along the ischial ramus and inferior ramus of the pubis beneath the deep fascia of the urogenital diaphragm. It penetrates the diaphragm anteriorly to follow the course of the dorsal artery of the clitoris along the dorsal surface of the clitoris.

ANAL PERINEUM

Posterior Perineal Triangle and Ischiorectal Fossa

As with the fascia over the urogenital perineum, the superficial fascia covering the anal portion is thick and adipose.

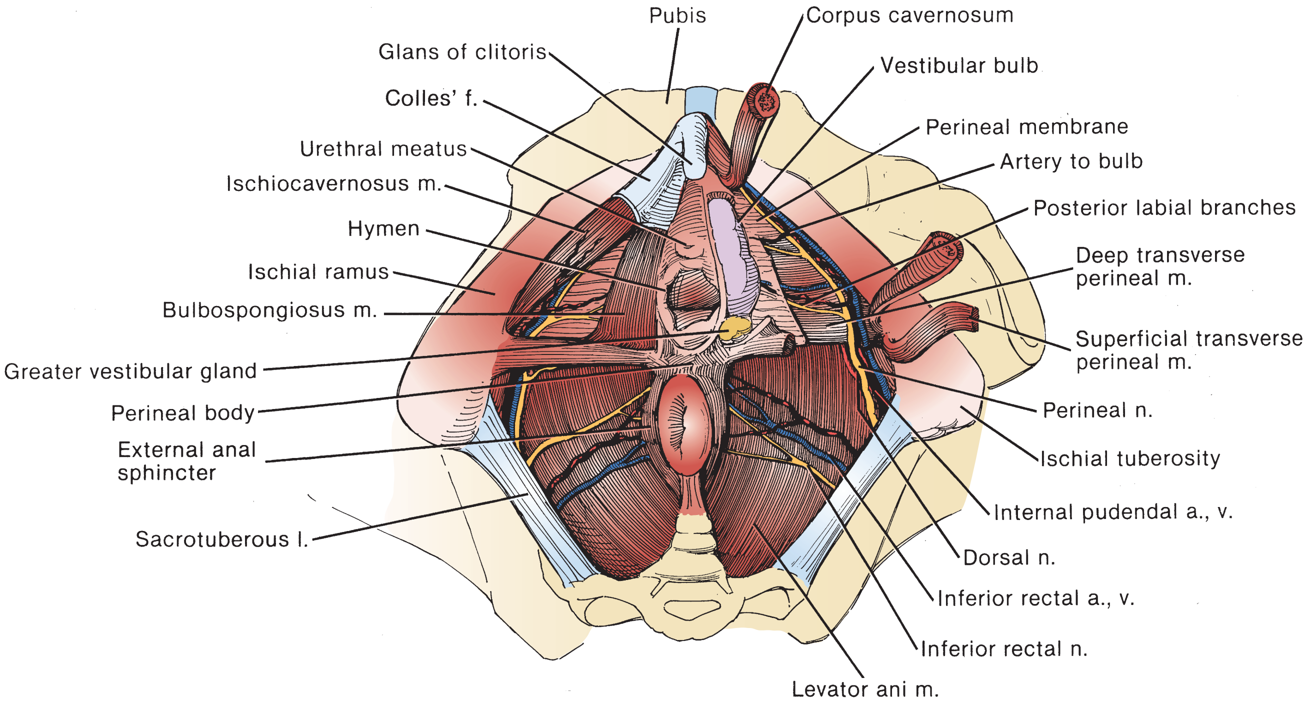


FIGURE 11-9.

Sphincters

The anal sphincters are both internal and external. The internal anal sphincter is a thickening of the smooth muscle coat lining the anal canal. The striated **external anal sphincter** has three parts: (1) the lowest is the **subcutaneous external anal sphincter**, (2) the middle portion is the **superficial external sphincter**, and (3) the most proximal is the **deep external sphincter** (Fig. 11-10).

On entering the fossae by sharp incision of the superficial perineal fascia on either side, two fingers can be inserted anterior to the rectum under the superficial and deep external sphincter to allow division of the median raphe and exposure of the **lamina propria** of the rectum preliminary to perineal exposure of the prostate (see Fig. 11-15).

The deep part of the external anal sphincter is contiguous with adjacent muscular structures such as the urogenital

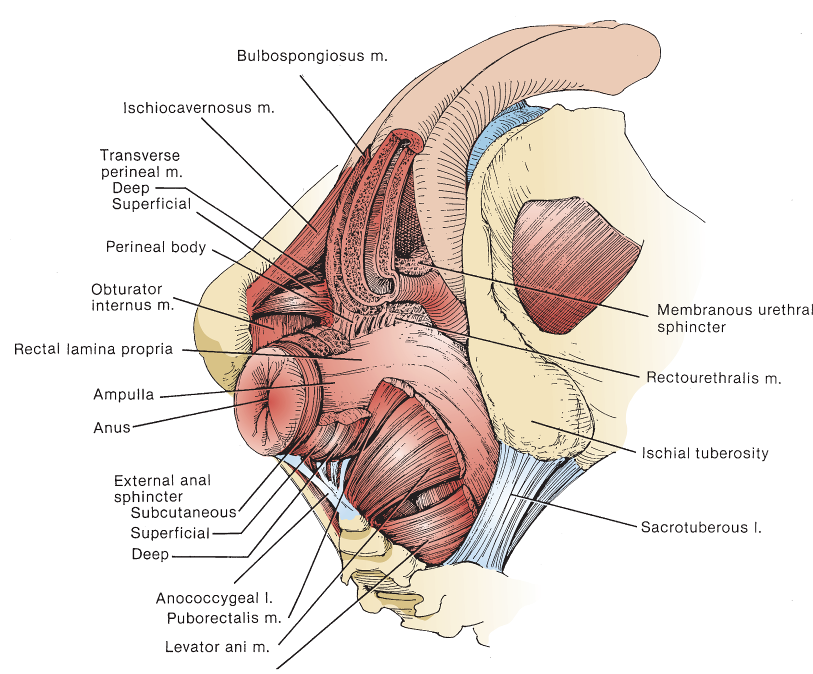


FIGURE 11-10.

muscles in the deep perineal space (deep **transverse perineal muscles** and the membranous external sphincter) that join the perineal body and the muscles in the superficial perineal space (bulbospongiosus and superficial transverse perineal muscles).

Fascias

Support for the rectum comes from the pararectal fascias. The most important is the fascia of Waldeyer that connects the anorectal junction to the sacrum. Posterolaterally, the fascia accompanying the middle rectal vessels to the posterolateral wall of the pelvis form the lateral ligament of the rectum. Anteriorly, the rectovesical fascia joins the rectum to the prostate and the seminal vesicles.

Anal Sphincters and Pelvic Floor, Coronal Section

Anal Sphincters

Two sets of sphincters encase the **anal canal**, the terminal 4 cm of the gut, one smooth muscle and one striated.

The nonstriated **internal anal sphincter** is a thickening of the circular coat of the wall lying outside the **internal rectal venous plexus**. It serves to keep the canal empty except during defecation.

The **external anal sphincter** is formed of striated fibers and has three parts: (1) subcutaneous, (2) superficial, and (3) deep (Fig. 11-11). The **subcutaneous external sphincter** is placed horizontally at the junction of the anal canal with the skin. Above it lies the larger **superficial external sphincter**, which is attached by the fibrous anococcygeal ligament to the coccyx and is also connected anteriorly to the perineal body. The **deep external sphincter** is narrower and lies caudal to the pubococcygeus and iliococcygeus. It has close connections anteriorly with the superficial transverse perineal muscles and posteriorly with the puborectalis where it blends with the levator ani. In fact, fibers from the levator ani join the outer layers of the external sphincters all the way to the skin.

Ischiorectal Fossa

The **ischiorectal fossa** is a wedge-shaped space filled by a fatty extension of the superficial (Colles') fascia whose apex reaches the line of junction of the fascias of the **obturator internus** and the **pubococcygeus** portion of the levator ani. The medial boundary is the external anal sphincter, and the lateral boundary is the tuberosity of the ischium and the obturator fascia. The superior fascia of the urogenital diaphragm limits it anteriorly, and the gluteus maximus limits it posteriorly.

Vessels and Nerves

The internal pudendal vessels and nerves run on the lateral wall of the ischiorectal fossa inside a fascial sheath, the **pudendal (Alcock's) canal**.

The **internal rectal venous plexus** intervenes between the **ampulla** of the rectum and the puborectalis and levator ani muscles. Dilatation results in hemorrhoids.

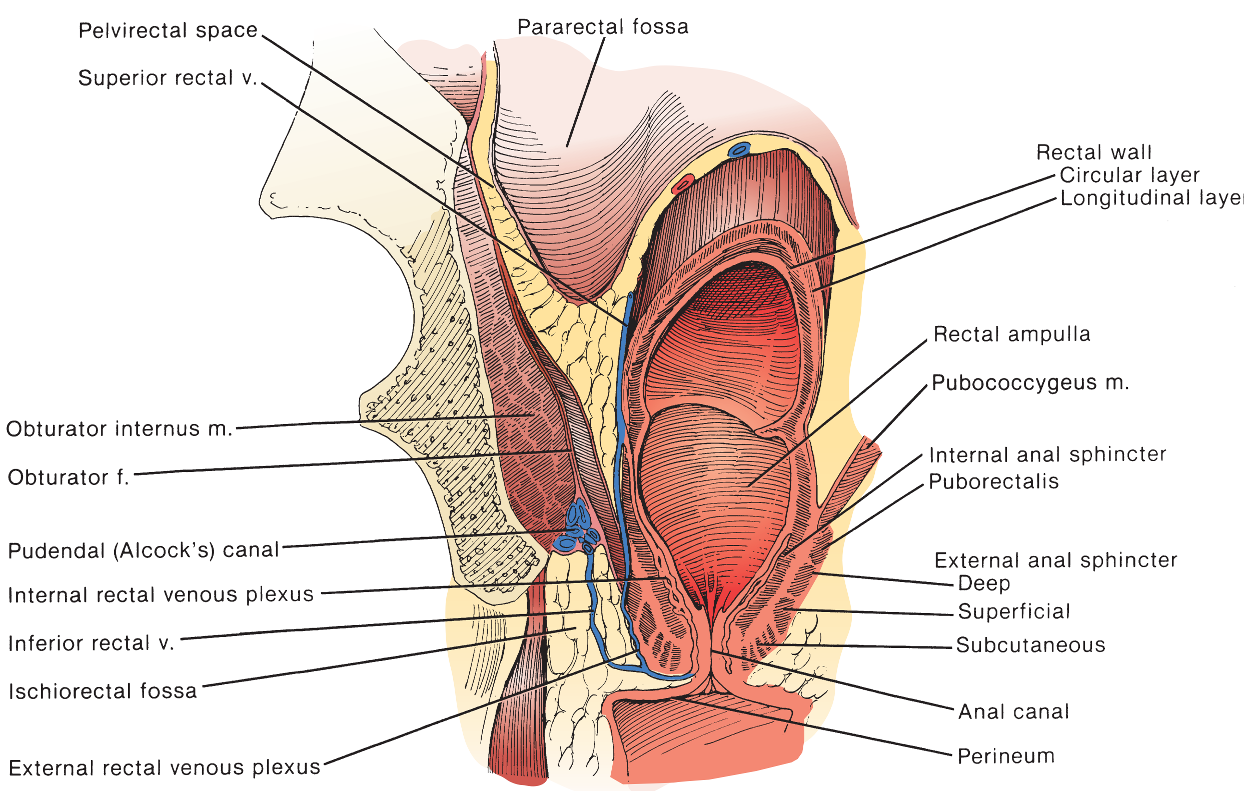


FIGURE 11-11.

The **external rectal venous plexus** lies deep to the rectal sphincters. Both plexuses are drained by the middle rectal vein into the internal iliac vein and the **superior rectal vein** into the inferior mesenteric vein. The **inferior rectal vein** joins the pudendal vein near the pudendal canal.

Superficial Perineum, Posterior View

When part of the fat in the **ischiorectal fossa** surrounding the **pudendal vessels** and nerves is removed, the **levator ani** and the **obturator internus** muscles are exposed (Fig. 11-12). The **anococcygeal ligament** provides some support for the anal canal.

Deep Perineum, Posterior View

The **superficial transverse perineal** muscles attach to the **perineal body** behind the **bulbospongiosus**. Deep to the **levator ani** (divided in the figure) is the **membranous urethral sphincter** (Fig. 11-13). The **pudendal vessels** and **nerves** are seen leaving Alcock's canal, which is formed by the fascia over the **obturator internus**. The **neurovascular bundle** to the penis passes posterolateral to the **prostate**.

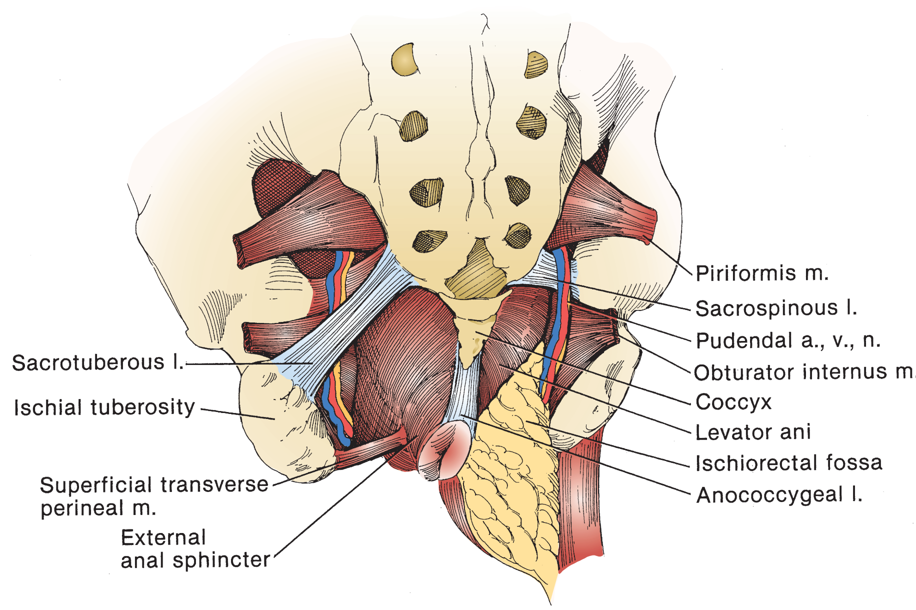


FIGURE 11-12.

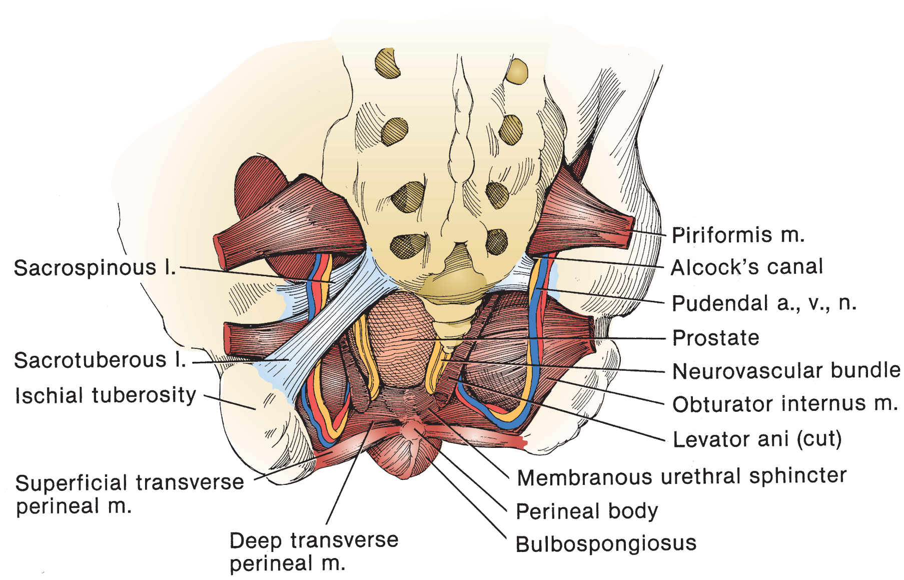


FIGURE 11-13.

Surgical Route to the Prostate, Viewed from Below

The exposure for the *Belt approach* to the prostate is shown here in relation to the regional anatomic structures (Fig. 11-14). Through a curved skin incision, the rectourethralis muscle, as a condensation of the rectal musculature, is approached by following the **lamina propria of the rectum** under the superficial and deep **external anal sphincters** (Fig. 11-15). The external anal sphincter is elevated and serves to keep the dissection away from the perineal body and the **superficial transverse perineal muscles** that lie anteriorly (Fig. 11-16).

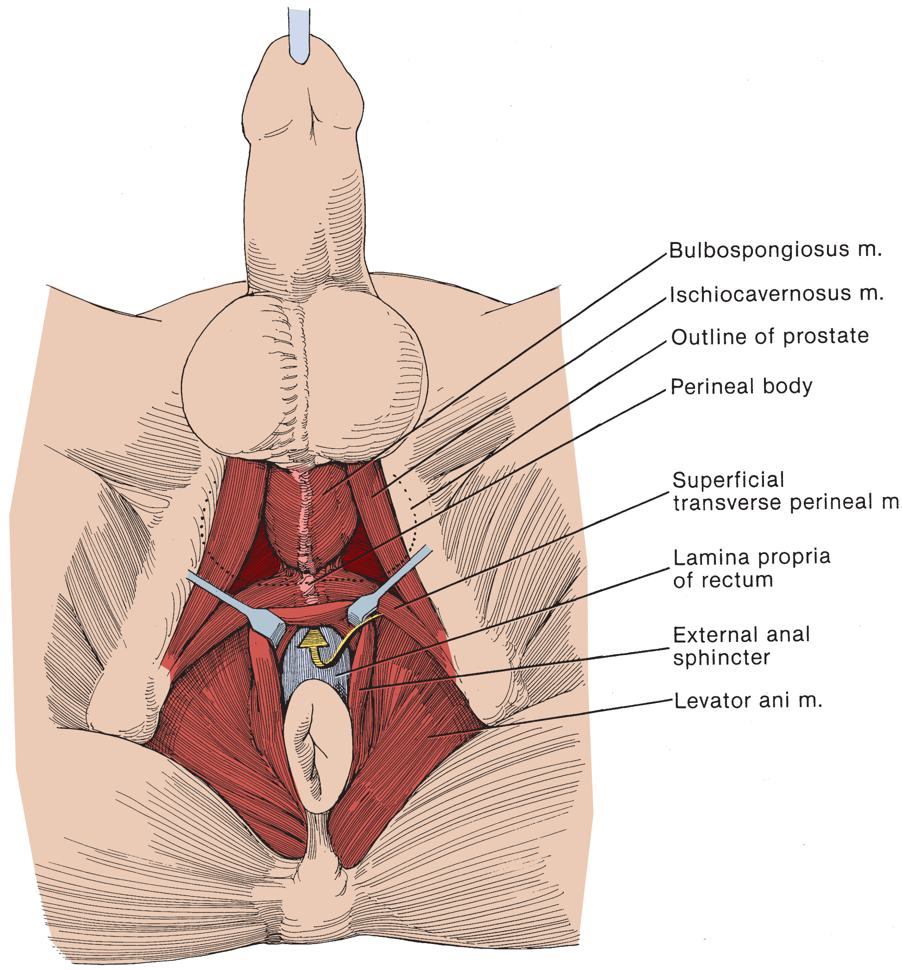


FIGURE 11-14.

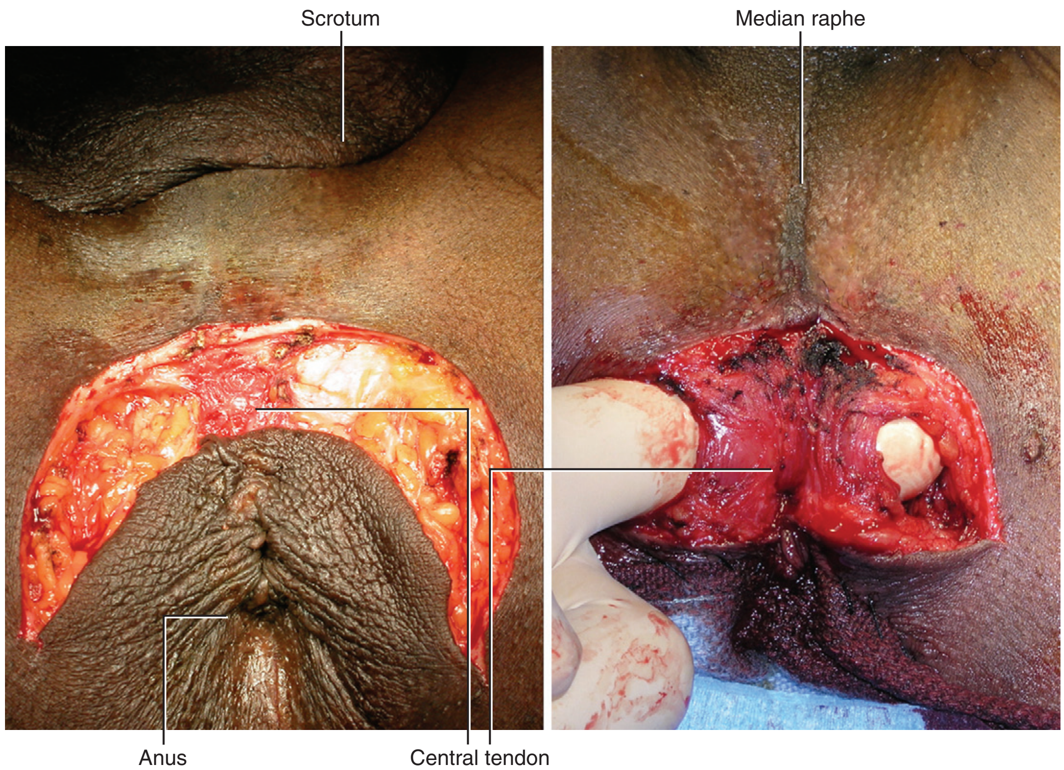


FIGURE 11-15. At left, the perineal skin has been incised, exposing the central tendon. At right, the central tendon has been separated from the underlying rectum and is about to be cut across distal to the external anal sphincter, taking care not to disturb that structure. *(Image at left courtesy of Nehemia Hampel, MD. Image at right courtesy of Martin Resnick, MD.)*

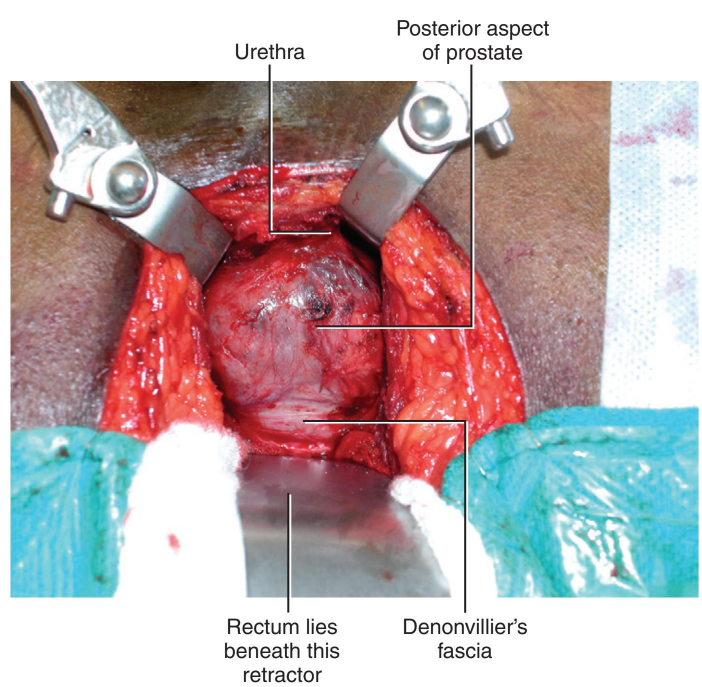


FIGURE 11-16. The posterior aspect of the prostate has been separated from the rectum, which lies beneath the lower retractor. The junction between prostate and urethra has been exposed, and is ready to be cut across. The upper retractors elevate the external anal sphincter away from the operative site. *(Image courtesy of Nehemia Hampel, MD.)*

Section III

ORGANS

Chapter 12

Kidney, Ureter, and Adrenal Glands

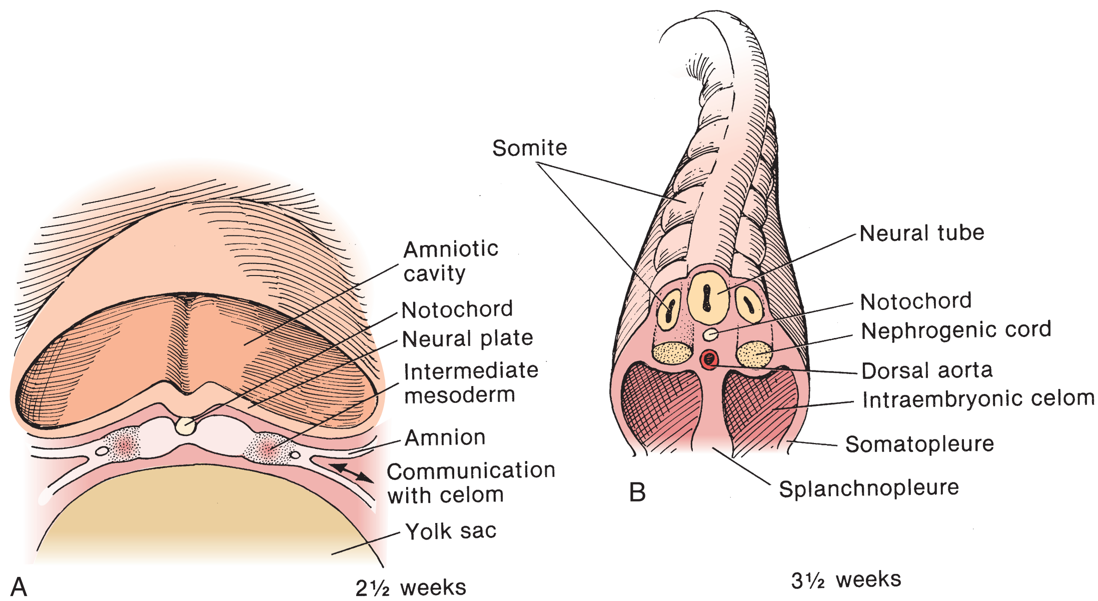


FIGURE 12-1.

My reynes or Kidneis, hath chiden me unto the night.

MORE

Picus Wks. 20/1, 1510.

That the watry humour may be separated from the blood, Nature hath added the Reins to the rest of the bowels.

N. CULPEPER

Culpeper's Last Legacy. London, N. Brook, 1661.

DEVELOPMENT OF THE KIDNEY, URETER, AND ADRENAL GLANDS

Development of the Kidney Nephrogenic Cord and Pronephros

2½ weeks

In each **somite,** the intermediate cell mass of mesodermal tissue, the **intermediate mesoderm,** develops at the junction of the **amnion** and **yolk sac,** a region medial to the **communication** between the intraembryonic and extraembryonic **celoms** (Fig. 12-1A).

3½ weeks

The intermediate mesoderm that lies caudal to the **intraembryonic celom** forms the **nephrogenic cord** (urogenital ridge), from which the embryonic kidneys, gonads, and mesonephric (wolffian) ducts arise.

Pronephros

Three sets of kidneys develop from the intermediate mesoderm during human embryogenesis. The pronephros is rudimentary, the mesonephros is provisional, and the metanephros becomes the permanent kidney (Fig. 12-1B).

The rudimentary pronephros in humans is not clearly demarcated from the mesonephros because it is made up of small aggregations of cells, the nephrotomes, which arise from stalks in the nephrogenic cord of the seven cephalad somites.

The nephrotomes are drawn into hollow tubes to form nephroceles, which in turn interconnect to join the primary excretory duct. Although the pronephros is not functional and will degenerate, the tubular portions become part of the primary excretory duct (the mesonephric or wolffian duct) that grows caudally to empty into the cloaca.

Mesonephros

The mesonephros, like the pronephros, is formed in the intermediate mesoderm from the nephrogenic cord. As the mesonephros grows, it expands into the body cavity as part of the **urogenital fold,** which will later contain the müllerian duct and reproductive gland (Fig. 12-2). The fold will become divided longitudinally into a genital fold and a mesonephric fold and be partially separated from the body wall by the formation of a mesentery. The genital portion subsequently acquires its own mesentery, the mesovarium or mesorchium. Mesodermal cells, beginning cranially, aggregate within the cord to form vesicles that elongate into 40 or more **mesonephric tubules.** One end of each tubule connects with the **mesonephric duct,** and the other invaginates to become the **glomerular** (Bowman's) **capsule.** The mesonephric nephrons degenerate, starting from the cranial end, leaving only a few caudal remnants in the male.

The **dorsal aorta** supplies blood to the mesonephric tubules, and the **postcardinal veins** provide venous drainage from them as well as the caudal body wall and the neural tube (see Figs. 1-2 and 2-6).

Mesonephric Duct and Ureteric Bud

The **mesonephric (wolffian) duct** develops caudally, so that by 4 weeks it joins the cloaca.

After the urogenital sinus separates from the rectum, the mesonephric duct will form the superficial part of the trigone. In the male, it contributes to the formation of the epididymis, vas deferens, ejaculatory duct, and seminal vesicle. In the female, it degenerates, leaving only vestiges. The derivations and homologies of the urogenital organs are shown in Table 12-1.

About the middle of the fifth week of gestation, the mesonephric duct develops a single branch, the **ureteric bud,** where the duct bends at a right angle at the termination of the **common excretory duct** proximal to its junction with the **cloaca** (Fig. 12-3). At first, the bud grows from the dorsolateral surface toward the spine and then turns cranially until it meets the mesenchyme of the caudal portion of the nephrogenic ridge, the **metanephric blastema.** This region of the nephrogenic cord had separated earlier. At the level of the second lumbar vertebra, the mesenchymal mass blocks further ascent of the bud. As the body lengthens and the kidney ascends, the bud (now the ureter) keeps pace. As it branches, it will eventually form the pelvis, calyces, and collecting tubules of the mature kidney. The steps of development are outlined in Table 12-2.

At this time, the **urorectal septum** starts to separate the **hindgut** from the **urogenital sinus,** a process that will end when the septum arrives at the **cloacal membrane.**

Divisions of the Ureteric Bud

During the sixth week, perhaps under the inductive stimulus of the nephric cap, the tip of the ureteric bud elongates craniocaudally to form an **ampulla** with a central cavity, the

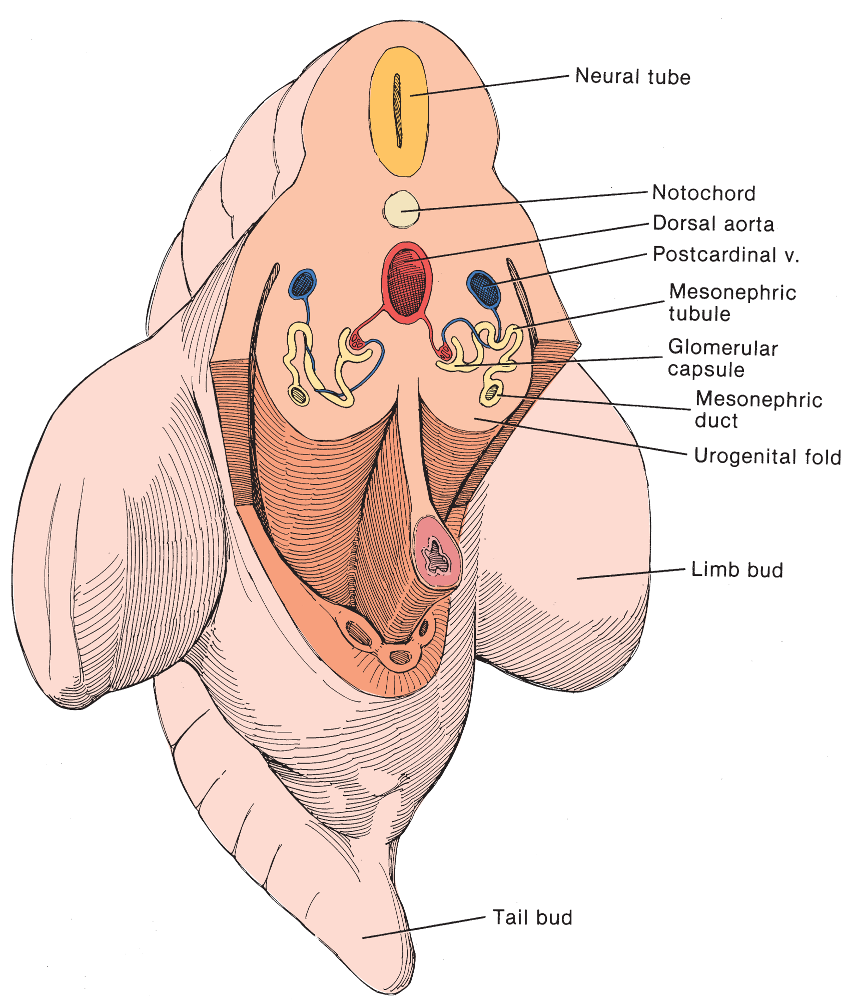


FIGURE 12-2.

UROGENITAL HOMOLOGIES

TABLE 12-1

Precursor	Male Organ	Female Organ
Indifferent gonad	Testis	Ovary
Primordial germ cells	Spermatozoa	Ova
Sex cords	Seminiferous tubules	Follicular cells
Mesonephric tubules	Efferent ductules, paradidymis, appendix epididymis	Epoöphoron
Wolffian (mesonephric duct	Ductus deferens, seminal vesicles	Gartner's canal
Müllerian (paramesonephric) duct	Appendix testis (hydatid), prostatic utricle	Fallopian tube, vagina (part)
Upper urogenital sinus	Bladder, prostatic urethra	Bladder, urethra
Lower urogenital sinus	Urethra	Vestibule
Genital tubercle	Penis	Clitoris
Genital folds	Penile urethra (floor)	Labia minora
Genital swellings	Scrotum	Labia majora

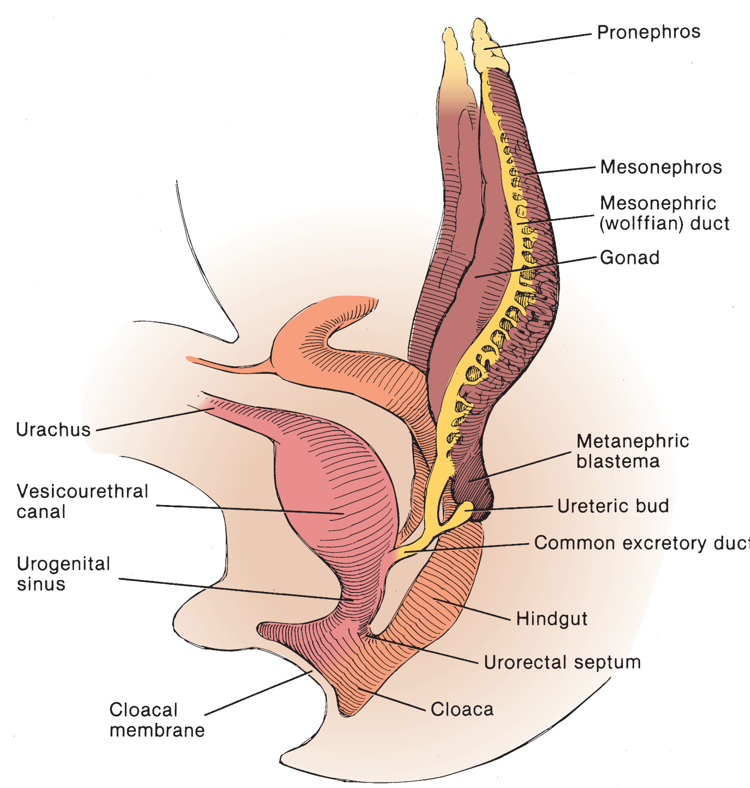


FIGURE 12-3.

primitive pelvis (Fig. 12-4A). As the ureter pushes cranially, the cap of blastema that will form the future renal parenchyma moves away from its site at the end of the nephrogenic cord. Neurons entering the cap with the bud may also play a role in renal morphogenesis.

The bud divides into paired **primary branches** that will form the major calyces (Fig. 12-4B).

Each branch progressively divides into **secondary branches** at the same time that the nephrogenic blastema proliferates to cap the divisions (Fig. 12-4C).

The bud ultimately will branch 15 times. The earliest four to six branches from the ureteric bud become incorporated into the growing renal pelvis. The next three to five branches are the primary branches: the **cranial pole branch, dorsal and**

TABLE 12-2

STEPS IN THE NORMAL DEVELOPMENT OF THE KIDNEYS

Gestational Days	Embryologic Event
22	Cloaca and pronephric duct present
24	Mesonephric (wolffian) ducts and mesonephric tubules develop
28	Wolffian duct joins cloaca; ureteral bud emerges from it
32	Ureteral bud enters metanephric mesenchyme; common excretory duct (wolffian duct and ureter) opens into cloaca
37	Pelvis and primitive calices form
44	Wolffian duct (caudal) and ureter (cranial) separately enter urogenital sinus after division of cloaca
48	Nephrons and collecting tubules are formed; urogenital membrane opens
52	Formation of glomeruli
63	Onset of renal function
70	Degeneration of wolffian or müllerian ducts
84	Urinary and genital tracts become joined in the male
110	Mesonephros involutes
150	Appearance of ureteropelvic junction

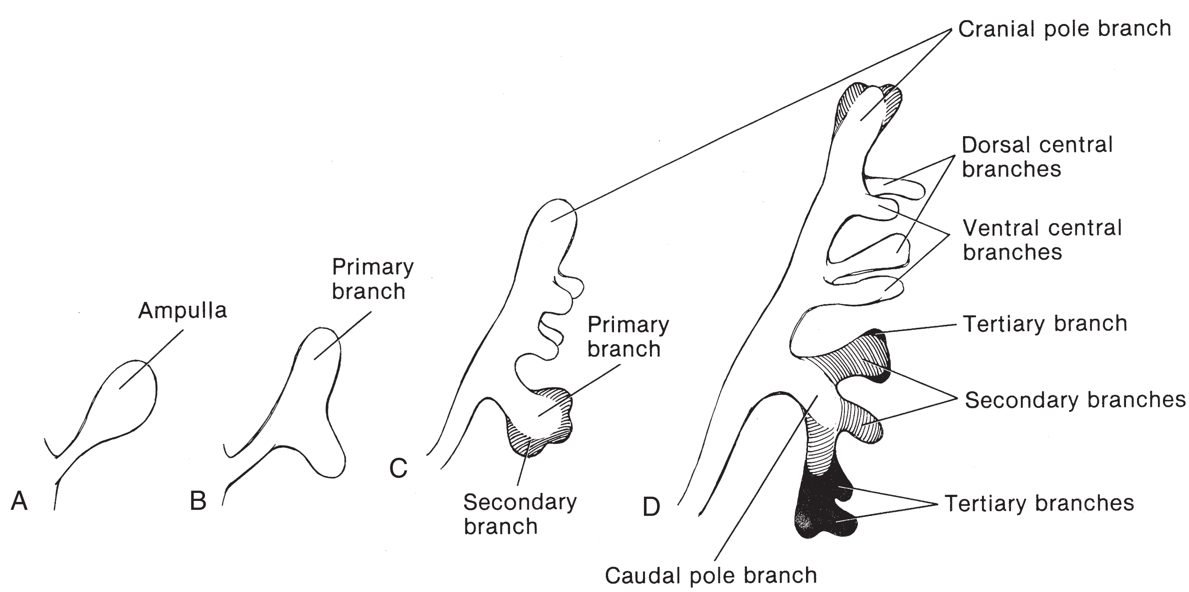


FIGURE 12-4.

ventral central branches, and a **caudal pole branch** that become incorporated into the two or three major calyces (Fig. 12-4D). Because the branches are not supported by nephric tissue, with the onset of urine formation, they will dilate to assume the shape of the pelvis and calyces. Branching occurs with greater frequency at the renal poles; thus, the organ elongates and becomes reniform. The next three to five **secondary** and **tertiary branches** form ampullae and become the minor calyces. At this point, the renal parenchyma encroaches on the tip of each branch to form a papilla so that the final five to seven branchings are left to form the collecting ducts.

Minor Calyces

The fetal minor calyces, 14 in number at the most, are first arranged in pairs, one facing anteriorly and the other posteriorly. However, at the upper pole, three pairs face superiorly, and at the lower pole, two pairs face caudally. Each calyx drains a single papilla. A longitudinal groove on the surface of the kidney indicates the line between the paired pyramids of collecting tubules based on this anteroposterior calyceal division. There follows a period of calyceal fusion: The anterior and posterior calyces in the upper and in lower poles fuse across the frontal plane of the kidney, and the anterior calyces in the middle portion fuse with each other, as do posterior calyces, leaving an average number of eight or nine, with a range from 5 to 20. Papillae also fuse, especially at the poles, leaving two or more of them within one calyx. The usual result is that the upper pole has three calyces, which may be on a single major calyx with papillary fusion or on two short minor calyces with three papillae on each. The two pairs of middle calyces usually face anteriorly and posteriorly, but each of the pairs may fuse, leaving a single trunk. In the lower pole, less fusion occurs, usually leaving two pairs of minor calyces. Thus, in the adult, the pelvis has two general forms. In one, the upper major calyx is long and slender and the lower calyx is shorter and wider, which represents the double-calyceal arrangement of Sykes. In the other form, the minor calyces tend to empty directly into the pelvis without intervening infundibula.

Fused pyramids forming compound and conjoined calyces, in which the cone shape of the papilla is modified, are found most often at the renal poles, where they are more likely to be associated with intrarenal reflux.

Development of Lobes and Pyramids

Branching of the ureteric bud into calyces results in the development of **lobes** (ranunculi), each with a central calyx and peripheral tubules. In the 10-week-old fetus, only two lobes are seen, but the number increases with age. The cap over the ureteric bud segregates itself into smaller caps lying over each of the four to six first-order **collecting tubules** that form the individual **pyramids.** The lobes are separated by the **interlobar septa of Bertin,** which are indicated by **grooves** of fetal lobulation on the surface. Secondary and tertiary pyramids are similarly formed (Fig. 12-5). After the sixth branching, the tip of each generation of collecting ducts joins the renal tubule with its attached glomerulus that has developed in the adjacent nephrogenic mesenchyme. The maximum number of branchings is 14, reached by the 28th week, after which some disappear. Each of these fetal lobes could be considered a separate kidney, similar to the arrangement found in marine mammals.

Interlobar Septa

A double layer of connective tissue and a layer of less differentiated cortex lie between the pyramids of each lobe to form an interlobar septum or renal column of Bertin. Traditionally, these have been called *columns* even though they do not have a columnar shape; *septa* has been proposed as a better term.

The surface lobulation seen in fetal kidneys persisting after the age of 4 years is caused by bulging of the several pyramids as the cortex grows between the relatively fixed interlobar septa. It is often associated with extrarenal branching of the arteries and an abnormal renal pelvis. Usually, as the cortex fills out, the lobulation almost completely disappears, although in half of adult kidneys, some residual lobulation is found, usually on the anterior surface. The basic lobar arrangement within the kidney persists, however, except in the arrangement of the vessels.

The number of papillae present in the developing kidney is probably fixed at that number at the stage at which urine formation begins and causes differentiation between calyx and collecting duct. The actual number of papillae found in the adult kidney depends on the degree of subsequent fusion between the pyramids.

Ascent of the Kidney

At 6 weeks, the lower margin of the nephrogenic ridge lies opposite the second sacral segment, well caudal to the level of the lower lumbar segments, when it is reached by the ureteric bud. The **metanephros**, which now can be called a kidney, capped by a large **adrenal gland**, grows cephalad behind the **mesonephros** to reach and pass ventral to the umbilical artery (Fig. 12-6A). It is at this stage that the upper and lower poles can be identified.

As the caudal end of the vertebral column straightens and that portion of the body grows during the sixth week, the kidney increases rapidly in size and rounds up to become shorter, enabling it to move away from the angle of the umbilical artery (Fig. 12-6B). It thus appears to ascend, so that at 6 weeks it lies opposite the 3rd lumbar vertebra.

By 8 weeks, the kidney assumes its adult level at the 2nd lumbar vertebra (Figs. 12-6C and D). Thus, ascent is the result of both renal and skeletal growth.

The renal pelvis at first lies anteriorly because the initial direction of the ureteric bud was posterior, but during ascent, the pelvis is moved to a medial orientation as the kidney rotates. The upper pole moves laterally and the lower pole moves medially so that the kidney assumes a more upright position.

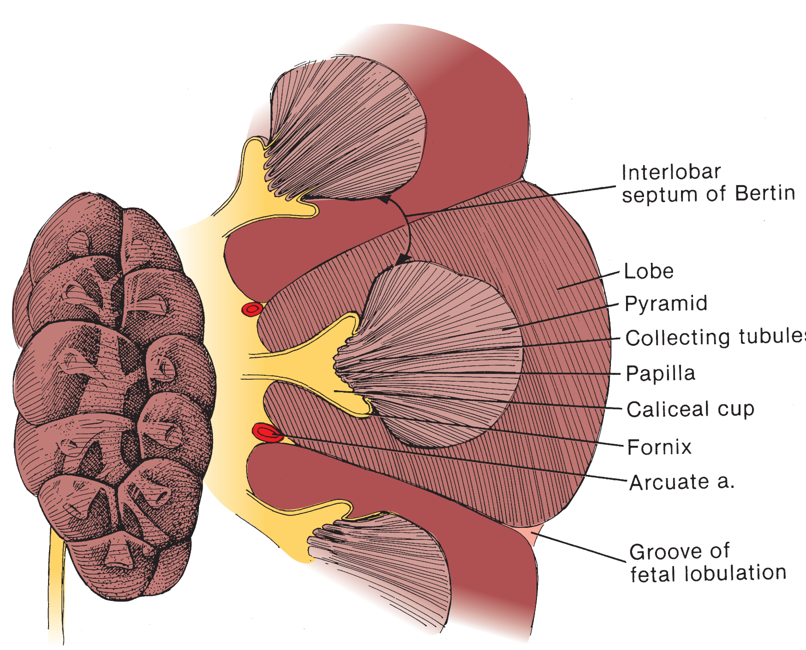


FIGURE 12-5.

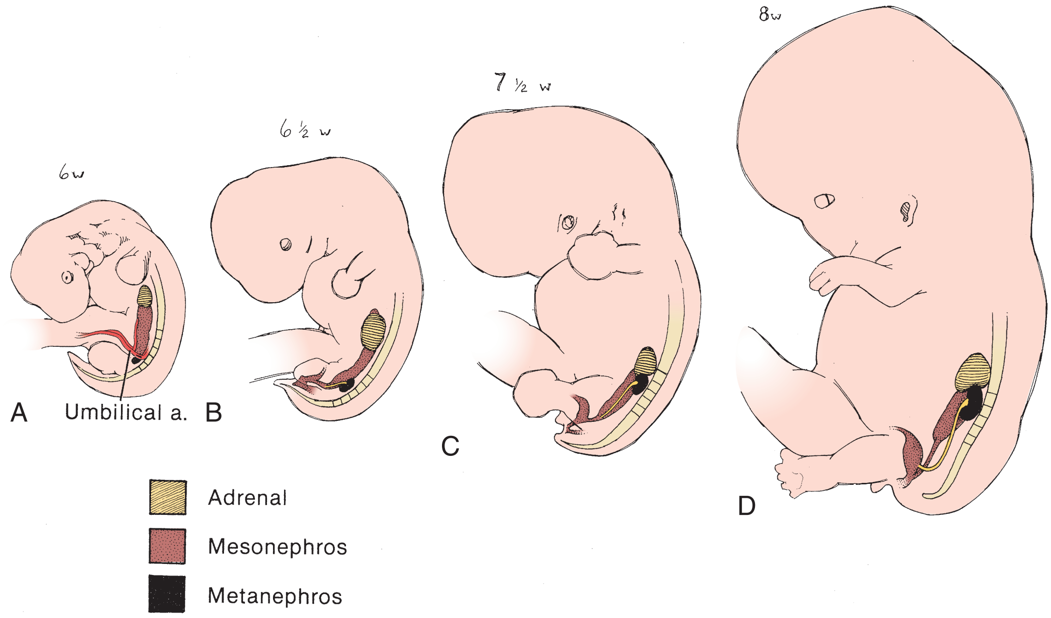


FIGURE 12-6.

DEVELOPMENT OF THE RENAL VESSELS

Because the kidney ascends mainly by differential growth of the body, it acquires an arterial supply successively from the segmental mesonephric vessels as it moves cephalad relative to the major vessels. The development of the renal vasculature is closely related to that of the mesonephros and adjacent structures. Arteries enter the kidney from successive sources, and veins drain the kidney into nearby as well as distant visceral and parietal pathways. Many variations are found, as would be expected from vessels that develop from evolving embryologic systems.

Arteries

At 4½ weeks, approximately 30 lateral branches develop as **segmental arteries** from the **dorsal aorta,** extending from the 6th cervical to the 3rd lumbar segments. The more cranial of these roots gradually degenerate as more caudal ones develop to supply the **urogenital** (mesonephric) **arterial rete**. At this stage the **mesonephros** as well as the **gonad, adrenal gland,** and **ureter** obtain their blood supply from this source. As the **metanephros** differentiates into a kidney, under the influence of the **ureter** branching from the **mesonephric** (wolffian) **duct,** and rises with differential body growth, it successively acquires the segmental arteries that connect the rete to the aorta (Fig. 12-7). Most of the root vessels to the rete degenerate, leaving the kidney vascularized by a single enlarged branch, the renal artery. Accessory arteries are not rare. Because arterial degeneration begins at the cephalad end of the metanephros, the segmental branch to the lower pole is the one most likely to persist as an accessory vessel.

Although within the kidney the renal segmental arteries have a constant relationship with the renal segments (see Fig. 12-71), infinite variations occur in their origin and site

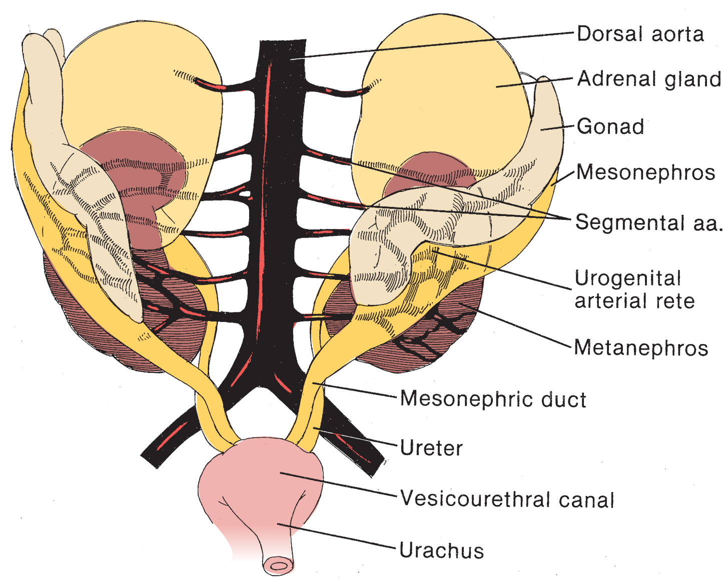


FIGURE 12-7.

of division in relation to the hilum (Figs. 12-8 and 12-9). The apical and lower segmental arteries may originate independently directly from the aorta, in which case the renal segmental artery may supply a larger segment of the kidney than it would if it were a branch of the main renal artery (Fig. 12-10).

Multiple Renal Arteries

Although they are anomalous, accessory renal arteries are evidence of the persistence of one or more of the segmental mesonephric roots extending from the 6th cervical to the 3rd lumbar segments, the more caudal of which once supplied the renal arterial rete. The five segments of the normal kidney are each provided with an artery; thus, accessory

FIGURE 12-8. Magnetic resonance angiogram transverse section, showing right and left renal arteries arising from the aorta and supplying their respective kidneys. (*Image courtesy of Raj Paspulati, MD.)*

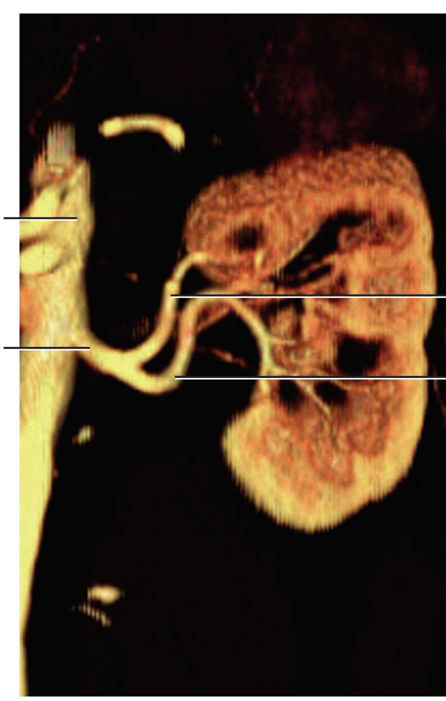


FIGURE 12-9. Three-dimensional magnetic resonance angiogram**,** showing the divisions of the renal arteries. See also Figure 12-71. *(Image courtesy of Raj Paspulati, MD.)*

arteries may be considered to be normal arteries that have a more cranial or caudal origin. Such vessels may supply either pole of the kidney (Figs. 12-11 and 12-12).

On the right side, persistent arteries may lie anterior or posterior to the vena cava, and on the left, they may actually enclose the renal vein. Some arise from the base of the renal artery or from the aorta. Extra vessels are found in

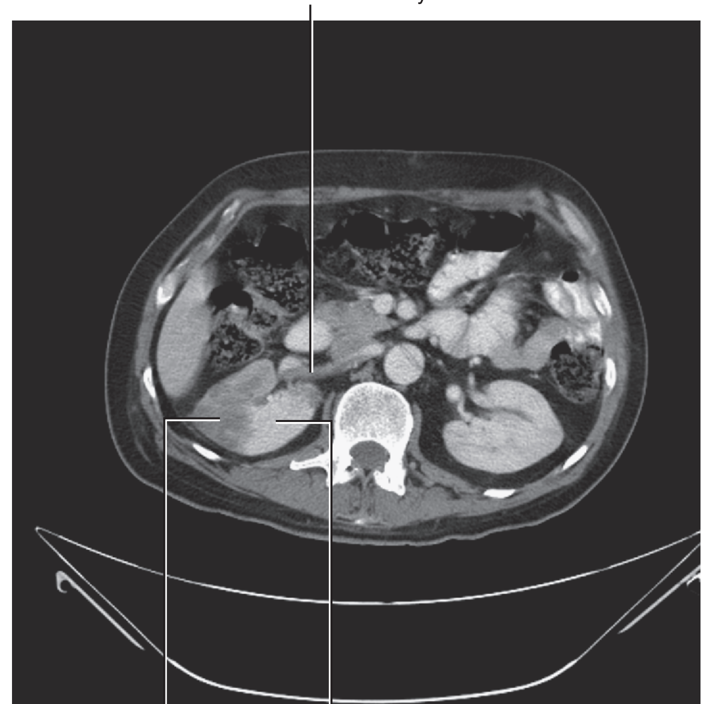


FIGURE 12-10. Contrast enhanced CT scan, transverse section, showing segmental renal infarction from renal artery thrombosis. *(Image courtesy of Vikram Dogra, MD.)*

10 to 40% of autopsy cases, and vessels to the lower pole are twice as common as those to the upper pole.

A **persistent segmental artery** to the lower pole may provide the origin of the **gonadal artery,** and one to the upper pole may also provide an **adrenal artery.** In addition to segmental arteries, smaller accessory arteries, usually multiple, may come from the inferior phrenic or from an adrenal artery.

Venous Anomalies

The renal veins develop from venous plexuses and pass through a complicated evolution by formation and absorption of the postcardinal, supracardinal, and subcardinal veins, which are involved in the formation of the inferior vena cava. Venous maldevelopment provides a continuum from almost normal to frankly abnormal configurations. Should the renal vein or vena cava become occluded, these persistent embryonic transitional pathways can provide alternative routes of drainage.

The veins do not follow the arterial pattern. In fact, those vessels that make up the venous complex develop at a deeper level than that occupied by the arteries, although near the vena cava, the renal veins come to lie anterior to the arteries.

The right renal vein rarely has tributaries, except for the gonadal vein in a fifth of cases, but the left renal vein (a vessel that embryologically could be considered a segmental left vena cava) always receives the adrenal vein and gonadal

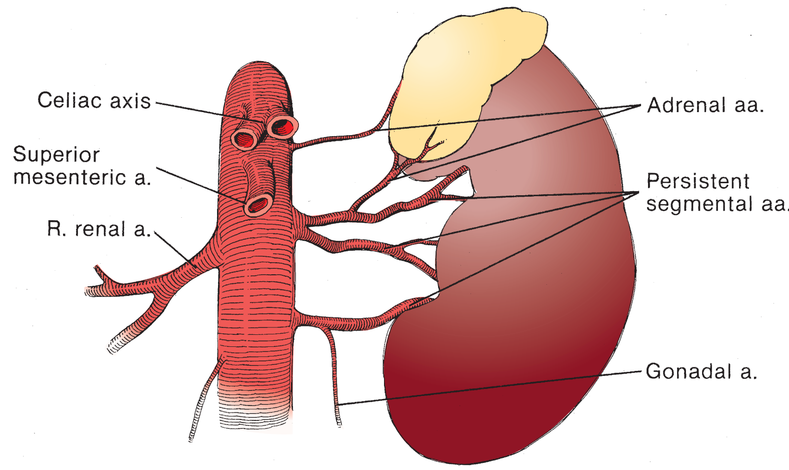


FIGURE 12-11.

FIGURE 12-12. Contrast enhanced CT scan, coronal section, demonstrating the presence of persistent segmental renal arteries, supplying the upper and lower poles separately. Patient also has dilatation of the right renal pelvis from congenital ureteropelvic junction obstruction. *(Image courtesy of Raj Paspulati, MD.)*

vein on that side, and most often has lumbar, ascending lumbar, or hemiazygos communications. The reasons for this difference may be found in the development of the inferior vena cava.

To understand renal and ureteral venous anomalies, it is necessary to review the development part of Chapter 2. The left renal vein from the hilum of the kidney to the ends of the adrenal and gonadal veins is formed from the subcardinal vein, in addition to connection with the residua of the intersubcardinal anastomosis. Also, as the renal vein crosses the midline it picks up the veins draining adjacent organs and the lumbar veins. This complex origin explains the greater length and larger number of veins draining into the left renal vein compared with the veins on the right, where these tributaries drain directly into the vena cava.

The anomalies of the venous supply to the kidney that result from retention of embryologic pathways are described in Figures 2-9 and 2-10. Most apparent clinically are the persistence of the left caval vein, the circumaortic venous ring, and the formation of retroaortic renal veins.

RENAL ANOMALIES

Renal Agenesis

Absence of the metanephros may be due to defects in the development of the nephrogenic ridge, but the usual finding in clinical practice is its absence from failure of formation of the mesonephric duct and the ureteric bud. Thus, renal agenesis in the male is often associated with defects of the other derivatives of the duct. In 12% of males with a single kidney, a genital abnormality is found, including absence, hypoplasia, or cyst formation of the seminal vesicle, vas deferens, and ejaculatory ducts. Important surgically is that the remaining kidney may be abnormal in formation or position.

In the female, genital anomalies are frequently associated with renal agenesis (44%) because of the close developmental association of the müllerian duct with the wolffian duct at the urogenital sinus. The uterus may be unicornuate, bicornuate, or hypoplastic. The vagina may fail to form, or it may be septate or even obstructed, resulting in unilateral hematocolpos. A syndrome is recognized secondary to interruption of growth of the wolffian duct consisting of unilateral renal agenesis, absence of the fallopian tube, and absence of half of the uterus. With bilateral absence of the ducts, and thus absent kidneys, multiple anomalies associated with oligohydramnios are the rule, including pulmonary hypoplasia, and the infant will show Potter's facies (Fig. 12-13).

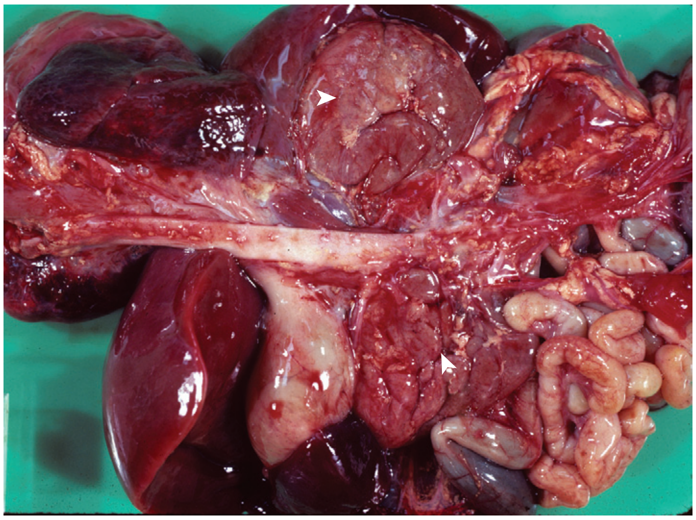


FIGURE 12-13. Bilateral renal agenesis (Potter's syndrome). Autopsy study of a stillborn infant demonstrating that neither kidney is present in the retroperitoneum. The white arrows indicate the adrenal glands, which are typically large at birth, but diminish by almost 50% by the 9th to 14th week after birth. *(Image courtesy of Gretta Jacobs, MD.)*

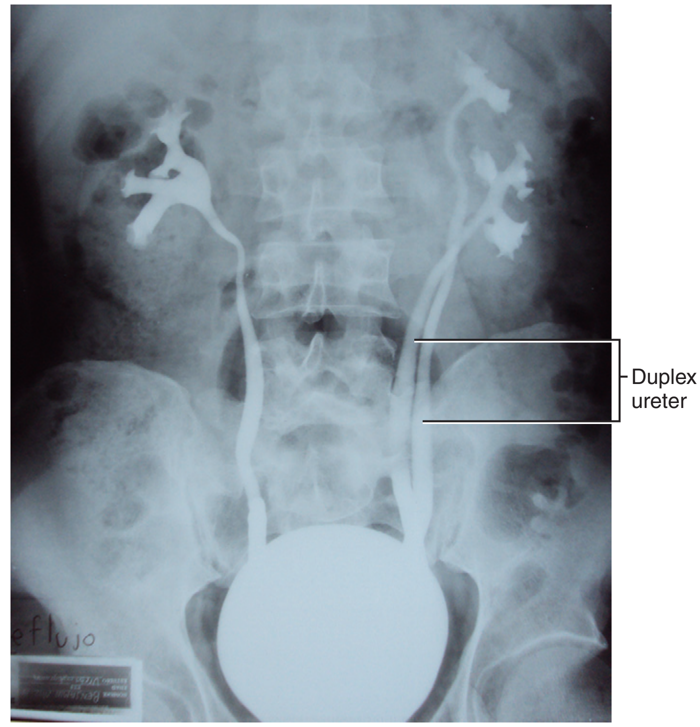


FIGURE 12-14. Intravenous pyelogram, showing a duplex collecting system on the left. From this study, it is not apparent whether the ureteral duplication is complete or incomplete. (*Image courtesy of Vikram Dogra, MD.)*

Duplex, Ectopic, and Horseshoe Kidneys

Renal duplication, the most common anomaly, occurs when the ureteric bud divides and two ureters enter the blastema (Figs. 12-14 and 12-15). These kidneys have normal vasculature because the arterial distribution is not influenced significantly by abnormalities of the pelviocaliceal system. In contrast, the rare *supernumerary kidney* that results from a split of the nephrogenic blastema often has abnormal vessels.

The anomalies of *renal fusion and ectopia* may be placed in five categories: crossed with and without fusion, not crossed with and without fusion, and fused caudally, the horseshoe kidney.

Ectopia occurs when ascent is prevented at the time that the kidney lies at a level between the 3rd sacral and the 2nd lumbar vertebra. Thus, there may be pelvic, iliopelvic, iliac, or lumbar ectopia (Fig. 12-16). Because arrest occurs at a relatively early stage of embryologic development, ectopia is usually associated with incomplete rotation, a short ureter, and a blood supply that arises from local lateral segmental vessels, connections that account for the fixation of the kidney found at operation. In addition, anomalies of the external and internal genitalia and of structures associated with the cloaca are common. The typical **pelvic kidney** is usually smaller, lobulated, and of an abnormal (pancake-like) shape. The **adrenal gland,** however, is usually in a normal position. At any level of arrest, the kidney, ureters, and associated vessels will reside inside the envelope of the renal (Gerota's) fascia.

The kidney may be malpositioned from any one of the factors responsible for its arrest; including malformation of the ureteric bud or of the metanephric tissue, or persistence of the primitive segmental structure of the arterial system, although this condition is usually secondary. In addition,

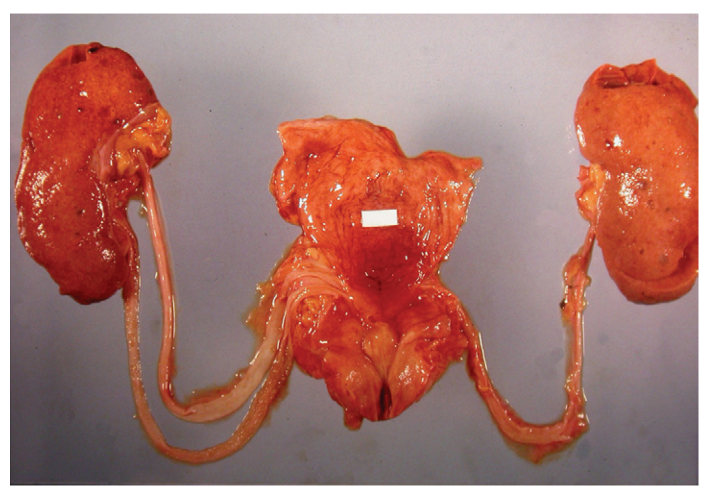


FIGURE 12-15. Ureteral duplication. On the right there are two complete ureters, each draining separate portions of the kidney, and each with its own ureteral orifice in the bladder. In a setting of complete duplication, the orifice of the upper pole ureter is sometimes ectopically placed, closer to the bladder neck, or outside the bladder proper (e.g., in the urethra, or even in the vagina in a female); this may result in obstructive changes in the renal segment drained by the anomalous ureter. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. Springer-Verlag London Limited, 2011, with permission.)*

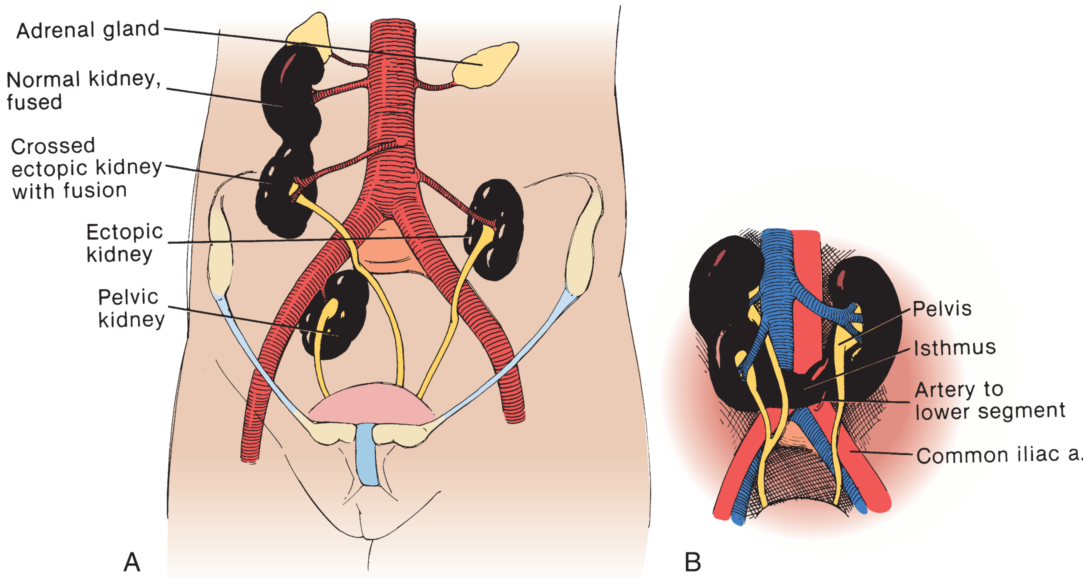


FIGURE 12-16.

vertebral anomalies have been shown experimentally to result in renal ectopia, similar to abnormalities of the urinary tract found clinically with congenital scoliosis.

The **ectopic kidney** may be found low on the ipsilateral side or, as in **crossed ectopia,** on the opposite side, or it may be fused with the other kidney as **crossed ectopia with fusion.** It may remain wholly within the pelvis as a **pelvic kidney.** In half of the cases the opposite, normally situated kidney is abnormal, and in a tenth of the cases, it is absent.

Should upward movement be arrested, as with an ectopic or horseshoe kidney, the regional blood supply is maintained, arising from the iliac, inferior mesenteric, or the middle sacral arteries, or even from segmental vessels from the aorta below the inferior mesenteric artery.

In fewer than 5% of cases of renal ectopia, the affected kidney undergoes excessive cranial migration; this results in a **superior ectopic kidney**. Most superior ectopic kidneys lie below the diaphragm, but rarely part or all of the kidney may lie above the diaphragm, and in this circumstance the kidney is designated as an **intrathoracic kidney** (Figs. 12-17, 12-18, and 12-19).

By definition, *fused kidneys* are a single conglomerate mass of renal tissue having two ureters that empty into each side of the bladder (Fig. 12-20). They include two major groups: (1) crossed ectopia with fusion, and (2) horseshoe kidneys, although there are many variations.

In **crossed ectopia with fusion,** the ectopic renal mass lies on one side of the vertebra and its ureter reaches the bladder on the opposite side (Figs. 12-21 to 12-24). The anomaly may result from lateral flexion of the lumbosacral spine in the tail portion of the embryo that displaces the distal portion of the nephrogenic cord across the midline, thus requiring one of the ureteric buds to cross to join the single asymmetric nephrogenic mass. Vertebral and high anorectal anomalies may be anticipated with fusion disorders. The location of the ureteric orifice in the bladder is variable, sometimes being in an ectopic position.

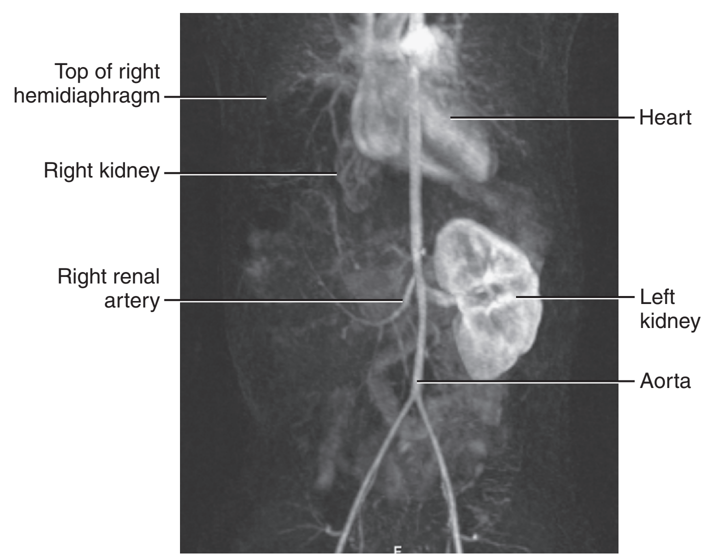


FIGURE 12-17. Three-dimensional magnetic resonance contrast-enhanced angiogram. Left kidney is of normal size and is in normal position. The right kidney appears behind the cardiac shadow. *(Image courtesy of Nami Azar, MD.)*

The **horseshoe kidney** is the result of fusion in the midline of a portion of one metanephric blastema with the opposite blastema before the sixth week, when the two normally lie close together. At that time, the definitive kidney moves out of the pelvis and its blood supply shifts to segmental aortic branches. At the same time, the kidney normally rotates medially on its long axis. Should the caudal portions of the metanephric blastemas come in contact with each other and fuse, normal rotation and ascent is prevented, resulting in the persistence of an anteriorly oriented pelvis, with ureters passing anterior to the fused poles, and in persistence of some of the pelvic arterial supply (Figs. 12-25 to 12-28). It has been speculated that the fusion might

FIGURE 12-18. Coronal T2-weighted magnetic resonance image. Same case as shown in Figure 12-17. The right kidney lies superior to the liver. *(Image courtesy of Nami Azar, MD.)*

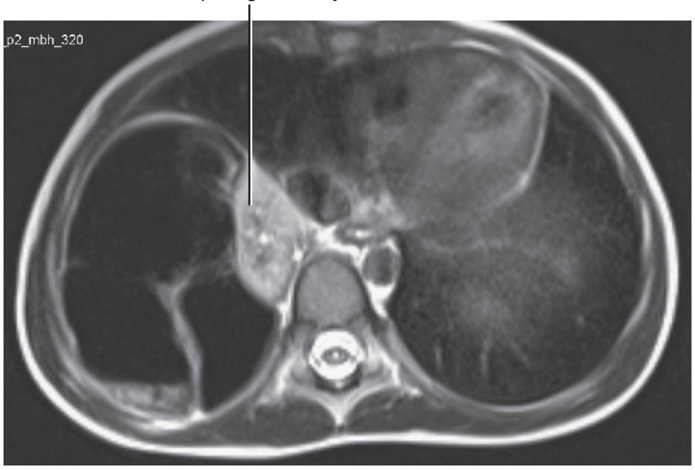


FIGURE 12-19. Axial T2-weighted magnetic resonance image. Same case as shown in Figure 12-17. The right kidney is in a superior location, but its exact location was not evident from this study. Surgical exploration confirmed that the diaphragm was intact; the right kidney, although located superiorly, was not intrathoracic. *(Image courtesy of Nami Azar, MD.)*

result from crowding in the pelvis by the large umbilical arteries at the time that the blastemas would normally diverge after passing them.

Horseshoe kidney occurs once in about 500 births, occurs twice as often in males as in females, and is the most common of the fusion anomalies. It probably outnumbers crossed ectopia by a ratio of 6 to 1. A wide variety of associated anomalies are often seen, some of which may be incompatible with life.

FIGURE 12-20. Lump or cake kidney. This is a fusion anomaly somewhat similar to horseshoe kidney, but the fusion is more diffuse, rather than being localized to the inferior poles. Both ureters enter the bladder normally. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. Springer-Verlag London Limited, 2011, with permission.)*

The pattern of the blood supply within each half of a **horseshoe kidney** is usually the same as that of a normal kidney: Each kidney has single or double arteries angled caudally. Each segment of the kidney is supplied by a segmental branch of the renal artery, without collateral connections between. Thus, within the renal substance the distribution of blood is little different from that in normal kidneys.

The exception to a fully normal vascular pattern is the presence of an **artery to the lower segment**. This vessel typically has an abnormal origin, most often arising from the aorta at a level lower than the normal renal artery or from the common iliac artery or even from the internal iliac artery. Thus, an accessory artery may enter the kidney above or below the isthmus. If a substantial **isthmus** forms, it may be partially supplied by an additional vessel arising from the caudal part of the aorta or from the **common iliac artery**.

Malrotation is actually the result of arrest of rotation. The renal pelvis remains in an anterior position, its orientation before ascent. However, the kidney may occasionally be found overrotated, so that the pelvis lies posteriorly.

No consistent embryologic explanation for these several renal anomalies is available. However, associated anomalies of the genitalia and vertebrae are not unusual, suggesting a common embryologic disturbance.

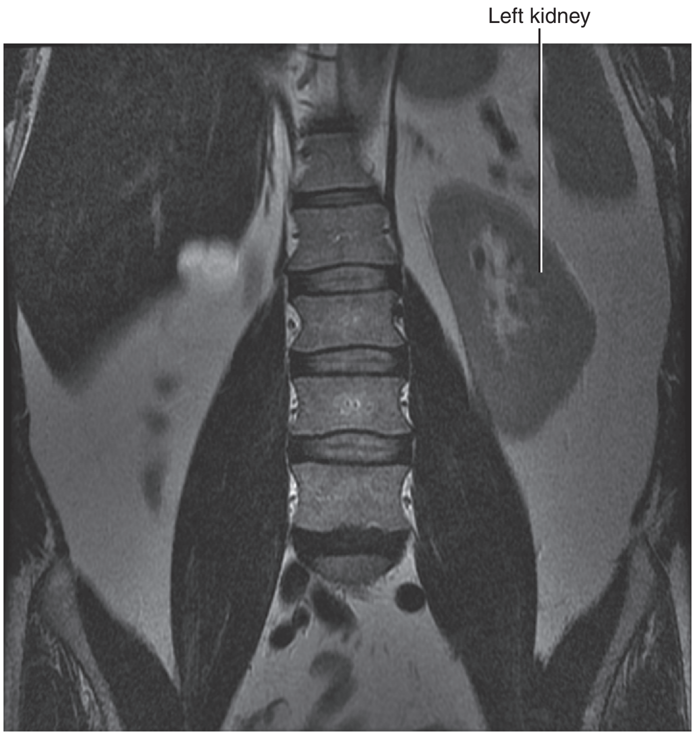


FIGURE 12-21. Crossed fused renal ectopia, demonstrated on sequential T2-weighted magnetic resonance images that run from posterior to anterior in the coronal plane (see Figs. 12-22 to 12-24). This image demonstrates an empty right renal fossa. *(Image courtesy of Vikram Dogra, MD.)*

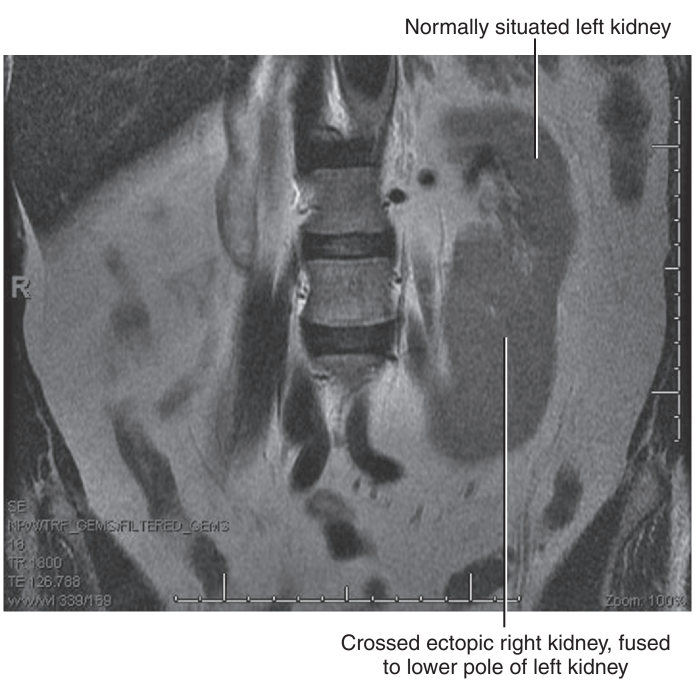


FIGURE 12-22. A portion of the crossed fused ectopic right kidney becomes apparent on the left side. *(Image courtesy of Vikram Dogra, MD.)*

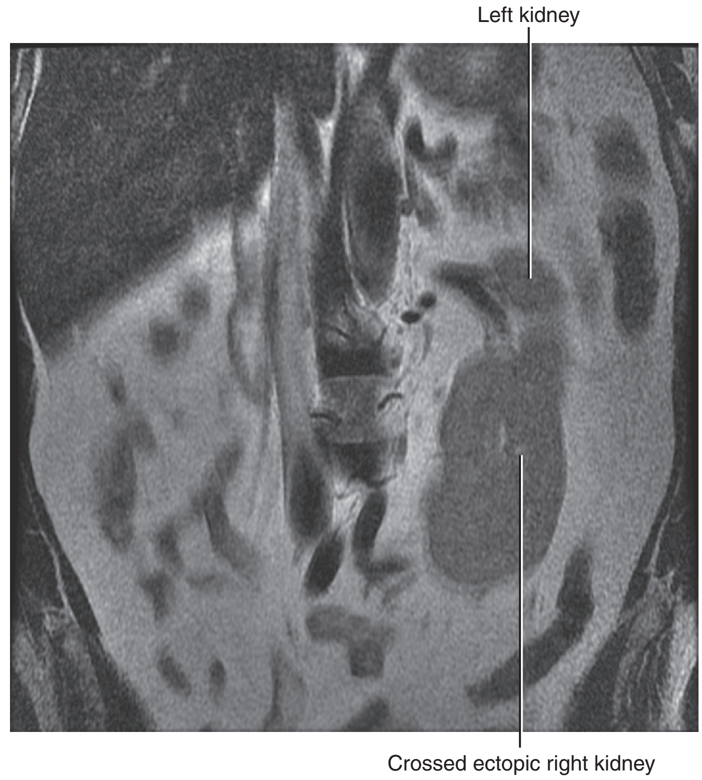
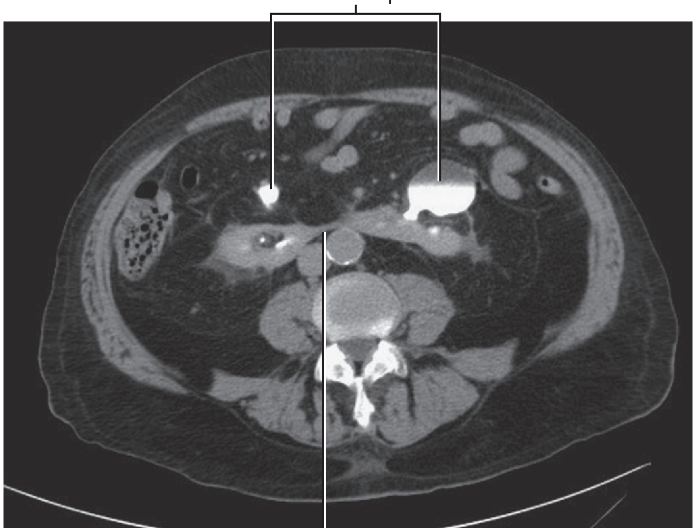


FIGURE 12-23. The crossed fused ectopic right kidney is more clearly evident. *(Image courtesy of Vikram Dogra, MD.)*

FIGURE 12-24. The left kidney is no longer apparent. *(Image courtesy of Vikram Dogra, MD.)*



FIGURES 12-25. Horseshoe kidney. Contrast-enhanced axial computed tomography urogram in delayed phase, demonstrating a horseshoe kidney with contrast-filled dilated renal pelves, and an isthmus of tissue connecting the lower poles of the two kidneys. *(Image courtesy of Vikram Dogra, MD.)*

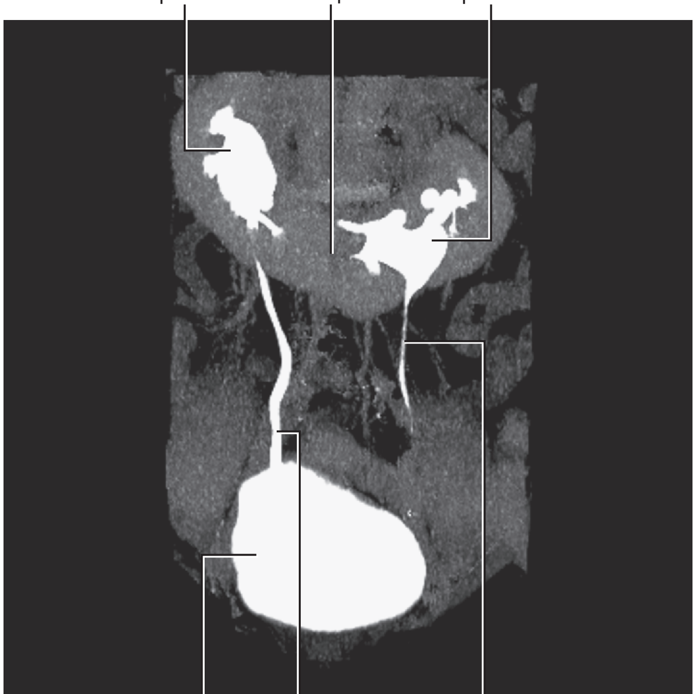


FIGURE 12-26. Horseshoe kidney. Three-dimensional volume reconstruction image, CT urogram, showing fusion of the lower poles of the right and left kidneys. Both kidneys appear to have dilated renal pelves and some degree of caliectasis, suggesting impaired drainage. *(Image courtesy of Raj Paspulati, MD.)*

FIGURE 12-27. Horseshoe kidney. The two renal units are joined at their lower poles. One kidney shows hydronephrotic changes due to obstructed drainage. *(From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

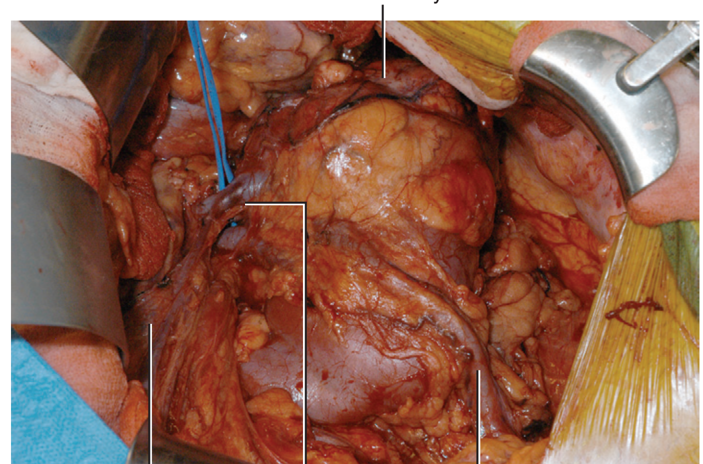


FIGURE 12-28. Horseshoe kidney, with a renal cell carcinoma involving the upper pole of one moiety. The vessels and ureter have been isolated; the blue loop surrounds the renal artery. (*Image courtesy of Rabii Madi, MD.)*

CYSTIC DISEASE

The development of cystic disease of the cortex depends on deviation from the exact process with which the collecting duct must join the renal tubule. Disturbances in the connection result in various forms of cystic disease depending on the time of interference (Figs. 12-29 to 12-32).

FIGURE 12-29. Infantile autosomal recessive polycystic kidney disease. In this condition, both kidneys are massively enlarged, which can impede lung development and result in stillbirth or death in early neonatal life from respiratory failure. The kidneys retain their reniform shape, and collecting systems are normal. Their cut surfaces have a spongy appearance because of the presence of innumerable small cystically dilated structures. *(Image courtesy of Pedro Ciarlini, MD.)*

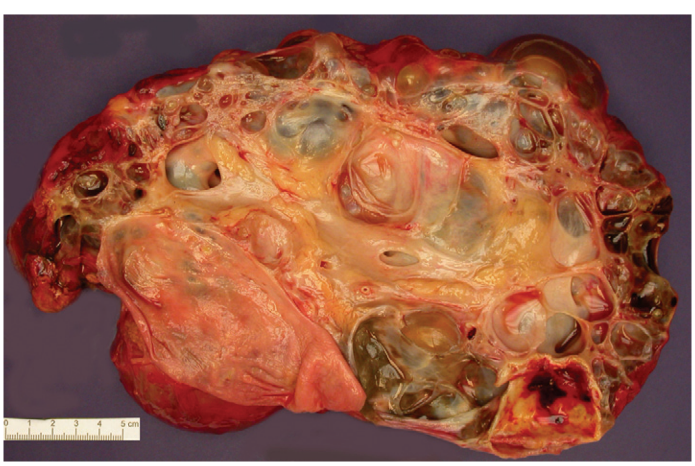


FIGURE 12-30. Adult autosomal dominant polycystic kidney disease. This is the most common genetically transmitted disease and the most common cystic renal disease. When bilateral nephrectomy is performed in such patients, the kidneys have often attained massive size, as in this case. The cut surfaces demonstrate the presence of innumerable cysts of variable size. The collecting system is normal. Despite distortion by the cysts, the kidneys retain a reniform shape. *(Image courtesy of Pedro Ciarlini, MD.)*

FIGURE 12-31. Renal dysplasia: multicystic kidney. The term *dysplasia* connotes arrested organ development, with persistence of structures that never completely developed. Aplastic and multicystic dysplastic kidneys represent opposite ends of a spectrum, varying only in the degree of cyst formation, which is variable. Aplastic dysplastic kidneys are extraordinarily small and exhibit very limited or absent cyst formation, in contrast to the multicystic kidney shown here. In all instances, the ipsilateral ureter is atretic or obstructed at the level of the ureteropelvic junction. *(Image courtesy of Paul Grabenstetter, MD.)*

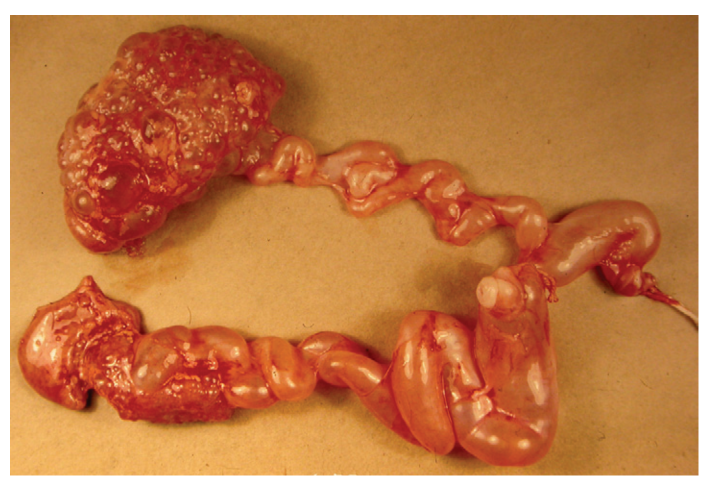


FIGURE 12-32. Bilateral renal dysplasia. Lower urinary tract obstructions, such as congenital bladder neck obstruction, posterior urethral valves, and urethral stenosis and prune-belly syndrome (which was the etiology of the bilateral renal dysplasia in this case), can result in dysplasia that involves both kidneys. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. Springer-Verlag London Limited, 2011, with permission.)*

DEVELOPMENT OF THE URETER

Musculature and Luminal Development

Longitudinally oriented elastic fibers form in the adventitia of the ureter at about 10 weeks, coincident with the onset of the formation of urine. These are followed by the appearance of randomly oriented muscle fibers in the layer that will become the muscularis. The number of elastic fibers increases linearly with the thickness of the ureteral wall. In contrast to the muscularis, those fibers associated with the submucosa are radially disposed. Fewer fibers develop in the lower ureter than in its middle portion, a finding that might help explain the occurrence of adynamic segments distally.

By 16 weeks, muscle extends the length of the extramural ureter and, by the 36th week, involves the entire ureter, including the orifice. Muscle cells and, to a lesser extent, elastic fibers increase progressively to double their number by the age of 12 years, either by multiplication of the existing cells or by mesenchymal differentiation. The size of the cells also increases but to a lesser degree.

Into the early postnatal period, the muscle fibers are arranged more circularly but become more oblique with time. By adulthood, the fibers have assumed the characteristic helical arrangement (see Fig. 12-83).

At first, the ureter has a lumen. Beginning at around 5½ weeks, the lumen becomes occluded, first in the midportion and, then by 7 weeks, is blocked proximally and distally as well, events coincident with cessation of function of the mesonephros. By 8 weeks, recanalization begins, extending in both directions from the middle of the ureter, so that a week later, the channel is open. Metanephric function is not a factor because it will not begin until the 10th week, but ureteral lengthening may be a factor in clearance of the obstruction. These observations may explain the greater frequency of ureteric valves in the proximal and distal segments, where delayed developmental arrest would be more likely.

URETERAL ANOMALIES

Most anomalies of the ureter occur either at the ureteropelvic or the ureterovesical junctions. A rare exception to this is the blind-ending ureteric bud, a blind-ending hollow structure that joins the normal ureter at an acute angle, and that is by definition at least twice as long as it is wide. Its wall structures are identical to those of the normal ureter (Fig. 12-33). Ureteral anomalies that occur in the ureterovesical junctions are described in Chapter 13.

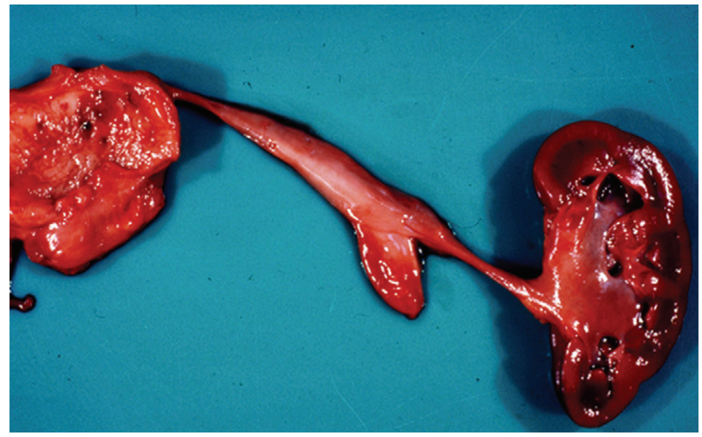


FIGURE 12-33. Incomplete bifid ureter with a blind end. The ureteral outpouching is most likely a portion of a bifid ureter that failed to connect to the renal parenchyma; less likely, it may represent a true congenital ureteral diverticulum. Both these entities possess a complete wall, including urothelium, lamina propria, and muscularis propria. *(From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

Congenital Obstruction at the Ureteropelvic Junction

Obstruction that occurs where the ureter joins the kidney may be due to extrinsic factors, but more often, the cause is faulty development.

Because the helical arrangement of muscle fibers needed for urine transport develops progressively with time, arrest of this process would leave only circularly oriented fibers at the junction, an arrangement more likely to be obstructive than conductive. Alternatively, elongation of the ureter leaving predominantly longitudinal fibers would likewise be a poorly conducting arrangement. Other factors such as agenesis or reduction in fiber numbers would also leave a nonconducting segment. It is clear that several factors are involved. Primary defects in programming the development of the ureteric bud may lead to intrinsic, focal lesions such as ureteropelvic junction obstruction or ureteral valves (Figs. 12-34 to 12-36).

Extrinsic causes of ureteropelvic junction obstruction are usually an aberrant vessel or a band passing anterior to the junction, although this may only contribute to intrinsic factors (Fig. 12-37). Another cause may be reflux that overloads a quasi-normal junction as urine returning to the bladder supplements newly secreted urine.

Retrocaval Ureter (see Fig. 2-9)

The postcardinal vein may remain dominant rather than giving way to the supracardinal vein, or the periureteric ring may persist. As the permanent kidney ascends, the postcardinal vein runs at first lateral and then medial to the kidney. As a result of the displacement and consolidation of the veins, the ureter lies dorsal to the vena cava.

Ureteral Valves

Several theories have been proposed for the origin of ureteral valves, including failure of complete canalization after a normal period of closure in the sixth week. They may occur when the axes of the lumina are eccentric so that the ureter is overlapped at the site of the obstruction, resulting in a common wall, or they may result from persistence of mucosal folds left over from the pleats formed during ureteral lengthening. Finally, they might arise if the ureter elongates faster than the kidney ascends.

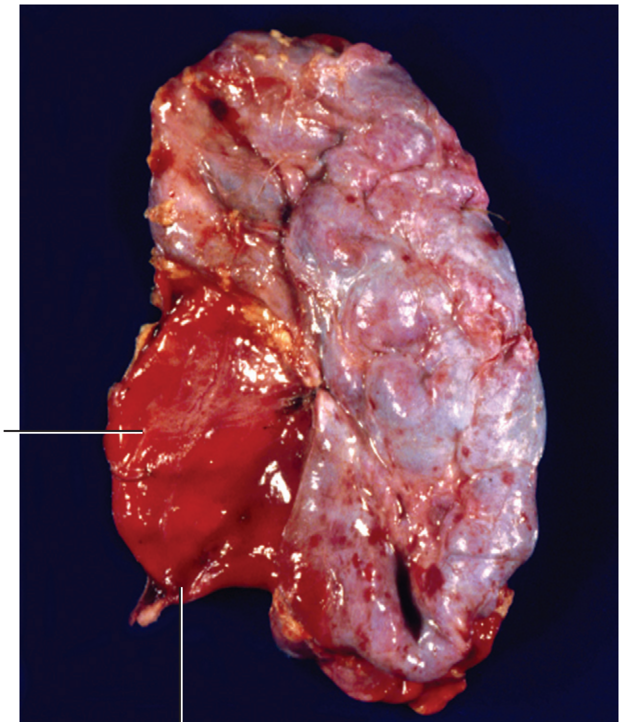


FIGURE 12-34. Congenital ureteropelvic junction obstruction. The renal pelvis is distended, but the ureter below the ureteropelvic junction is of normal size. The renal cortex appears scarred. *(From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

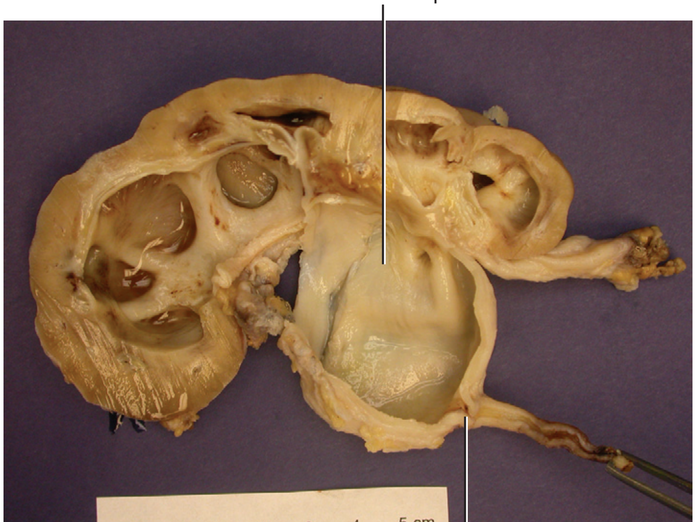


FIGURE 12-35. Congenital ureteropelvic junction obstruction. The renal pelvis is markedly dilated. The chronically obstructed kidney shows pronounced caliectasis, loss of the renal pyramids, and thinning of the renal cortex.

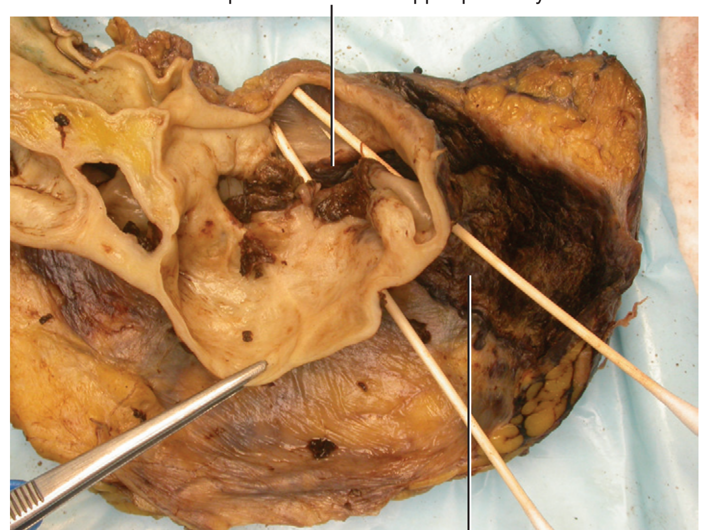


FIGURE 12-36. Congenital ureteropelvic junction obstruction. Patient presented with flank pain and massive retroperitoneal bleeding. He was found to have ureteropelvic junction obstruction, with marked hydronephrosis of one half of a horseshoe kidney, treated by excision of the obstructed half of the horseshoe kidney. The retroperitoneal hematoma appeared to be related to disruption of a thinned upper pole calyx (defect indicated by small wood sticks). There was no history of recent trauma. *(Image courtesy of Lisa Stempak, MD.)*

FIGURE 12-37. Congenital ureteropelvic junction obstruction. Sagittal reconstruction image of contrast-enhanced computed tomography. This radiologic image shows a blood vessel adjacent to the ureteropelvic junction. It is a matter of debate whether such vessels contribute significantly to the obstructive process. *(Image courtesy of Raj Paspulati, MD.)*

DEVELOPMENT OF THE ADRENAL GLANDS

Fetal adrenals are very large during fetal life, especially in the second trimester, mostly resulting from expansion of the cortical cells. They are still relatively large at birth, only to regress rapidly during the first 3 weeks of life (see Fig. 12-13). During the eighth gestational month, the zona glomerulosa appears, followed by the zona fasciculata at term; the zona reticularis follows in the next 3 to 6 months, with the cortex completely differentiated by 2 years.

At birth, the large adrenal gland is vascular and easily injured during delivery.

Origin of the Adrenal Cortex and Medulla

Two separate tissues contribute to the formation of the adrenal glands, providing layers that remain distinct into adult life (Table 12-3).

The adrenal **cortex** comes from mesothelial buds on the upper third of the **mesonephros** that project into the **primitive celom** with the **gonad** (Fig. 12-38). The buds form a cellular aggregate on either side of the **aorta**. Some cells may not join the aggregation, accounting for accessory adrenal cortical tissue about the adrenal gland and kidney, with the spermatic vessels or testis in the male and within the broad ligament and ovary in the female.

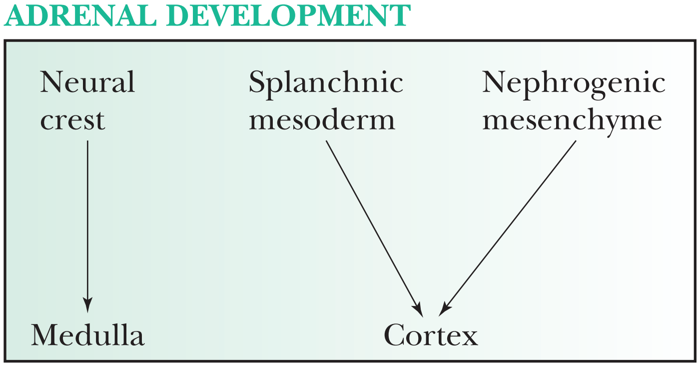
The adrenal **medulla** is derived from primitive ectodermal cells of the neural crest in the developing sympathetic nervous system (see Fig. 4-2). These sympathogonia normally mature into sympathoblasts and ultimately into ganglion cells within the **sympathetic ganglion**. Alternatively, and of importance to the formation of the adrenal medulla, they may migrate and differentiate into chromaffin endocrine cells, the pheochromoblasts, that will mature into chromaffin cells after penetrating the adrenal cortical primordium to form the adrenal medulla (Table 12-4).

Distribution of Fetal Chromaffin Bodies

In fetal life, the pheochromoblasts form **chromaffin bodies** that are distributed along the **aorta**, providing the main source of catecholamines (Fig. 12-39A). These cells migrate to and invade the adrenal cortical aggregation to form the adrenal medulla.

TABLE 12-3

ADRENAL DEVELOPMENT



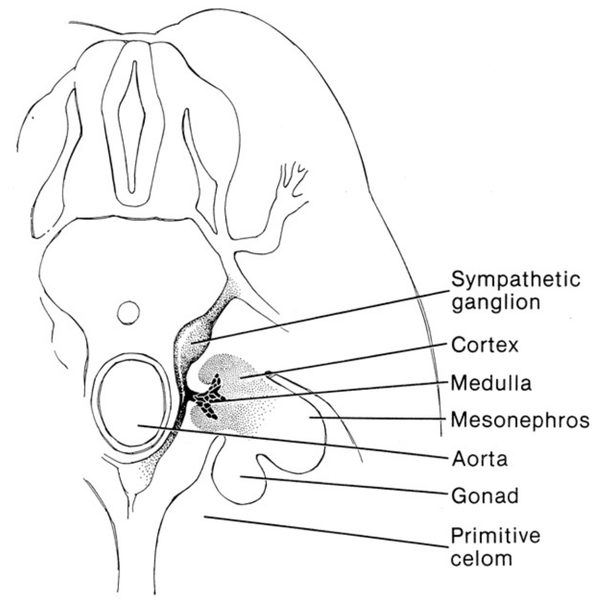


FIGURE 12-38.

Some of these chromaffin bodies regress only partially after birth and remain as the *paraganglion system* distributed within and adjacent to the prevertebral sympathetic ganglia and in the several sympathetic plexuses and ganglia (**celiac, mesenteric, renal** and **adrenal**, and **hypogastric**) as well as a plexus at the aortic bifurcation, the **organ of Zuckerkandl** (Fig. 12-39B). This system is a secondary source of catecholamines throughout life and may become the tissue of origin of pheochromocytomas. This is especially possible in children in whom 30 percent of pheochromocytomas are extra-adrenal; they are not infrequently malignant.

Two larger aggregates of chromaffin tissue related to the superior hypogastric plexus, the **para-aortic bodies**, remain on either side of the aorta in an inverted U-shape looped over the **inferior mesenteric artery**. These bodies enlarge during early postnatal life, only to virtually disappear at puberty.

Adrenal Blood Supply

Arteries

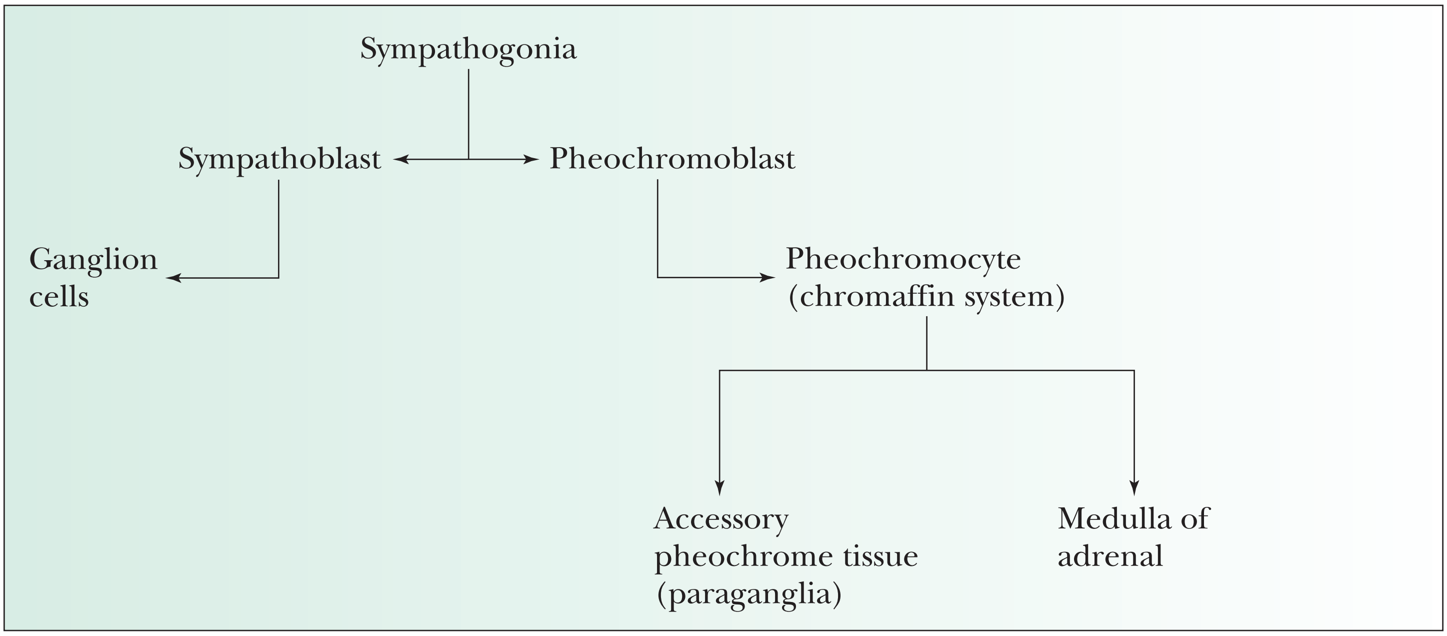
The source of blood for the adrenal is the most cranial of the segmental mesonephric roots that once supplied the urogenital (mesonephric) arterial rete. Especially on the right side, smaller accessory arteries, usually multiple, may come from the inferior phrenic or the renal arteries.

Veins

Resolution of the renal venous plexus on the right leaves a single, short vein running obliquely that connects to the posterior surface of the vena cava. On the left, the residual left subcardinal vein (see Fig. 2-7) is also single but often receives blood from the inferior phrenic vein in addition to that from the capsular veins. The left vein is longer and descends vertically to join the renal vein.

ADRENAL SYMPATHETIC DIFFERENTIATION

TABLE 12-4



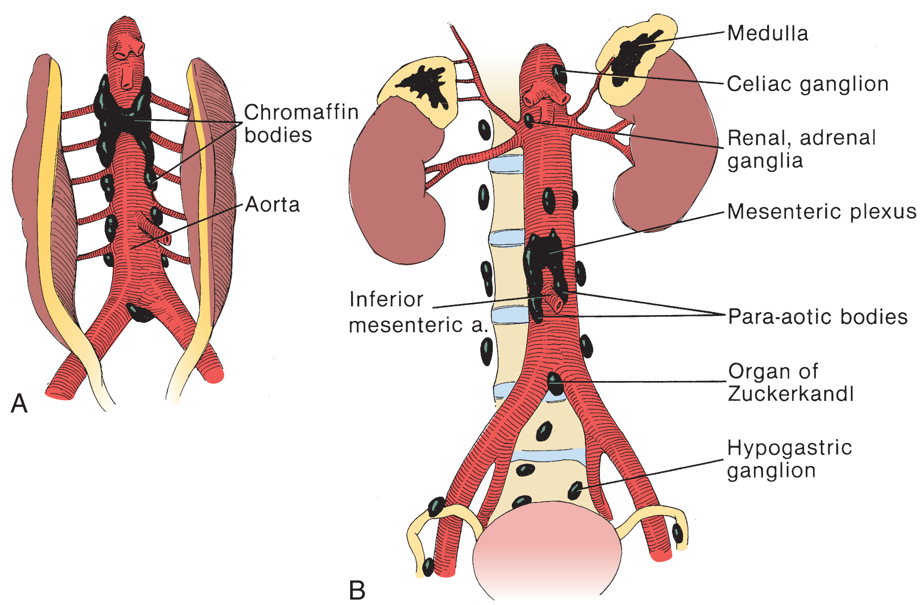


FIGURE 12-39.

ADRENAL ANOMALIES

At 8 weeks, the adrenal gland has migrated to lie adjacent to the kidney and will subsequently rise as the kidney ascends. However, the position of the adrenal gland is independent of that of the kidney, because with an ectopic kidney, the adrenal gland is found in its normal position.

Agenesis may occur, often associated with renal agenesis secondary to failure of the entire blastema. Adrenal ectopia may be found. Of surgical importance when operating on a solitary kidney is the rare possibility that the single adrenal gland lies under the renal capsule (Figs. 12-40 and 12-41). Accessory adrenal cortical rests are found intra-abdominally and retroperitoneally within abdominal and sexual organs (Fig. 12-42). As noted previously, extramedullary chromaffin tissue is commonly found and may become transformed into a pheochromocytoma.

DEVELOPMENT OF THE PERIRENAL FASCIAS

Development of the Strata of the Retroperitoneal Fascias

At first, a continuous sheet of mesenchyme lies between the epithelium of the skin and the mesothelium lining the celomic cavity, but as the muscles and skeleton develop in this space, the remaining mesenchyme becomes split into a subcutaneous layer and a retroperitoneal layer. The subcutaneous layer differentiates into the dermis, superficial fascia, and deep fascia of the body wall. The retroperitoneal layer, as the retroperitoneal connective tissue, lines the body wall and surrounds the gastrointestinal and urinary organs (Table 12-5) (see Fig. 8-4).

With maturation, three strata can be distinguished in the retroperitoneal connective tissue. One is an *inner*

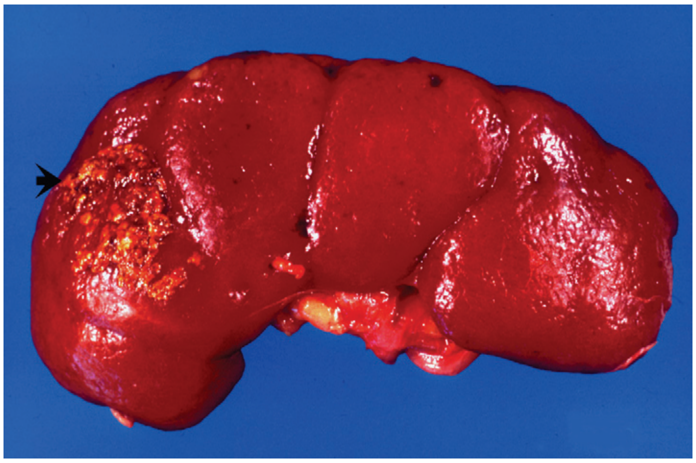


FIGURE 12-40. Ectopic adrenal in kidney. The ectopic adrenal tissue is usually subcapsular and is most often in the upper pole. It may assume a plaque-like form (as in this image) but can also be wedge-shaped or spherical. The gross appearance of this anomaly can raise concern for neoplasia. *(From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

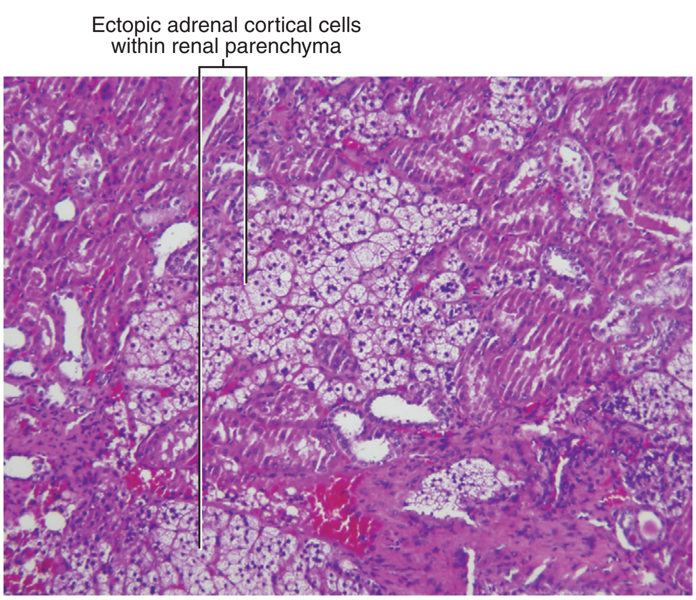


FIGURE 12-41. Ectopic adrenal in kidney. Adrenal cortical tissue intermingles with normal renal tissue. The lack of circumscription imparts an infiltrative appearance, and the histologic similarity between normal adrenal cortical tissue and clear cell carcinoma can create diagnostic difficulty on intraoperative frozen sections.

stratum embedding the gastrointestinal system. Beneath this layer is the *intermediate stratum* embedding the urinary system that differentiates into dorsal and ventral layers in the region of the kidneys.

Local conditions play a role in fascial development. Distinct fascial layers in the intermediate stratum form in areas of organ mobility, possibly resulting from shearing action; they do not develop in the absence of the kidney.

The *outer stratum* invests the inner layer of the body wall and pelvis as the transversalis fascia and its extensions, the

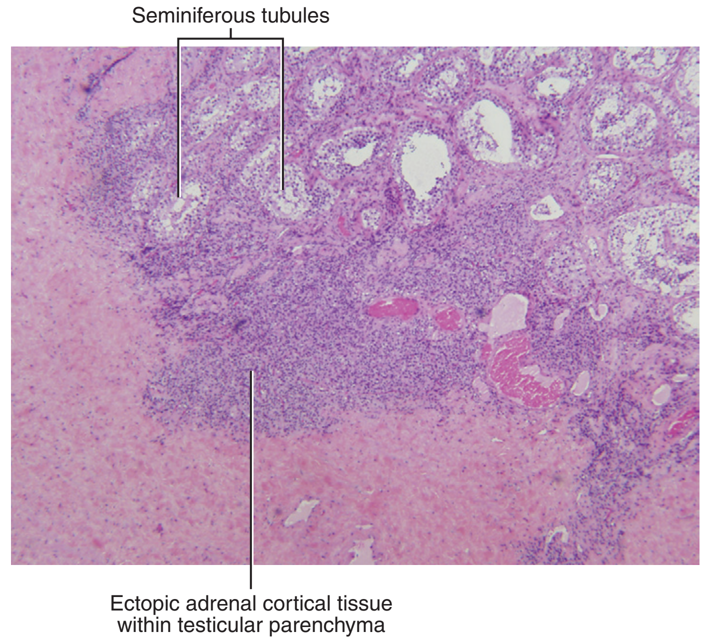


FIGURE 12-42. Ectopic adrenal tissue in testis. Nodules of intratesticular ectopic adrenal tissue are usually less than 0.5 cm in size. The small aggregate of ectopic adrenal cortical cells shown here was an incidental finding in a testis excised for unrelated reasons. Diagnosis was confirmed by appropriate immunostains.

endopelvic fascia, and terminates in continuity with the internal spermatic fascia.

Fusion of the Colonic Mesenteries

In addition to a covering of primary retroperitoneum, the kidneys acquire a secondary coat from the fusion of the colonic (and on the left, duodenal) mesenteries as the bowel rotates into its final position. The sequence of intestinal rotation is illustrated in Figure 6-5. At first, the dorsal mesentery forms a barrier between the right and left sides as it runs the length of the peritoneal cavity. Rotation of the intestinal loop begins counterclockwise. The future ascending colon rotates over the base of the mesentery, exposing the right side of its mesentery. At the same time, the descending colon with its mesentery merely rises into the left upper quadrant, thus maintaining the original right and left orientation of the surfaces of the original colonic mesentery.

As the left mesocolon meets the primary peritoneum on that side, its left side fuses with it, and the underlying mesothelial layers disappear. This places the connective tissue of the inner strata of the mesentery (two layers) and the primary peritoneum (one layer) in contact, forming a three-ply layer (shown in Figure 6-6). A layer so formed is termed fusion-fascia.* On the right, the left side of the mesocolon also fuses with the right primary retroperitoneum,

**Fusion-fascia* is a thin membranous layer formed by the apposition of two mesothelially covered surfaces of peritoneum and the subsequent loss of the mesothelium. By definition, it is continuous with the tunica propria of two peritoneal surfaces. It differs from the *migration fascia* that results from the migration of primitive tissues during development in which migration produces linear orientation of the connective tissue fibers, which, in turn, are compressed by further growth.

TABLE 12-5

DIFFERENTIATION OF MESENCHYME

Primitive	Late Fetal	Adult
Subcutaneous layer	Dermis	Dermis
	Superficial fascia	Camper's fascia, Scarpa's fascia
	Deep fascia	Deep fascia
Body layer	Muscles, ligaments, bones	Muscles, ligaments, bones
Retroperitoneal layer	Outer stratum	Transversalis fascia
	Intermediate stratum (urogenital embedding)	Gerota's fascia
	Inner stratum (intestinal embedding)	Intestinal fascia

because the bowel had rotated 180°. In addition, the mesoduodenum fuses with a part of the primary retroperitoneum. Here, the result is fusion of two layers of mesentery (or four layers of peritoneal surface, each with its associated inner stratum of connective tissue) with the primary retroperitoneal surface and its layer of inner stratum.

This layer of fusion-fascia is superimposed over the intermediate stratum of retroperitoneal connective tissue that will form the renal (Gerota's) fascia, and thus covers most of the kidney and ureter on each side.

By the seventh month of gestation, the layers of the intermediate stratum are well developed and form the renal fascia as the ventral layer splits into two layers, an anterior lamina (Toldt) with the perirenal fat and a posterior lamina (Zuckerkandl). The kidneys and related structures are enclosed between them. These lamina fuse laterally on each side behind the ascending and the descending colon, where they form a single layer, the so-called lateroconal fascia (Fig. 12-43).

Thus, the peritoneum is associated with only one layer of inner stratum of retroperitoneal connective tissue in all but two areas: (1) where the mesenteries of the duodenum and ascending and descending colon fuse to the primary retroperitoneum, and (2) as Denonvilliers' fascia, in the retroprostatic pouch.

KIDNEY, URETER, AND ADRENAL GLANDS: STRUCTURE AND FUNCTION

Retroperitoneal Fascias

Fascial Strata of the Retroperitoneal Connective Tissue

The connective tissue between the body wall and the peritoneum can be separated into three layers: an *inner stratum*, just beneath the peritoneum associated with the intestinal tract and its vessels and nerves; an *intermediate stratum* investing the kidneys, adrenals, ureters, and their vessels and nerves; and an *outer stratum* covering the epimysium of the parietal muscles (Table 12-6).

The conventions used in this book for naming the fascial layers are shown in Table 12-7.

Multiple layers of fascia appear in areas of visceral mobility (mobility-fascia). For example, fascial layers are especially numerous about the kidney as well as about the pelvic and scrotal organs but are absent about the umbilicus.

Retroperitoneal Fascias and Spaces

The retroperitoneal *fascias* form the boundaries for the retroperitoneal *spaces* (Figure 12-43A).

Fascias

In the renal area, the fascias of surgical importance are the renal fascia and its extension, the lateroconal fascia, and the fusion-fascia under the colon.

Renal Fascia

The **renal** or Gerota's **fascia** is derived from the intermediate stratum of the retroperitoneal connective tissue, the stratum related to the urinary organs. The renal fascia has an anterior and a posterior lamina, with the kidney and adjacent structures lying between in the **perirenal space**.

Anterior Lamina

The **anterior lamina** of the renal fascia (fascia of Toldt), a layer that includes the attached **perirenal fat**, is formed by local thickening of the intermediate stratum. Perirenal fat can be distinguished by its paler color and finer texture compared with that of the pararenal fat that lies outside the renal fascia. The perirenal fat contains connective tissue fibers that are especially concentrated about the upper renal pole, and the fat is of greater thickness over the posterior and lateral surfaces of the fascia than over the anterior surface. It accumulates in larger quantities in men than in women, and its bulk accounts for the more anterior placement of the colon in males compared with the lateral

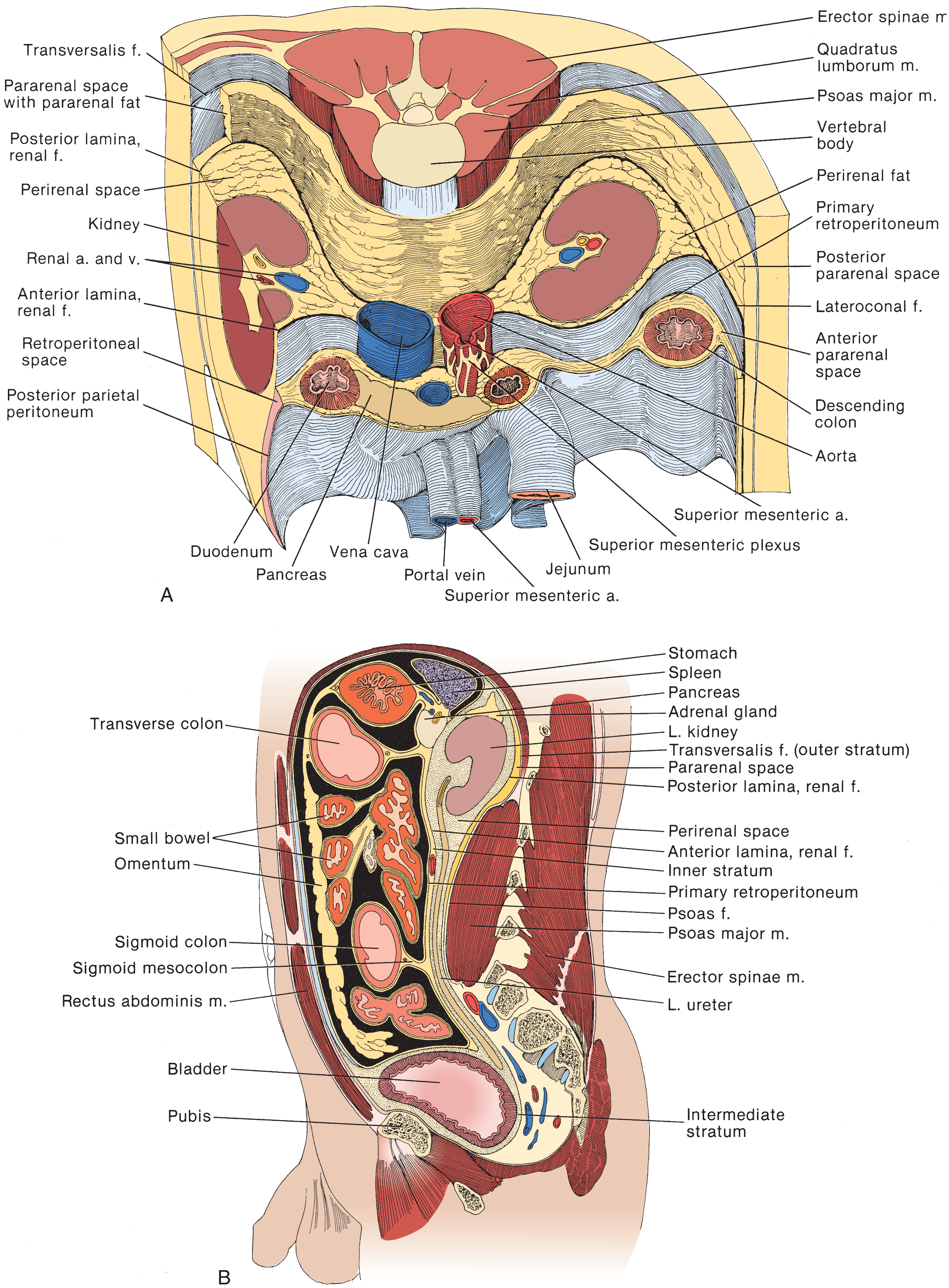


FIGURE 12-43. A, Transverse-oblique view. **B,** Sagittal section.

TABLE 12-6

FASCIAL LAYERS

Layer	Structure	Function
PERITONEUM		
	Primary retroperitoneum	Lining of body cavity
	Secondary retroperitoneum (mesenteric)	
RETROPERITONEAL CONNECTIVE TISSUE LAYERS		
Inner stratum	Intestinal fascia, fusion-fascia	Intestinal embedding
Intermed. stratum	Renal fascia	Urogenital embedding
Outer stratum	Transversalis fascia (endopelvic fascia, lateral pelvic fascia, obturator fascia)	Lining of body wall
BODY WALL		
	Epimysium, muscles	

TABLE 12-7

CONVENTIONS FOR RETROPERITONEAL FASCIAL LAYERS

Lamella	Lumbodorsal fascia	Posterior, middle, and anterior
	Denonvilliers' fascia	Anterior and posterior
Lamina	Renal (Gerota's) fascia	Anterior and posterior
Stratum	Retroperitoneal computed tomography	Inner, intermediate, and outer

situation in females. The anterior lamina covers the anterior surface of the **kidney** and adrenal gland.

The anterior lamina also becomes fused with the inner (intestinal) stratum at the sites where the vessels to the digestive tract pass through from the aorta and vena cava. This stratum is difficult to illustrate as a separate layer because it is so closely related to the overlying **primary retroperitoneum**.

Posterior Lamina

The **posterior lamina** of the renal fascia (fascia of Zuckerkandl), also derived from the intermediate stratum, is thicker than the anterior one. The **pararenal fat** lying dorsally is formed from it.

Over the psoas major and quadratus lumborum, the posterior lamina becomes fused with the fascia of the outer stratum, represented by the **transversalis fascia**. In the midline, the lamina is attached to the ventral surfaces of the **vertebral bodies** and to the anterior lamina of the renal fascia as the two laminas fuse and blend with the connective tissue around the **aorta, vena cava**, and the **renal artery and vein** as well as the tissue surrounding the autonomic nerves of the **superior mesenteric plexus**. Because the anterior lamina also joins the dense connective tissue around the great vessels, communication between the perirenal spaces on the two sides is virtually precluded.

Lateroconal Fascia

Laterally, behind the ascending and the **descending colon**, the anterior and posterior laminas of the renal fascia fuse to make a single layer. The line of fusion is most commonly found directly lateral to the plane of the renal pelvis, but considerable variation is found. This single layer is called the **lateroconal fascia** by radiologists from its appearance on computed tomography scans. It separates the **anterior** from the **posterior pararenal spaces** (see Fig. 12-53).

The lateroconal fascial layer joins the properitoneal fascia (from the inner stratum) at the **white line of Toldt**, closing the anterior pararenal space at its lateral margin.

Because the lateroconal fascia does not fuse with the transversalis fascia but spreads anterolaterally around the body wall between the transversalis fascia and the peritoneum, the posterior pararenal space continues forward as the properitoneal space with its contained properitoneal fat. It is this extension of fat that provides the radiologically visualized flank stripe. More anteriorly, the lateroconal fascia ceases to be a distinct boundary between the two pararenal compartments; they become a single space.

Colonic-Peritoneal Fusion-Fascia

With rotation of the colon and its mesentery, the peritoneum on each side of the colonic mesentery fuses with the single layer of the primary retroperitoneum behind them to form a single layer of fusion-fascia (see Figure 6-15). The margin where this fusion-fascia meets the lateral parietal peritoneum and the fused lamina of the renal fascia (laterconal fascia) is marked by a linear thickening, the white line of Toldt.

The single layer from the three-layered peritoneal fusion-fascia may be separated from the underlying anterior lamina of the renal fascia by blunt dissection, so that the ascending or descending colon can readily be mobilized medially, leaving the kidney still covered by the anterior lamina.

On the right side, the fused layer covers the ventral surface of the caudal half of the right kidney, and its caudal limit depends on how much of the cecum is fixed to the primary retroperitoneum. On the left, the caudal third of the kidney is beneath the fusion-fascia and the fixation ends at the sigmoid colon.

Spaces

Three clinically important spaces or compartments lie between the fascial layers, which are revealed not only by anatomic dissection but also by roentgenography and computed tomography. These are (1) *an anterior pararenal space*, (2) *a perirenal space*, and (3) a *posterior pararenal space*.

Anterior Pararenal Space

This compartment lies between the inner stratum, the layer associated with the posterior **parietal peritoneum**, and the **anterior lamina** of the **renal fascia**. It is limited superiorly by adherence of the renal fascia to the inner stratum in the colic gutters but is continuous laterally with the properitoneal compartment. Because of the folding of the mesocolon and the formation of layers of mesentery, radiologists, from their studies on the diffusion of ascites and pancreatic fluid, have included the **ascending and descending colon** and the **duodenum** and **pancreas** and their mesenteries within the anterior pararenal space. However, on a developmental basis, this radiologic space is in the intermesenteric domain (see Figure 6-16 **B**). Thus, the anterior pararenal space proper lies behind the layers of fusion-fascia created by the posterior fixation of the colon to the primary peritoneum, and it lies over the anterior lamina of the renal fascia. It is actually a potential space; normally, it is empty. In surgery, it is important because it is the plane of this space that is followed medially from the white line of Toldt during mobilization of the colon to expose the kidney.

Perirenal Space

The perirenal compartment lies between the anterior and posterior lamina of the renal fascia and contains a kidney, adrenal gland, and ureter encased in fine areolar tissue and perirenal fat. The compartment is limited medially, laterally, and superiorly by fusion of its fascias.

Posterior Pararenal Space

This compartment separates the posterior lamina of the renal fascia from the transversalis fascia (of the outer stratum of the abdominal fascia). It is continuous with the properitoneal space in the flank. This space contains coarse fatty-areolar tissue, the **pararenal fat**, derived as the posterior layer of the renal fascia (intermediate stratum). It has a yellow-orange color compared with the light yellow color of the perirenal fat.

Medially, the posterior lamina of the renal fascia fuses with the transversalis fascia to close the pararenal space over the psoas major and quadratus lumborum, although the site of junction and thus the extent of the posteromedial extension of the pararenal space varies by as much as 10 cm. The line of fusion encountered surgically is a dense band that usually must be divided sharply.

The peritoneum over the **transverse colon** is continuous with the parietal peritoneum made up of the fusion-fascia of the two layers of mesocolon and a single layer of primary peritoneum (Fig. 12-43B). Under the peritoneum, the **inner stratum** of the retroperitoneal connective tissue overlies the **anterior pararenal space**. The **anterior** and **posterior laminas** of the **renal fascia** confine the **kidney** and **ureter** within the **perirenal space**.

Retroperitoneal Fascias and Spaces; Coronal View

For renal surgery, two layers of fascia are of concern. One is the renal fascia, described earlier from a transverse-oblique view and shown here from a coronal view (Fig. 12-44), and the other is the transversalis fascia.

Renal Fascia

At the upper margin of the **adrenal** gland, fusion of the anterior and posterior laminas of the **renal fascia** to the intrinsic fascia of the **diaphragm** closes the cephalad end of the **perirenal space**. The seal is not complete because perirenal gas has been observed to escape into the mediastinum.

An incomplete fascial septum has been described separating the adrenal gland in a compartment above the kidney, but such a division has not always been described on dissection nor is it found at surgery or during perirenal gas insufflation.

Because both laminas extend into the pelvis, one can picture Gerota's fascia as a large, fairly sturdy but elastic bag. It is known to be elastic because it will retain a large amount of blood under pressure after renal injury. The bag is inverted over the kidneys and adrenal glands, with its front and back sides adherent to each other in the midline. Thus, hemorrhage from the kidney may extend only in a caudal direction because it is restricted superiorly and medially by fascial fusion. Bleeding may be slowed or arrested by the limiting distensibility of the anterior layer of the renal fascia.

In the pelvis, the posterior lamina of the renal fascia merges with the **transversalis fascia** of the outer stratum. The anterior lamina continues caudally to enclose the ureter in a sheath as far as the bladder region.

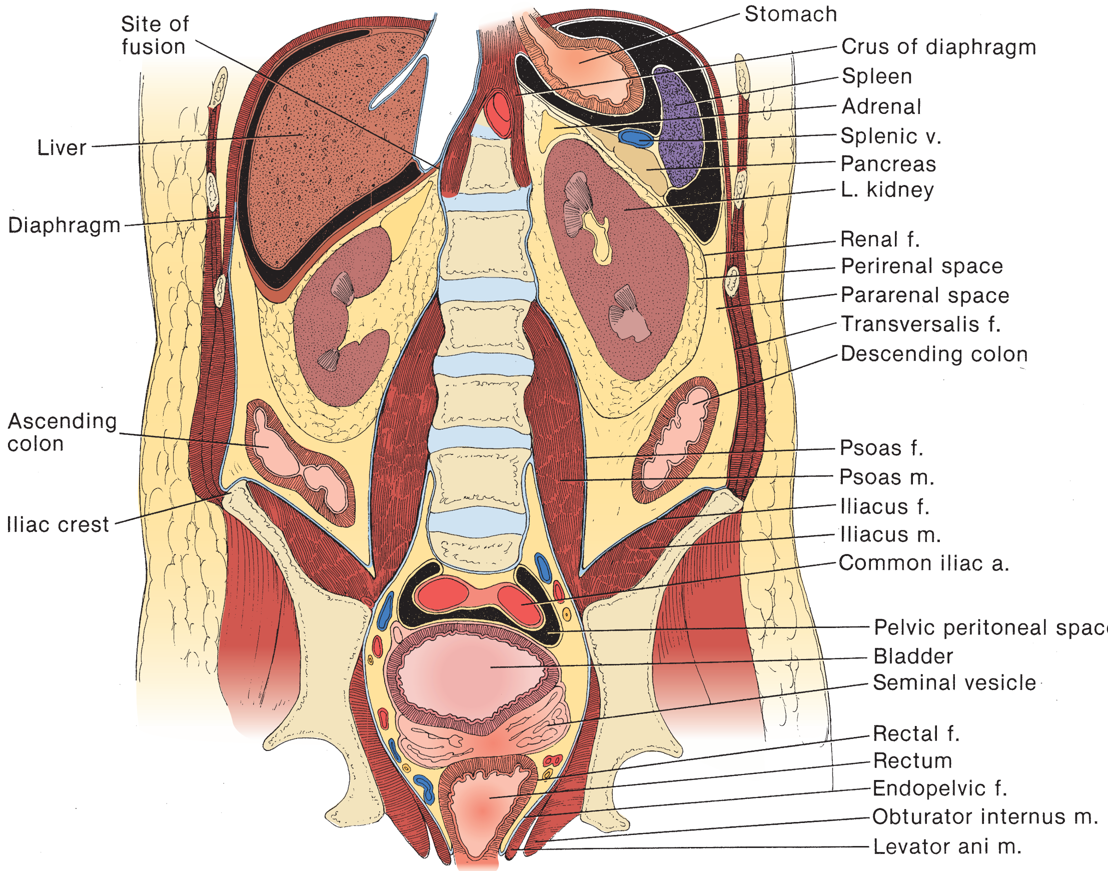


FIGURE 12-44.

Periureteral fibrosis involves only the intermediate stratum of retroperitoneal connective tissue within the renal fascial laminas. The caudal margins of the two layers of the renal fascia are not firmly fused because gas instilled perirectally into the space fills the perirenal area. Similarly, barium suspension injected perirenally exits into the perivesical and perirectal areas.

Transversalis Fascia

The **transversalis fascia**, as well as those fascias of the pelvis with which it is continuous, are derivatives of the outer stratum of the retroperitoneal connective tissue. The transversalis fascia has been called the parietal fascia, analogous to the parietal peritoneum, to differentiate it from migration-fascias and fusion-fascias and to indicate that it is the lining of the abdominal and pelvic cavities. It is a substantial layer of connective tissue intimately related to, but not part of, the epimysium of the underlying muscles. It is called the transversalis fascia because of its wide distribution beneath the transversus abdominis, but because this same stratum is distributed over all the muscles lining the abdomen and pelvis, the transversalis fascia must be considered part of an extended layer that includes the fascia of the pelvis. Thus, it is continuous with the obturator and **iliacus fascia**, the fascia of the pelvic diaphragm, the fascia of the femoral sheath and canal, and the internal spermatic fascia. It may be fused with the intrinsic fascia (epimysium) of the psoas major. It is also continuous with the so-called **endopelvic fascia**, although technically the term *endopelvic fascia* may be better reserved for that portion of the transversalis fascia that forms collars around exiting organs, such as the prostate in males (where it has been called the lateral pelvic fascia), the urethra and vagina in females, and around the lower rectum and anal canal.

Renal Envelope and Adjacent Body Wall

Fascias And Spaces

The fascial layers over the kidney are shown cut away (Fig. 12-45). From posterior to anterior, they are the **psoas fascia, pararenal space, posterior lamina** of **rectal fascia, perirenal space, anterior lamina** of the **renal fascia, pararenal space**, and fusion-fascia (behind the ascending and descending colon and peritoneum, not shown).

Diaphragm and Ligaments of the Posterior Body Wall (see Fig. 8-10)

The *diaphragm* is attached to the vertebral column by the left and **right crus**, between which the great vessels run. These crura are attached to the bodies of the upper two lumbar vertebrae and are joined anteriorly over the vessels as the **median arcuate ligament**.

Lumbocostal arches or arcuate ligaments are formed from the transversalis fascia. The **medial arcuate ligaments** are bandlike thickenings of the fascia that extend from the tip of the transverse processes of the L1 vertebra across the psoas muscles to attach to the disk between the L1 and L2 vertebrae and to adjacent tendinous parts of the crura of the diaphragm. The **lateral**

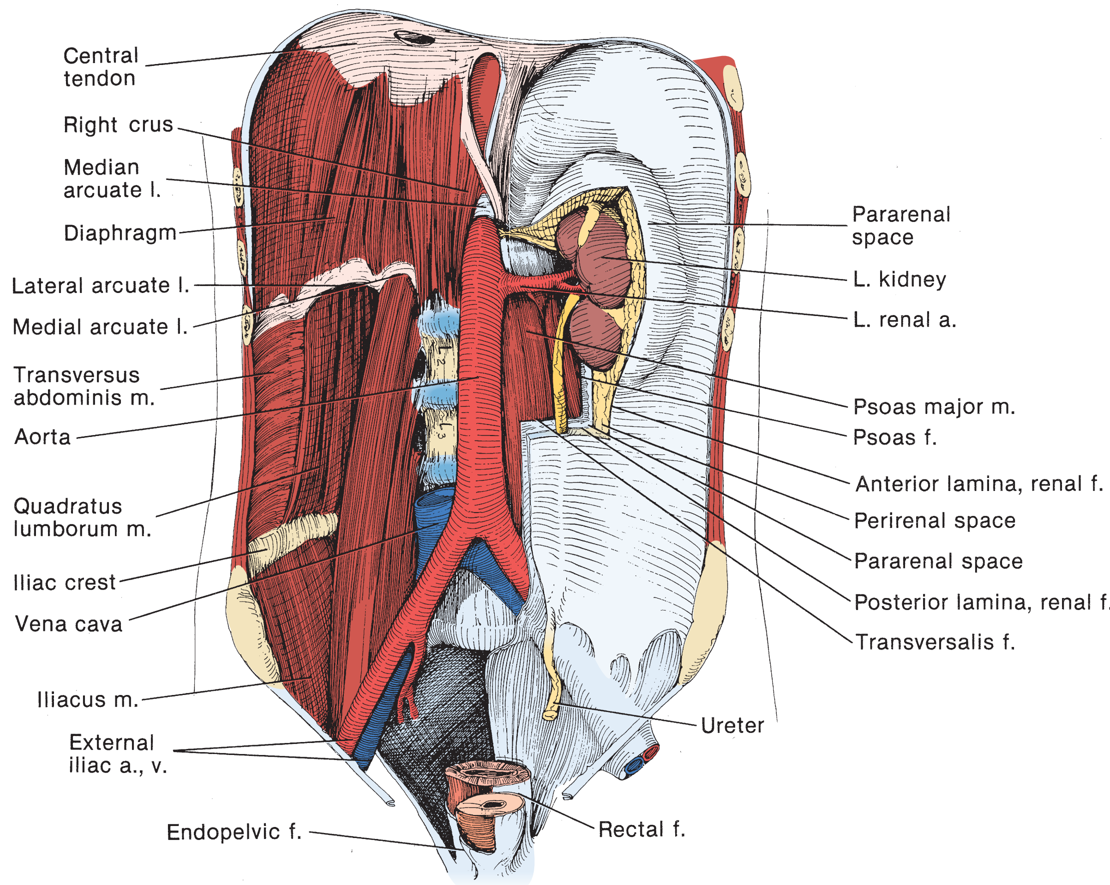


FIGURE 12-45.

arcuate ligaments are similar thickenings of the transversalis fascia that extend from the tip of the transverse processes of the L1 vertebra across their respective **quadratus lumborum** muscles to attach near the tips of the 12th ribs. They are the site of origin of parts of the diaphragm and, in some areas, they limit the upper border of the renal fascia.

Surgical Planes

The kidney may be approached without entering the renal fascia through two separate planes, one through the posterior and the other through the anterior pararenal space (Fig. 12-46).

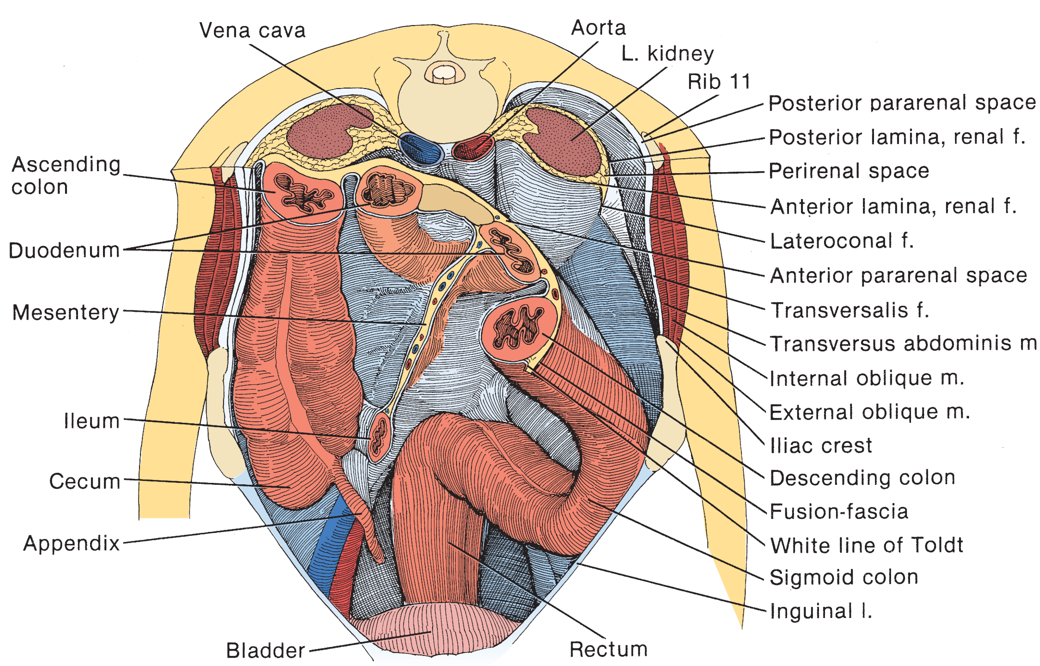


FIGURE 12-46.

The *posterior aspect* of the kidney may be approached through the **posterior pararenal space** by dissecting between the **posterior lamina** of the **renal fascia** and the **transversalis fascia**, a dissection aided by the intervening pararenal fat layer.

Access to the *anterior aspect* of the kidney and its vessels is accomplished by opening the **anterior pararenal space** by medial mobilization of the fusion-fascia of the descending or ascending mesocolon (including the **parietal peritoneum**) from the underlying **anterior lamina** of the **renal fascia** (see Fig. 12-45). starting at the **white line of Toldt**.

As the diaphragm is approached, the layers of the renal and transversalis fascias almost disappear, leaving the intrinsic fascia (epimysium) of the diaphragm against the peritoneum.

To avoid entering the peritoneum, dissection may be performed beneath the diaphragmatic intrinsic fascia.

POSTERIOR BODY WALL

Anterior View

Removal of the transversalis fascia exposes the structures on the internal surface of the posterior body wall and the great vessels (Fig. 12-47).

Diaphragm

Three openings are found. Uppermost is the **vena caval aperture** that opens through the diaphragm in the **central tendon** at the junction of its **right leaf** and central part. The aperture accommodates the **vena cava** and the right phrenic nerve. More central is the **esophageal aperture** that goes though the muscle fibers of the **right crus** opposite the 10th rib. The fascia of the diaphragm, continuous with the transversalis fascia, encircles the diaphragmatic portion of the esophagus as a collar at its entrance into the abdomen, forming the phrenico-esophageal ligament. The most caudal opening is the **aortic aperture**. The **right** and **left crura** of the diaphragm pass on either side of the 2nd and 3rd lumbar vertebrae to provide this opening for the **aorta**. Here, the diaphragm lies anterior only to the **aorta**, which, in turn, lies against the vertebral bodies. The thoracic duct also passes through this aperture, as well as the thoracic splanchnic nerves that go to the **celiac plexus**.

The diaphragm is attached to the 1st lumbar vertebra by the **medial arcuate ligament** and to the 12th rib by the **lateral arcuate ligament**.

Musculature

The **quadratus lumborum** emerges from beneath the lateral arcuate ligament to reach the lower border of **12th rib** and the transverse processes of the first four lumbar vertebrae. Caudally, it joins the iliolumbar ligament and the medial part of the **iliac crest**. The **iliacus** is attached above to the inner surface of the **ilium** and **sacrum**, and ends below in the **tendon of the psoas major**. The **psoas major** passes under the medial arcuate ligament to attach to the body of the 12th thoracic vertebra and to the anterior surfaces of all the **lumbar vertebrae**. It terminates on the lesser trochanter of

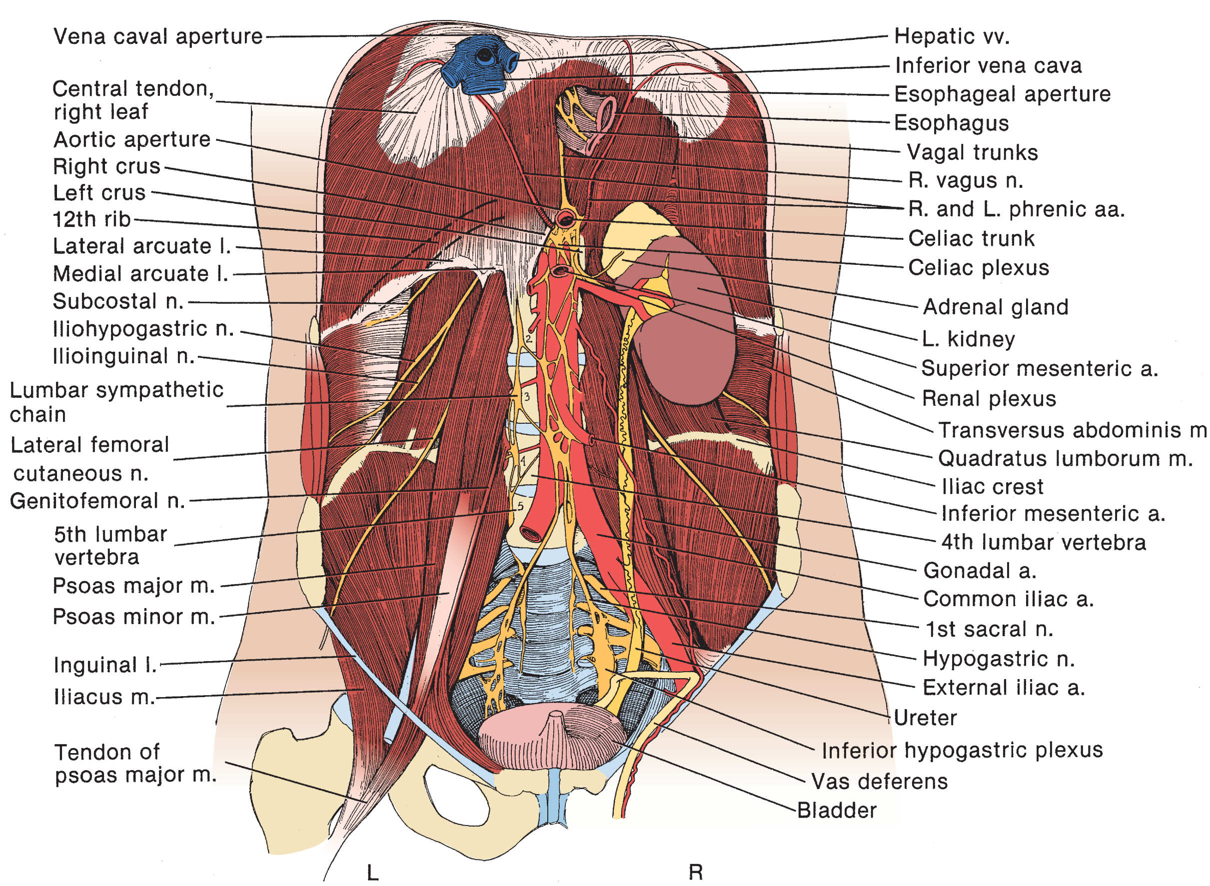


FIGURE 12-47.

the femur. The **psoas minor**, lying over the psoas major, has a narrow tendon that attaches to the iliopubic eminence.

Nerves

Four important nerves lie adjacent to the kidney. The **subcostal** (12th thoracic) **nerve** reaches the retroperitoneum at the lateral border of the superior lumbar triangle to pass anterior to the **quadratus lumborum**. The **iliohypogastric** and **ilioinguinal nerves** enter the retroperitoneum from behind the **psoas major** and traverse the **quadratus lumborum**. The **genitofemoral nerve** exits from the **psoas major** at the level of the lower pole of the **kidney** to cross behind the **ureter** before branching.

The largest of the abdominal plexuses is the **celiac plexus** that lies at the level of the lower margin of the 12th thoracic vertebra. The plexus joins the two celiac ganglia that are found between the adrenal gland and the take-off of the celiac artery. Each of the celiac ganglia is connected above to the greater splanchnic nerve and below, as the aortorenal ganglion, to the lesser splanchnic nerve originating from T12. The aortorenal ganglion, in turn, supplies the **renal plexus** that lies at the base of the renal arteries (see Fig. 4-12).

THE KIDNEY

Relations of the Kidney to Adjacent Organs

The **liver** lies over the upper part of the anterior surface of the **right kidney** (Fig. 12-48). The relative positions are important in thoracoabdominal approaches to the kidney and in injuries to either organ. For percutaneous approaches to the upper pole of the kidney, the posterior edge of the liver must be avoided where it extends posteriorly to wrap around the kidney. The liver is attached to the diaphragm by the right triangular ligament, which must be severed prior to removal of a malignant caval thrombus. The ascending and the descending colons cover the lower portion of the right and left kidneys. The **duodenum** occupies a medial position over the hilum and pelvis of the right kidney; it may be impinged on during percutaneous or surgical approaches to the pelvis.

From above downward, four organs are near the left kidney: the spleen, stomach, pancreas, and jejunum. The **spleen** extends medially and is especially vulnerable to simultaneous injury with the kidney, either by blunt trauma or during renal surgery. The **stomach** lies over the upper half of the kidney. During left renal operations, the body and tail of the **pancreas** are separated from the kidney only by the anterior lamina of the renal fascia. The **jejunum** is adjacent to the lower pole.

The left adrenal gland forms a cap over the upper pole; an adrenal mass will depress the kidney. The **right adrenal** gland covers the medial aspect of the upper pole; a mass located here rotates the upper pole laterally.

Relation of the Kidney to the Thorax

Half of the left kidney and one-third of the right kidney lie above the 12th rib and so are within the thoracic cage (Fig. 12-49). Behind the upper pole of either kidney is the **pleural reflection**, its edge running in a transverse plane along the periosteum of the **12th rib**, where it intersects the rib at its midpoint, which is 4 cm from the **costovertebral joint**. For estimation of the level of the pleural reflection and sulcus, the presence or absence of the 12th rib must be determined by viewing a film or counting the ribs.

The percutaneous approach to the kidney is best made below the 12th rib because of the appreciable risk of pneumothorax or hydrothorax from the endoscopic tract traversing the pleura. If the endoscopic instrument is placed too close to the rib, maneuverability is limited.

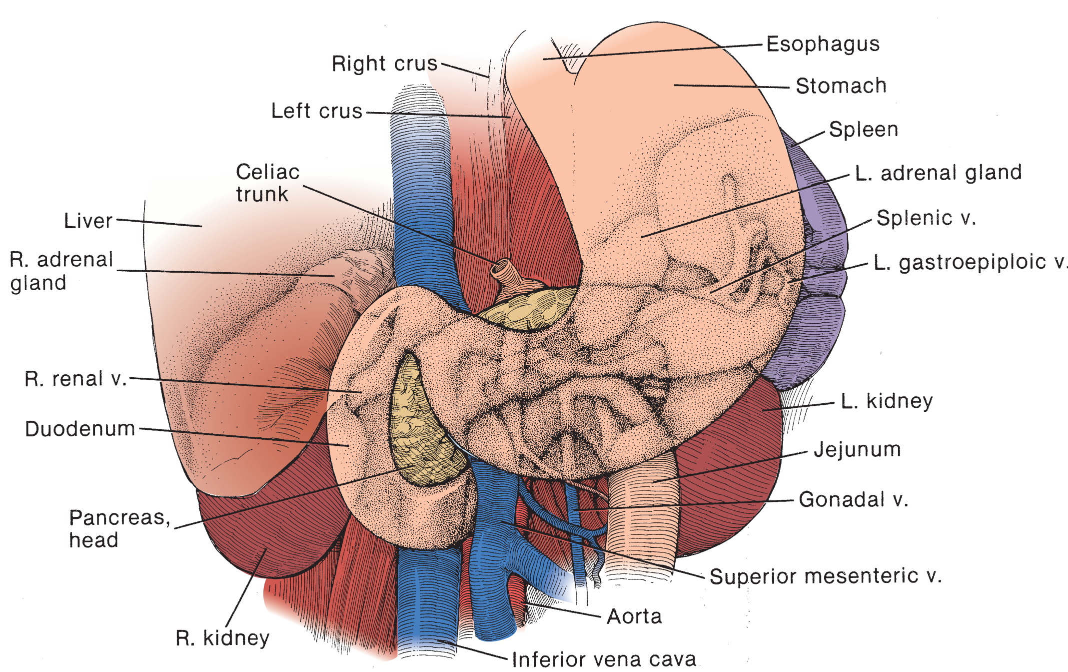


FIGURE 12-48.

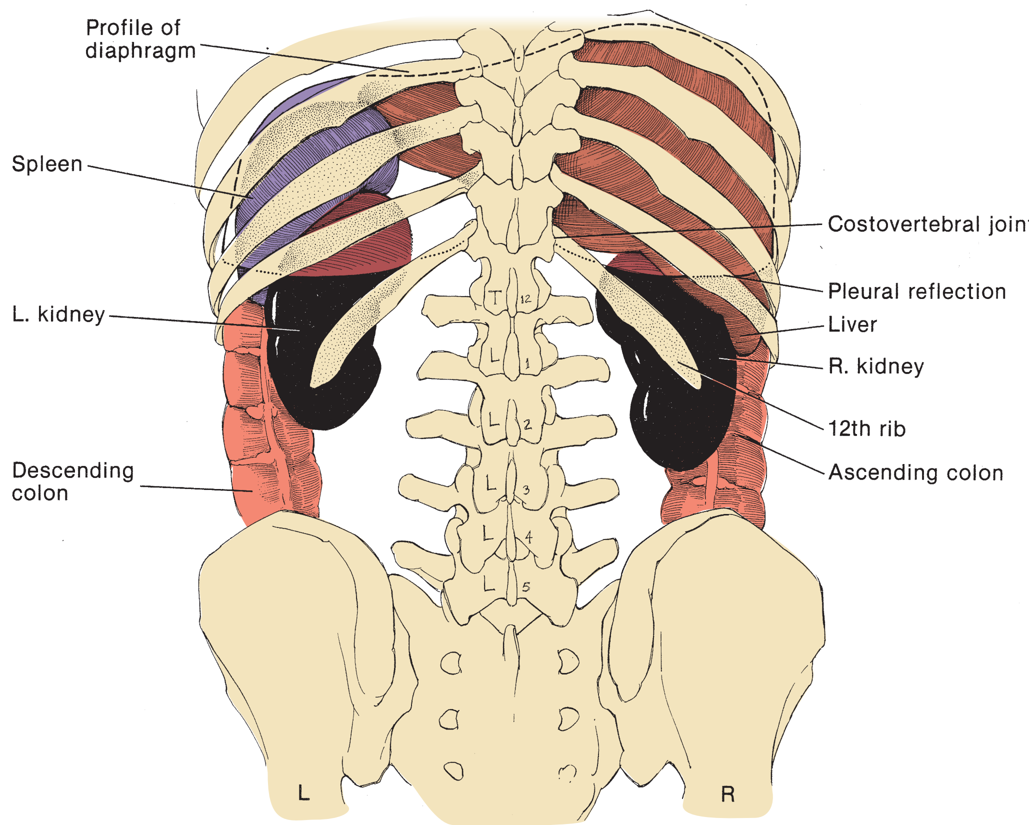


FIGURE 12-49.

Transverse Body Section, T12 Level, Viewed from Below

Right Side (R)

The upper pole of the **right kidney** is surrounded by fat in the **perirenal space** contained within the **anterior** and **posterior laminas** of the **renal fascia** (Fig. 12-50). The **adrenal** is in the anterior portion of the compartment. The **transversalis fascia** and **crus of the diaphragm** lie dorsally. The **11th intercostal artery** and **nerve** run beneath the **11th rib** anterior to the intercostal musculature. The **right lobe of the liver**, with the **right** and **middle hepatic veins**, is within the **peritoneal cavity** anterior to the **renal fascia**. The **inferior vena cava** is anterior to the **right crus**.

Left Side (L)

The section crosses the upper portion of the **left kidney** and the lower part of the **left adrenal gland**. The two laminas of the **renal fascia** enclose them and continue laterally as the **lateroconal fascia**. The **posterior pararenal space** lies dorsal to these fascias. The **spleen** and **stomach**, surrounded by **visceral peritoneum**, are suspended by the **gastrosplenic ligament**. A portion of the **pleural space** is seen anterior to the **diaphragm**. The **thoracic aorta** lies behind the **left crus of the diaphragm** adjacent to the **thoracic duct**.

Transverse Body Section at the L1 Level

The **renal arteries** divide into **segmental arteries** as they enter the renal hila (Fig. 12-51). The lowest part of the **adrenal gland** is at this level on the right. At this level, neither **diaphragmatic crus** covers the front of the **aorta**. The **celiac ganglia** lie anterior to the right and left crura of the diaphragm to cover the anterior surface of the aorta. The **ascending lumbar vein** lies against the body of the L1 vertebra. The **epiploic foramen** marks the entrance to the **lesser sac**, and separates it from the **peritoneal cavity** (greater sac). The **portal vein** and **common bile duct** are anterior to the foramen. The splenic vein runs to the left.

Dorsal to the **12th rib** and the **right** and **left kidneys** are the **iliocostalis muscles** with the adjacent **longissimus**.

Transverse Section at the L2 Level

The **right ureter** is anteromedial to the lower pole of the kidney. The **right lobe** of the **liver** covers the **right kidney**.

The **left renal vein** issues from the vena cava, and the **left renal artery** branches from the aorta (Fig. 12-52). The **left gonadal vein** lies lateral to a main branch of the renal vein. The **portal vein** is anterior to the **vena cava**. The **splenic** (left colonic) **flexure** is anterior to the renal fascia and intervenes between the **spleen** and the **left kidney**. The tail of the **pancreas** overlies the left kidney.

The **quadratus lumborum** forms a backing for the kidney, with the **erector spinae** posteriorly and the **latissimus dorsi** laterally.

Transverse Section at the L2–l3 Level

The **jejunum** lies anterior to the **left kidney** behind the body of the **pancreas**. The **ascending colon** is anterior to the **right kidney** behind the right lobe of the **liver** (Fig. 12-53). The **ureters** are placed in line with the lateral

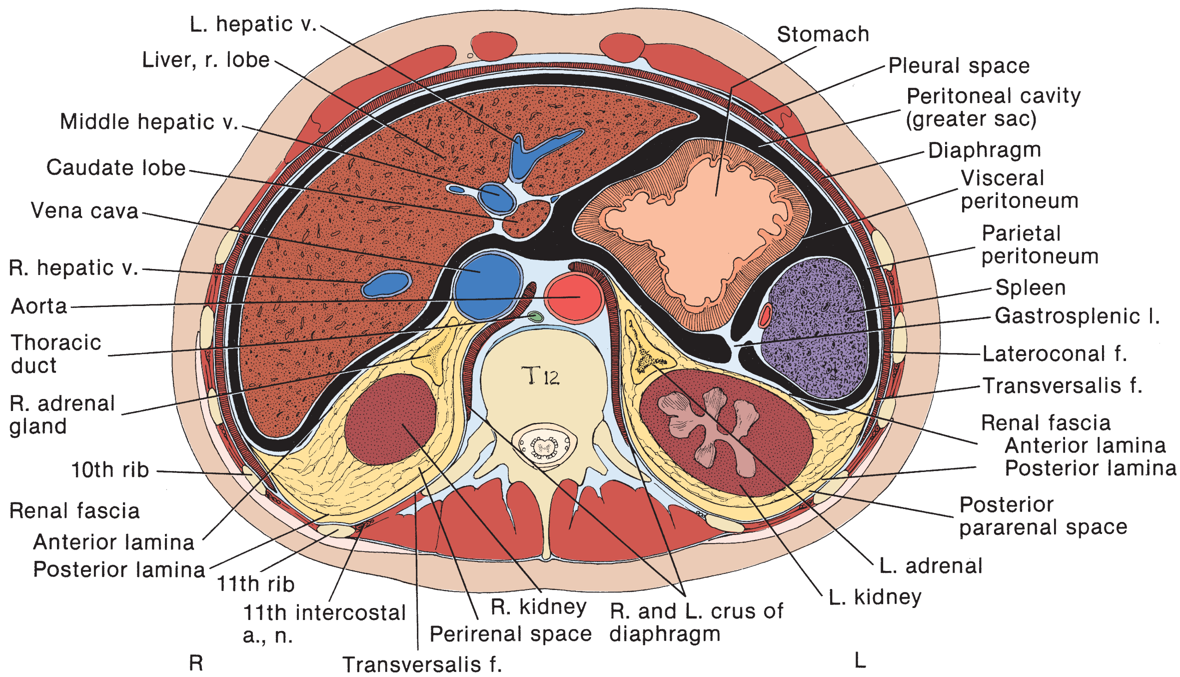


FIGURE 12-50.

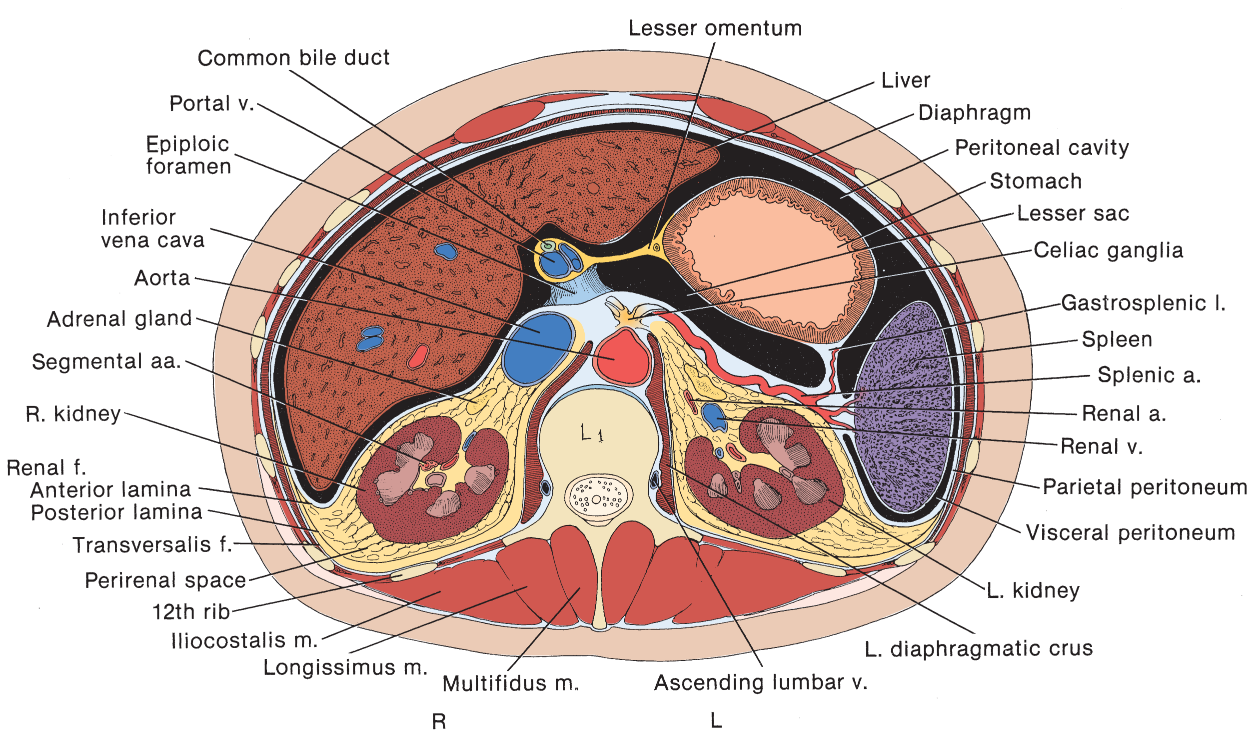


FIGURE 12-51.

aspects of the **vertebral body**. The **left gonadal vein** lies anteromedially from the ureter. The **aorta** is in the midline. The diaphragm does not reach this level. The **lateroconal fascia** extends anteriorly from the fusion of the two laminas of the **renal fascia**.

The left kidney is backed by the erector spinae (iliocostalis, longissimus, and multifidus) behind the quadratus lumborum.

Sagittal Section of Upper Trunk on the Right Side, Through the Renal Hilum

The descending portion of the duodenum and the hepatic flexure of the colon lie above the jejunum. The gallbladder, portal vein, common hepatic duct, and the right lobe of the liver with the ligamentum teres lie in a plane slightly cephalad.

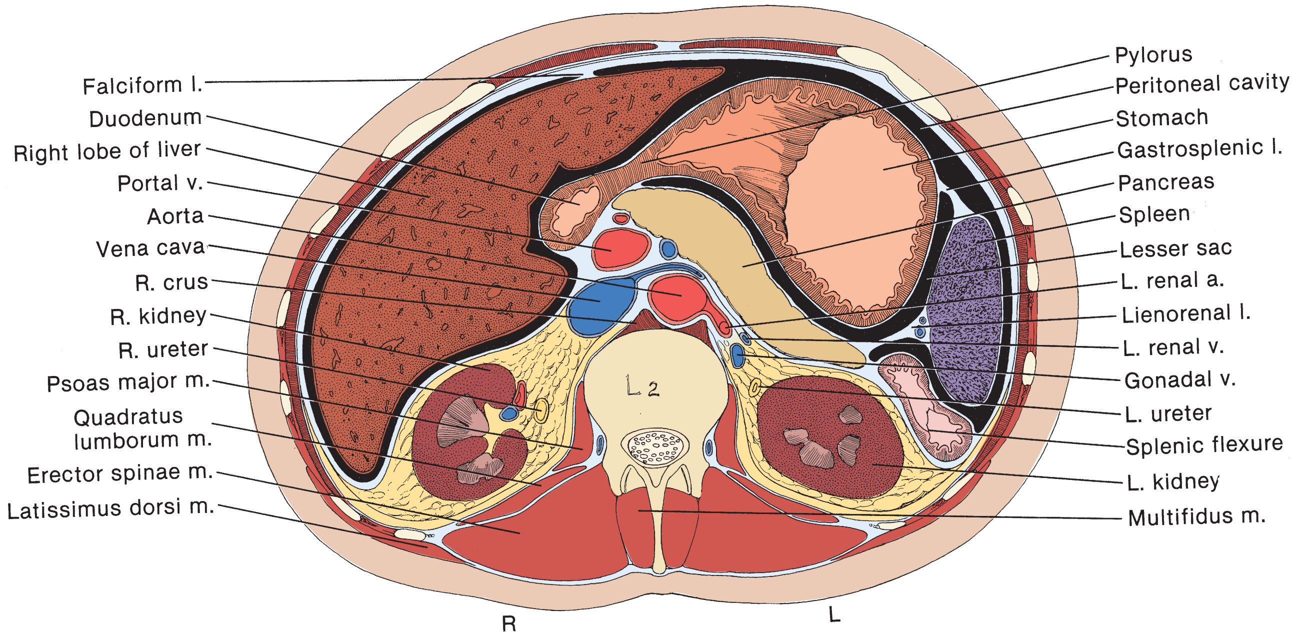


FIGURE 12-52.

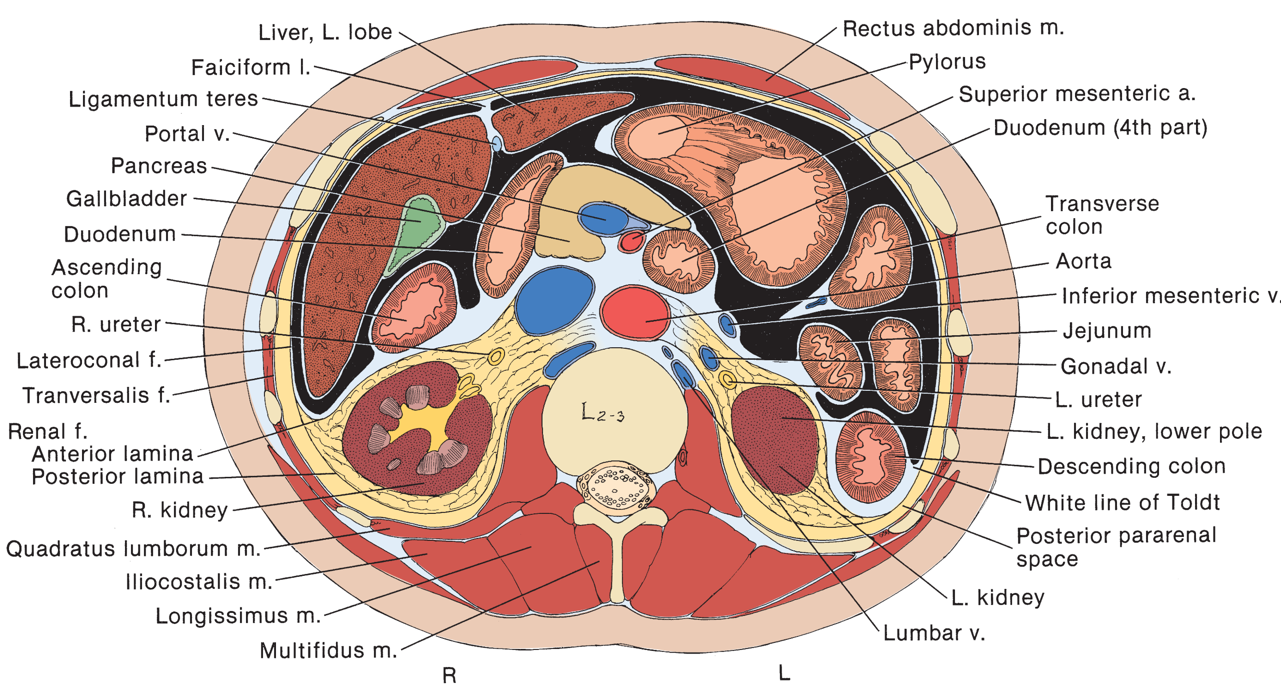


FIGURE 12-53.

The **right kidney** lies deep to the **latissimus dorsi,** the **iliocostalis** part of the erector spinae, the **quadratus lumborum,** the **12th rib,** and the **psoas major** (Fig. 12-54). The **renal hilum** contains branches of the renal artery and the renal vein.

The **anterior** and **posterior lamina** of the **renal fascia** enclose the **perirenal space,** with the **pararenal space** posterior over the **transversalis fascia.**

Sagittal Section Through the Right Adrenal

The **right adrenal** lies at a level between the 11th and 12th ribs below the **caudate lobe of the liver** and is adjacent to the **inferior vena cava** (Fig. 12-55). The superior and descending portions of the **duodenum** lie slightly inferiorly. The **right renal artery** crosses in the **perirenal space.**

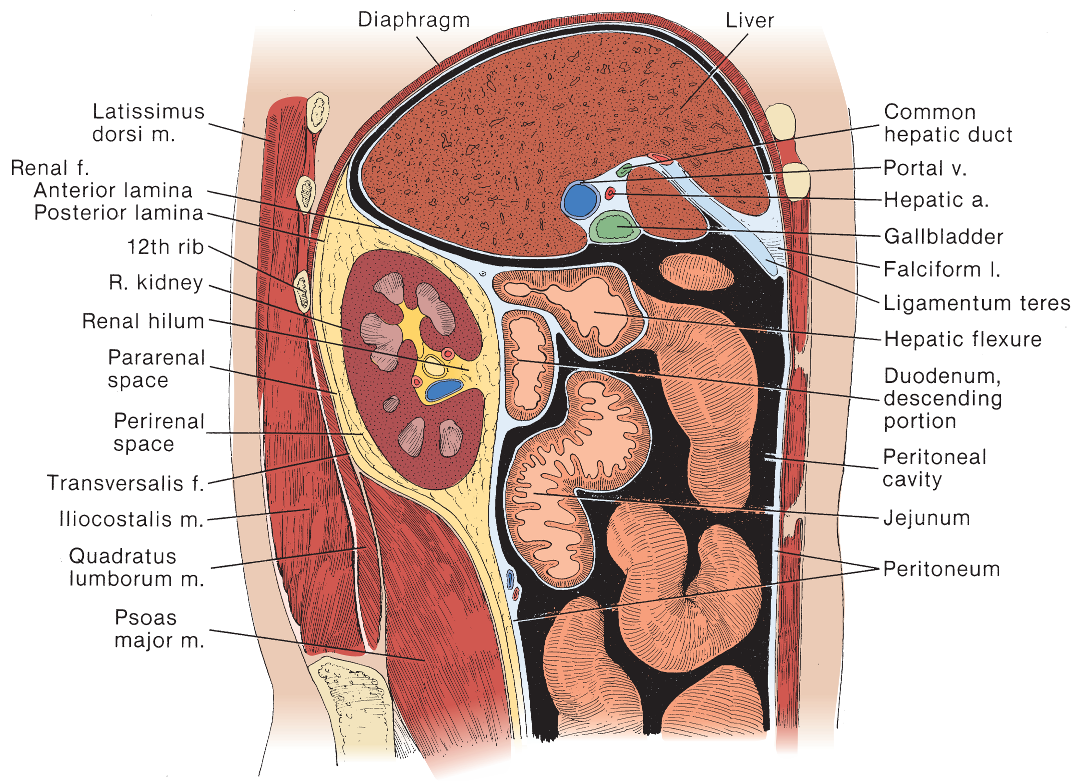


FIGURE 12-54.

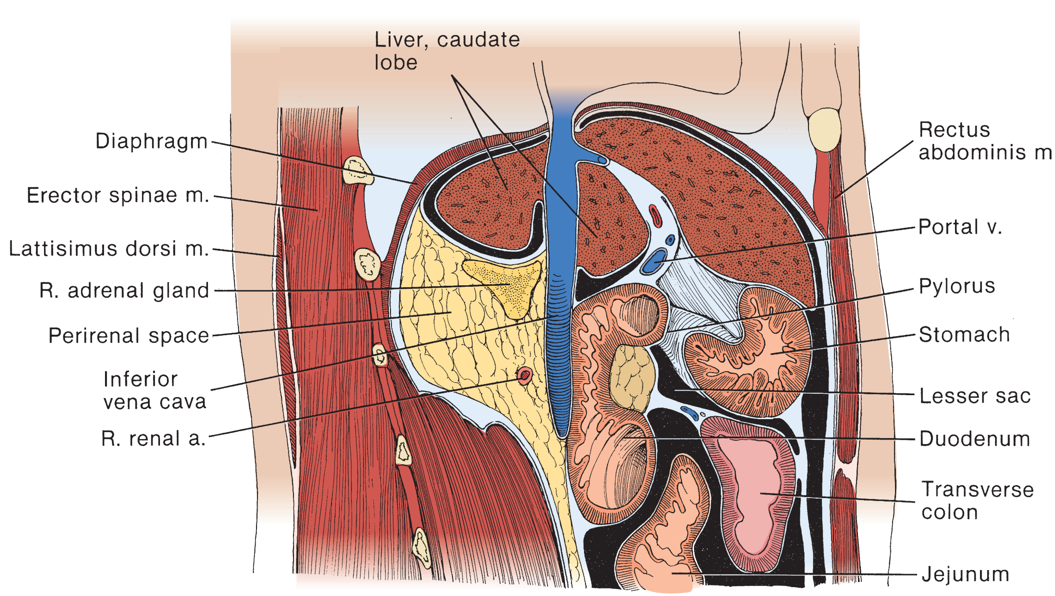


FIGURE 12-55.

Sagittal Section Through the Left Kidney

The **body of the pancreas** and the **splenic vein** and **artery** lie anterior to the upper pole of the **left kidney,** with the **spleen** situated superiorly and the **body of the stomach** anteriorly (Fig. 12-56). The **short gastric arteries** are found between the spleen and pancreas. The **greater omentum** joins the stomach to the **transverse colon,** which in turn is supported by the **transverse mesocolon.** The **descending colon** is anterior to the lower renal pole. The branches of the renal artery and the renal vein are in the hilum, and the ureter lies just outside. The **quadratus lumborum** and **iliocostalis** overlie the kidney dorsally.

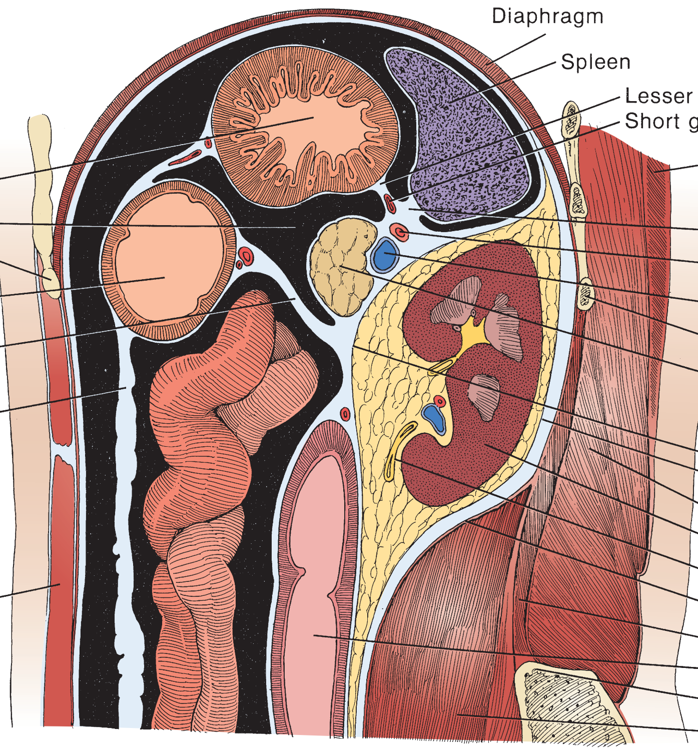


FIGURE 12-56.

Coronal Section Through the Renal Hila

On the right side, the **right kidney** is opposite the **L2** and **L3 vertebrae,** next to the **psoas major,** encased in the **perinephric space** (Fig. 12-57). The **right adrenal gland** is superior, adjacent to the lumbar portion of the **diaphragm.**

On the left side, the **left kidney** is opposite **L1** and **L2,** with the **head of the pancreas** and **splenic artery** and **vein** above. The **left adrenal gland** is over the upper pole. The **splenic flexure** lies lateral to the kidney.

RENAL STRUCTURE

Developmentally and anatomically, the kidney may be divided into two parts: secreting and conducting. The secretory structures are the glomeruli, proximal convoluted tubules, loops of Henle, and distal convoluted tubules. The conducting structures are the collecting tubules, the minor and major calices, and the pelvis.

Gross Structure

The kidneys tend to be of the same dimensions and general configuration, the size depending on that of the individual. The exception is that in newborns, the size of the kidney relative to body weight may be as much as three times that of the adult. The kidney of the adult male is about 12 cm in length, 6 cm in width, and 4 cm in thickness and weighs about 150 g; that of the female is slightly smaller, with a weight of around 135 g.

Lateral Aspect

The anterior surface of the kidney is rounded, whereas the posterior surface is flatter (Figs. 12-58A and 12-59).

The depressions or lobulations seen on the surface of the kidney in young children are reflections of the **interlobar septa** or renal columns of Bertin that mark the divisions between the lobes. Before the age of 4 years, these grooves are prominent, but with the thickening of the peripheral cortex, they disappear. Their persistence indicates a different arterial arrangement, the arteries dividing extrarenally instead of in the hilum.

A deeper, **longitudinal groove** (the white line of Brödel) is seen anterior to the plane of the greater curvature. It marks the major division between the anterior and posterior row of pyramids and the corresponding rows of calices. Because the arteries do not follow the pattern of the calices, this depression is not an indication of the so-called avascular plane. In fact, major arteries to the anterior portion of the cortex cross this line.

Coronal Section

An opening in the concave border of the kidney, the **renal hilum**, admits the **renal pelvis, renal artery** and **vein,** lymphatics, and nerves into the **renal sinus** (Figs. 12-58B and 12-60). The sinus contains fatty tissue that is continuous with the perirenal fat. Although earlier anatomists believed the sinus to be closed at the hilum, observations on peripelvic extravasation show it to be open.

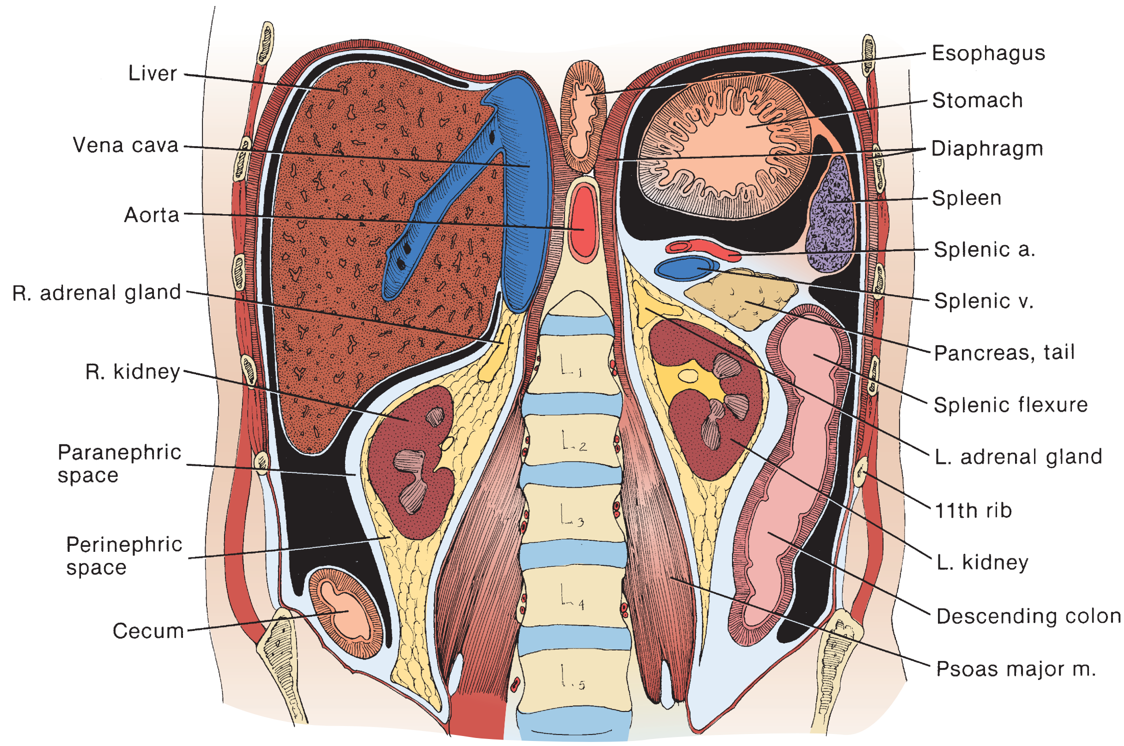


FIGURE 12-57.

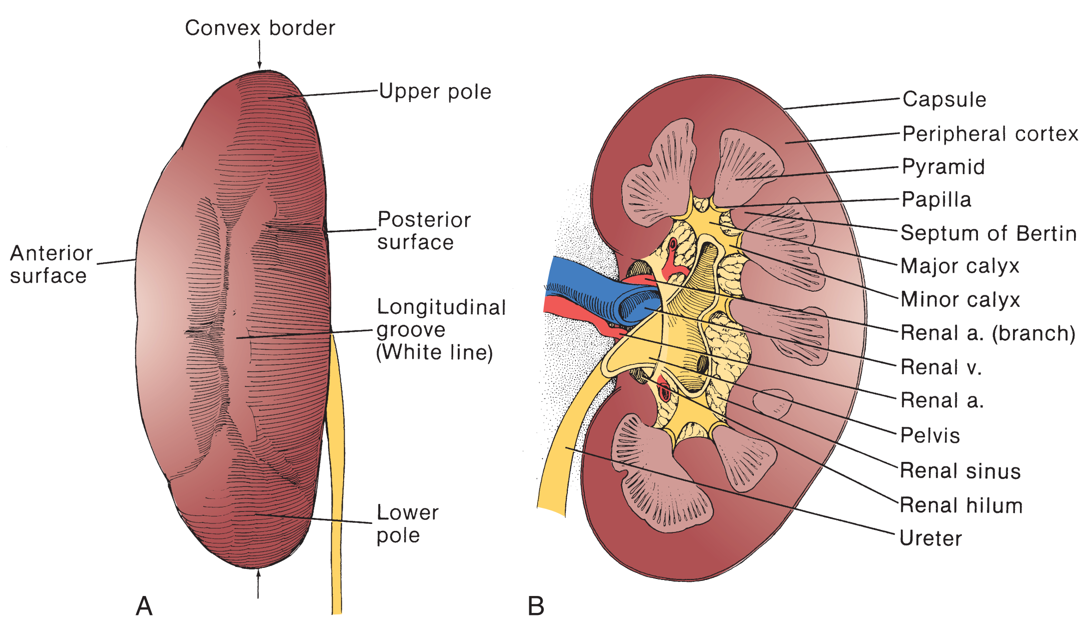


FIGURE 12-58.

The kidney is enclosed in a fibrous **capsule** that is readily separable from its surface, unless it has been involved in inflammation.

The tensile strength of the capsule is not great but is usually enough to hold mattress sutures, especially if bolsters are used. It has enough substance to be felt as resistance to a trocar entering for percutaneous nephrostomy.

The renal pelvis is joined by both **major** and **minor calices** into which the terminations of each **renal pyramid** intrudes as a **papilla.**

Calyces and their Parts

The conducting structures, ureter, pelvis and calyces, are a continuous entity, as one would expect from their embryonic origin as branches from the wolffian duct. They have similar coats and the smooth muscle in each has a helical arrangement as in the ureter, although the musculature of the ureter is thicker.

From a lobe, the **collecting ducts** in a **pyramid** empty into a **calyx** through a **papilla.** They open through a **cribriform**

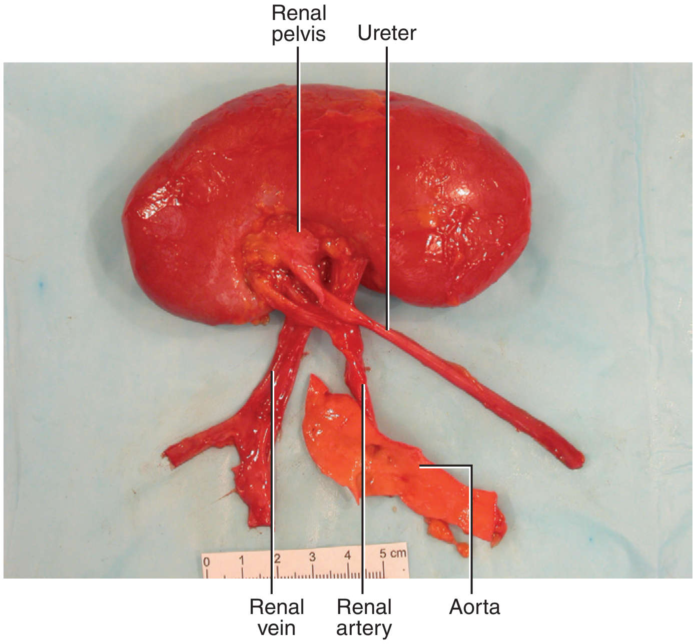


FIGURE 12-59. Normal kidney, showing gross structures before sectioning.

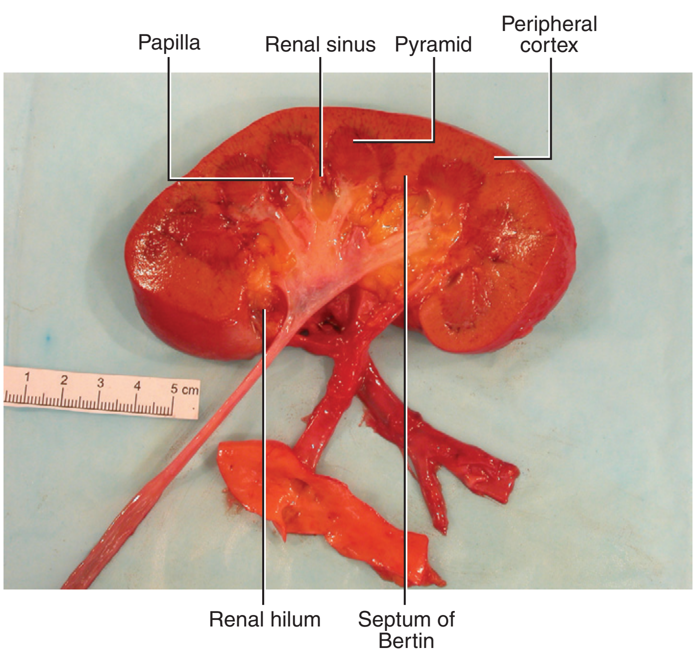


FIGURE 12-60. Normal kidney, coronal section through the center.

plate that is ringed by a **fornix.** A **minor calyx** drains a single, compound or conjoined papilla; a **major calyx** drains two or more minor calyces (Figs. 12-61A and 12-61B).

A **papilla** may be single and drain one **pyramid** of the kidney (**simple papilla**). Two or more papillae may fuse and come to lie together as a single entity. With the fusion, the medial margins of the calyceal cups lose their individual identity, resulting in a **compound papilla** that empties into a **compound calyceal cup.** With lesser degrees of pyramidal fusion, both papillae retain partial identity as **conjoined papillae** and drain into two calyceal cups that also retain their identities but do not develop separate necks. The result is **conjoined papilla** with a **conjoined** or composite **calyceal cup**.

The term *calyx* is applied to the combination of three elements: (1) a cup-shaped receptacle, (2) a connecting neck, and (3) a funneled tube that opens into the renal pelvis. The word *calyx* is also applied to the isolated cup and neck. Strictly, calyx means cup, so the word is appropriate for that cup-shaped portion into which the papilla protrudes. Because calyx is also the word used for the entire complex through such usage as *minor calyx* and *major calyx*, confusion arises when attempting to refer to the subdivisions of the complex. Despite the disadvantages of adding another term, for clarity the word *calyceal cup* replaces the strict meaning of *calyx* in this text. The term *infundibulum* is defined anatomically. The word *calyx* then means the combined system of cup, neck, and infundibulum (Figs 12-61C, D, E and 12-62).

The **calyceal cup** is the hemispherical portion of the calyx that is indented to accommodate the papilla. The proximal portion of the cup has a conical taper that connects the cup with the more proximal narrow part of the system, which is named the **calyceal neck** (Fig 12-61C). In a **minor calyx**, the neck provides the transition from the taper of the cup to the expanse of the renal pelvis. In a **major calyx**, the neck is the connection of the cup to the wider lumen of the next segment, the **calyceal infundibulum.** The infundibulum intervenes between the necks (and cups) of two or more papillae before connecting to the pelvis. The term is appropriate because the structure resembles and functions as a funnel, collecting from the necks and emptying at the **infundibulopelvic junction.** Thus, by definition, a minor calyx has one neck and one cup; a major calyx has at least two necks and two or more cups joined to the pelvis by an infundibulum.

To summarize, a *minor calyx* is a combination of *calyceal cup* and *calyceal neck*. A *major calyx* drains two or more *calyceal cups* and accompanying *calyceal necks* through a *calyceal infundibulum* into the renal pelvis.

The **pelvis** can be considered a dilated portion of the **ureter**, with the **calyces** as its branches.

The pelvis divides primarily into two or three **major calyces**, defined as those with an infundibulum and two or more necks and cups (Fig. 12-61D). Secondary division of the major calyces results in seven or eight nonbranching **minor calyces**. In the typical kidney, these are arranged in two longitudinal rows, with the calyceal necks of those in the posterior row being more attenuated than the stubbier anterior ones. The ends of the kidneys are drained by upper and lower pole calyces that are frequently compound or conjoined.

Two types of pelves are recognized: The common one has a funnel shape that remains open to receive urine prior to ureteral peristalsis; the other has a more rounded shape with an apparently closed outlet, the box pelvis. From a surgical viewpoint, the pelvis is considered intrarenal or extrarenal depending on its relation with the hilum, and intermediate variations are possible. An intrarenal pelvis may be viewed as the result of later division of the ureteric bud, resulting in shorter calyces than in the extrarenal type.

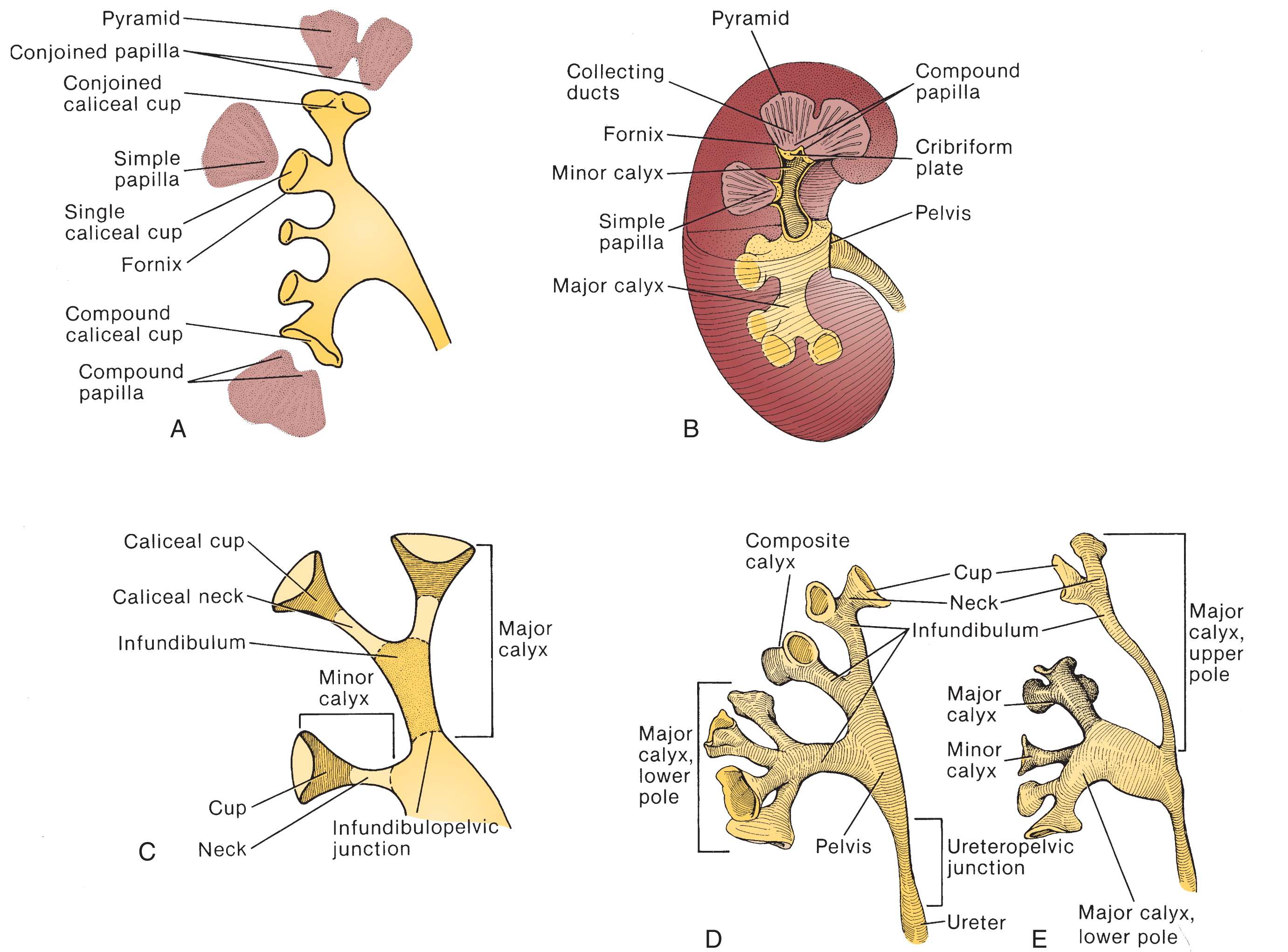


FIGURE 12-61.

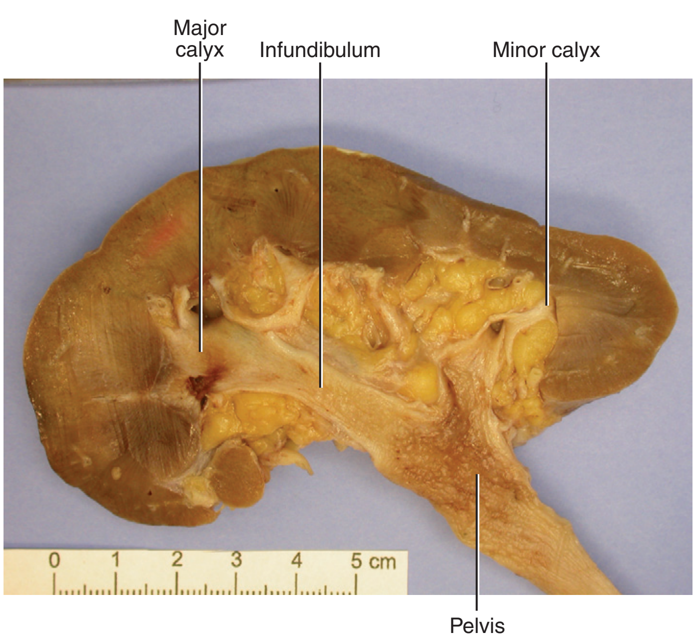


FIGURE 12-62. Normal kidney, coronal section, showing features of the upper collecting system. *(Image courtesy of Pedro Ciarlini, MD.)*

Such a pelvis makes surgical access to and manipulation within the interior of the kidney more difficult. The capacity of the pelvis is about 6 ml; volumes higher than 15 ml may be considered abnormal.

The major calyces may develop from a single pelvis (true pelvis of Brödel), from a transitional form, or from a divided pelvis with a zone of cortical substance between the second and third, and the fourth and fifth complete calyces.

The divided pelvis, the extreme of which is the bifid pelvis shown in the figure, has a smaller **upper pole major calyx** and a larger **lower pole major calyx**, leaving the midportion of the kidney without branches (Fig. 12-61E). In the divided kidney, the arrangement of the minor calyces seldom follows the usual anteroposterior pattern, thus posing problems for calyceal puncture and requiring oblique radiographs.

Radiologic Orientation

The kidneys usually extend from the level of the T12 to L3 vertebrae, being slightly lower in females. The right kidney lies 1 to 2 cm lower than the left. The kidneys are slightly rotated on a vertical axis in three planes: coronal, transverse, and sagittal.

Coronal Projection

The upper pole is more medial than the lower by an angle of 13° (Fig. 12-63A).

Transverse Projection

The pelvis and hilum have a more anterior position than the outer convex border by an angle of 30° (Fig. 12-63B).

Sagittal Projection

The long axis of the kidney is angled posteriorly by about 10° (Fig. 12-63C).

Radiologic Orientation for Endourology, Right Kidney

In transverse section, the body is shown placed in the oblique position preparatory to puncture of a posterior calyx.

It is necessary to know the angles that the calyces take relative to the coronal plane of the body prior to percutaneous puncture (Fig. 12-64). The use of lateral and oblique radiographic views in addition to an anteroposterior view allows mental construction in three dimensions. Computed tomographic reconstruction of pyelograms produces a three-dimensional image that can be useful.

The orientation of the calyces is variable. At the poles, the angles taken by the necks of the compound or conjoined calyces are not constant, but those in the midportion of the kidney are aligned in two rows anteriorly and posteriorly at an angle of about 70° to each other (right, 60° + 16° = 76°; left, 63°).

Measurement from the Coronal Plane of the Body

For the right kidney, the angle of the **axis** of the **anterior calyces**, measured anteriorly from the coronal plane of the body, averages 16°. The angle of the **posterior calyces** averages 60° posterior to the coronal plane.

Measurement from the Frontal Plane of the Kidney

From the **frontal plane** of the kidney, the angles are 46° anteriorly for the **axis** of the **anterior calyces** and 30° posteriorly for that of the **posterior calyces.**

Radiologic Orientation for Endourology, Left Kidney

Orientation from the Coronal Plane of the Body

The angle of the **axis** of the **anterior calyceal angle** is 3° anterior to the **coronal plane of the body**. The typical anterior set of calyces lies close to the coronal plane. Therefore, most portions of an anterior calyx are visualized on a urogram of a supine subject, whereas the posterior calyces appear end-on. The angle of the **axis** of the **posterior calyx** is 60 degrees posteriorly from the coronal plane (Fig. 12-65).

Orientation from the Frontal Plane of the Kidney

From the **frontal plane of the kidney**, the **anterior calyces** have an angle of 33° anteriorly; the **posterior calyces** have a similar angle of 30°, but posteriorly. However, there is great variation in calyceal morphology and arrangement.

For an estimation of renal mass, measurement from the papillary tip of an anterior calyx to the surface is fairly

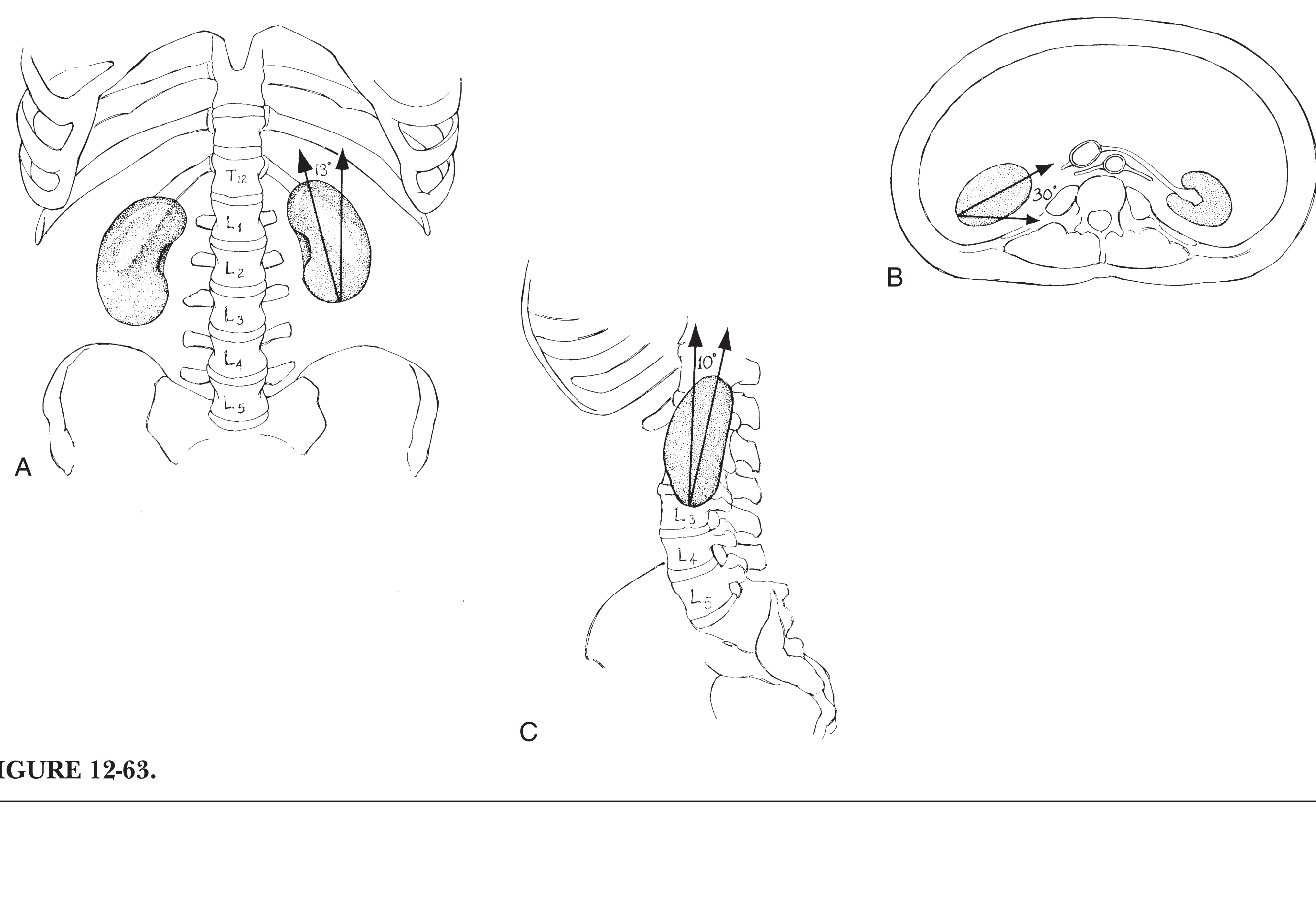


FIGURE 12-63.

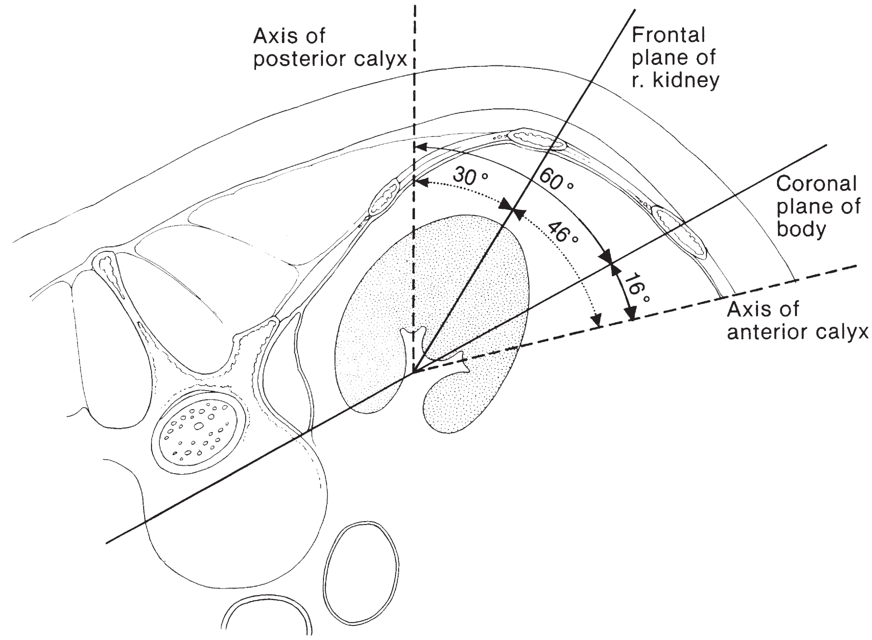


FIGURE 12-64.

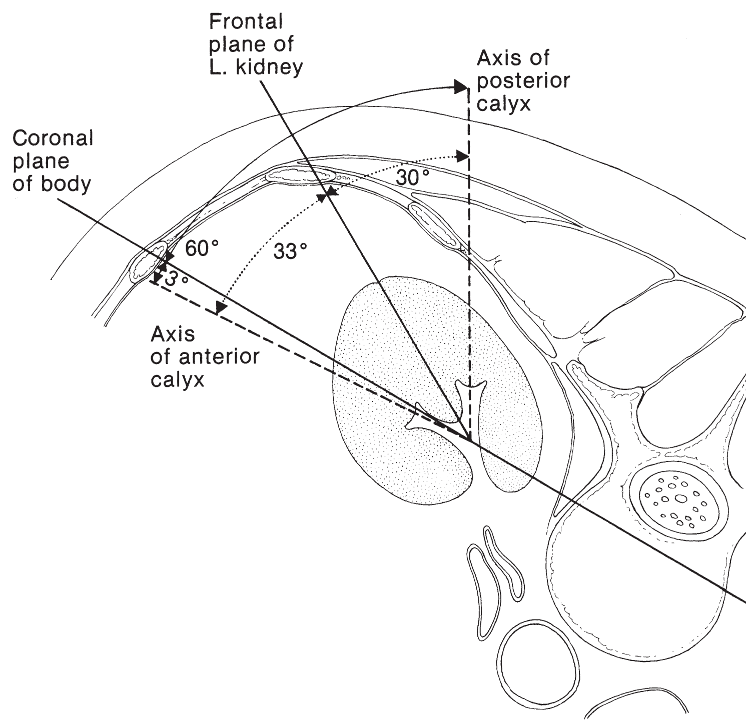


FIGURE 12-65.

reliable if it is combined with measurement of overall renal length.

INTRARENAL STRUCTURES

Fornix and Papilla

The **papilla** of the renal **pyramid** invaginates into the **calyceal cup** of a minor calyx (Fig. 12-66). The **fornix** marks the site where the wall of a calyceal cup joins the **renal parenchyma**; it appears as a rim around the base of the papilla. The fornix is marked at the margin of the papilla by a change from the thick, whitish epithelial wall of the calyx to the darker and more transparent covering of the papilla. Microscopically, the transitional epithelium of the calyx changes abruptly to a single layer of low cuboidal epithelium where the calyx joins the papilla at the fornix (Fig. 12-67).

Beneath the fornix, an extensive **vascular bed** drains into the interlobar arteries and veins and into lymph collectors. In addition, the fornical rim acts as a hinge for mobility of the wall of the cup because the fornix is able to round out during ureteral obstruction, making the calyceal cup appear more spherical on pyelography. With gross overdistention, the junction between cup and papilla ruptures, allowing urine access into the veins (pyelovenous backflow), into the lymphatics (pyelolymphatic backflow), and into the

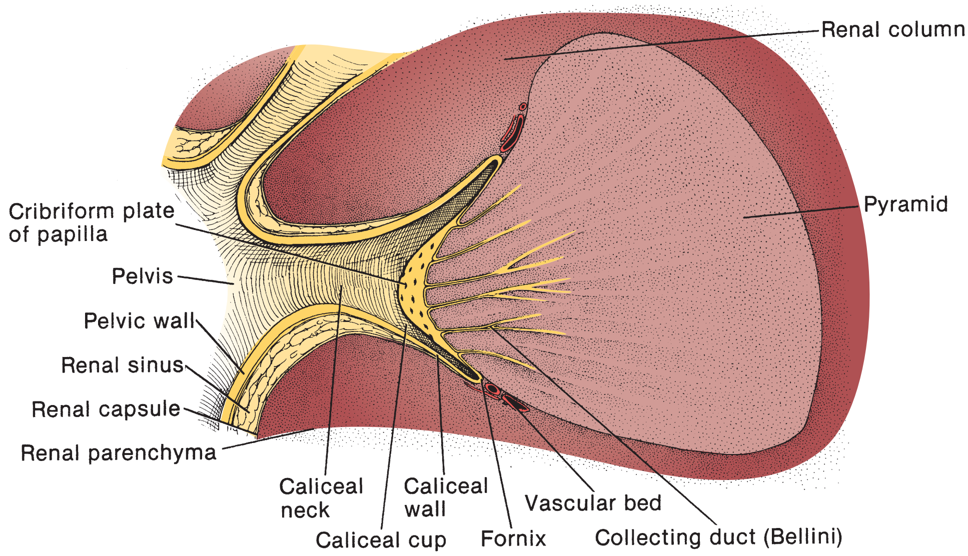


FIGURE 12-66.

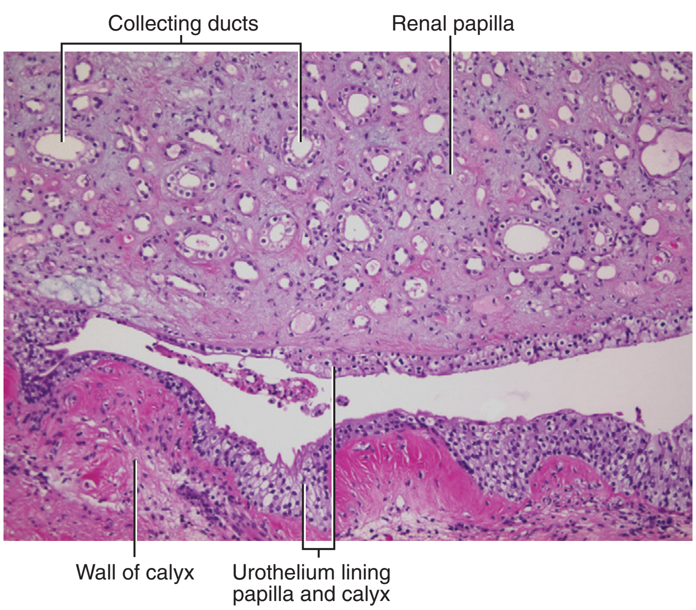


FIGURE 12-67. Normal kidney. In the upper half is the tip of a papilla, with cross sections of collecting ducts. In the lower half is a minor calyx, lined by layers of urothelial cells. *(From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

renal sinus between the **calyceal wall** and the **renal capsule** (peripelvic extravasation). Studies using injection of India ink have shown that the pathway developing during acute obstruction passes from the fornix to the perirenal space through the renal sinus.

The papilla is surmounted by the **cribriform plate**, on which the **collecting ducts** of Bellini open.

Structure of the Pelvic and Calyceal Wall

The conducting structures are contained in the *renal sinus*, which extends from the fornix at the papillary rim to the hilum. Areolar tissue surrounding the pelvis and the vessels, and the nerves and the lymphatics in the hilum is continuous with perirenal fat.

The *pelvis and calyces* have three coats. An inner mucosa is lined with transitional epithelium distributed over a submucosa. A muscular layer is formed from a coat of muscle fibers, each fiber following a more or less helical path that together forms three layers interspersed with elastic tissue (see Fig. 12-83). The muscle is covered by a connective tissue sheath.

The *pelvicaliceal muscle* has been found to be of two types. A so-called typical form of smooth muscle lines the pelvis that is similar to the muscle of the ureter. An atypical form is found in each minor calyx extending into the fornix in a way that links adjacent calyces. More distally, these atypical cells form a thin coat over the typical muscular layer as far as the ureteropelvic junction. They are thought to influence the muscular activity of the calyces and pelvis that is initiated by spontaneously active pacemakers situated at the ends of the minor calyces. From these sites, a basic contraction rate is started that passes down the calyceal wall to the pelvis and thence to the ureteropelvic junction. Depending on the rate of urine production, fewer or more of the impulses are transmitted through the junction into the ureter, where they initiate ureteral peristalsis. A contraction initiated in a calyx may be coordinated with those from other calyces and result in a pelvic contraction, or if it is not in phase, it is the contraction from the calyx with the highest frequency of contraction that will dominate. With obstruction, coordination is disrupted. Although nerve impulses play a role, the principal factor in peristalsis is the quantity of urine within the calyx, pelvis, or ureter that stimulates myogenic activity, as shown by its continuation after renal denervation.

A pacemaker function has also been found at the ureteropelvic junction, an area that responds to increased flow by increased activity that is then passed down the ureter by myogenic transmission.

Organization of the Renal Parenchyma

LOBES. Anatomically, the kidney has two divisions: (1) a peripheral **cortex** beneath the **renal capsule** and (2) a central **medulla**, consisting of the **renal pyramids** (Fig. 12-68A).

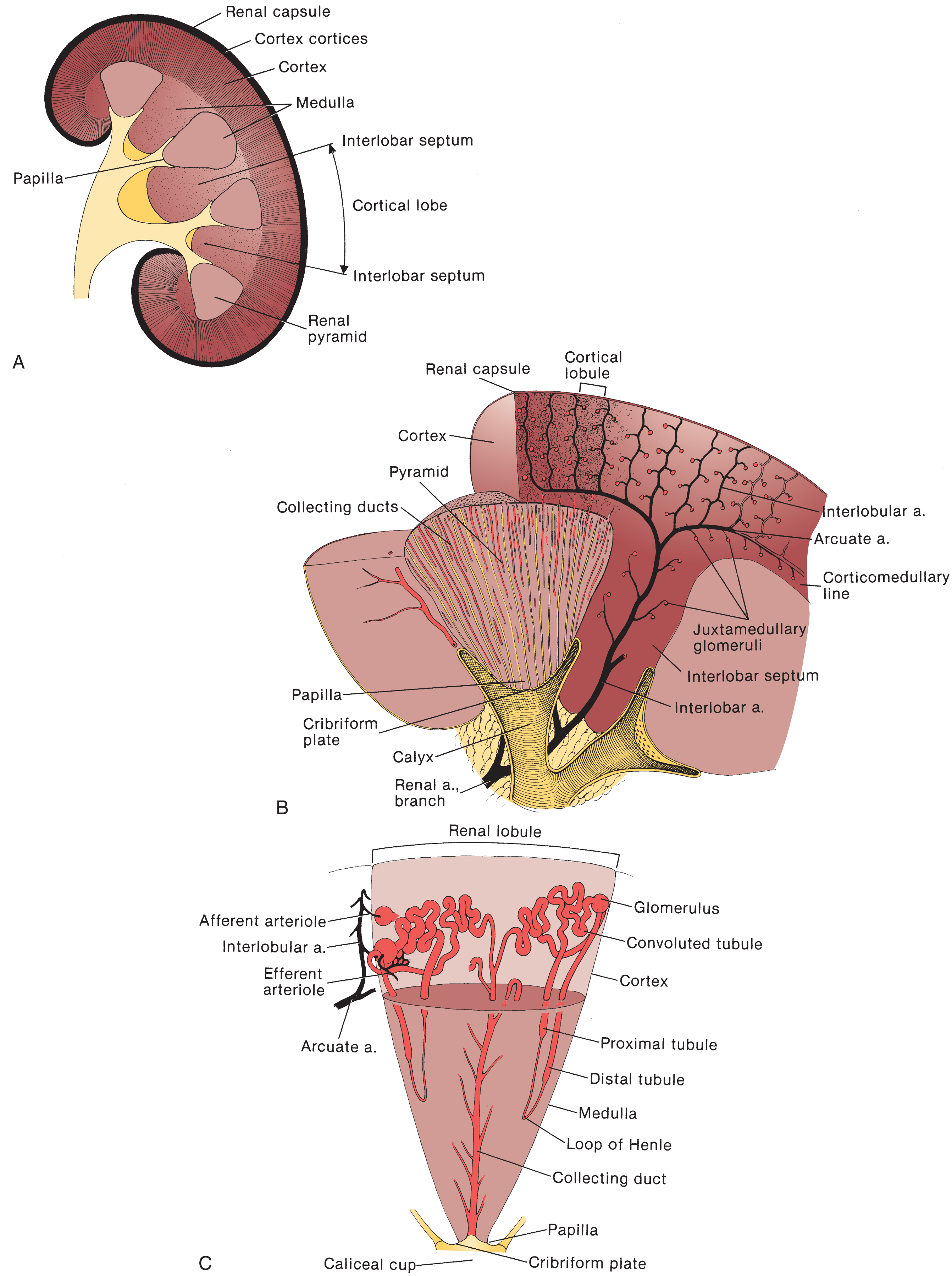

Renal capsule
Cortex cortices
Cortex
Medulla
Interlobar septum
Papilla
Cortical lobe
Interlobar septum
Renal pyramid
A
Renal capsule
Cortical lobule
Cortex
Pyramid
Collecting ducts
Interlobular a.
Arcuate a.
Corticomedullary line
Juxtamedullary glomeruli
Interlobar septum
Interlobar a.
Papilla
Cribriform plate
Calyx
Renal a., branch
B
Renal lobule
Afferent arteriole
Interlobular a.
Efferent arteriole
Arcuate a.
Glomerulus
Convoluted tubule
Cortex
Proximal tubule
Distal tubule
Medulla
Loop of Henle
Collecting duct
Papilla
Cribriform plate
Caliceal cup
C

FIGURE 12-68.

The outer zone of the cortex, the **cortex cortices**, is composed of convoluted tubules and contains no glomeruli. The **cortical lobes** make up most of the cortex, covering the base of the **pyramids** and intervening between them as **interlobar septa** (renal columns of Bertin). The cortex is thicker at the poles and also about the renal sinus, where it folds inward as the hilar lip.

The **interlobar septa** (renal columns) divide the kidney into compartments called **cortical lobes**, or ranunculi. There are usually seven lobes arranged in a row anteriorly and seven posteriorly, each having a **pyramid** containing the **collecting ducts** and loops of Henle, and a **calyx** (see Fig. 12-61).

Lobar Vasculature

The interlobar arteries ascend through the interlobar septa and divide into arcuate arteries at the corticomedullary line (Fig. 12-68B).

The **cortex** proper extends from the base of the pyramids to the **renal capsule**. It is subdivided into **cortical lobules** supplied by **interlobular arteries**. Between the cortex and the medulla are primitive **juxtamedullary glomeruli**.

The Renal Lobule

The **renal lobule**, the structural unit of the kidney, is a cylindrical conglomerate structure made up of several sets of **glomeruli** and **convoluted tubules** and **loops of Henle** that drain into a single **collecting duct** (duct of Bellini) (Figs. 12-68C and 12-69). The lobule is supplied by **interlobular arteries** through the **afferent arterioles**, which become **efferent arterioles** after passing through the **glomerulus** (Fig. 12-70). In the **medulla**, in addition to the collecting ducts, are portions of the **proximal** and **distal tubules** and the **loops of Henle**.

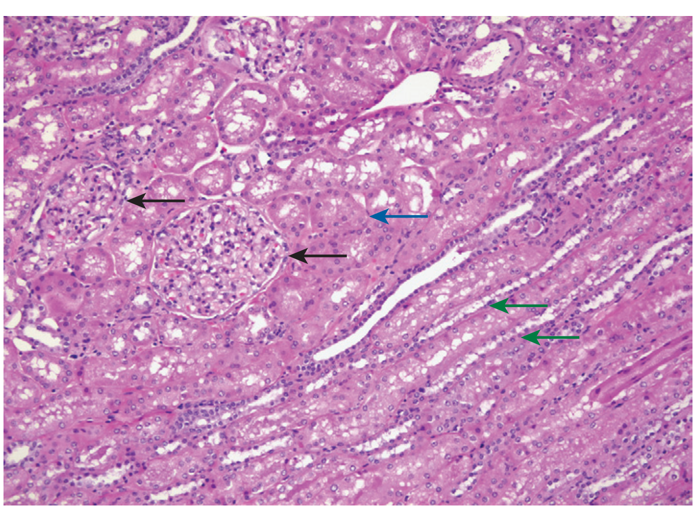


FIGURE 12-69. Normal kidney. The section is from the corticomedullary junction, and demonstrates glomeruli *(black arrows)* surrounded by convoluted tubules *(blue arrows),* and long straight medullary rays of Ferrein *(green arrows). (From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

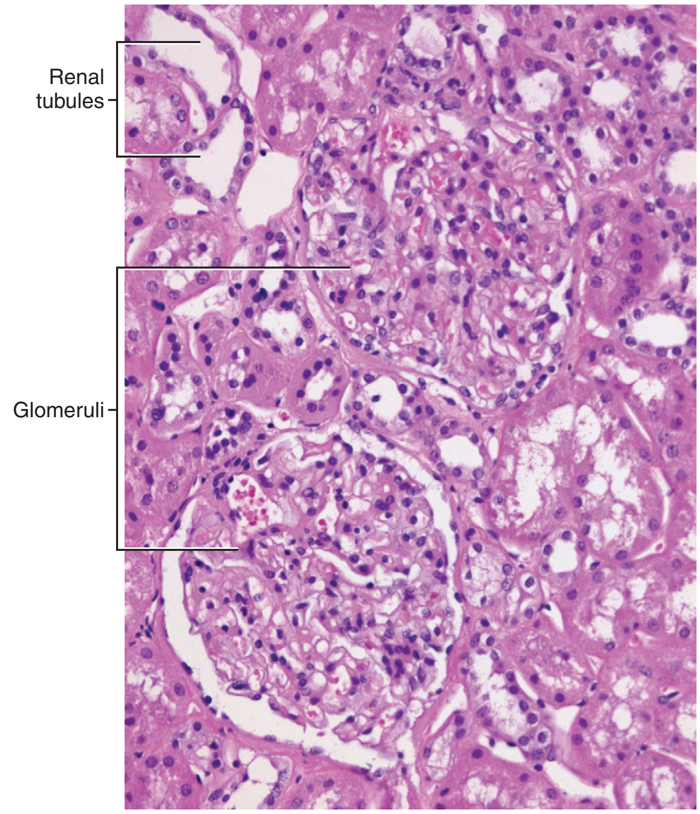


FIGURE 12-70. Normal glomeruli, surrounded by cross sections of convoluted tubules. *(From MacLennan GT, Resnick MI, Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

Renal scars from reflux pyelonephritis or papillary necrosis may be on a lobular basis from partial involvement of the papilla with multiple lobules involved, or in advanced cases, it may be on a lobar basis if the entire renunculus is involved.

Renal Blood Supply

Renal Arteries

The main renal arteries arise from the abdominal aorta and are single on both the right and left in three-quarters of cases. Arterial duplication is more common on the right and, if it is duplicated, both arteries are of approximately equal size. The main arteries almost always lie between the upper edges of the 1st and 3rd lumbar vertebrae, although the right artery is more often found slightly higher than the left, even though the right kidney itself is usually lower. In a quarter of cases, additional small vessels may go to the poles of the kidney from the abdominal aorta. If they are large, the accessory vessels are often arranged serially from the aorta, because they represent segmental arteries. A majority of accessory arteries to the lower pole enter the cortex directly. Arteries to the upper pole are typically small and arise from the main renal and pass on to the adrenal gland, with which the renal arterial supply has a close relationship. Supernumerary renal arteries also arise from the spermatic and superior mesenteric arteries.

Renal Arterial Supply, Right Kidney

The **renal artery** forms an **anterior division** that typically carries three-quarters of the blood supply and a **posterior division** that carries the rest. The avascular plane between these divisions lies in the axis of the posterior calices (Figs. 12-71A, 12-71B, and 12-71C).

Segmental Arteries

From the major anterior and posterior divisions, five important branches originate as segmental arteries: (1) apical or suprahilar, (2) upper, (3) middle, (4) lower, and (5) posterior segmental arteries. However, it must be understood that many different arrangements occur. These branches supply the five corresponding segments of the kidney.

Variations in the separation into anterior and posterior divisions can occur anywhere from the aorta to the renal hilum. Graves has classified the variations of arterial distribution of the other segmental arteries into three groups. In the first group, the lower artery branches off before the upper and middle arteries; in the second group, the lower artery arises with the upper artery and the middle artery branches from it; and in the third group, the vessels branch together.

Anterior Division

The **apical segment** lies on the medial side of the upper pole like a small cap and involves both the anterior and posterior portions of the kidney. Its arterial supply comes from the **apical segmental artery**, which typically arises from the **anterior division** of the renal artery, or from the artery to the upper segment, but variations are more frequent than with the other segmental arteries.

The **upper segment** is a region restricted to the anterior portion of the kidney and involves the remainder of the upper pole and the upper portion of the central part of the kidney. It is supplied through an upper and a lateral branch of the **upper segmental artery**.

The **middle segment** is that part of the anterior portion of the kidney between the upper and the lower segments. It receives blood from the **middle segmental artery**, a branch of the anterior division of the renal artery.

The **lower segment** involves the entire lower pole; thus, it is larger than the apical segment. Its supply, the **lower segmental artery**, may arise from the renal artery or its anterior division, from the upper segmental artery, or from the main artery at the same point as the other segmental arteries. After the artery passes anterior to the pelvis, it divides into an anterior branch supplying the anterior portion

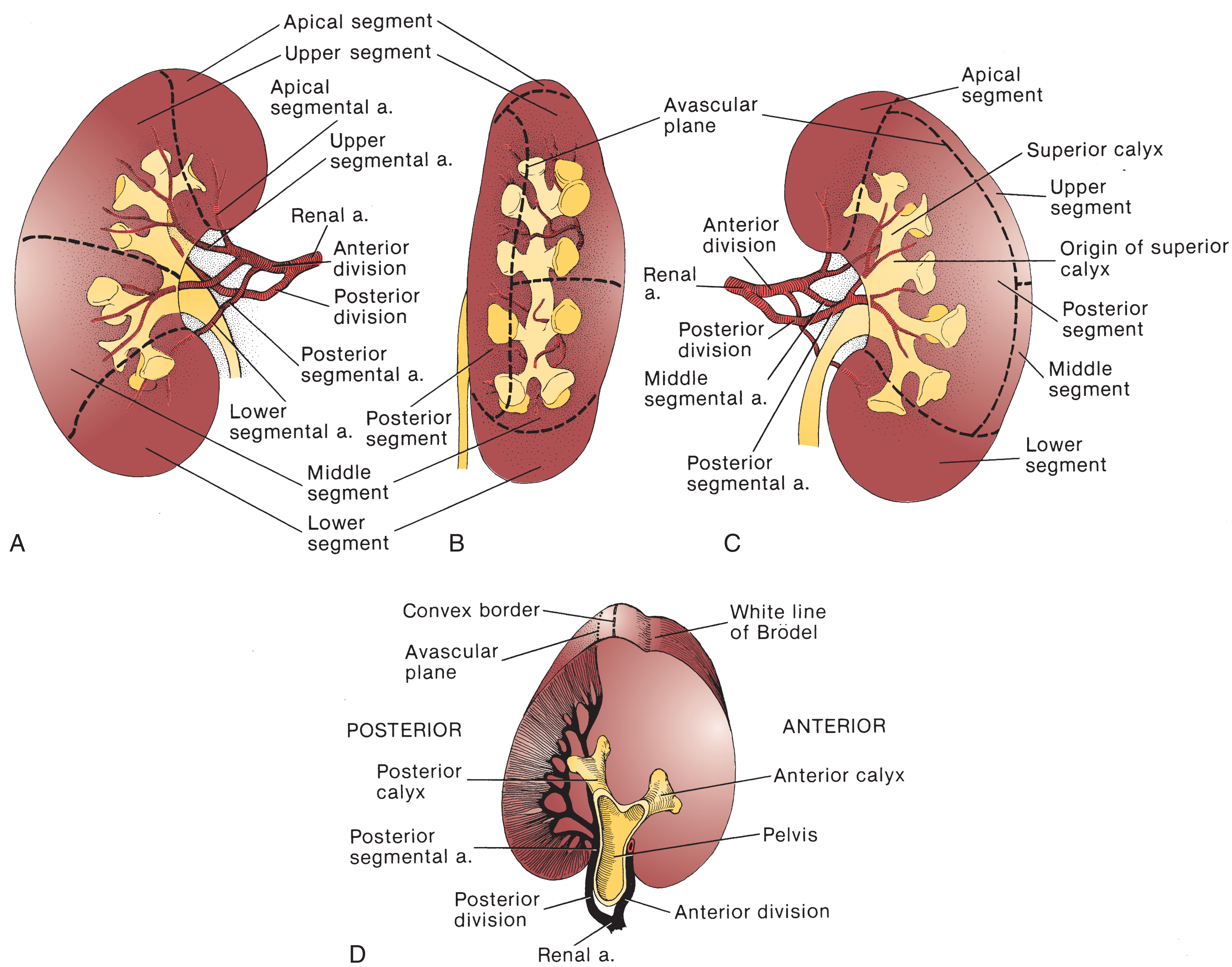


FIGURE 12-71. A, Anterior view. **B,** Lateral view. **C,** Posterior view. **D,** Transverse section showing the avascular plane.

of the lower pole and a posterior branch that runs behind the infundibulum of the inferior calyx (a site where it may be entered inadvertently) to supply a small portion posteriorly.

Posterior Division

The **posterior segment** involves all of the posterior portion of the kidney except that taken up by the polar segments. It is supplied by the **posterior segmental artery**, which constitutes the entire **posterior division** of the renal artery.

Of importance for surgery is the fact that the posterior segmental artery crosses behind the upper portion of the pelvis at a point very close to the origin of the **superior calyx** but also may be involved during mid-kidney and lower pole resection.

End-Arteries

The segmental arteries are end-arteries. In contrast to the venous system, there are no collateral branches to neighboring segments. However, intersegmental arterial anastomoses can be found between the capsular arterioles and those in the perirenal fat, although these are not of sufficient caliber to perfuse the kidney after loss of the major supply. Peripheral to the corticomedullary line, the size of the vessels decreases significantly, making incisions in that region less hazardous.

Heminephrectomy

Although the kidney is organized into lobes corresponding to papillary drainage, the vascular supply does not follow this embryonic arrangement. The line of incision for resection of a lobe, or more often, for heminephrectomy, follows the midplane of the interlobular septa (columns of Bertin) as far as the arcuate vessels, encountering little vascular interference from interlobular vessels. The arcuate vessel is then ligated on the incisional side of the interlobar artery, causing minimal devascularization.

The size of an artery is a guide to the size of the area supplied. During an operation, injection of indigo carmine into a segmental artery accurately outlines the segment supplied.

Percutaneous Approach

With a percutaneous approach to the collecting system for removal of renal calculi, bleeding is usually caused by injury either to one of the anterior segmental arteries or to the posterior segmental artery. The fewest vessels are found over the fornix of a papilla, so that puncture aimed end-on at a calyx is the safest method. For this reason, the preferred approach is posterolateral, with the instrument directed toward the fornix or an infundibulum of a middle or lower pole calyx. Too medial a direction encroaches on the posterior segmental artery where it crosses the posterior aspect of the renal pelvis. An anterior segmental artery may be injured when the puncture crosses the pelvis and enters the opposite wall.

Vascular Impressions

Indentations of the renal pelvis and caliceal infundibula by the renal artery are common, especially with an intrarenal pelvis, and may suggest renal masses. The defects may be divided into five groups: (1) indentation by the dorsal or, less often, the ventral branch of a renal artery as it crosses the neck of the upper calyx; (2) pressure of a ventral branch against the caliceal infundibulum; (3) deformation from a normal posterior segmental artery behind the pelvis; (4) indentation by a ventral branch against the pelvis; and (5) distortion of the ureteropelvic junction by a crossing renal artery. In addition, transient multiple defects are seen with incomplete filling of the pelvis.

Avascular Plane

The typical longitudinal depression on the curvature of the kidney marking the division between the anterior and posterior renal lobes has been called the **white line of Brödel** in the erroneous assumption that he had proposed it as the preferred route for nephrotomy. Brödel actually warned against this approach because he found that it would divide large branches of the anterior system. What he did find in his dissections was a plane lying more posteriorly than the white line and just anterior to the **posterior calices**, where the separation of the **renal artery** into **anterior** and **posterior divisions** provides a minimally vascularized zone between the arteries. This so-called avascular plane must lie posterior to the greater curvature of the kidney, because the anterior branches of the renal artery supply three times as much parenchyma as the posterior branch (Fig. 12-71D).

Vascularization of the Cortex and Medulla

The segmental arteries, after they pass between the calices, branch into interlobar arteries at the level of the fornix. Two or three run radially between the renal pyramids within the interlobar septum to the corticomedullary junction, where each interlobar artery turns at an angle to branch into an average of five to seven arcuate arteries that arch over the bases of the pyramids to terminate near their centers. In turn, an arcuate artery branches peripherally to form interlobular arteries and smaller perforating capsular arteries, both of which run vertically into the cortex (Fig. 12-72). The interlobular arteries may or may not branch before they supply afferent glomerular arterioles to one or more glomeruli, nutrient arteries to the convoluted tubules, or perforating capsular arteries (Table 12-8).

Afferent glomerular arterioles arise at all levels from the interlobular arteries "like branches from a tree." But some long afferent arterioles may come from the arcuate or interlobar arteries, where they first supply glomeruli and then pass centrally as **arteriae rectae**. The peripheral arterioles take a more vertical course, appearing as continuations of the interlobular arteries. The afferent glomerular arteriole forms a terminal **glomerular capillary plexus** within the glomerulus, the branches of which reunite as the **efferent**

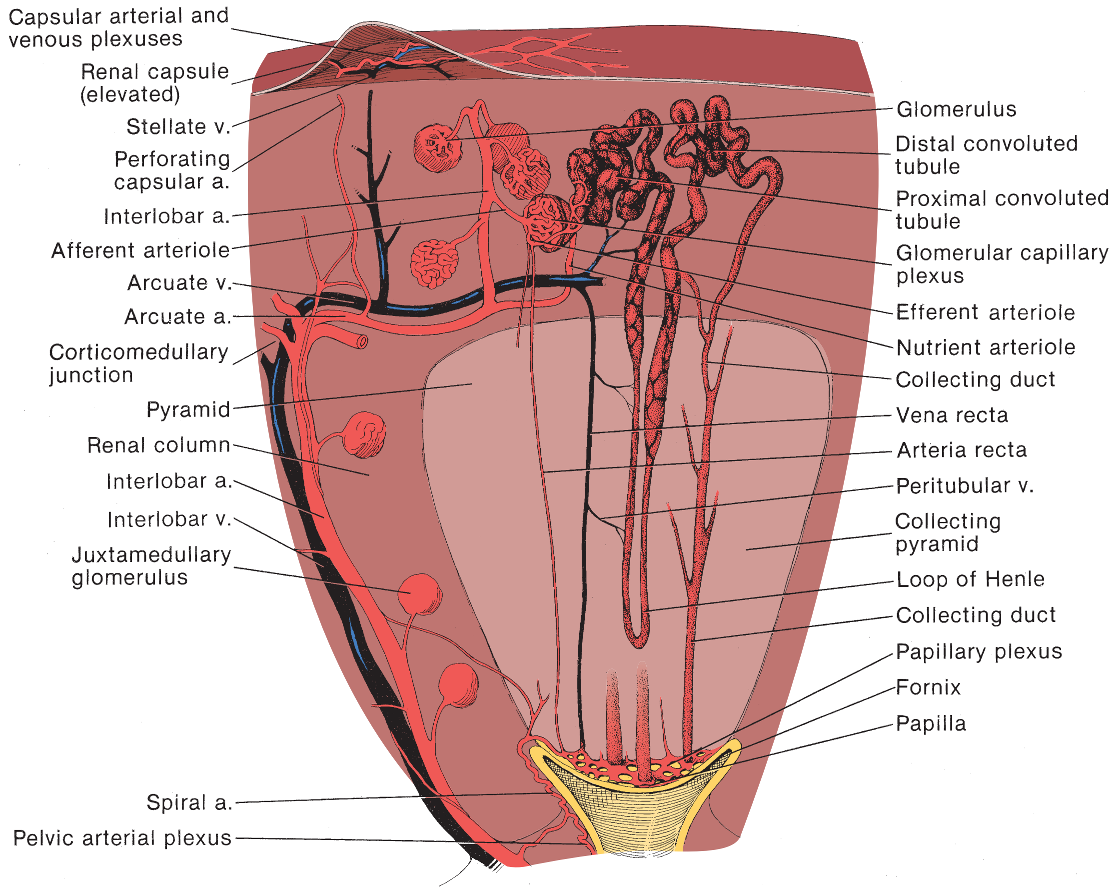


FIGURE 12-72.

glomerular **arteriole**, which continues centrally to supply the tubules. In the corticomedullary zone, the efferent vessel divides. One branch supplies the **convoluted tubules** and the **loops of Henle**, and the other runs centrally as **arteriae rectae** to supply the **collecting ducts**. (Arteriae rectae have been classified by the presence of glomeruli as arteriae rectae spuriae or by their absence as arteriae rectae verae. The latter probably results from degeneration of the glomerulus and so should not be classified separately.) Arteriae rectae terminate in a capillary bed, the **papillary plexus**, about the ends of the collecting ducts. The **venae rectae** arise from this plexus and drain peripherally into the **arcuate veins**.

Perforating capsular arteries are similar to interlobular arteries but serve few or no glomeruli. They pass to the surface of the kidney to join the **capsular arterial** and **venous plexus**, where they form a collateral circulation, the blood flowing from the kidney to the perirenal tissue. The direction of flow may become reversed in states of renal ischemia, depending on the pressure gradient. The plexuses become less numerous with age

The **papilla** has a dual blood supply. Branches enter from the **pelvic arterial plexus** in which the vessels along the wall of the calyx form an oval pattern. These vessels curve over the **fornix** as **spiral arteries** and turn beneath the mucosa of the papilla to join the capillary bed of the papillary plexus around the papillary ducts. They also supply the connective tissue in the fornix and around the bases of the interlobar vessels. So-called straight veins may accompany the spiral arteries. The fine arteriae rectae provide the second, more tenuous source of blood.

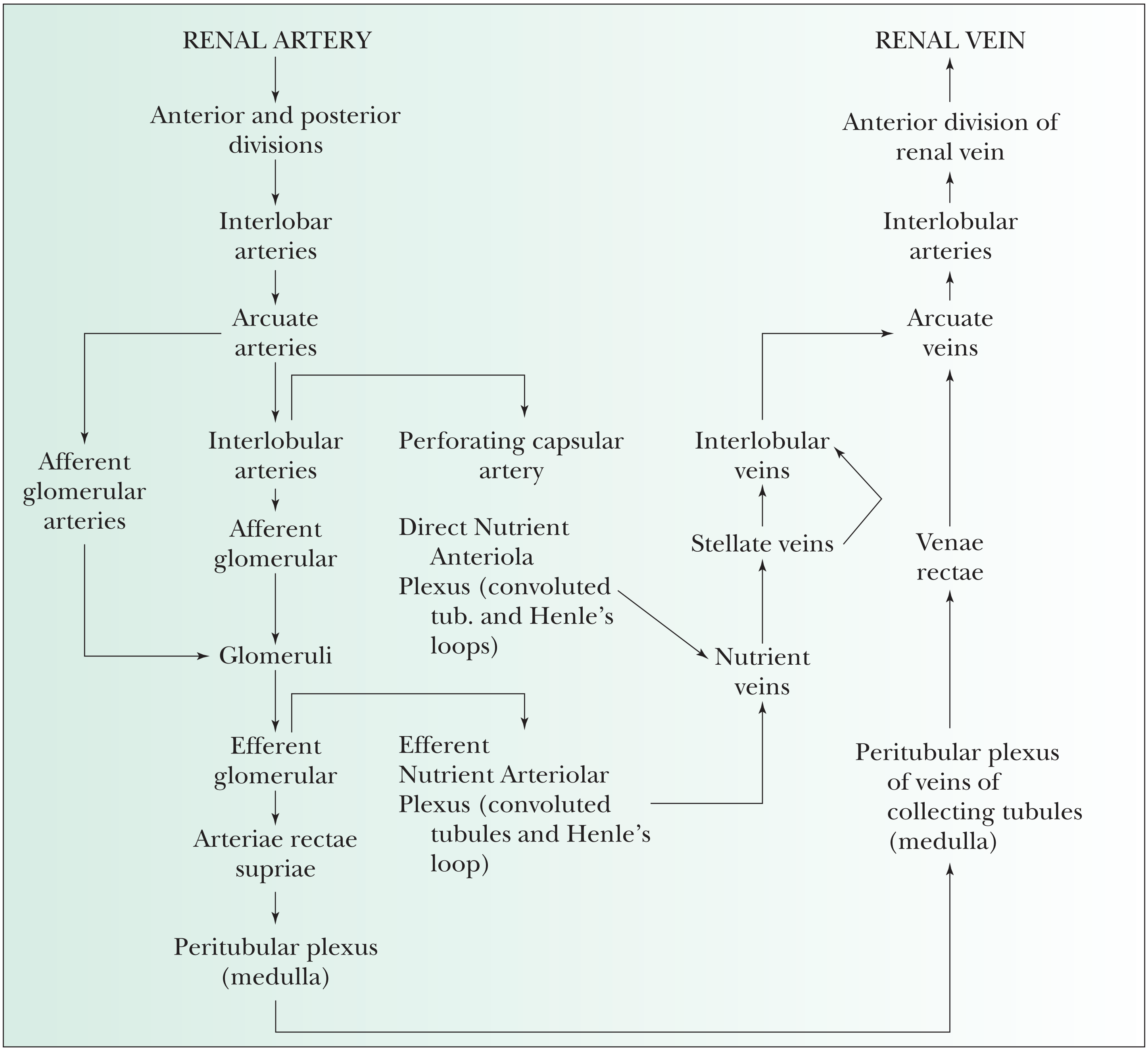
Should the pelvic arterial plexus be damaged, as by chronic infection and diabetes or obstruction, the papilla depends on the delicate vasae rectae for vascular support. These anatomic findings help explain acute papillary necrosis.

Blood Supply to the Capsule

The **capsular** arterial and venous **plexus** is a distinct system of blood vessels that anastomoses with intrarenal and extrarenal sources. The capsule is supplied by three peripheral vessels that have a characteristic spiral form (Fig. 12-73). A **superior capsular artery**, usually a branch of the **adrenal artery**, follows the lateral margin of the upper pole of the kidney. A **middle capsular artery** emerges at the hilum from the main **renal artery** to supply the dorsal and ventral aspects. The third is a small **inferior capsular artery** that arises from the **gonadal artery** to run along the lateral border of the kidney. Anastomoses are frequent with the **lumbar**, internal iliac, intercostal, and other retroperitoneal vessels. The capsular plexus is also supplied by an average of six relatively large **perforating arteries** that run directly from the **arcuate arteries** (see Fig. 12-72). These arteries may be an important source of collateral circulation and also may distort determinations of medullary blood flow by acting as a shunt.

TABLE 12-8

THE RENAL VASCULATURE



Adapted from Hinman F: The Principles and Practice of Urology. Philadelphia, W. B. Saunders Company, 1935.

Blood Supply to the Pelvis and Calyces

Rich **pelvic arterial plexuses** lie in the peripelvic connective tissue sheath of the wall of the **pelvis** and the **major** and **minor calyces**. They are supplied by branches from an **interlobar artery** that passes to the wall of a nearby calyx, where the branch becomes very tortuous, forming a **spiral artery**, a vessel that becomes more convoluted with age. The caliceal arterial plexus is formed of equal-sized vessels arranged in a somewhat polyhedral pattern that freely anastomose with vessels from the other side of the calyx (Fig. 12-74). The vessels terminate in small arteries that penetrate the muscular coat to form a caliceal or pelvic **submucosal plexus**. The pelvis also receives blood directly from the renal artery through a **ureteral branch** and from **arteries** in the **perinephric fat**.

Renal Venous System

The **right renal vein** is shorter than the left and drains into the **inferior vena cava** without gaining tributaries, the rare exception being entrance of the **gonadal vein**. The right renal vein is usually single, but in a sixth of cases, it is double; in the cases they reported, each vein was of approximately equal size.

The **left renal vein** is longer than the right, with an average length of 16.4 cm in one study, but is rarely double. It is

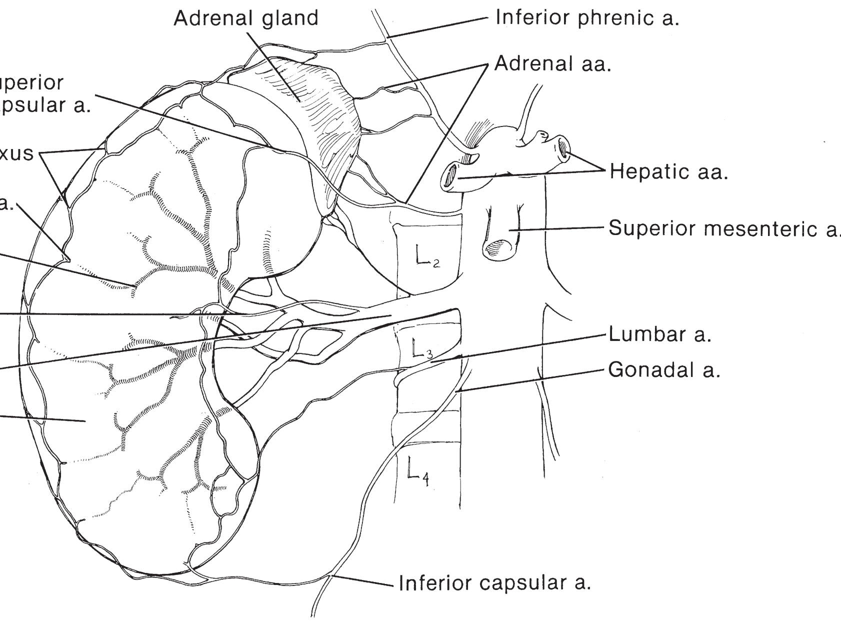


FIGURE 12-73.

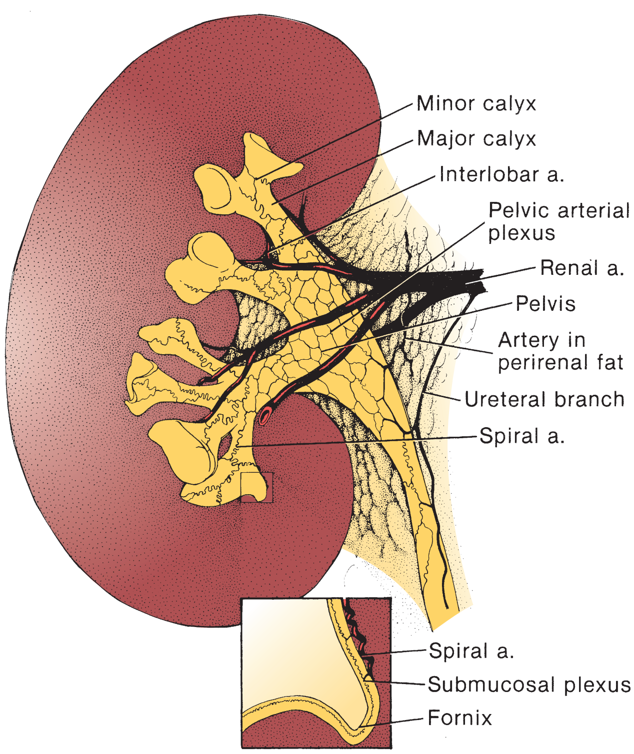


FIGURE 12-74.

more complex than the right, being regularly joined by the **adrenal** and **inferior phrenic veins**, the **gonadal vein**, and one of the **lumbar veins** (Fig. 12-75).

The connections of the vena cava with the retroaortic venous plexus belie the term renal pedicle. The variations are important to recognize because the common situation is the direct entrance of a lumbar vein into the renal vein, an arrangement that may complicate retroperitoneal node dissection or nephrectomy. While a single renal vein anterior to the aorta is the rule, the renal venous plexus may be complex retroaortically. The first or second lumbar vein may enter the renal vein independently or may enter jointly. Alternatively, the first or second lumbar vein may join a hemiazygos tributary vein before entry or the second or third lumbar veins, or both may join the gonadal vein before entry. Finally, several lumbar veins may join the longitudinal remnant of the primitive left vena cava. An anastomosis between the left renal vein and the paravertebral veins (such as the azygos and intervertebral veins and the epidural plexus) (see Fig. 2-16) may be found in a third of cases. Supracardinal channels may persist as longitudinal veins that join the inferior vena cava or the renal vein (see Fig. 2-6). A circumrenal venous network may be formed from capsular vessels that receive blood from neighboring structures. The network empties into the renal vein.

Of importance to the surgeon is the difference between the right and left renal veins, the left having tributaries that are rarely found on the right. In fact, the right very seldom has a tributary, and if it does, it is always the gonadal vein. Surgically, it may be convenient to consider the left renal vein in two parts: a complicated proximal segment and an accessible distal segment. The proximal segment, originally part of the left subcardinal vein, drains the kidney parenchyma, the calices and pelvis, part of the upper ureter, and the renal capsule, and in addition, collects from the adrenal gland, the testis or ovary, and the perirenal tissue. The distal segment of the left renal vein, derived from the anastomosis between the right and left subcardinal veins (see Fig. 2-8), is relatively fixed and accessible so that it is readily opened for extraction of a thrombus.

In rare instances, the left caval vein may persist, arising from the left common iliac vein. The circumaortic venous ring may remain, and the renal veins may be retroaortic (see Fig. 2-9B).

Collateral Circulation

Lumbar Veins

The **lumbar veins** are an important link for collateral circulation. Like those in the intercostal system, they recur typically at each vertebral level, with all five lumbar veins connected by an **ascending lumbar vein** on each side. On the left side, the trunk of the ascending lumbar veins connects with the **lumbar azygos vein** more medially. These veins lie against the **vertebral bodies** covered by the investing fascia of the psoas major, deep to the sympathetic trunk.

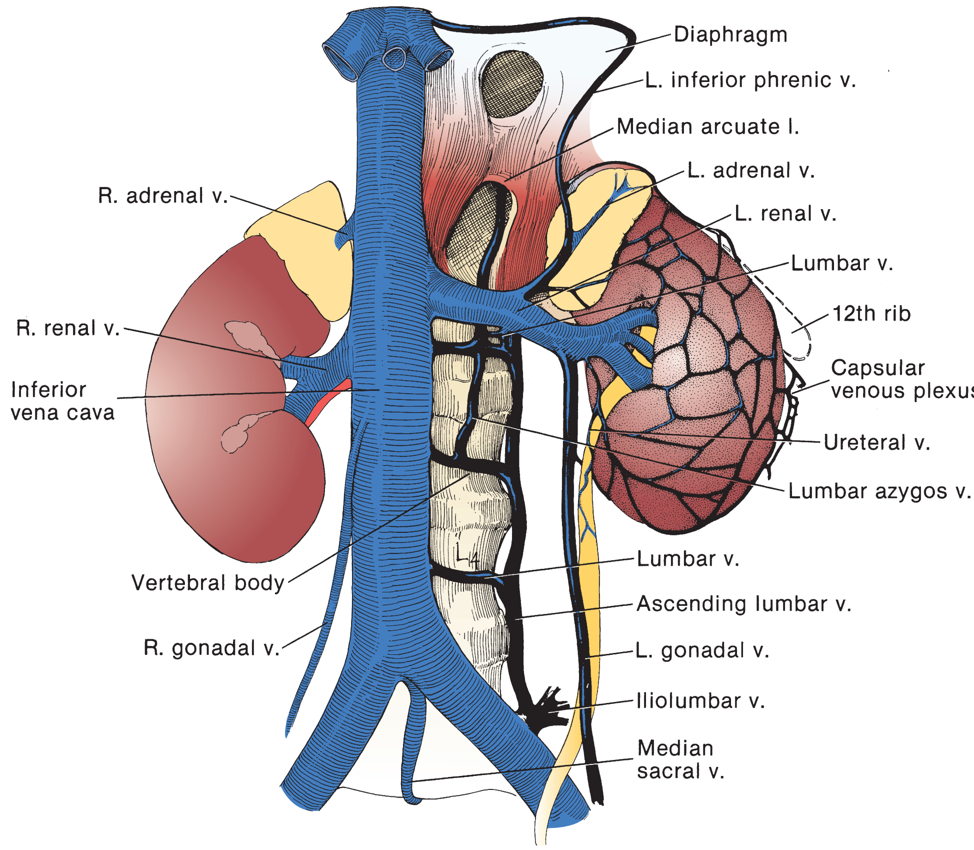


FIGURE 12-75.

As with the other veins in the region, variations are common. The fifth lumbar vein is frequently absent, and occasionally, veins at other levels are not formed. Of importance is the rich anastomotic system between the lumbar veins after they have emerged from the edge of the psoas major and the vena cava and other venous channels. The lumbar veins drain not only the psoas major and adjacent muscles but also the intervertebral veins that receive blood from the cord and its coverings and from the vertebrae and their ligaments. In one study, a quarter of the lumbar veins were found to empty directly into the vena cava and another quarter formed trunks before that connection, but in half they drained other vessels or structures in the region.

The lumbar venous system is related to the spread of tumors from the pelvis in a way similar to the vertebral (meningorachidian) veins described by Batson, except that the lumbar veins are larger and have more direct connections (see Fig. 2-20). The lumbar system is also important as a collateral route after obstruction of the vena cava.

Gonadal and Adrenal Collateral Circulation

After division of the left renal vein, circulation depends on the integrity of the gonadal and adrenal veins, as well as on supplementation from the pelvic and **capsular venous plexuses**. Thus, division of the renal vein must be proximal to the entry of these vessels, and the vein cannot be divided after renal mobilization. In 95% of cases, the opening of numerous collateral channels allows the kidney to survive. The **gonadal vein** provides the principal route, anastomosing with the internal iliac veins, especially in women, but it is functional only if the valves are incompetent. The **left adrenal vein** by its connection with the **inferior phrenic vein** may bypass the renal vein. The renoazygolumbar channel is a very large collateral that could possibly handle the entire flow. This channel runs from the inferior or posterior border of the **left renal vein** across the left border of the aorta to divide into an inferior branch that drains into a **lumbar vein** and a superior branch that ascends to join a tributary of the **hemiazygos vein**. This channel joins the intravertebral plexuses that surround the nerve roots, and its failure accounts for the quadriplegia associated with stenosis of the left renal vein. In addition, the network in the perirenal tissue provides some collateral circulation by enlarging and draining into the inferior phrenic, subcostal, adrenal, lumbar, and gonadal veins as well as into the vena cava itself.

Conversely, obstruction of the portal vein may be compensated for by flow through the left renal vein.

Intrarenal Veins, Right Kidney

The **peritubular capillary plexus** of veins about the collecting tubules in the medulla drains through the venae rectae into the **arcuate veins** (see Fig. 12-72). Small venules join the **interlobular vein** that courses with the corresponding interlobular artery (Fig. 12-76).

Stellate veins on the surface of the kidney communicate with the capsular venous drainage and so form a connection between the intrarenal and extrarenal drainage systems. They may be found along the grooves on the surface of the kidney; they represent the margins of fetal lobulation. The stellate veins and veins from the cortex drain into the interlobular veins, then into the arcuate veins that accompany the arcuate arteries. The flow is then passed into the

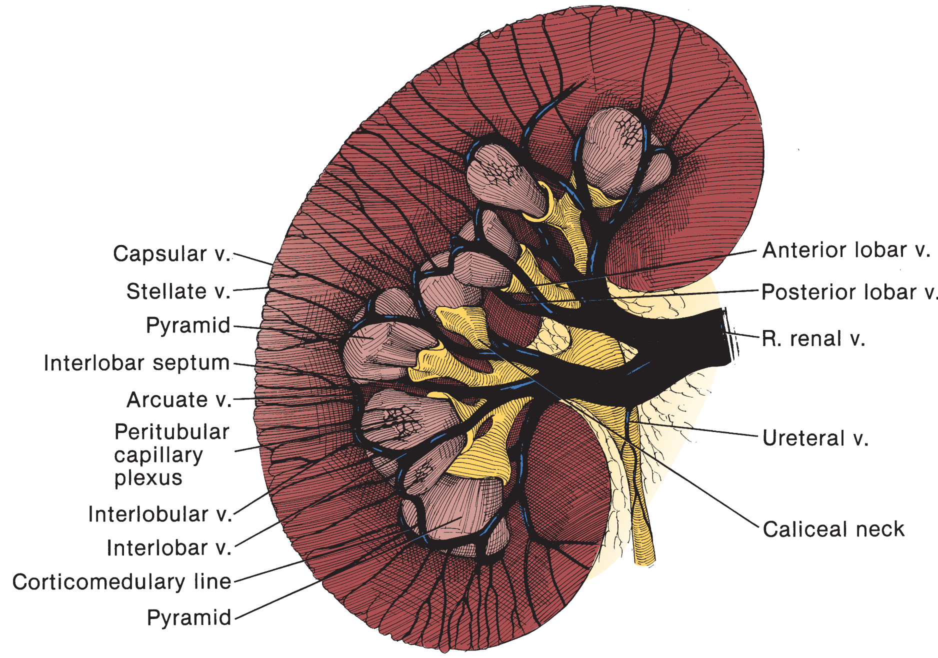


FIGURE 12-76.

interlobar veins adjacent to the interlobar arteries. The interlobar veins join together to form two or three trunks that empty into the **renal vein**.

The arcuate veins form interconnecting arches around the bases of the **pyramids** at the **corticomedullary line**. From the arches, large interlobar veins run centrally beside the pyramids to reach the distal portion of the **calyceal necks**, where they form another set of anastomotic collars around them. The **posterior lobar veins** draining the posterior portion of the kidney pass between the calyceal necks of the minor calyces to join an **anterior lobar vein**. These crossing veins may be divided during a misdirected nephrotomy. Two sets of anterior and posterior lobar veins are usually found; one drains the superior portion, and the other drains the inferior portion of the kidney. The lobar veins unite within the renal sinus or at the lip of the hilum to form two trunks that pass anterior to the pelvis.

The intrarenal veins, unlike the arteries, do not have a segmental arrangement, and in addition, they freely anastomose within the renal substance. Thus, they are not terminal but form longitudinal arcades at three levels: (1) between the stellate veins, (2) between the arcuate veins, and (3) between the interlobar veins. There are abundant anastomoses at each level. Additional anastomotic veins cross from anterior to posterior over the calyces. The anastomotic arrangement of the sets of veins permits ligation of major channels without fear of venous obstruction.

The intrarenal veins are large; intraoperative section or injury during percutaneous procedures may result in considerable blood loss. Because the venous anastomoses that form collars about the necks of the calyces and the lobar veins curving around the calyces are much larger in the anterior portion of the kidney, the posterior approach that is taken to avoid the arteries is equally useful in avoiding the larger veins. For nephrolithotomy, this means following the arterial avascular plane. Incisions into the wall of the calyx for plastic revision or for stone removal may inadvertently enter the veins crossing between the calyceal necks. For an endourologic approach (see Figs. 12-64 and 12-65), puncture is best made directly into the fornix in the line of the calyx. This approach not only reduces arterial injury but also avoids entering the venous collar. For endoscopic incision of the ureteropelvic junction, it is important to appreciate that in two-fifths of cases an inferior tributary to the renal vein courses on the anterior aspect of the renal pelvis, making a lateral incision necessary.

A *retropelvic vein* is present in two-thirds of cases, draining some of the posterior portion of the kidney. It frequently has azygolumbar connections.

This 5-mm vein can be of surgical importance because it lies in the margin of the hilum, where it is susceptible to division during calicotomy and may be injured along with the posterior segmental artery during direct puncture of the renal pelvis (see Fig. 12-71).

Capsular Veins

The **capsular veins** communicate with small veins in the perirenal tissue that constitute a network of accessory veins in the perirenal fat. The accessory veins receive blood from adjacent muscles and from the adrenal gland and the diaphragm separately from retroperitoneal channels and drain it into the left renal vein. The accessory veins have a superficial and deep system. The superficial system lies immediately beneath the overlying perirenal fascia and peritoneum and drains into the deep system. The deep system, in turn, passes blood to the major veins that drain the renal parenchyma. This arrangement explains pericapsular involvement by renal carcinoma.

Capsular veins may be divided into two groups: principal and accessory. Of the principal veins, the superior capsular veins exit from the perirenal space between the kidney and adrenal to drain into the adrenal vein. The inferior capsular veins come from the lower pole to drain into the gonadal vein or into a branch of the renal vein (see Fig. 12-75). The accessory veins are of small caliber and have variable courses. With obstruction of the left renal vein, all these channels enlarge to form a dense network about the kidney that drains into the inferior phrenic, subcostal, adrenal, lumbar, and gonadal veins and into the inferior vena cava itself.

LYMPHATIC DRAINAGE

Renal Lymphatic System, Right Kidney

Renal lymphatic plexuses among the tubules in both cortex and medulla are arranged around the blood vessels, especially the veins. Lymphatic vessels run from the plexuses into a dense **basal network** over the base of the **pyramids**, where the channels from the cortex join with those from the medulla to reach the region of the calyceal **fornix** (Fig. 12-77). From there, the lymphatics run with the blood vessels around the **calyceal necks** to the **renal sinus**, where they empty into several large **valved collectors** lying on the surface of the **pelvis** and accompany the **renal vein** out of the hilum to terminate in a few nodes along the renal vessels and in the aortic nodes.

The **renal capsule** contains many lymphatics, which may be divided into two groups: a superficial and a deep system. The **superficial system** of the **capsular plexus** lies immediately beneath the overlying renal fascia and peritoneum. It drains into the **deep system** beneath the renal capsule, which, in turn, passes through the same collectors as do the lymph channels of the renal parenchyma. This arrangement provides a second explanation for pericapsular involvement with renal neoplasms. The capsular lymphatics anastomose with **peritoneal lymphatics** that cover adjacent intraperitoneal organs such as the liver and the colon. Intercalated nodes occasionally are found along the collectors behind the superior pole of the kidney and anteriorly in the hilum.

The renal **pelvis** and **calyces**, with a different embryologic origin, have a somewhat separate lymphatic drainage from that of the **renal parenchyma.** In the pelvis, the lymphatics are arranged in submucous networks that are continuous with those of the **ureter.** After the collectors pass through the hilum, they anastomose and empty into nodes overlying the psoas muscle or the crus of the diaphragm to join the lateral aortic nodes about the ipsilateral artery, often with an intercalated node.

Retroperitoneal Lymph Nodes

Anterior and posterior collecting trunks emerge from the kidneys. The three or four **anterior collecting trunks** that drain lymph from the anterior portion of the kidney lie first in front of the **renal artery**, then in front of the **renal vein.** The three to five shorter **posterior collecting trunks** run behind the artery and vein (Fig. 12-78).

Drainage flows into 20 to 30 nodes lying about the abdominal aorta. These nodes also drain lymph from the adrenal and testis. Poirier and Cunéo organized them into four groups: (1) the left and (2) right paraaortic nodes, (3) the preaortic nodes, and (4) the retroaortic nodes. The paraaortic nodes are the ones most involved in renal drainage.

The **left kidney** drains through anterior collecting trunks that pass in front of the renal vein and end in four or five para-aortic nodes on the left side of the **aorta** near the renal vein. The **left para-aortic nodes** run as a continuous chain along the left side of the aorta overlying the vertebral attachments of the psoas major muscle and the left crus of the diaphragm. The most cephalad node lies against the left

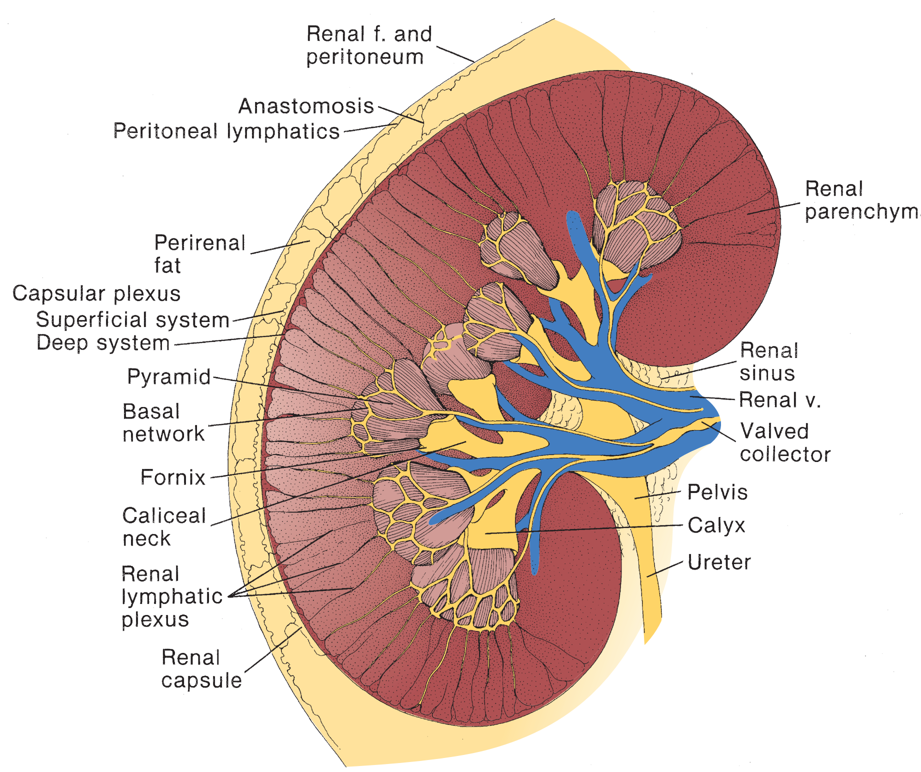


FIGURE 12-77.

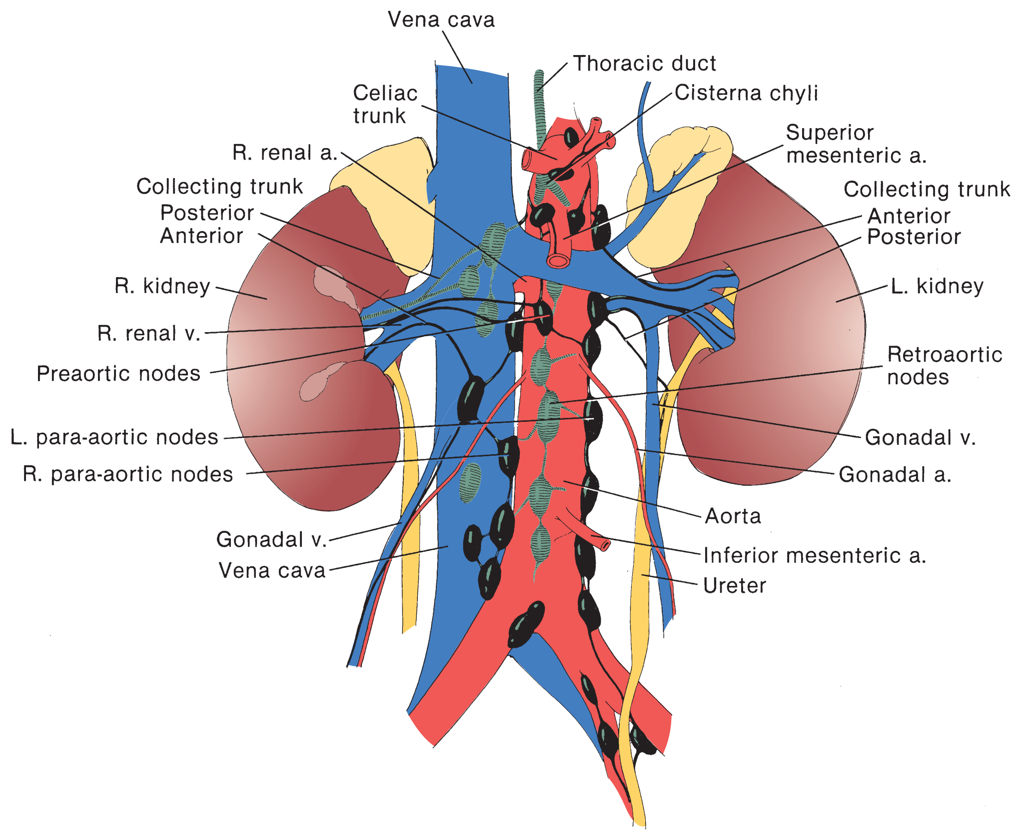


FIGURE 12-78.

crus, and channels also pass through the diaphragm to the thoracic duct. The lymph from the kidney also drains though three or four posterior trunks that run behind the renal artery to end in the para-aortic nodes near the take-off of the left renal artery. The lymph from these nodes, in turn, drains into **preaortic** and **retro-aortic nodes** or, more frequently, drains into a common trunk that enters the **cisterna chyli**, or it may empty directly into the **thoracic duct.**

The **right para-aortic nodes** are distributed about the **vena cava.** The prevenous nodes lie beneath the entrance of the renal veins; the retrovenous nodes lie over the attachment of the psoas muscle and the right crus. The afferent and efferent drainage fields are similar to those described for the left system.

NERVE SUPPLY TO THE KIDNEY

Renal Nerves

A very large number of autonomic nerves, primarily with vasomotor activity, come from widespread sources to a focus in the **renal plexus.** Four to eight renal branches arise from the **celiac plexus** on each side and, at first, run cephalad to the renal vessels and then pass ventral to them as the nerves approach the renal plexus. The **greater, lesser**, and **least splanchnic nerves** provide nerve supply to the kidney, usually indirectly, partly via the **aortorenal ganglion** and partly through the **celiac ganglion.** Branches to the renal plexus also arise from the **second lumbar sympathetic ganglion** and run directly to the kidney or by way of the **posterior renal ganglion.** Other branches come from the upper parts of the aortic plexus. Finally, branches pass from the lower part of the aortic plexus to the renal plexus, with or without communication with the **superior hypogastric plexus**.

In the renal sinus, the nerves converge to form the **renal plexus**, which lies principally on the ventral surface of the **renal artery** (Fig. 12-79). None of the plexus is in front of the vein or behind the pelvis, but filaments are given off to those structures as well as to the capsule in company with the superior and inferior capsular veins. With separate renal arteries, the plexus may be divided between them.

Most of the connections between preganglionic and postganglionic fibers occur in small ganglia in the renal plexus and along the nerves associated with it, not in the aortorenal or celiac ganglia. Afferent and efferent nerves follow the renal arteries to supply the glomeruli, tubules, and blood vessels of the kidney.

THE URETER

Divisions of the Ureter

Three regions that differ structurally are recognized: (1) the ureteropelvic junction, (2) the middle spindle, and (3) the ureterovesical junction. The ureterovesical junction may be further subdivided into two parts: (1) a juxtavesical ureter and (2) a terminal ureter, which, in turn, is divided into intramural and submucosal segments (shown in conjunction with the bladder in Figure 13-65). The so-called pelvic spindle lies in the upper part of the pelvic ureter between the iliac vessels and the medial umbilical ligament.

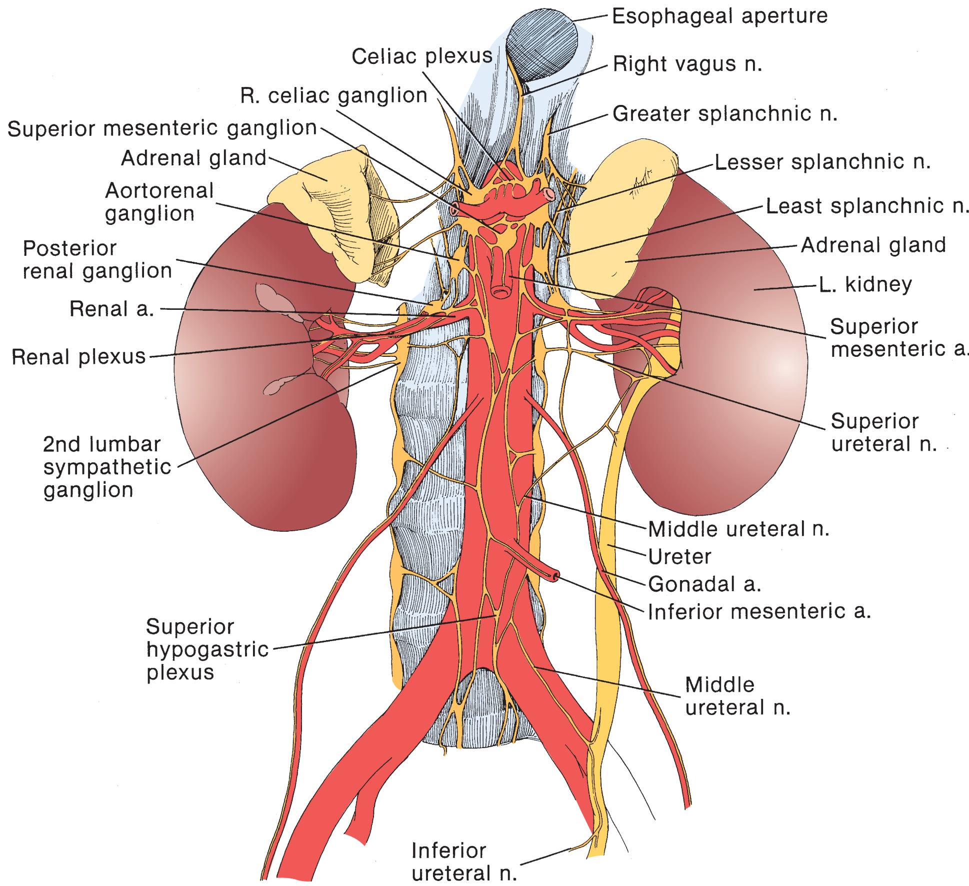


FIGURE 12-79.

Ureteral Course in the Abdomen

The ureter, measured from the ureteropelvic junction to the bladder, is 28 to 34 cm long. The left ureter is slightly longer than the right. It is enclosed in the intermediate stratum of the retroperitoneal fascia within the envelope of the renal fascia, which is intimately attached to the peritoneum. Evidence of this attachment is the adherence of the ureter to the peritoneum as it is mobilized medially at operation. Each ureter passes over the medial part of the **psoas major** in line with the ends of the **transverse processes** of the lumbar vertebrae (Fig. 12-80). It goes over the **genitofemoral nerve**, and at its midpoint passes under the **gonadal vessels** into the pelvis near the bifurcation of the **common iliac vessels.** The ureter adheres to the **mesocolon**, so that injury to its abdominal portion during surgery on the sigmoid colon occurs, especially when the mesosigmoid is involved in an inflammatory disease. The proximity of the **inferior mesenteric artery** to the ureter presents another hazard.

Pelvic Relations of the Ureter in the Male

After crossing the common iliac artery in the pelvis, the ureter follows the course of the **internal iliac artery** and runs along the anterior border of the **greater sciatic notch,** and turns medially at the **ischial spine** to lie along the **levator ani** before reaching the **bladder** (Fig. 12-81A). The **vas deferens** crosses in front of it, and the ureter, in turn, passes in front of the tip of the **seminal vesicle.**

For an *endoscopic approach*, the first portion of the **ureter** will be found to run posterolaterally, passing under the **vas deferens.** It then curves up over the **obturator artery** to the crossing of both **internal** and **external iliac arteries** or of the **common iliac artery** (Figs. 12-81B and 12-81C). The site of crossing is marked by a pulsatile indentation in the posteromedial aspect of the ureter. After passing over the common iliac vessels at the **sacral promontory**, the ureter then bends posteriorly to take a more or less straight course under the spermatic vessels to the renal pelvis. On the left, the ureter runs under the **left colic artery** at the junction of its middle and upper third, whereas on the right, the right colic and ileocolic vessel are not a problem because they lie at a high level and more anteriorly.

Pelvic Relations of the Ureter in the Female

Because of the comparative frequency of female nonurologic pelvic surgery, the course of the ureter is of greater surgical importance in the female than in the male. From an oblique view of the right side of the pelvis, the **right ureter** is seen running over the **common iliac** and **internal iliac artery** to enter the pelvis (Fig. 12-82). Passing medially at the level of the ischial spine, it lies behind the **ovary** in close association with the **suspensory ligament of the ovary** and forms the posterior limit of the ovarian fossa. The **ovarian vessels** make an oblique crossing over the ureter. Entering the parametrium of the **broad ligament**, it runs successively through the uterosacral ligament, the cardinal

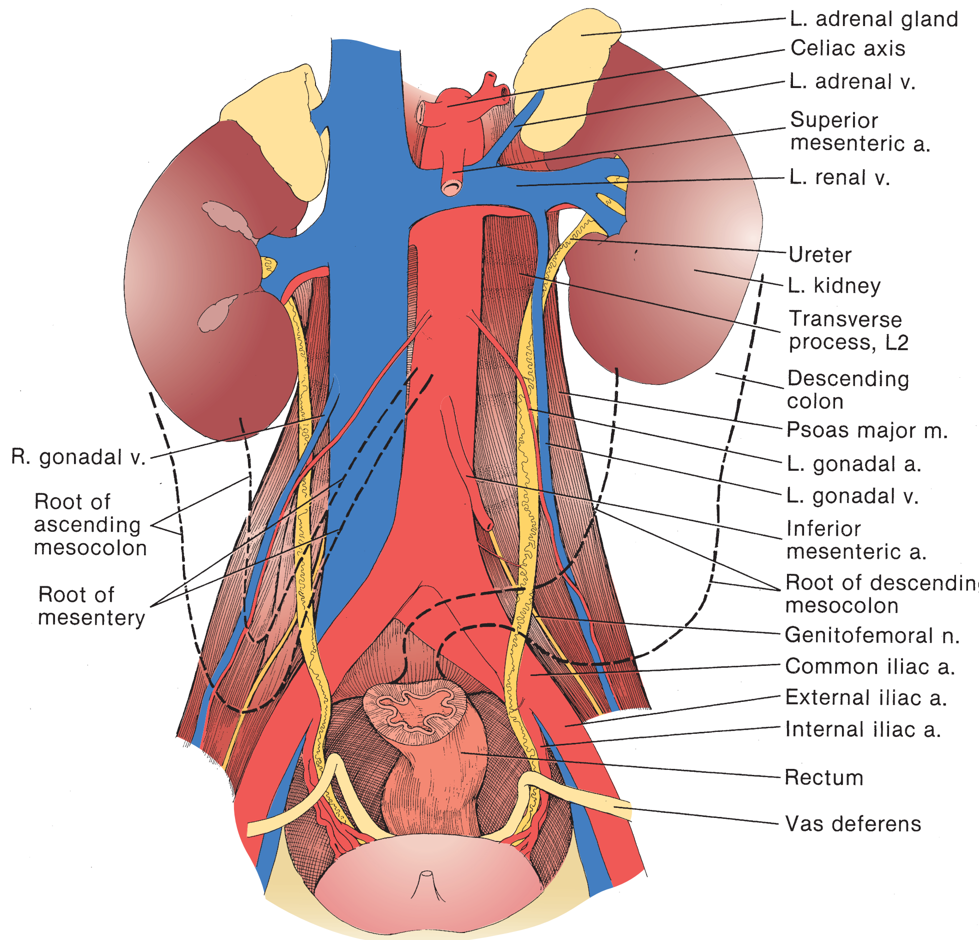


FIGURE 12-80.

ligament, and the vesicouterine ligament. In its course, the ureter runs for a short distance with the **uterine artery**, which, originating from the internal iliac artery, lies lateral and anterior to it. The artery then crosses over the ureter and runs medial to it on its course to the **uterus.** The **left ureter**, in its lower course, is surrounded by the vaginal and perivesical venous plexuses as it passes under the **uterine artery** to run anteromedially about 1 cm above the **lateral vaginal fornix** and from 1 to 4 cm lateral to the **cervix** to reach the anterior aspect of the vagina before joining the **bladder.**

Manipulation of the ovarian and uterine vessels during gynecologic procedures carries risk of ureteral injury.

For a retrograde *endoscopic approach*, the course of the ureter is found to be similar to that in the male, but the ovarian vessels, especially prominent on the right side, must be negotiated.

Ureteral Wall

Ureteral Sheath

The ureter is encased in a loose **ureteral sheath.** The sheath is a specialized but ill-defined layer of the intermediate stratum of the retroperitoneal connective tissue lying just under the peritoneum to which it is adherent.

Proximally, both the ureteral sheath and the adventitia are continuous with the corresponding layers of the renal pelvis. Distally, the sheath and adventitia are more prominent in the terminal portion of the ureter, where they join Waldeyer's sheath, formed from the deep trigone as it extends from the bladder wall about the ureter (see Figure 13-65). In the female, the sheath is closely associated with the uterovaginal and vesicovaginal plexuses of veins within the parametrium, making the ureter more difficult to free during operations on the uterus. Here, it is susceptible to injury and devitalization, as well as to subsequent fixation in fibrous tissue.

Arteries

Ureterosubperitoneal arteries between the ureter and peritoneum divide to give off a subperitoneal branch and a ureteral branch. The ureteral branch has ascending and descending branches in the ureteral sheath that enter the adventitia through secondary branches (Fig. 12-83). The sheath also contains fine fibrous strands and some adipose tissue that enclose the ureter loosely, presumably to enable free peristaltic activity (Fig. 12-84). The spermatic vessels lie in a thin vascular layer that is separable from the condensation that forms the ureteral sheath.

At the sites where the ascending and descending branches anastomose, the secondary branches pass to a deeper layer to penetrate the adventitial coat of the ureter and there form a freely anastomotic periureteral arterial plexus that extends for the entire length of the ureter. Smaller penetrating vessels arise from the plexus to pass into and through the muscularis.

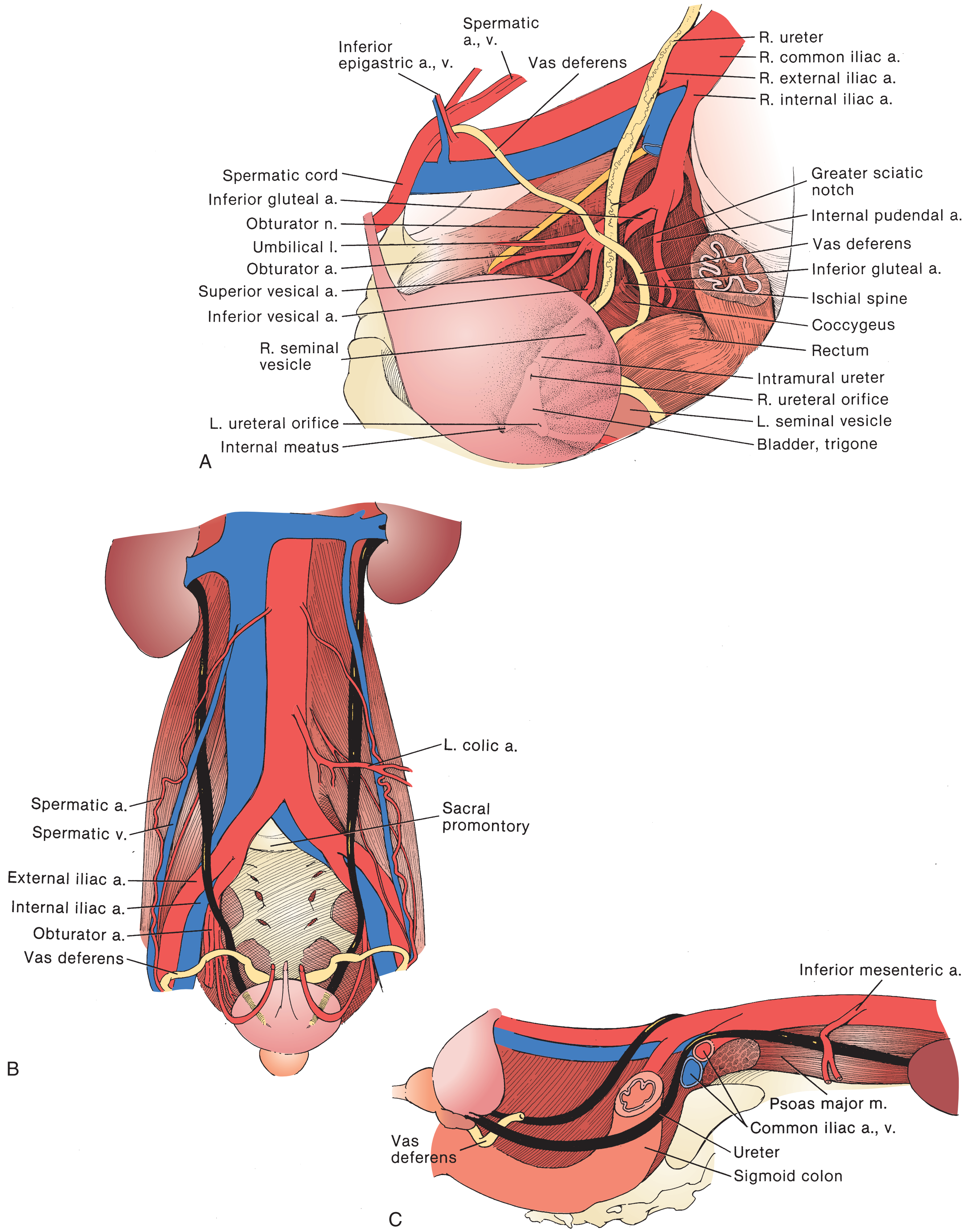


FIGURE 12-81. **A,** Oblique view. **B,** Coronal view. **C,** Lateral view.

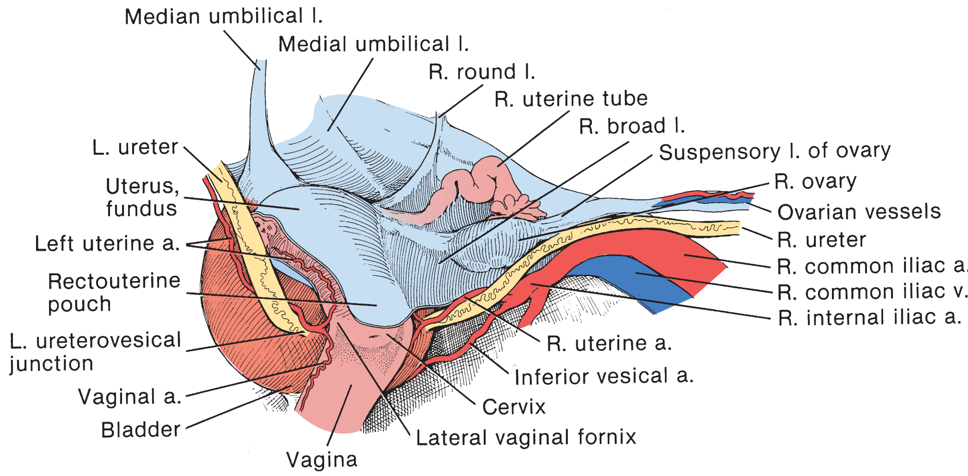


FIGURE 12-82.

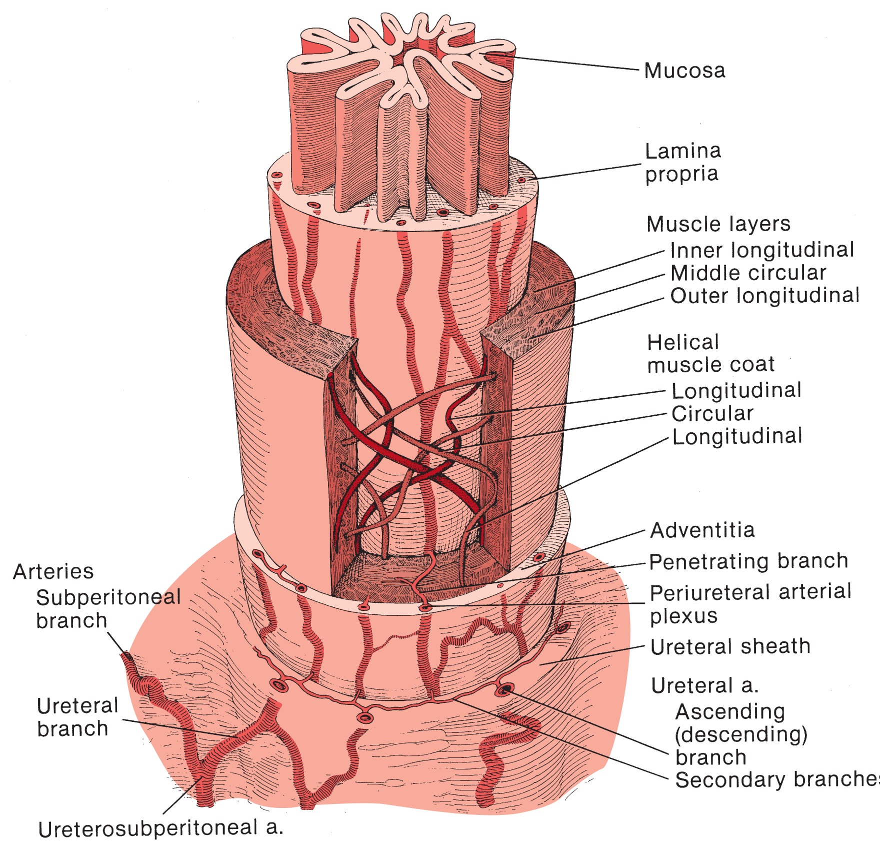


FIGURE 12-83.

This vascular arrangement does not limit the sites of division of the ureter because the anastomoses within a sectioned ureter prevent ischemia. On the other hand, interference with the arterial plexus jeopardizes the viability of the end of the ureter whether the damage occurs directly during surgery or as the effect of electrocoagulation or infection. Viability of the distal ureter may be tenuous in secondary operations on the previously mobilized or resected ureter. An example of this is the friable state of the ureteropelvic junction following prolonged impaction of a calculus that has interfered with the proximal blood supply.

With destruction of the sheath, adherence of the ureter to adjacent structures may result in functional obstruction. The sheath supplements the adventitia to act as a barrier to periurethral neoplastic and inflammatory processes. This is best appreciated after retroperitoneal inflammation, when the sheath is found to be composed of a series of onion-skin layers that allow some peristaltic movement of the ureteral wall to continue.

Ureteral Wall

The layers of the ureter are continuous with those of the renal pelvis and are similar to them, consisting of an adventitial layer lying inside a retroperitoneal sheath, a muscular coat, and a mucosa.

The **adventitia** is composed of collagen fibers running longitudinally. It contains many fine unmyelinated nerve fibers and numerous blood vessels that take a longitudinal course to form the **periureteral arterial plexus.** The adventitia

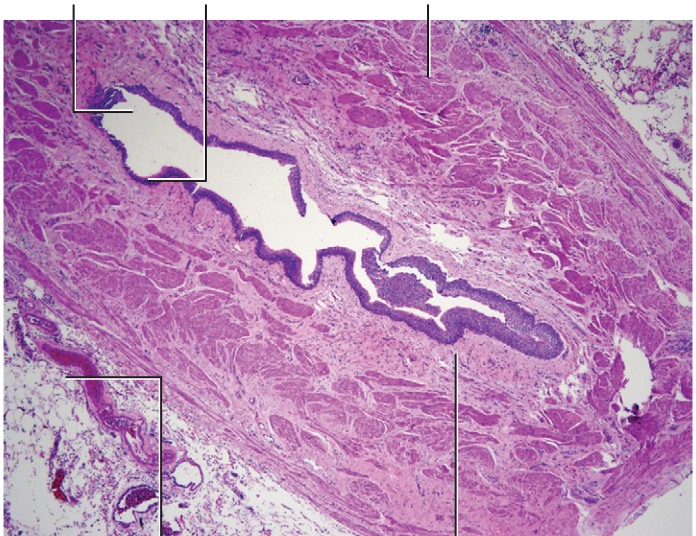


FIGURE 12-84. Normal histology of ureter, cross-section.

is loosely attached to the underlying muscularis, leaving it free to move.

The **muscular layers** are formed from smooth muscle cells that are arranged in bundles and interspersed with collagen fibers. On cross section, three layers are seen: **inner, middle,** and **outer.** Actually, the bundles, continuous with those in the renal pelvis, are arranged in interlacing **helices**, with a single fiber becoming **longitudinal,** then **circular,** then **longitudinal** again as it passes from one layer to another. The exception to this arrangement is in the intramural ureter where only longitudinally oriented fibers are found.

The individual smooth muscle cells are connected by nexuses that allow the spread of electrical excitation from one cell to the next. There are more muscle cells in the middle spindle than in the distal segment or at the ureteropelvic junction. The tonus and rhythmic contractions of the ureter require no autonomic nervous stimulus; urine from the kidney initiates peristalsis by stretching the smooth muscle fibers. Nerves play only a modulating role (see Fig. 12-79).

The **mucosa** lies directly on a relatively thick but loosely arranged fibroelastic layer, the **lamina propria**, there being no submucosa as such. The mucosa consists of transitional epithelium with multiple layers of cells, more layers than in the pelvis or calices.

Ureteral Blood Supply

Ureteral Arteries

The ureter is so exceptionally well supplied by multiple arteries that anastomose along its length that division of any (or all except the most proximal ones) does not produce ureteral ischemia.

Several retroperitoneal vessels supply a variable number of uretero-subperitoneal arteries (Fig. 12-85). The sources have been determined by anatomic studies. The proximal ureteral arteries most often are supplied by the renal artery (30%). The aorta provides 15.4%, and the gonadal arteries provide 7.7%. Distally, the most frequent sources are the superior and inferior vesical arteries (12.8 and 12.9%, respectively), but ureteral vessels also arise from internal iliac arteries (8.5%). These vessels provide the richest supply to the lower portion of the ureter. This leaves the middle portion of the ureter between the lower pole of the kidney and the brim of the pelvis as the most poorly vascularized. A branch may come directly from the aorta or from the common iliac artery and the gonadal and uterine arteries may also contribute.

The **uretero-subperitoneal arteries** lie outside the **ureteral sheath.** At the ureteral wall, the arteries divide into ureteral arteries to supply the **periureteral arterial plexus** and **subperitoneal arteries** supplying the periureteral tissue.

The **ureteral arteries** branching from the ureterosubperitoneal vessels usually divide on entering the loose ureteral sheath into long **ascending** and **descending branches.** These branches anastomose with descending branches from above and with the ascending branches from below.

The preservation of the ureteral trunks in the ureteral sheath is essential when operating on long segments of the ureter, as when transplanting a kidney or tapering a megaureter. However, in about one-quarter of the cases, the vessels do not have long branches but immediately form plexuses. In fact, in infants, the vascular arrangement of the distal ureter is almost entirely plexiform. Ureters with this type of arterial distribution are more readily rendered avascular by division.

The **subperitoneal arteries** from the uretero-subperitoneal vessels supply the periureteral tissue and also provide some

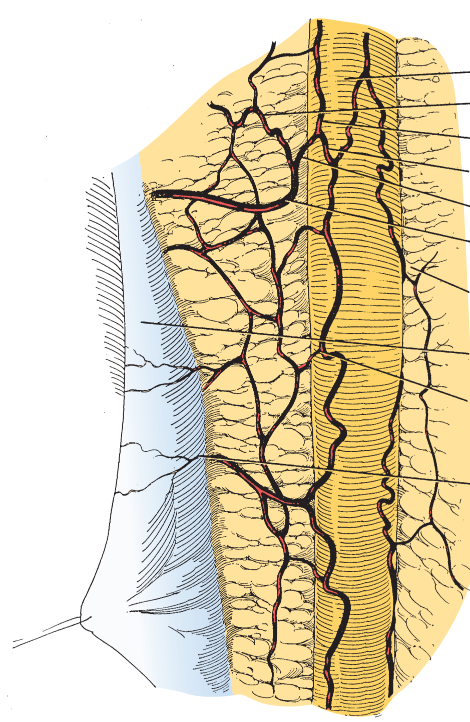


FIGURE 12-85.

distribution to the peritoneum. They freely anastomose with neighboring vessels as they contribute blood to the ureter. Separation of the ureter from the peritoneum by division of the arterial twigs may compromise ureteral blood supply, especially in the lower ureter.

Ureteral Veins

Venules are distributed as a fine network throughout the adventitia of the ureter. They drain at either end of the ureter, but additional drainage occurs along its length. At the proximal end, small veins are collected into a few superior ureteral veins that drain into the lowest branch or trunk of the renal vein or into the adjacent gonadal vein. At the distal end, inferior ureteral veins drain into the those of the broad ligament (which explains the varicose dilations about the ureter that may be found in women) and into the pelvic plexus and adjacent veins.

Ureteral Lymphatics

The ureter is drained by multiple lymphatic vessels in the lamina propria under the mucosa and in the muscle. They exit diagonally to join those collectors traveling up and down in the adventitia, to enter efferent lymph stems going to related abdominal nodes. Lymph from the upper ureter joins the caliceal drainage channels from the hilum or goes directly to the aortic nodes around the origin of the gonadal artery. In general, the midureteral lymphatics follow the arteries and drain into the common iliac nodes, and the drainage from the lower ureter passes upward and downward into nodes about the common, external and internal iliac vessels and the interaortocaval nodes.

Ureteral Nerves

As illustrated in Figure 12-79, the ureter receives its nerve supply from the **superior ureteral nerve** through the **renal** and aortic plexuses, from the **middle ureteral nerve** through the **superior hypogastric plexus,** and from the **inferior ureteral nerve** through the pelvic plexus, although such designations are somewhat arbitrary because of the great variability in nerve distribution. These nerves terminate as bundles of efferent, mainly nonmyelinated fibers among the collagen fibers of the adventitial sheath of the ureteral wall. Some mingle with the muscle cells of the ureter. They innervate the musculature of the longitudinal arteries and those within the muscle layer and of the submucosal capillaries, as well as the ureteral musculature itself.

Ureteral Peristalsis

Because no autonomic ganglion cells have been found and because the nerves may be stripped from the ureter without affecting function, ureteral peristalsis is not activated by the nervous system. The nerves may have a modulating function, although the ratio of axons to muscle cells is only about 1 to 100 (compared with that of the vas deferens, which is 1 to 1 or 1 to 2). That both adrenergic and cholinergic nerves are found together in a nerve bundle suggests some form of interaction. Because the ureter is well supplied with both types of fibers, their purpose may well be to modulate ureteral activity. In addition, purinergic nerve terminals are found whose function is uncertain. The minor effects of drugs on the ureter can be explained by the presence of nerves among, but not entering, the muscle fibers. Just how much influence autonomic control has on ureteral function is unknown, because the myogenic function of the ureter by nexuses between the muscles is adequate for peristalsis.

Afferent nerve endings that are found in the lamina propria may act as stretch receptors or react to pH or osmolarity. Pain from the ureter itself is poorly perceived; few pain receptors can be found in the wall. The pain experienced when the ureter is forcibly dilated is referred to the body regions supplied by spinal nerves T11 to L2, such as the genitalia, groin, and upper thigh; however, this sensory input may be through parasympathetic fibers. The severe pain associated with ureteral colic comes from distention of the renal pelvis and capsule secondary to urinary obstruction rather than from local ureteral spasm.

THE ADRENAL GLANDS

Adrenal Structure

The adrenal gland consists of a bright yellow cortex and a dark red medulla (Figs. 12-86, 12-87, and 12-88). The **cortex** has three zones: glomerulosa, fasciculata, and reticularis (Fig. 12-89). The **medulla** contains columns of chromaffin cells among venous sinusoids. The gland is covered by a thin **capsule** that is easily penetrated during surgery, and the cortex is friable.

In the central portion, within the medulla, a portal system collects blood from both cortex and medulla and delivers it to the **central vein**. The main branches of the central vein have longitudinal muscle bundles whose apparent function is venous closure to hold blood in the

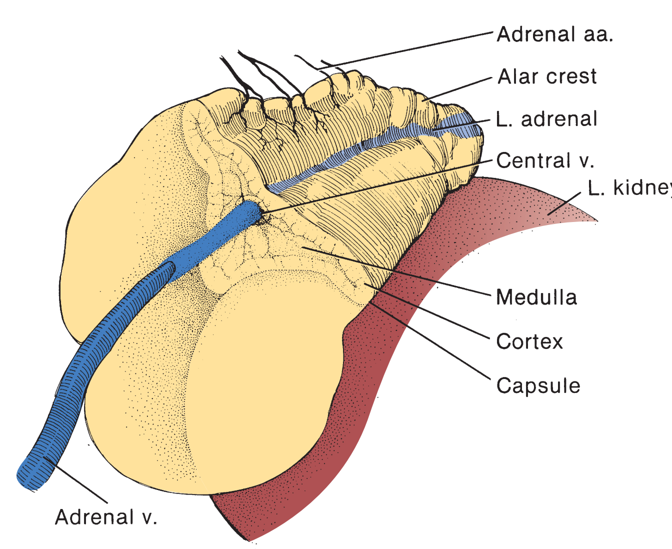


FIGURE 12-86.

FIGURE 12-87. Normal adrenal glands from an adult, with a combined weight of 11 grams. Both are elongate and semilunar. Often, the right adrenal is flattened and triangular. *(Image courtesy of Linda Ho, MD.)*

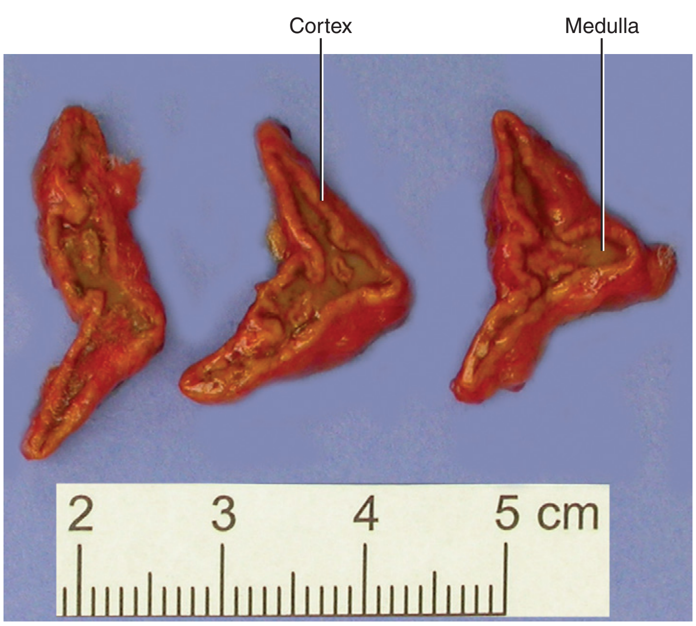


FIGURE 12-88. Adrenal glands in cross-section. The peripheral cortex is uniformly thin and bright golden yellow. The central medulla is pale grey-white. *(Image courtesy of Linda Ho, MD.)*

medullary sinuses. The **alar crest** running on the posterior aspect of the gland is flanked by winglike portions (alae) where the venous drainage is into a central linear system lying in a raphe devoid of medulla. The central vein becomes the adrenal vein after exiting from the gland.

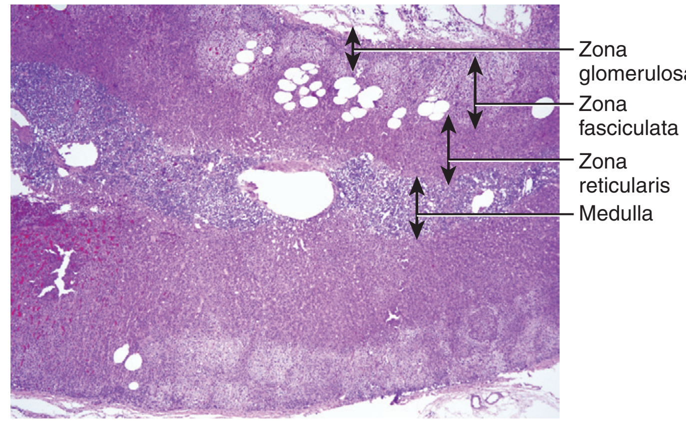


FIGURE 12-89. Normal histology of adrenal gland. The zona glomerulosa lies immediately beneath the capsule, and is thin, indistinct, and focally incomplete, consisting of cells with minimal eosinophilic cytoplasm and small round dark nuclei. Beneath it lies the zona fasciculata, which consists of long columns of large cells with pale vacuolated cytoplasm. The zona reticularis lies innermost and consists of short anastomosing cords of eosinophilic cells. Zona fasciculata and zona reticularis are richly supplied with sinusoids and capillaries. The medulla comprises about 10% of adrenal mass. It is composed of polyhedral cells with granular basophilic cytoplasm, uniform round to oval nuclei and inconspicuous nucleoli, arranged in nests and short cords intermingled with numerous capillaries.

Adrenal Relationships and Vascular Supply

The adrenal glands cap the anterior and medial portions of the upper poles of the kidneys on either side (Fig. 12-90). The adrenal gland lies in the same compartment as the kidney, within the intermediate stratum of the retroperitoneal connective tissue, that is, inside the renal fascia.

The **right adrenal gland** has a triangular shape, with its flat anterior surface against the liver and against the vena cava to which it is joined by a short **adrenal vein**. The posterior surface lies against the **diaphragm** and, inferiorly, against the **right kidney,** often directly on the renal artery and vein. The medial portion is frequently retrocaval. The **left adrenal gland** is more attenuated, making contact with the stomach anteriorly, the spleen laterally, the upper pole of the **left kidney** and the **diaphragm** posteriorly, and the pancreas and splenic vessels inferiorly.

Adrenal Arteries

The arteries are multiple and focus on the adrenal from several variable sources, but they are principally from the **inferior phrenic artery**. The vascular supply may be viewed as a network lying in the rectangular area above the renal vessels. Three groups of arteries have been identified: (1) the constant **superior adrenal arteries** that are related to the phrenic artery; (2) a major **middle adrenal artery** from the **aorta**, but occasionally from the renal artery or celiac

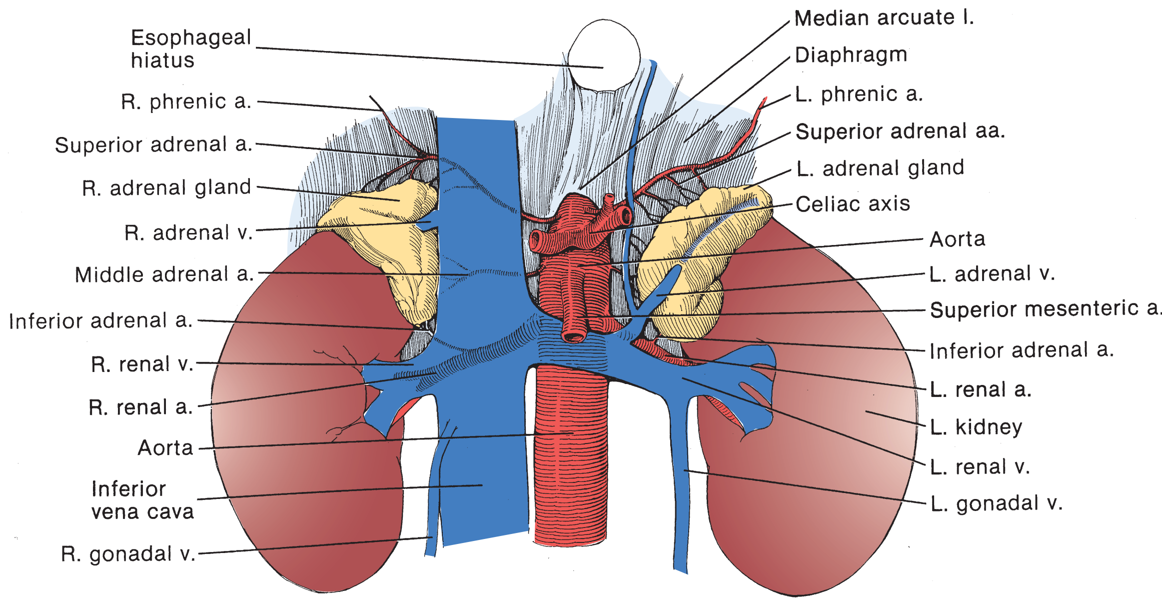


FIGURE 12-90.

artery; and (3) an **inferior renal artery** from the **renal artery**. In addition, accessory adrenal arteries may be found having multiple origins, such as from the renal artery, the aorta, and rarely, from the celiac, gonadal, and superior mesenteric arteries. There is little distinction between the arrangement of the right and left adrenal arterial systems. As the arteries divide and subdivide, as many as 60 branches may enter an adrenal, forming a plexus on the surface of the gland, from which arterioles penetrate to supply the sinusoidal vessels of the cortex and the sinuses of the medulla.

Adrenal Veins

The veins, in contrast to the arteries, have a simple organization.

The **right adrenal vein** is single and very short. It has no tributaries and empties directly into the posterolateral aspect of the **inferior vena cava**. Both the length and posterior position of entry may present hazards at surgery.

The **left adrenal vein** is also single but is longer than that on the right and runs vertically. It passes the left celiac ganglion behind the pancreatic body before joining the **left renal vein**. It often receives the inferior phrenic vein in addition to renal capsular veins. It may also be joined by the gonadal and the second or third lumbar veins.

Adrenal Lymphatics

The adrenals are drained by three sets of lymphatics. One set drains the capsule by vessels that connect with those within the gland itself. Another set drains the cortex by delicate vessels among the cortical cells that go to collectors running through the capsule with the arteries. The third set, in the medulla, is composed of very fine vessels among the cortical cells that are gathered in the trabecular system about the veins. These three sets form one or two collecting trunks that accompany the adrenal vein. The cortical and medullary collectors intercommunicate; in fact, overlap occurs within the gland at the corticomedullary junction.

Adrenal Nerves

The chromaffin cells of the adrenal medulla are connected to a rich nerve supply of preganglionic sympathetic fibers arising from spinal levels T10 to L1. The nerve supply is carried by the **greater splanchnic nerve** (shown in Fig. 12.42) and the greater splanchnic ganglion. Postganglionic fibers synapse with chromaffin cells, and others supply the blood vessels.

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Chapter 13

Bladder, Ureterovesical Junction, and Rectum

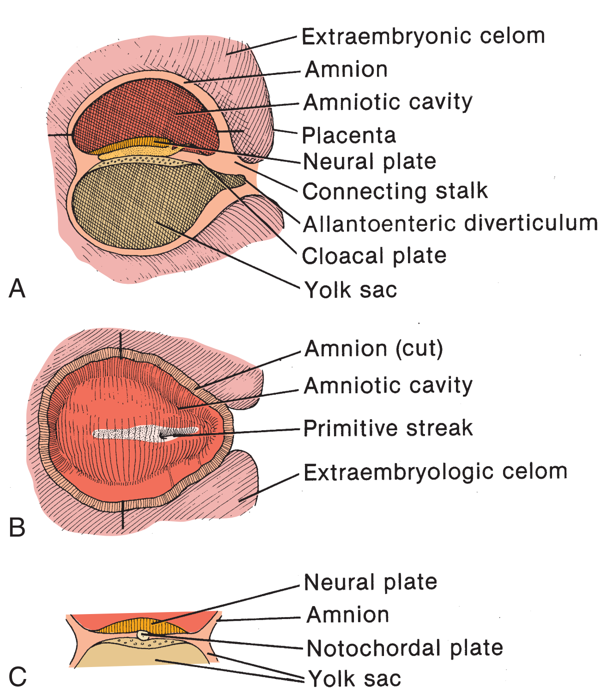


FIGURE 13-1. Formation of hindgut and allantois, 16 days' gestation. Coronal (A), frontal (B), and transverse(C) sections. (Lines indicate plane of figure below.)

Every beest that gendreth hath a bladder.

TREVISA
Barth. De P.R.v.xliv (1495) 161, 1398.

Because a man should do something else besides continually piss, the bladder was added to containe the urine.

N. CULPEPER
Culpeper's Last Legacy. London, N. Brook, 1661.

DEVELOPMENT OF THE BLADDER

Formation of Hindgut and Allantois

During the blastocyst stage, the fetus lies within the **amniotic cavity**. As the yolk duct becomes obliterated, an outgrowth of the **yolk sac** forms the **allantoenteric diverticulum** within the **connecting stalk** that joins the fetus to the **placenta**. The **cloacal plate** is formed dorsal to the connecting stalk (Fig. 13-1).

Incorporation of the Allantoic Duct into the Hindgut

The **cloaca** is that portion of the gut caudal to the opening of the **allantoenteric diverticulum**. The endodermal ventral lip of the cloaca makes contact with a patch of ectoderm of the body wall as the intervening mesoderm of the cloacal plate becomes thinned and is moved aside. This fused area of endoderm and ectoderm is the **cloacal membrane**. The membrane becomes oriented at an angle with the long axis of the embryo, defining the end of the primitive hindgut, and acts as a guide for the development of the region (Fig. 13-2).

Cloacal Membrane and the Cloaca

The **cloacal membrane** becomes oriented even more in the frontal plane, defining the **cloaca** behind it. The membrane extends cephalad from the opening of the **allantoenteric diverticulum** to the caudal end of the cloaca (Fig. 13-3).

Incorporation of the Allantoenteric Diverticulum

At about 28 days, the **dorsal section** (enteric part) of the **allantoenteric diverticulum** moves dorsally, so that the diverticulum opens into the **cloaca** cephalad to the persisting portion of the **cloacal membrane** (Fig. 13-4). The membrane becomes oriented in a still more coronal plane, resulting in a deeper cloaca. As the cloaca elongates caudally with growth of the tail, so does the cloacal membrane, until it constitutes the whole of the ventral wall of the cloaca.

The Urorectal Septum

By the middle of the fourth week of gestation, the **cloacal membrane** has been moved caudally by encroachment of abdominal mesoderm and is ready to play a role in urogenital differentiation. The **hindgut** can be recognized proximal to the cloaca and the **tailgut** distal to it.

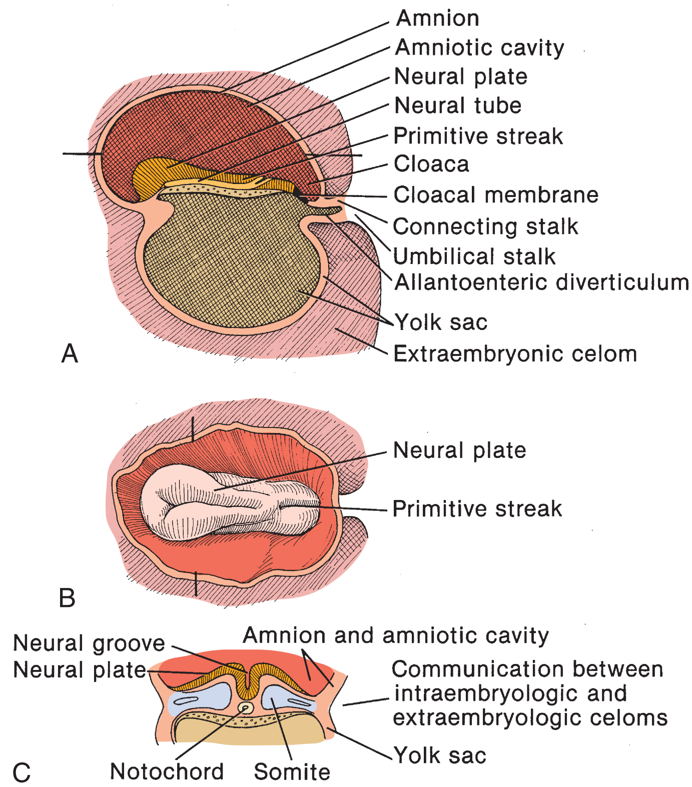


FIGURE 13-2. Incorporation of the allantoic duct into the hindgut, 19 days' gestation. Coronal (A), frontal (B), and transverse (C) sections.

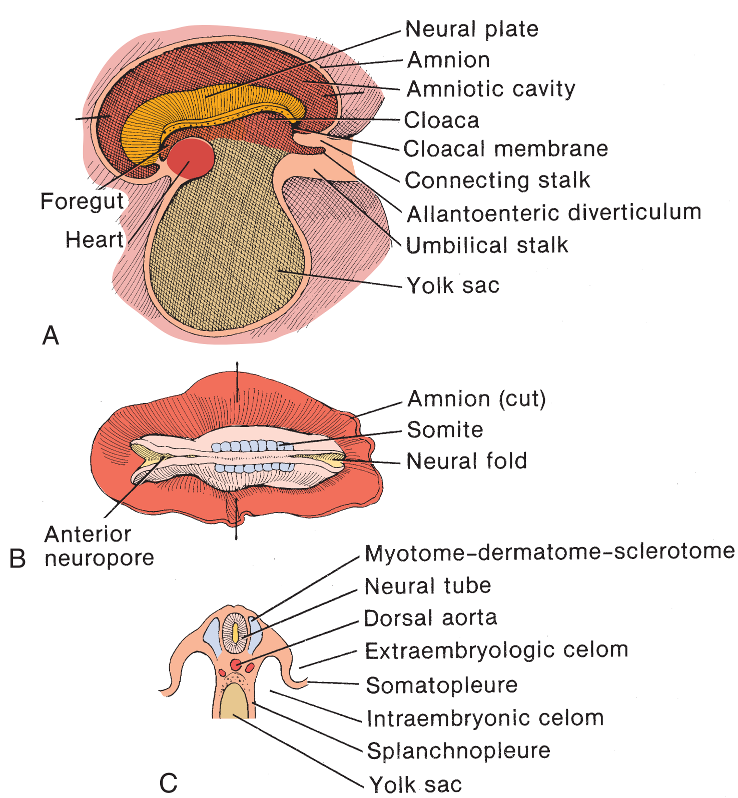


FIGURE 13-3. Cloacal membrane and the cloaca, 24 days' gestation. Coronal (A), frontal (B), and transverse (C) sections.

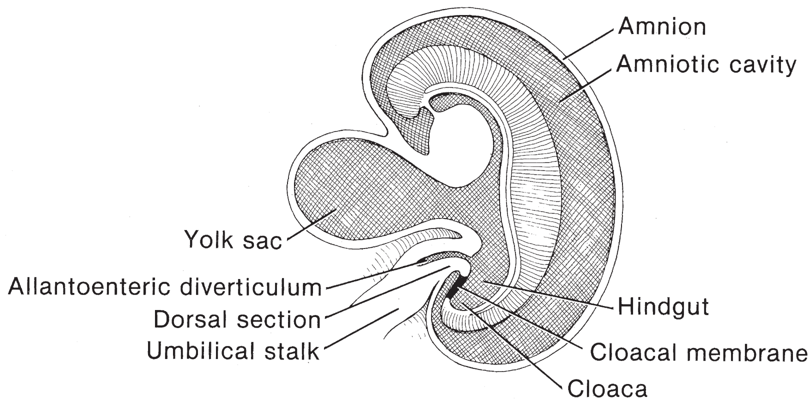


FIGURE 13-4.

At this time, a **saddle** appears between the **allantoenteric duct** and the intestinal opening of the **cloaca** (Fig. 13-5). This saddle develops into the **urorectal septum**, which descends as a partition between the ventral portion of the cloaca, destined to become the rudimentary bladder, and the dorsal portion, the hindgut. This places the allantoenteric duct at the ventral end of the future bladder.

Ectodermal and Endodermal Cloacas

As the **urorectal septum** divides the endodermal cloaca into the **urogenital sinus** and the **hindgut** (see Fig. 13-7), the **cloacal membrane** appears to subside into the ventral mesenchyme because of mesodermal growth around it. This leaves a shallow depression lined with ectoderm on the ventral surface, the **ectodermal cloaca**, from which the external genitalia and perineum will form (Fig. 13-6). The space on the dorsal side of the cloacal membrane constitutes the **endodermal cloaca**.

Mechanism of Cloacal Division

The cloaca is divided by a combination of direct downward progression of the **urorectal septum** into the cloaca and intrusion of folds from each side of it. Disturbance in this division is an important factor in the production of anorectal anomalies.

A tongue of mesenchyme extends caudally, forming the leading edge of the descending urorectal fold of Tourneaux (arrow **T**) (Fig. 13-7A). The shape of the tongue is concave because the lateral edges develop more rapidly than the center. It descends in the coronal plane but does not reach the **cloacal membrane**.

In addition to the descent of the tongue, a pair of folds press in laterally as the **urorectal folds of Rathke** (arrows **R**) (Fig. 13-7B). Rathke's folds unite in the midline and complete the urorectal septum, extending it from the ventral end of the urorectal fold of Tourneaux to the cloacal membrane.

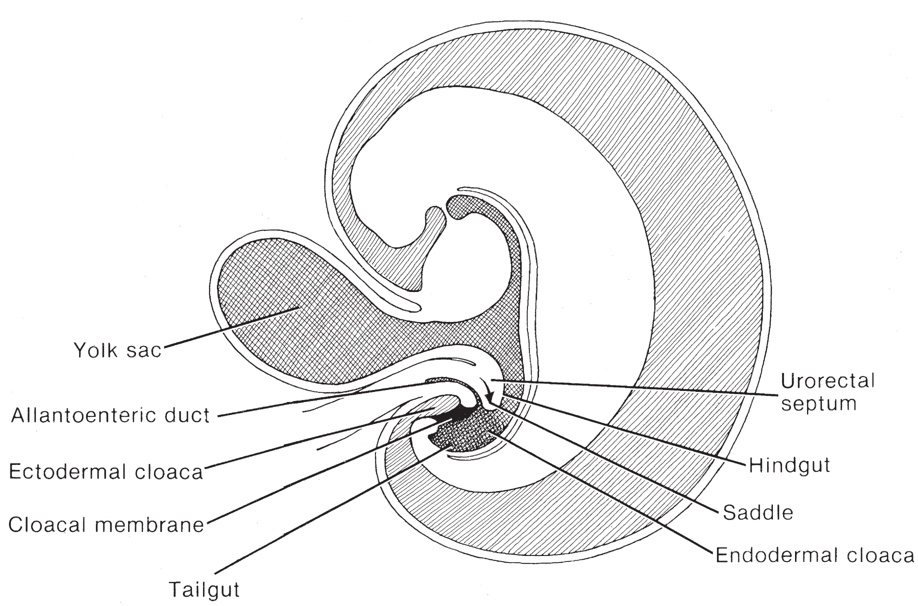


FIGURE 13-5.

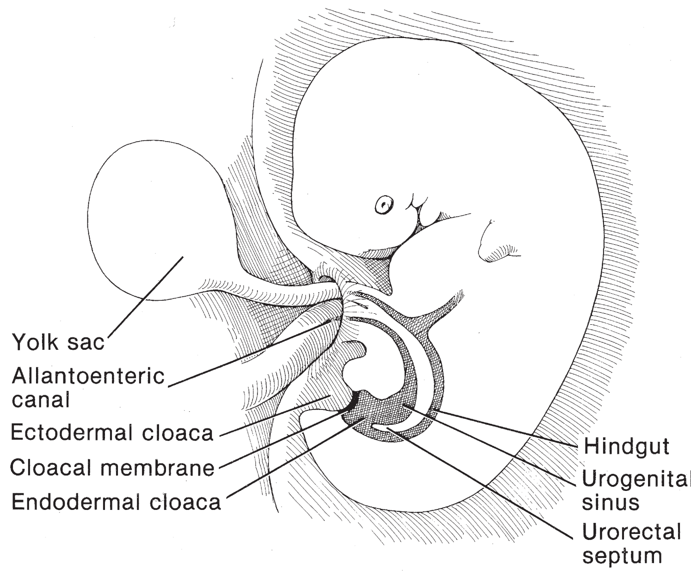


FIGURE 13-6.

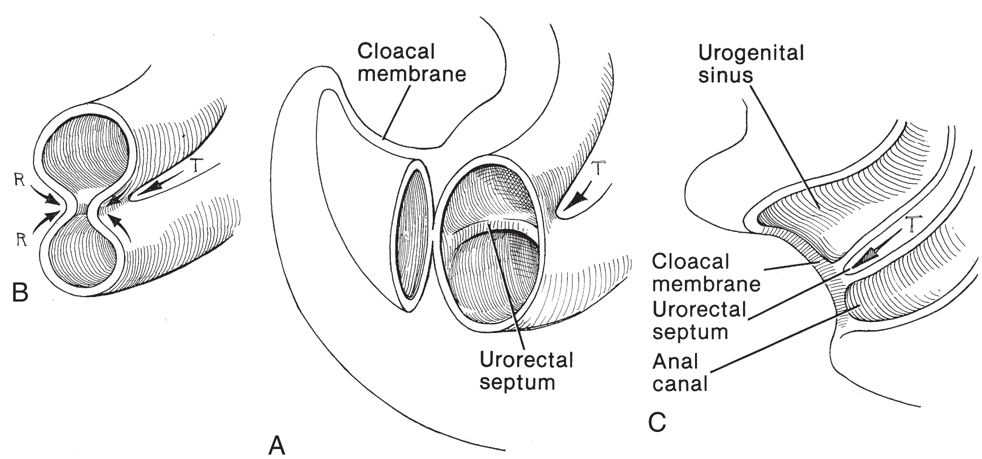


FIGURE 13-7.

The **urorectal septum** fuses with the **cloacal membrane** to complete the separation of the urinary tract into the **urogenital sinus** from the gut and the **anal canal** (Fig. 13-7C).

Vesicourethral Canal and Urogenital Sinus

By 7 weeks, the cloaca has been separated into the **urogenital sinus** anteriorly and the **anal canal** and **rectum** posteriorly. Contact of the **urorectal septum** with the cloacal membrane separates it into an anterior **urogenital membrane** and a posterior **anal membrane** (Fig. 13-8A). The urogenital membrane will open as the urogenital orifice, and the anal membrane will become similarly perforated to form the anus. The urogenital sinus subsequently becomes divided into three portions. The part continuous with the allantois and extending distally to the site of entrance of the **wolffian** (mesonephric) **ducts** at the müllerian tubercle forms the **vesicourethral canal**. The narrower middle portion constitutes the **pelvic part** of the urogenital sinus. The wider distal portion, the **phallic part**, extends to the urogenital membrane.

In the next week, the bladder and proximal urethra take form from the vesicourethral canal.

The bladder and proximal urethra are derived from two sources, even though they appear as one continuous structure (Fig. 13-8B). The bladder arises mainly from the endoderm of that portion of the urogenital sinus forming the **vesicourethral canal**, but parts of the proximal urethra and trigone are formed from mesoderm arriving during the incorporation of the end of the **wolffian duct**.

The urogenital sinus portion of the cloaca distal to the vesicourethral canal becomes reconfigured; its more proximal tubular portion becomes the **pelvic part** of the sinus, the site of the prostatic urethra, and the distal flattened portion, the **phallic part**, makes up the remainder of the urethra.

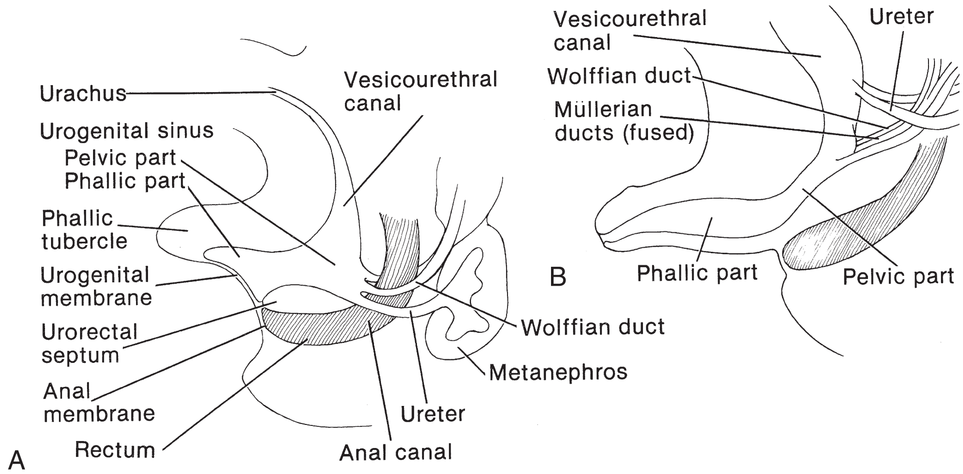


FIGURE 13-8.

The *bladder* is represented initially by the elongated upper portion of the vesicourethral canal. The lumen of this upper segment gradually enlarges compared with the narrow urethral portion, and the epithelial cells from the endoderm lining the bladder segment become larger as well. The surrounding mesenchyme, starting at the dome, differentiates into an outer connective tissue layer. In this layer, strands of smooth muscle form with little specific orientation, although three interlaced layers (inner longitudinal, middle circular, and outer longitudinal) can be identified relatively early in development. Later and independently, muscular development takes place at the base, being particularly abundant under the trigone and at the bladder neck, where the fibers take a more circular path to form the internal vesical sphincter. This portion of the bladder is also distinct from the dome because of its separate nerve supply as it acquires sympathetic innervation in contrast to the parasympathetic nerves that supply the detrusor.

By 13 weeks, the vesical neck has been formed and the bladder changes from an oval to a triangular shape.

The bladder lies within the anterior abdominal wall until the seventh week, when it is crowded out of the pelvis by the enlarging umbilical arteries on either side. It moves into the abdominal cavity on a temporary mesentery formed from the loose mesenchyme containing the urachus and umbilical arteries. The mesentery is present into the seventh month, during the time that the bladder remains in the abdominal cavity. The bladder gradually descends into the pelvis in late fetal life and early infancy, although at birth, because of the underdevelopment of the true pelvis, it still is essentially an abdominal organ. In the first 2 postnatal years, its descent into the pelvis is rapid, then it slows to become complete at the age of 20 years.

The *umbilical vesical fascia*, evolving from the temporary mesentery, is formed from the intermediate stratum of the retroperitoneal tissue. It extends cephalad to the umbilicus to enclose the urachus and the umbilical arteries and caudally to cover the bladder, seminal vesicles, and the prostate. Lateral condensations form the lateral true ligaments of the bladder and the puboprostatic ligaments (see Fig. 13-52).

Sinoutricular Cord, Verumontanum, and Formation of the Prostatic Utricle

As the tips of the fused and canalized **müllerian** (paramesonephric) **ducts** meet the **urogenital sinus**, they stimulate the sinus epithelium to form a protuberance into the sinus, the **müllerian tubercle** or verumontanum (Fig. 13-9A).

A second protuberance develops in the direction of the duct on the outside of the urogenital sinus. This projection is joined to the fused müllerian ducts to form the **sinoutricular cord** (Fig. 13-9B).

In the male, the distal portion becomes canalized to form the **prostatic utricle** or vagina masculina. In the female, this part forms the distal part of the vagina (Fig. 13-9C).

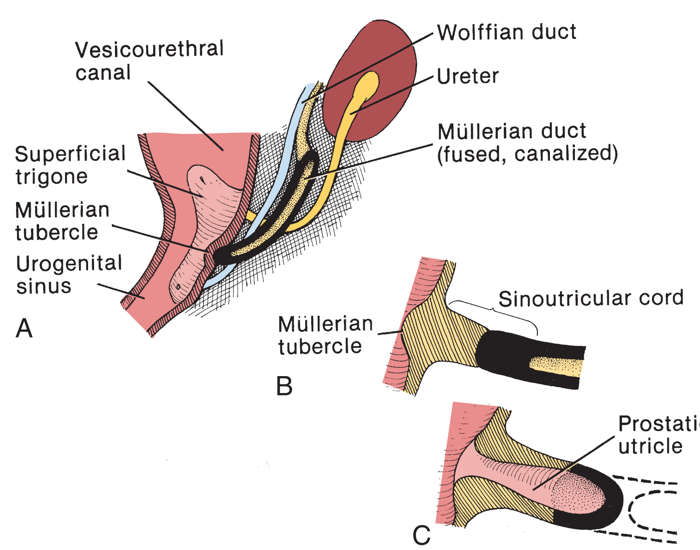


FIGURE 13-9.

URETEROVESICAL JUNCTION AND TRIGONE

Incorporation of the Common Excretory Duct

The mesodermal **common excretory duct** is defined as that portion of the **wolffian duct** distal to the ureteral bud (Fig. 13-10A). The tissue of the endodermal **vesicourethral canal** expands posteriorly toward the common excretory duct to form, in combination with the terminal piece of the common excretory duct, a funnel-shaped extrusion, the **cloacal horn**.

As the cloacal horn becomes reincorporated into the canal, it carries the terminal piece of the common excretory duct into the vesicourethral canal with the ureter attached and forms part of the superficial trigone (Fig. 13-10B). Another interpretation has the bladder wall intussuscept the wolffian duct to draw the ureter into the bladder because the cloacal horn looks like an intussusception as it is reincorporated.

The **ureter** had originally branched from the dorsal aspect of the wolffian duct, but during incorporation, the **ureteral orifice** changes position so that it is brought into the bladder wall directly lateral to the **orifice** of the **wolffian duct**.

The formation of the **superficial trigone** begins with the fusion of the mesoderm medial to the two ducts (Fig. 13-10C).

Although the **orifice** of the **wolffian duct** remains in place, the mesoderm that was originally part of the common excretory duct becomes active and enlarges. This mesodermal growth displaces the ureteral orifices cranially and laterally, shifting them from near the midline at the junction of the **vesicourethral canal** with the **urogenital sinus** into a lateral position in the **bladder**. The entire superficial trigone, a structure that extends from the verumontanum to the ureteral orifices, is formed by this mesodermal (wolffian) growth.

Incorporation of the Common Excretory Duct

The steps of incorporation are shown in three sets of drawings: Figs. 13-11A and B each have a coronal, sagittal, and frontal view. Figure 13-11C shows a frontal and a sagittal view. A **dashed line** across each frontal view indicates the original level where the wolffian duct made contact with the **vesicourethral canal,** defining the junction of the canal with the **urogenital sinus.**

The **common excretory ducts** and the future ostium of the fused **müllerian ducts** enter the **vesicourethral canal** on the **verumontanum** (müllerian tubercle) (Fig. 13-11A). The **ureteral buds** branch from the **wolffian duct** proximal to the **common excretory duct,** which is continuous with the **cloacal horn** that was derived from the tissue of the canal.

With the incorporation of the cloacal horn and the **common excretory duct** into the **vesicourethral canal,** the **wolffian duct** and the ureter enter side by side (Fig. 13-11B). The **ureteral orifice** enters lateral to the orifice of the **ejaculatory duct.** The terminal portion of the **müllerian duct,** now the **prostatic utricle,** opens between them.

The growth of mesodermal wolffian tissue (cross-hatched area) between the orifices of the **ureter** and the **ejaculatory duct,** combined with expansion of the bladder wall, results in the ascent and lateral displacement of the ureteral opening (Fig. 13-11C). In contrast, the opening of the wolffian duct is fixed in position at the verumontanum, not only from its close embryologic association with the müllerian duct but also because the entire lower portion of the urogenital sinus is fixed in solid mesodermal condensations so that expansion can occur only in a cephalic direction. The terminations of the wolffian ducts do, in fact, move a small distance cephalad, leaving a symmetric pair of longitudinally disposed remnants as **collicular**

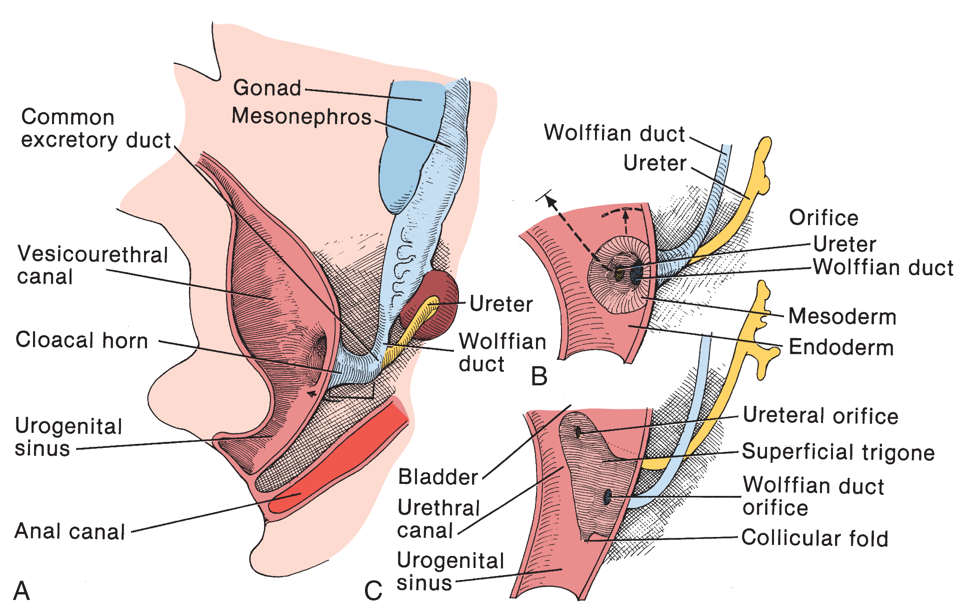


FIGURE 13-10.

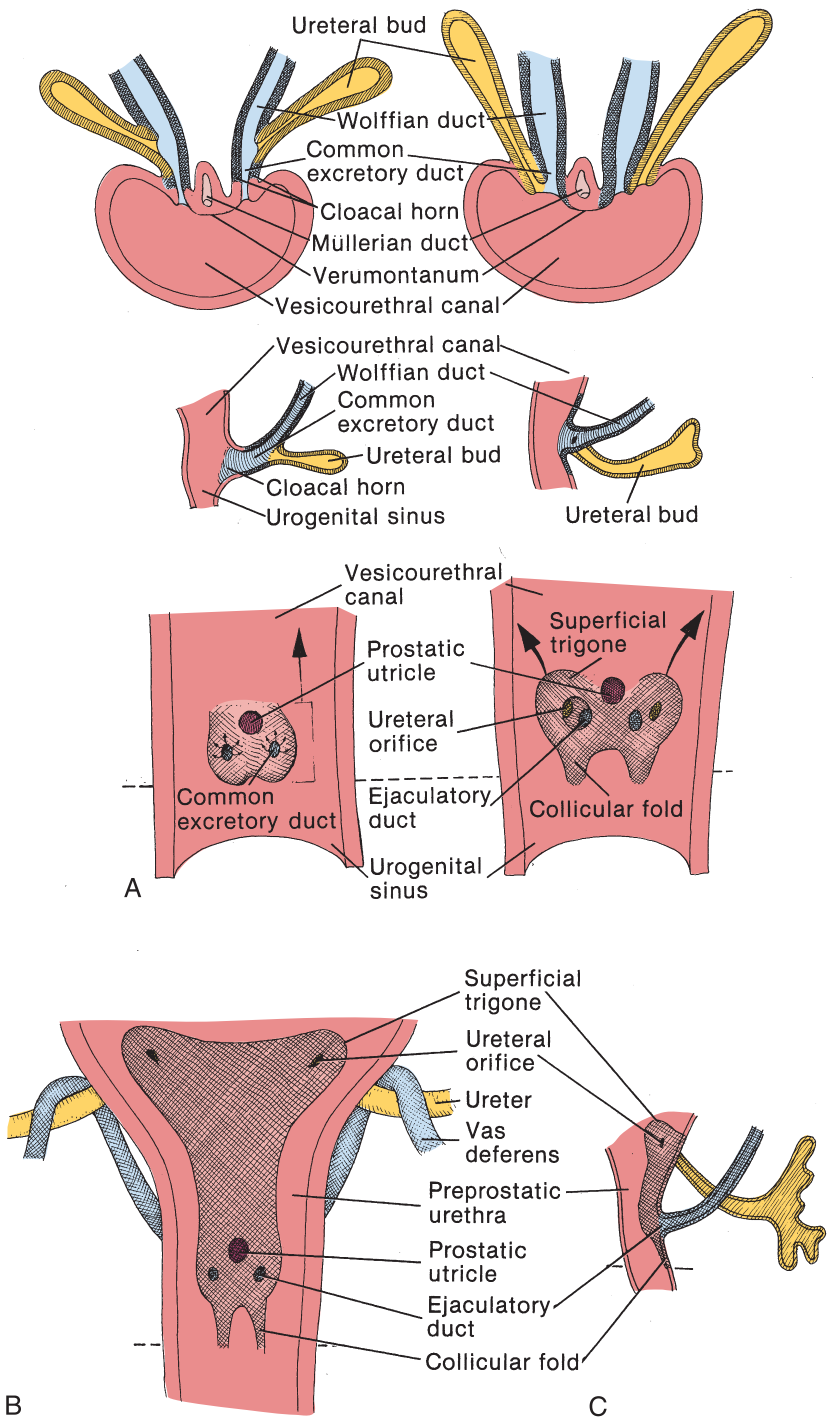


FIGURE 13-11.

folds. The **dashed line** shows the level at which the wolffian duct originally made contact with the vesicourethral canal. The length of the collicular folds is an indication of the distance that the ducts and verumontanum have moved cephalad.

In the mature stage, the tissue from the wolffian duct forms the **superficial trigone.** The **ureteral orifice** lies at its proximal extremity. Distally, in the **preprostatic urethra,** the verumontanum is found holding the **ejaculatory ducts** and **prostatic utricle.** Thus developmentally the muscles of the superficial trigone are continuous with those of the ureter, all being of wolffian origin.

Ductal Incorporation in Male and Female

Male

The ductal mesoderm (cross-hatched area) that was incorporated into the **vesicourethral canal** moves cranially and laterally and carries the ureteral orifices with it. As described previously, this tissue becomes distributed as the **superficial trigone** in the area between the ejaculatory ducts distally and the ureteral orifices proximally. At this stage, the **kidney** has become organized but the **mesonephros**

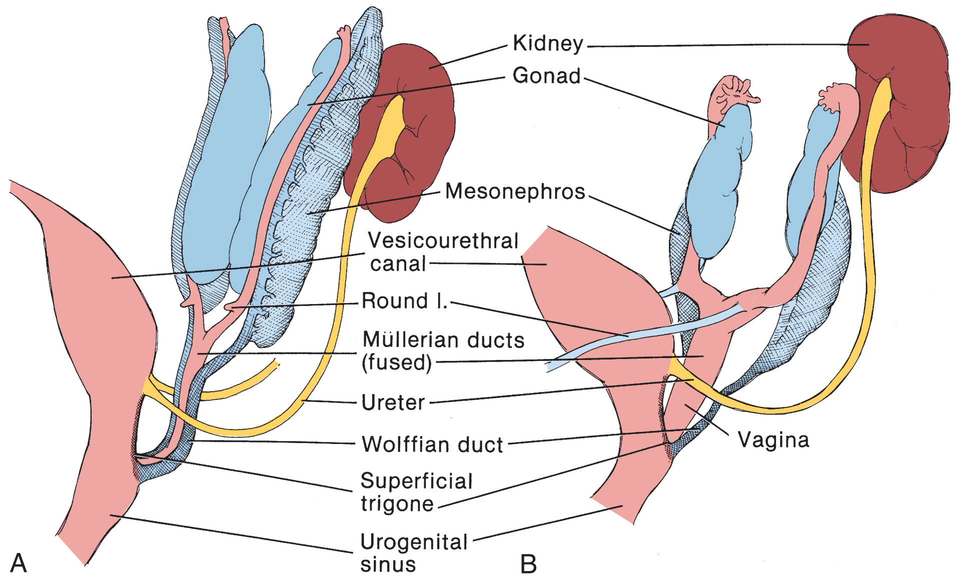


FIGURE 13-12.

remains lateral to the **gonad** (Fig. 13-12A). The fused **müllerian ducts** enter the canal at the verumontanum, which lies at the junction of the vesicourethral canal and the **urogenital sinus.** The ureters penetrate the bladder wall by a straight course; later development provides an oblique tunnel.

Female

The wolffian mesoderm is incorporated as in the male (Fig. 13-12B). Instead of resulting in a prostatic utricle, canalization of the sinoutricular cord in the female forms the terminal portion of the **vagina** (see Fig. 13-9). The entire female urethra develops from the urogenital sinus as the homologue of the posterior urethra of the male. The equivalent of the verumontanum containing the müllerian prostatic utricle could be viewed as lying at the introitus (see Fig. 15-6). Remnants of the wolffian ducts become the epoöphoron and paroöphoron, and are also represented in the adult as the Gartner ducts that extend the length of the vagina (see Fig. 15-3).

ANOMALIES OF THE URETEROVESICAL JUNCTION

Anomalies are common near the junction of the ureter with the trigone, resulting from the variations in the budding of the ureteral bud from the wolffian duct. They may be duplications consequent on the formation of a second bud on the wolffian duct or they may be ureteral ectopia from late arrival or vesicoureteral reflux from early arrival of the ureter at the vesicourethral canal.

Even if the ureteral bud forms at the proper place and time, it may be unduly large and result in formation of a dilated upper tract such as is seen in the nonrefluxing nonobstructed megaureter (see Fig. 13-28). The bud may not elongate (renal ectopy), it may not grow or have sufficient inductive ability (blind ending ureter and hypoplastic kidney), or it may divide before it has reached the nephrogenic blastema (renal duplication and triplication).

An inadequate response of the renal blastema to the stimulus arising from the branching ureteral bud may also result in a reduction of renal tissue. Renal dysplasia or dysgenesis (bad molding or bad generation) are not clearly defined as embryologic entities. They may be associated with obstruction but can occur in inheritable syndromes in the absence of obstruction. Renal dysplasia may be due to lack of inductive capacity in a ureteral bud. Or the bud may develop in a relatively abnormal position so that it attempts induction of a deficient region of the renal blastema. Evidence for this is that dysplasia is commonly found associated with a displaced secondary ureteral bud that empties laterally or distally into the urethra.

Anomalies at the Ureteric Hiatus

Paraureteral diverticula (saccules) arise at the upper extremity of the trigone just above the ureteric orifice as a transhiatal herniation of the bladder mucosa. Some are congenital, because they are found in the fetus and are not necessarily associated with obstruction. Deficient development of the hiatus and of the muscle of the superficial trigone is the probable cause in infants. Many are probably secondary to a weak inner longitudinal layer of the bladder musculature at the ureterovesical angle and to poor support from the outer longitudinal layer (Fig. 13-13).

With obstruction or neurogenic bladder, increased detrusor pressure may cause transhiatal herniation of the vesical mucosa to form the so-called saccule of mucosa forced through an overstretched hiatus. Hiatal diverticula disturb the submucosal course of the terminal ureter and, therefore, are associated with reflux.

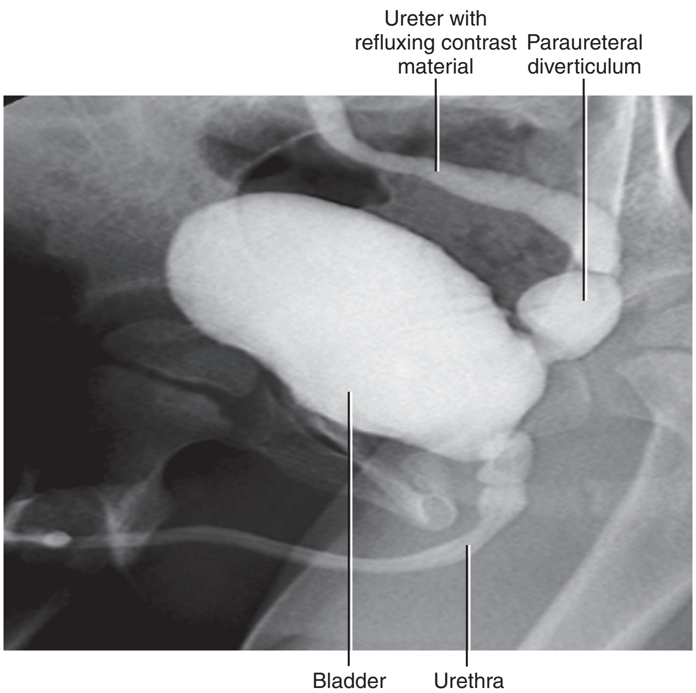


FIGURE 13-13. Paraureteral diverticulum. Patient was a 3-year-old boy who presented with hematuria. Voiding cystourethrogram (VCUG) shows a large para-ureteral diverticulum and vesico-ureteric reflux. *(Image courtesy of Jack Elder, M.D.)*

True diverticula may be present on a purely congenital basis; these will have some muscle strands in the wall.

Ureterocele

A ureterocele is a cystic dilation of the terminal ureter. How it develops is not well understood. One explanation is delayed rupture of the occluding epithelial membrane normally lying at the junction of the ureter and the urogenital sinus in the sixth week of gestation, when nephrogenic function is in abeyance; persistence of the membrane leads to obstruction at that site. Another explanation is delay in the absorption of the immature ureter into the vesicourethral canal (see Fig. 13-10). A third theory is that arrest in muscular development of a ureter situated too far caudally results in distention of the terminal portion.

A **simple ureterocele,** in which the cystic formation occurs at the site of the normal orifice, is rare in children and may actually be acquired rather than congenital (Fig. 13-14).

With **ectopic ureterocele,** the orifice lies between the normal position and the urethral sphincter, an anomaly that is five times more common in girls (Figs. 13-15, 13-16, 13-17, and 13-18). A distinction is made between an intravesical ureterocele, in which the orifice is within the bladder, and an ectopic ureterocele extending distal to the bladder neck, although its orifice may lie in the bladder.

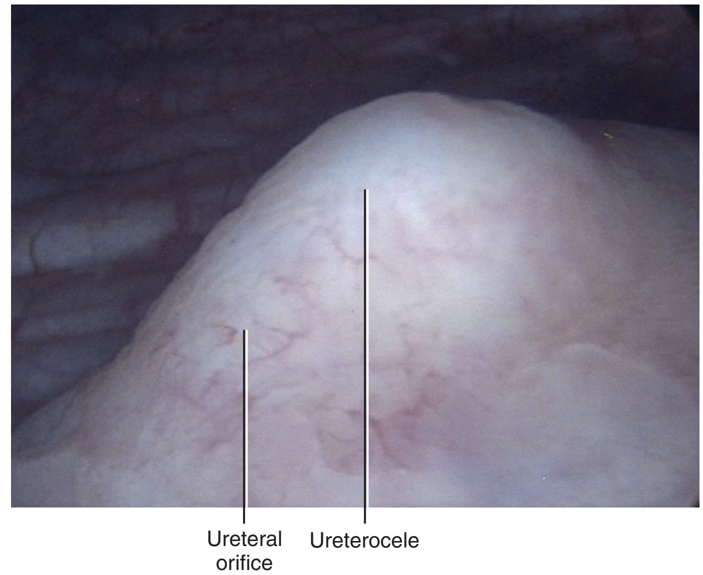


FIGURE 13-14. Ureterocele, cystoscopic view. The small ureteral orifice is indicated at left. *(Image courtesy of Donald Bodner, M.D.)*

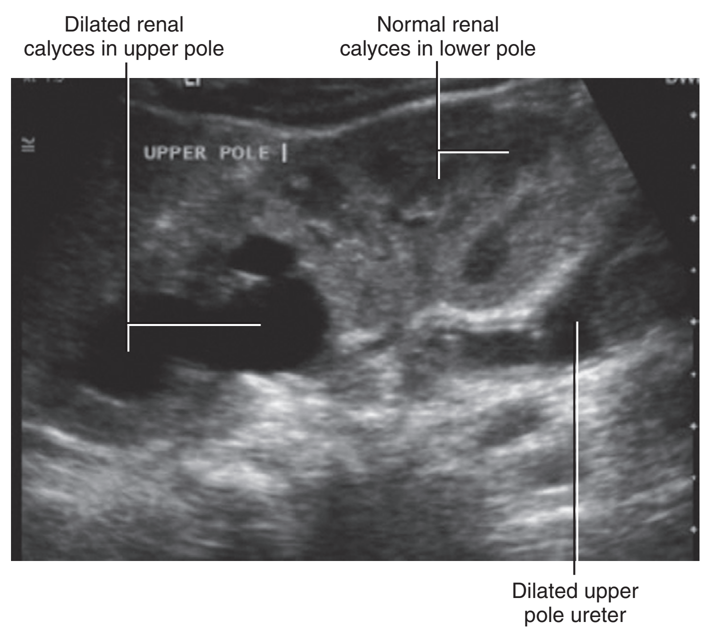


FIGURE 13-15. Ureterocele. Ultrasound shows that the upper pole calyces are markedly dilated. The lower pole calyces are normal. *(Image courtesy of Raj Paspulati, M.D.)*

Three types have been described. The simple *stenotic type* is intravesical and has a muscular wall with a narrow orifice on its summit. In the *sphincteric type* of ureterocele, the orifice lies within the internal vesical sphincter and empties only during voiding. A *sphincterostenotic orifice* forms the third type, having features common to the other two types.

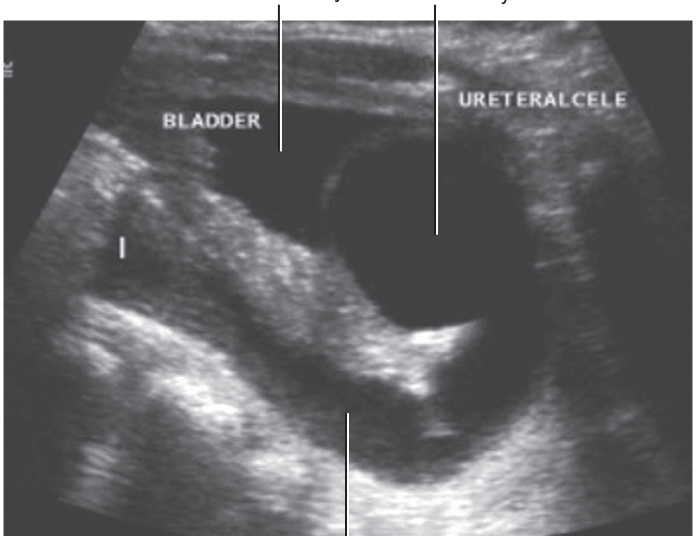


FIGURE 13-16. Ureterocele. Same patient as shown in Fig. 13-15. Ultrasound view of dilated distal ureter, and lesion in bladder. *(Image courtesy of Raj Paspulati, M.D.)*

FIGURE 13-18. Ureterocele. The distal ureter, at left, is markedly dilated. A decompressed ureterocele is at right. *(From MacLennan GT and Cheng L. Atlas of Genitourinary Pathology, Springer-Verlag London Limited, 2011, with permission.)*

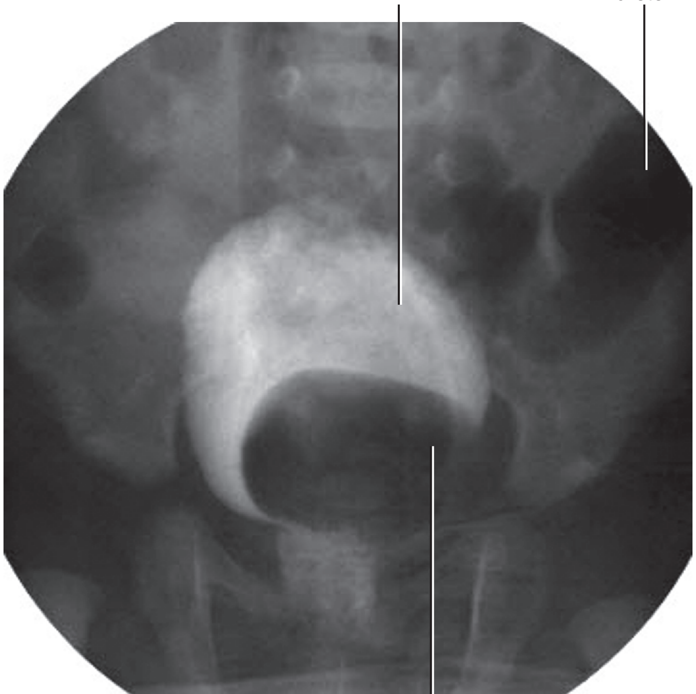


FIGURE 13-17. Ureterocele. Same patient as shown in Fig. 13-15. Cystogram, with a large filling defect resulting from the presence of a ureterocele. Dilated left ureter is also visible. *(Image courtesy of Raj Paspulati, M.D.)*

Illustrated in Fig. 13-19 are a **simple ureterocele** (stenotic type) and an **ectopic ureterocele** (sphincteric type) draining a dilated upper renal segment. The opening of the **ectopic ureter** into the ureterocele is, as expected, distal to that of the **orthotopic ureter.** The **orifice of the ureterocele** in this case lies in the bladder neck.

Ureteral Duplication

The ureter may be duplicated with both orifices lying together in an essentially normal position or one orifice may be ectopic. A single ureter with a single orifice may be displaced into an ectopic position by the same embryologic mechanism associated with a second duplicated ureter. The important factor is the time of arrival of the ureteral orifices at the vesicourethral canal and the differential growth of the wolffian mesoderm of the posterior wall of the canal.

Use of the terminology proposed by the Committee on Terminology, Nomenclature and Classification, Section on Urology, American Academy of Pediatrics avoids confusion in describing duplication anomalies. A *duplex kidney* has two pyelocaliceal systems. A *bifid renal system* has two pelves joined at the ureteropelvic junction, forming a *bifid pelvis.* A *bifid ureter* consists of two ureters joined above the ureterovesical junction. *Double ureters* are two completely duplicated ureters (Figs. 13-20 and 13-21). A *lower pole ureter* drains the lower pole of a *duplex kidney* through a *lower pole orifice* that is in the normal (*orthotopic*) position at the lateral corner of the trigone. An *upper pole ureter* drains the upper pole via an *upper pole orifice* that is *ectopic,* draining onto the trigone distal to the site of the orthotopic orifice or beyond the proximal lip of the vesical neck. In the male, the most distal

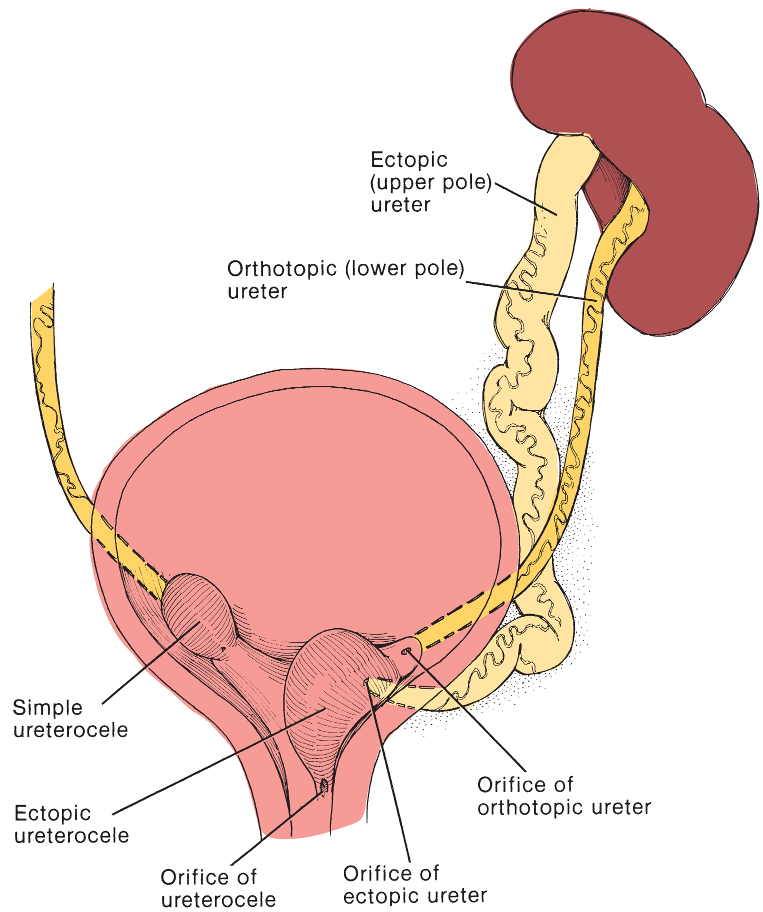


FIGURE 13-19.

FIGURE 13-20. Double ureters on the left, on intravenous pyelogram. *(Image courtesy of Raj Paspulati, M.D.)*

FIGURE 13-21. Double ureters. At cystoscopy, two ureteral orifices were identified on the right. *(Image courtesy of William Larchian, M.D.)*

position of an ectopic orifice is the verumontanum; in the female, it is the introitus (Figs. 13-22 and 13-23). Ectopic ureters initially follow the same course as the orthotopic one through the bladder wall and pass through the usual submucosal tunnel but take an abnormal course more distally.

FIGURE 13-22. Ureteral duplication with ectopic ureteral orifice. A catheter has been placed into the ureter via the ectopic orifice in the vagina. *(Image courtesy of Lynn Woo, M.D.)*

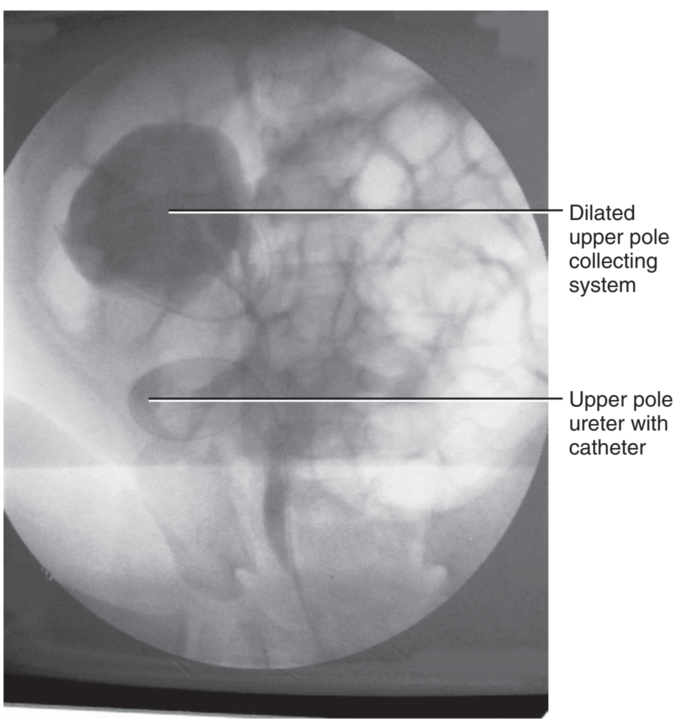


FIGURE 13-23. Ureteral duplication with ectopic ureteral orifice. Same patient as shown in Fig. 13-22. Injection of contrast via the intraureteral catheter shows marked distension of the upper pole renal moiety. *(Image courtesy of Lynn Woo, M.D.)*

Ureteral Duplication with Ectopic Orifice

The final site of the ureteral orifice depends on the original site of the bud from the wolffian duct. Typically, the ectopic orifice of a double system will lie in the bladder or urethra distal to the orthotopic one. Stephens has shown that there is an "ectopic pathway" that includes not only sites distal to the normal orifice but medially and superiorly to it. However, orifices in the latter positions would violate the Weigert-Meyer rule (see later section).

In Fig. 13-24, the dotted line indicates the level at which the wolffian duct joined the urogenital sinus. It marks the junction of the vesicourethral canal with the urogenital sinus.

With two separate ureteral buds developing from the **common excretory duct** (dark cross-hatched area), one ureteral bud (black) branches proximally from the duct and makes connection with the upper pole of the **nephrogenic blastema** as the **upper pole ureter** (Fig. 13-24A). The second bud (hatched area) branches from the common excretory duct distally, nearer the vesicourethral canal, and enters the lower pole of the blastema as the **lower pole ureter.**

As the **common excretory duct** (dark cross-hatched area) becomes incorporated into the **vesicourethral canal** to form the superficial trigone, the more distal portion of the common excretory duct to which the **lower pole ureter** (hatched area) is attached is the first to join the canal (Fig. 13-24B). As it becomes implanted lateral to the wolffian duct orifice, it is the first of the two ureteral orifices to be carried proximally and laterally on the expanding trigone.

The **upper pole ureter** arrives late because it remained attached to the duct for a longer time and has farther to go (Fig. 13-24C). When it joins the canal, much of the **superficial trigone** has been formed and the orifice of the **lower pole ureter** has already been moved proximally.

As the common excretory duct becomes totally incorporated and the formation of the trigone is completed, the orifice of the **upper pole ureter** remains distal to that of the **lower pole ureter** because it arrived too late to be carried cephalad by the growth of the ductal mesoderm (Fig. 13-24D).

This reversal of the upper-lower relationship vis-à-vis the kidney and bladder is incorporated in the Weigert-Meyer rule: with duplication, the ureter from the upper pole terminates more distally than that from the lower pole. Rare exceptions to the rule can be explained by the premature division of a single bud, so that both buds arrive at the sinus at the same time.

Should the second ureteral bud not separate but remain attached to the duct, it will empty with it at the verumontanum. It cannot terminate in the urethra more distally than at this site, although it may end in one of the wolffian duct derivatives, such as the ejaculatory duct or seminal vesicle. If the wolffian duct fails to separate from the ureteric bud as the ureter is incorporated into the vesicourethral canal, an ectopic vas deferens may empty into the ureter.

In the female, the wolffian duct is represented by the Gartner duct, which becomes incorporated into the vaginal wall. The "verumontanum" may be visualized as lying beyond the introitus, which is the homologue of the prostatic utricle. Thus the ureteral orifice may empty into the urethra along the course of the Gartner duct distal to the sphincter. It may also end in a derivative of the müllerian duct (uterus, cervix, or vagina), with resulting incontinence. These connections to the female genital tract are explained by the close association of the müllerian and wolffian ducts during development of the urogenital sinus. It has been postulated

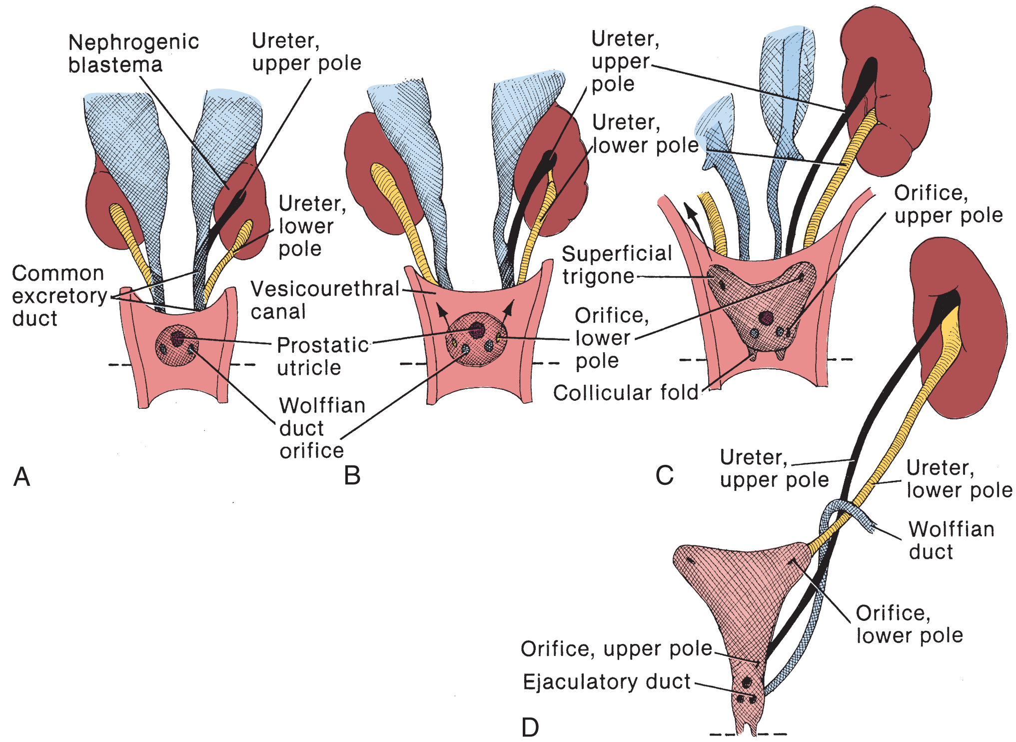


FIGURE 13-24.

that the ureter at first ends blindly in these structures and that the accumulation of urine then forces an opening to the exterior, with resulting urinary incontinence.

Ectopic Ureteral Orifice with a Single System

The ureteral bud forming the **ureter** (black) has branched from the **common excretory duct** (dark cross-hatched area) more proximally than normal, in a position similar to that of the upper pole ureter in a duplication anomaly (Fig. 13-25A; see also Fig. 13-24).

As the common excretory duct is incorporated into the **vesicourethral canal,** the **ureter** will arrive late. Losing the opportunity to ascend with the generating wolffian tissue, it will open through an **ectopic orifice** into the canal at a site distal to the **orthotopic orifice** (Fig. 13-25B).

Primary Reflux

Primary reflux may be explained by a **ureteral bud** that arises abnormally low from the wolffian duct, producing a short **common excretory duct**, which is just the opposite of what occurs in ureteral ectopy (Fig. 13-26A).

The early arrival of the bud at the vesicourethral canal allows extra time for craniolateral migration of the ureter in the enlarging wolffian mesoderm. The result is a large trigone and a **lateral ectopic orifice** that is displaced

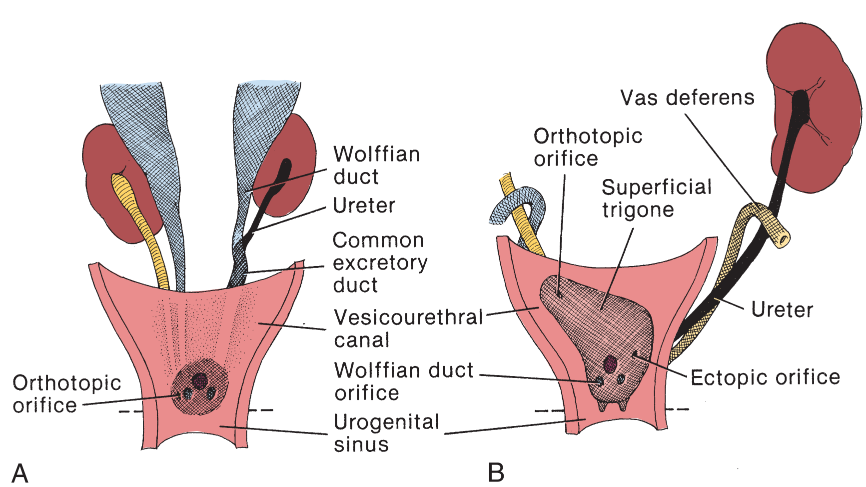


FIGURE 13-25.

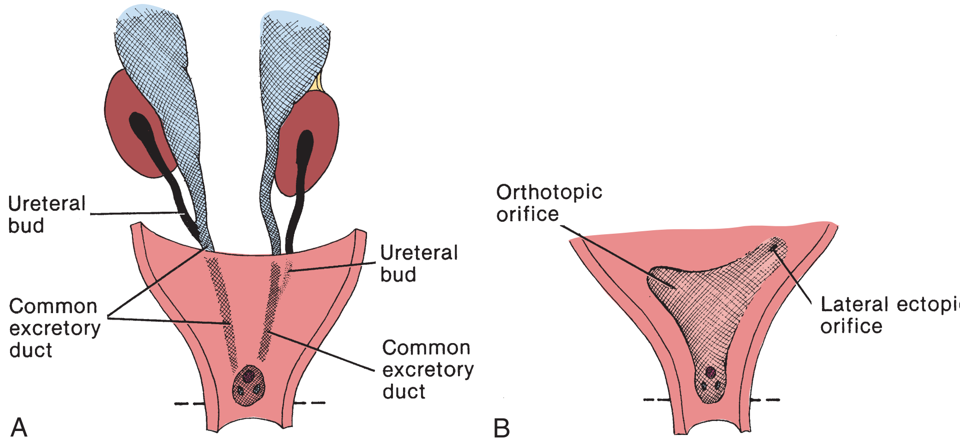


FIGURE 13-26.

proximally and laterally (Fig. 13-26B). Because the common excretory duct was short and so contributed less mesoderm to the formation of the trigone, the superficial trigone, as well as the intramural ureter, may be less well developed and consequently less able to maintain ureteral obliquity during voiding (Fig. 13-27).

Megaureter

Wide ureters can be divided into three categories (Fig. 13-28): (1) reflux megaureter, (2) obstructed megaureter, and (3) agnogenic megaureter. *Reflux megaureter* may be primary—that is, of unknown embryologic etiology as in the prune belly syndrome—or may be secondary to vesical obstruction or neurogenic bladder (Fig. 13-29). **Obstructed megaureter** may be primary if it arises from an increase in the connective tissue component (of undetermined etiology) that results in an adynamic distal ureteral segment, or it may be secondary from external obstruction or distal stenosis (Fig. 13-30). **Nonrefluxing–nonobstructed megaureter** or agnogenic megaureter may be primary if proved neither obstructed nor the result of polyuria, infection, or residual changes after release of obstruction (Fig. 13-31).

Of surgical importance is that these large ureters acquire a blood supply proportionate to the bulk of their walls, a supply derived from the ureteral, gonadal, and iliac arteries as well as from the vesical arteries. This supply runs in what appears as a “mesentery” to the surgeon viewing it through the peritoneum. The blood is distributed through an augmented number of longitudinal arteries in the ureteral wall connected with the uretero-subperitoneal arteries (see Fig. 12-85). The vessels may be four times normal size,

FIGURE 13-27. Vesicoureteric reflux, primary, evident on voiding cystourethrogram. *(Image courtesy of Vikram Dogra, M.D.)*

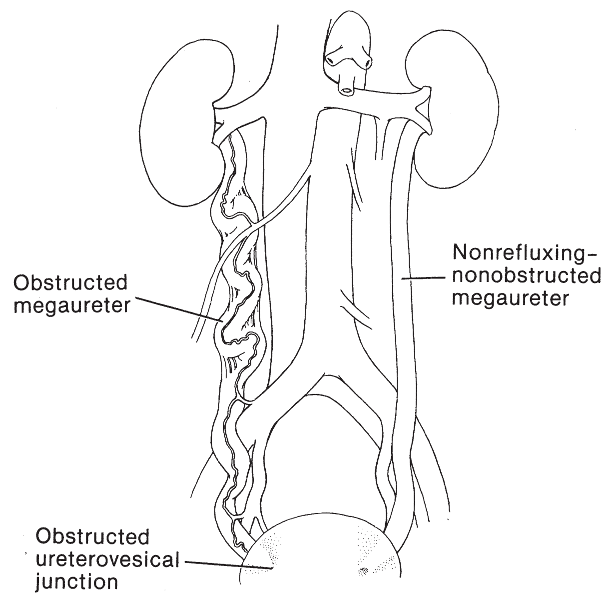


FIGURE 13-28.

FIGURE 13-29. Megaureter, secondary to vesicoureteral reflux. This post void film of a voiding cystourethrogram series demonstrates bilateral grade 5 vesicoureteric reflux. *(Image courtesy of Vikram Dogra, M.D.)*

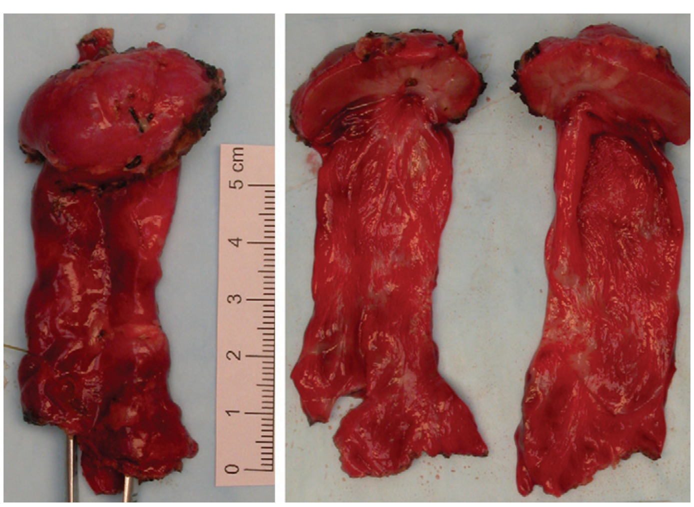


FIGURE 13-30. Megaureter secondary to obstruction. Upper pole heminephrectomy specimen from a 1-year-old female with recurrent urinary infection and obstruction of the upper pole moiety of a completely duplicated collecting system. Intact specimen is at left; bisected specimen is at right. The ureter is massively dilated.

forming a typical “palisade.” They may be preserved by leaving the adjacent retroperitoneal tissue and peritoneum intact over the ureter.

In some instances, the developing ureter may grow longer than the distance from bladder to kidney, thereby developing pleats. These usually clear with the growth of the body after birth. The intrinsic narrowings at the ureteropelvic junction, the ureterovesical junction, and the pelvic brim do not appear until the ascent of the kidney is complete.

FIGURE 13-31. Megaureter, agnogenic. Intravenous pyelogram shows bilateral massively distended ureters. In this case, neither vesicoureteric reflux nor ureteral obstruction was demonstrated, and the ureteral distension was considered idiopathic in origin. *(Image courtesy of Vikram Dogra, M.D.)*

FORMATION OF THE URACHUS

Allantois, Vesicourethral Canal, and Urachus

In the fetus, the vesicourethral canal is conical and is continuous with the allantois at the umbilicus (see Fig. 13-7). The urachus is formed from the cranial portion of the canal, with at most a small contribution from the allantois.

At birth, the bladder still extends well toward the umbilicus because the urachus is usually only 2.5 cm in length at that time, not counting an additional 0.5 cm traversing the bladder wall. It lies hidden between the very large umbilical arteries and passes through the transversalis fascia with them at the umbilicus. Through the agencies of differential growth rates, descent of the bladder into the pelvis, and localized degeneration, the distal end of the urachus is drawn down with the obliterated umbilical arteries to end at one of several sites. Occasionally, it may end at the umbilicus (anatomic variant Type I). Most often, the distal portion of the urachus degenerates, leaving it to terminate against one of the obliterated umbilical arteries at a point two-thirds distant from the umbilicus (Type II). It may join both umbilical arteries (Type III). Finally, it may regress to a length of a few centimeters, ending in fibrous bundles, each of which is the remnant of a urachal cell column from which the epithelium has disappeared. These bundles form the fibrous plexus of Luschka (Type IV).

The urachus resembles the bladder histologically, as would be expected from their common origin. It is lined with transitional epithelium that is surrounded by smooth muscle, around which is an adventitia.

A potential lumen persists in the more proximal part of the urachus throughout life. It consists of irregularly alternating dilated and narrow segments, lined with modified vesical epithelium and covered with an attenuated muscle coat. The lumen may be intermittently occluded with desquamated cells. The epithelial cells may retain the ability to multiply and penetrate the surrounding connective tissue, forming adenomas and cysts, and even carcinoma, later in life. After birth the urachus forms the median umbilical ligament.

The blood supply to the urachus comes from the urachal arteries as branches of the superior vesical arteries and passes along its anterior surface as far as the umbilicus.

URACHAL AND VESICAL ANOMALIES

Urachal Anomalies

Four groups of urachal anomalies are seen clinically: (1) congenital patent urachus, in which the lumen is open from bladder to umbilicus; (2) vesicourachal diverticulum, opening internally; (3) umbilical cyst and sinus, open externally; and (4) an alternating urachal sinus that opens both to the umbilicus and to the bladder (Table 13-1).

Patent Urachus

The bladder at birth is not a pelvic organ but lies so high that its apex may almost reach the umbilicus. In its descent into the pelvis, the portion that constitutes the urachus normally descends with the body of the bladder. Should the bladder not descend or the urachus fail to constrict, the open communication between bladder and umbilicus results in a **patent urachus** (Type II anatomic variant) (Fig. 13-32A).

TABLE 13-1 FACTORS IN URACHAL DISEASES

Diagnosis	Cause	Usual Age	Urinary Symptoms
Congenital patent urachus	Failure of vesical descent and urachal regression	Infant	Umbilical urinary fistula
Vesicourachal diverticulum	Dilation of urachal stump from vesical neck obstruction	Adult	Usually none except from obstruction itself
Umbilical cyst and sinus	Infection in persistent urachal remnant	Adult	Umbilical sinus and granuloma
Alternating urachal sinus	Infection in persistent urachal remnant	Adult	1. Recurrent umbilical sinus infection alternating with recurrent vesical infection 2. Occasional urinary fistula

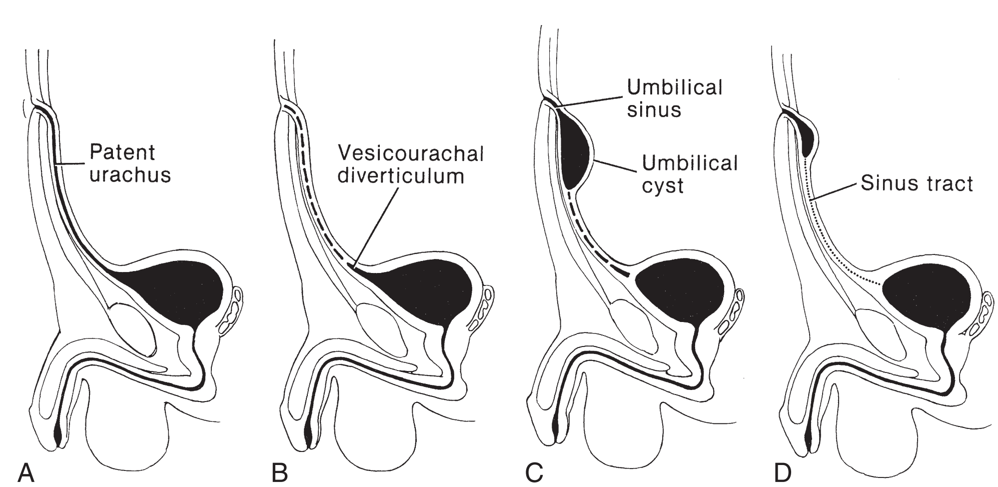


FIGURE 13-32.

Outlet obstruction does not appear to play a dominant role, because it is present in only 1 case in 7. Moreover, the urachal lumen normally would be closed before the urethra becomes patent.

As would be expected, this is a rare anomaly and one that is almost always detected in the neonatal period, even though the amount of urinary drainage at the umbilicus may be scanty. Two forms can be recognized: (1) persistence of the fetal bladder with prolongation of the bladder apex or, more commonly, (2) persistence of a sizable lumen from lack of normal urachal contraction and retraction.

Vesicourachal Diverticulum

The urachal segment adjacent to the bladder may not entirely constrict, remaining dilated for a short distance with the appearance of a small vesical diverticulum (Fig. 13-32B). With chronic stasis, as in the prune-belly syndrome, the diverticulum may be quite large and require removal (Figs. 13-33, 13-34, 13-35, and 13-36).

Umbilical Cyst and Sinus

If a segment of the urachal lumen does not become obliterated in the region of the umbilicus, it may form a urachal cyst or may become infected and drain as a sinus (Fig. 13-32C).

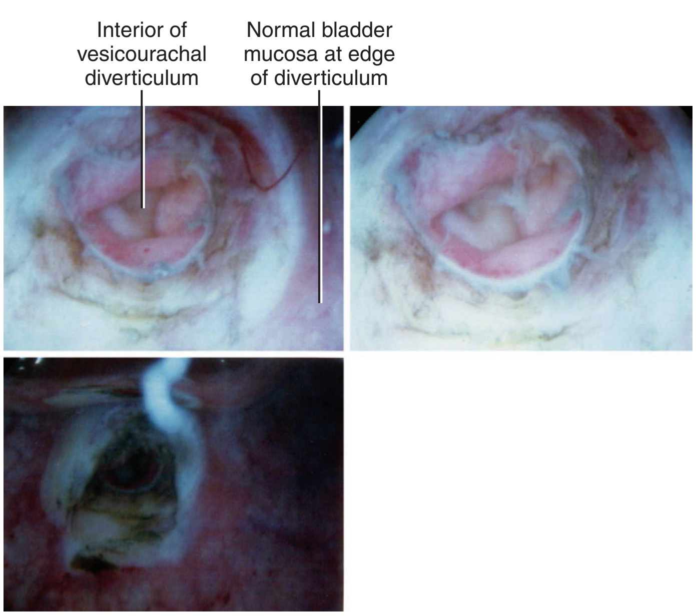


FIGURE 13-33. Vesicourachal diverticulum. This vesicourachal diverticulum in the bladder dome was unroofed during cystoscopy to assess microhematuria in a 45-year-old man. *(Image courtesy of Tom Leininger, M.D. From MacLennan GT and Cheng L. Atlas of Genitourinary Pathology, Springer-Verlag London Limited, 2011, with permission.)*

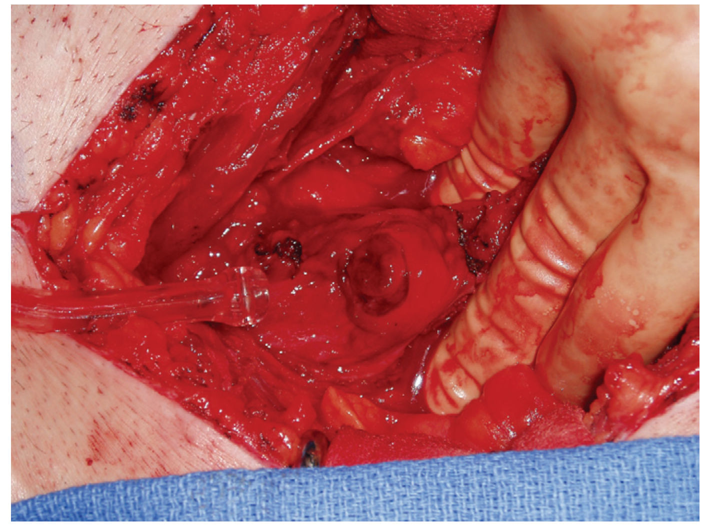


FIGURE 13-34. Vesicourachal diverticulum. Intraoperative photo of bladder dome diverticulum shown in Fig. 13-33. *(Image courtesy of Tom Leininger, M.D. From MacLennan GT and Cheng L. Atlas of Genitourinary Pathology, Springer-Verlag London Limited, 2011, with permission.)*

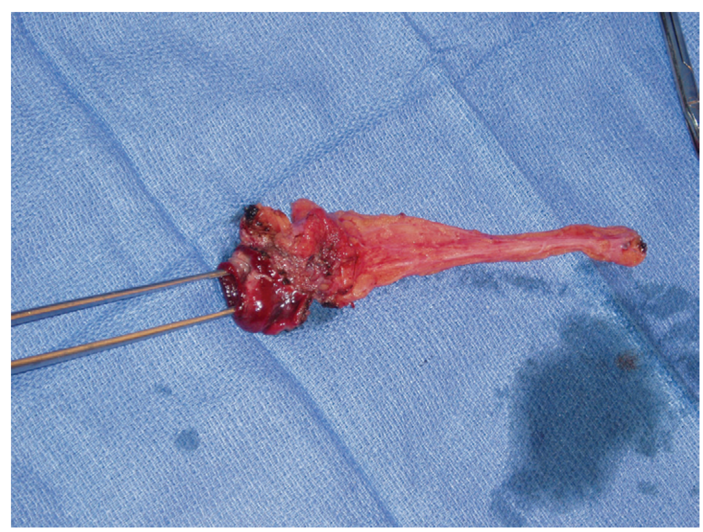


FIGURE 13-35. Vesicourachal diverticulum. The diverticulum and the urachal tract to the level of the umbilicus were resected. *(Image courtesy of Tom Leininger, M.D. From MacLennan GT and Cheng L. Atlas of Genitourinary Pathology, Springer-Verlag London Limited, 2011, with permission.)*

Alternating Urachal Sinus

With the Type II anatomic variant, the lumen may not regress completely but persist as a tract. Infection of the desquamated cellular debris in the canal will follow the potential lumen to the bladder at one time and to the umbilicus at another, alternately producing vesical infection and purulent periumbilical drainage (Fig. 13-32D).

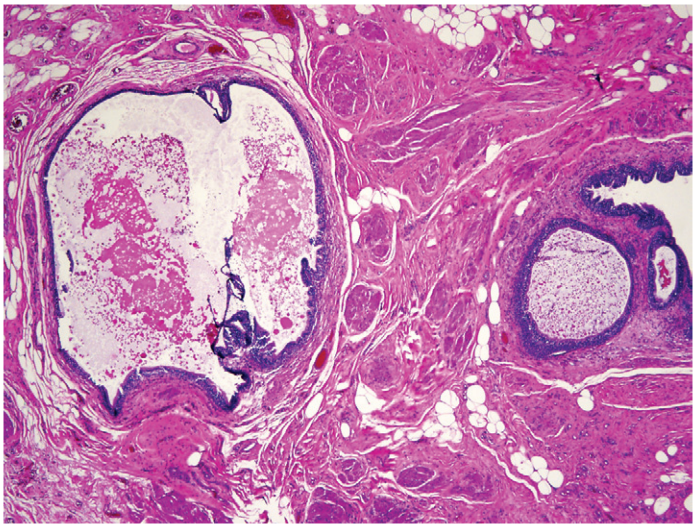


FIGURE 13-36. Vesicourachal diverticulum. Histologic section from the lesion shown in Fig. 13-35. Lesion was multilocular. The cystic spaces are lined by flat cuboidal or columnar epithelium. No malignancy was identified.

EXSTROPHY AND EPISPADIAS

Embryology of the Exstrophy-epispadias Complex

Normal Development (Fig. 13-37A)

(1) The anterior portion of the cloacal membrane retracts caudally and allows ingrowth of mesoderm that forms the **anterior abdominal wall** below the **umbilical cord**. The primordia of the **genital tubercle** separates the membrane from the anterior abdominal wall. (2) The **urorectal septum** later separates the **urogenital sinus** from the **anorectal canal** caudal to the genital tubercle.

Vesical Exstrophy (Fig. 13-37B)

(1) The **cloacal membrane** fails to retract, thus blocking the ingrowth of mesoderm. (2) This persistent ectodermal-endodermal layer, in turn, inhibits the fusion of the paired primordia of the **genital tubercle** so that they not only remain separated but lie caudal to the urogenital part of the cloacal

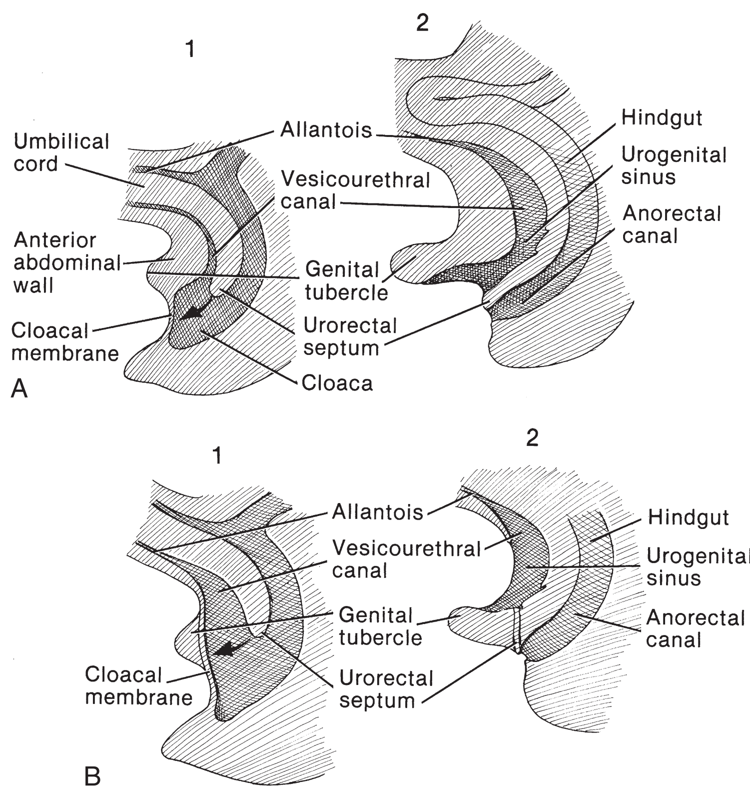


FIGURE 13-37.

membrane instead of joining ventral to it. This leaves the urethra and bladder open to the ventral abdominal wall. In another possible sequence, the paired primordia of the genital tubercle fuse so far caudally that they lie where the urorectal fold comes to the surface, preventing the mesoderm from completing formation of the ventral abdominal wall. The unsupported urogenital membrane would be prone to rupture farther forward than normal. In either case, fusion of the other structures of the anterior abdominal wall is inhibited and the pubes remain separated, producing the deformity of classic exstrophy.

Deformities of the genitalia depend on the degree of wedging that is produced by the membrane in holding the developing abdominal wall structures apart. This, in turn, is dependent on the time during development that the wedging occurs. For example, cloacal exstrophy, in which the intestinal tract is involved, is programmed before the urogenital sinus is subdivided by the **urorectal septum**. After the septum is formed, only the **urogenital sinus** will open onto the abdomen, the finding in classic exstrophy. If the membrane persists only in a limited area on the abdominal wall, the result is epispadias.

Exstrophy appears as a spectrum. *Classical exstrophy* is the most common form (60% of cases) and is consequent on dehiscence of the cloacal membrane after partition of the urorectal septum so that the portions of the urogenital sinus constituting the bladder immediately beneath the membrane are exposed to the surface. *Epispadias* resulting from partial persistence of the membrane is less common (35%). The rare *cloacal exstrophy* or vesicointestinal fissure, in which the dehiscence occurs before partitioning, leaves the cloaca with the primitive hindgut exposed between the bladder halves. It occurs in only 5% of cases. Abnormalities associated with cloacal exstrophy are omphalocele in most cases and myelomeningocele in 50% of cases. In the very rare event that the defect is limited to the umbilical area, the result is supravesical fissure.

Classic Exstrophy

Frontal View (Fig. 13-38A) and Sagittal Section (Fig. 13-38B).

The **bladder** and urethra lie anterior to the **symphyseal ligament**. In the male, the eversion extends from immediately below a bulging **umbilicus** to the end of the **penis** (see Fig. 10-5). The poorly supported anus lies more ventrally than normal. The corporal bodies diverge at the crura because of separation of the pubis, leaving a stubby, flattened penis covered dorsally by exposed **urethral mucosa**. The **scrotum** is small and not divided. In the female, the clitoris is bifid and the vagina may be tilted anteriorly and stenotic.

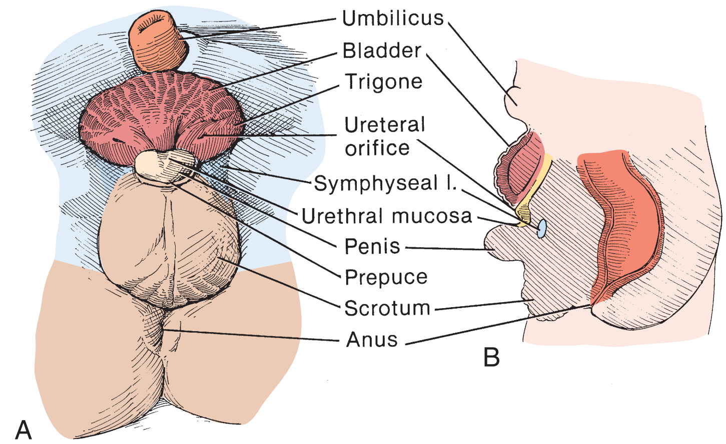


FIGURE 13-38.

Epispadias

Frontal View (Fig. 13-39A) and Sagittal Section (Fig. 13-39B)

Epispadias is the mildest form of exstrophy; complete epispadias with incontinence is the form embryologically closest to vesical exstrophy. Only the urethra is exposed and the pubic rami are not as separated, but the fibrocartilaginous **symphyseal band** connecting the pubic bones may lie either dorsal or ventral to the urethra. In the typical *penopubic epispadias*, the **urethral plate** lies above the symphyseal ligament and the orifice is flush with the abdominal wall. The plate is short, producing dorsal chordee. In the continent forms of *penile* and *balanitic epispadias*, the orifice lies more distally and the symphysis maintains a more normal relationship to the urethra.

Because of the abnormal development of the urethral plate, the corporal bodies are rotated outward, carrying the normally dorsal neurovascular bundle in a divided form laterally.

CLOACAL EXSTROPHY

In the developmental stage, the urorectal septum fails to form and divide the cloaca, leaving the bladder, ileum, and large bowel, as well as the hindgut, free to move ventrally **(arrows)** and will herniate through the cloacal membrane when it finally dissipates (Fig. 13-40A).

A segment of **terminal ileum** intussuscepts at the ileocecal junction but is held by the **cloacal membrane** (Fig. 13-40B).

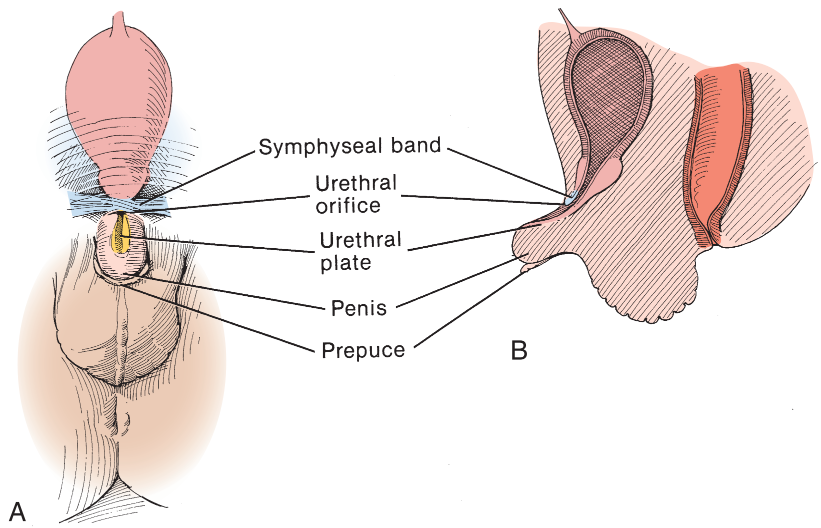


FIGURE 13-39.

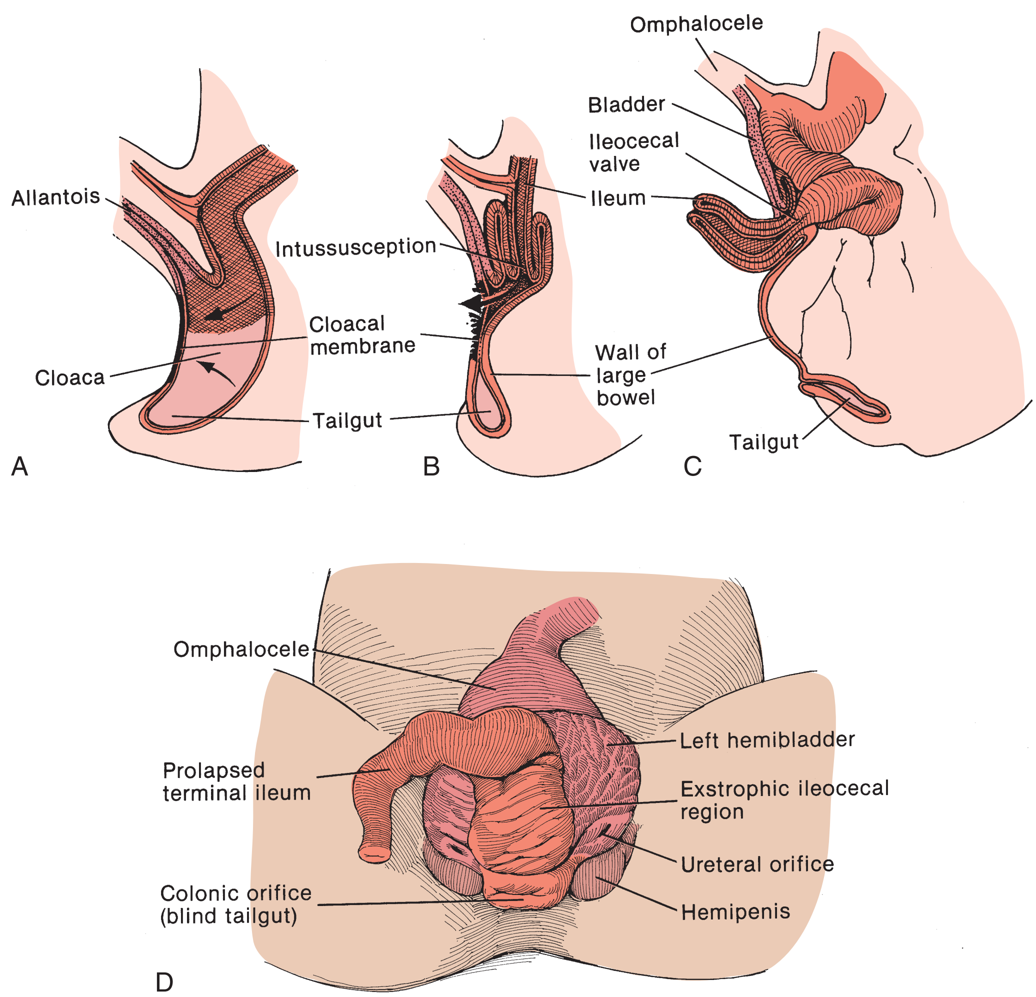


FIGURE 13-40.

With rupture of the membrane, the intussuscepted **ileum** and **ileocecal valve** are extruded to lie between the segments of the divided **bladder** (Fig. 13-40C). Posteriorly, a short section of colon **(tailgut)** ends blindly. The epispadiac penis is typically paired and usually rudimentary. In the female, the vagina is septate and accompanied by abnormalities of the uterus.

Viewed from the front, the prolapsed **terminal ileum** is prominent below the **omphalocele** (Fig. 13-40D). The **colonic orifice** of the **blind tailgut** lies below the prolapsed **terminal ileum** and **exstrophic ileocecal region**. The **ureteral orifices** open onto the everted right and left **hemibladders**. Beneath the bladders are the two parts of the penis **(hemipenis)** (Fig. 13-41).

Of surgical importance is that the autonomic nerve supply enters medially into the hemibladders, in contrast with the normal lateral approach of the nerves and vasculature, and thus may be transected during reconstruction.

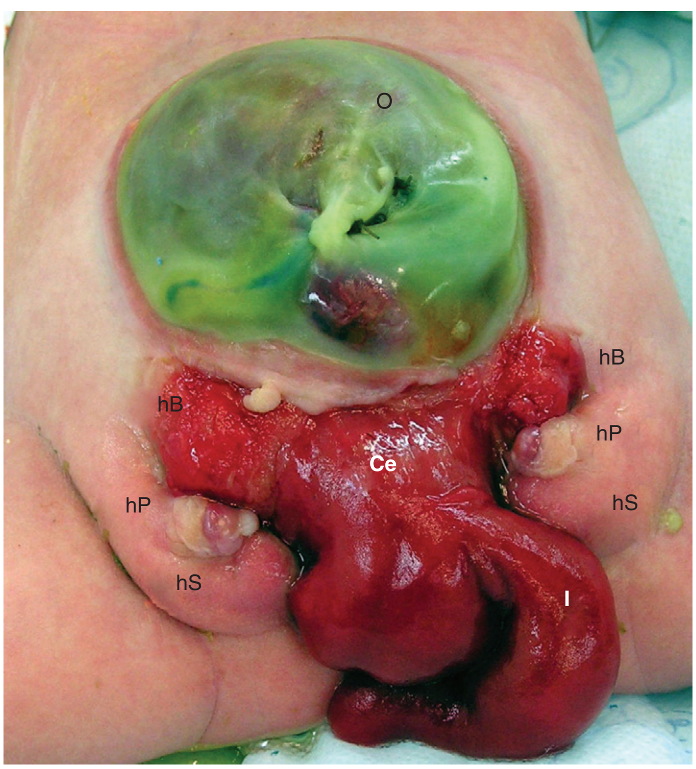


FIGURE 13-41. Cloacal exstrophy. The anatomic structures are labelled as follows: O, omphalocele; hB, hemibladder; hP, hemipenis; hS, hemiscrotum; I, ileum; Ce, cecum. *(Image courtesy of Lynn Woo, M.D. Reproduced with permission from Woo LL, Thomas JC, Brock JW. Cloacal exstrophy: a comprehensive review of an uncommon problem. J Pediatr Urol 2009, Oct 22.)*

Other Bladder Abnormalities

Agenesis of the bladder is a rare anomaly usually associated with other genitourinary defects. Duplication of the bladder and urethra may occur, often accompanied by duplication of the lower bowel, or the bladder may be merely septate. Congenital vesical diverticula occur rarely.

Neurogenic bladder may result from developmental injury to the nerves from spinal levels S2, S3, and S4. Early in fetal life, the spinal cord extends to the end of the spinal canal, but later, the conus medullaris ascends rapidly. By the second postnatal month, it lies opposite the L1 and L2 vertebrae. Should ascent of the spinal cord be arrested, tension could cause ischemic damage to the terminal cord. In addition, such a tethered cord would be subject to further ischemia during normal flexion of the spine.

ANORECTAL ANOMALIES

Imperforate Anus and Rectourethral Fistula

Normally, after the cloaca has been divided into the urogenital sinus anteriorly and the rectum and anal canal posteriorly by the combined downgrowth of the urorectal septum and ingrowth of lateral mesenchyme, the septum initiates the division of the cloacal membrane into an anterior part, the urogenital membrane, and a posterior section, the anal membrane (see Fig. 13-7). The inner and outer genital ridges contribute to the short canal that lies distal to the urogenital membrane, and the external rectal sphincter mechanism defines a similar canal below the anal membrane. The perineal body develops between the two canals. As the rectum migrates posteriorly, the two portions of the cloacal membrane rupture successively to provide, first, a urogenital and, later, an anal opening. Before the anal membrane opens, a shallow pit, the proctodeum, forms. Disturbances of this sequence result in abnormalities varying in site and severity, depending on the time of interference. High supralevator anomalies result from an earlier disturbance; low infralevator anomalies result from a later interruption. The types of anomalies found clinically and illustrated in Figure 13-42 may be tabulated by level and thus related to particular embryologic misadventures (Table 13-2).

Low Infralevator Rectal Anomalies

Normal Development

The urorectal septum joins the rectal part of the cloacal membrane that is resorbed (Fig. 13-42A).

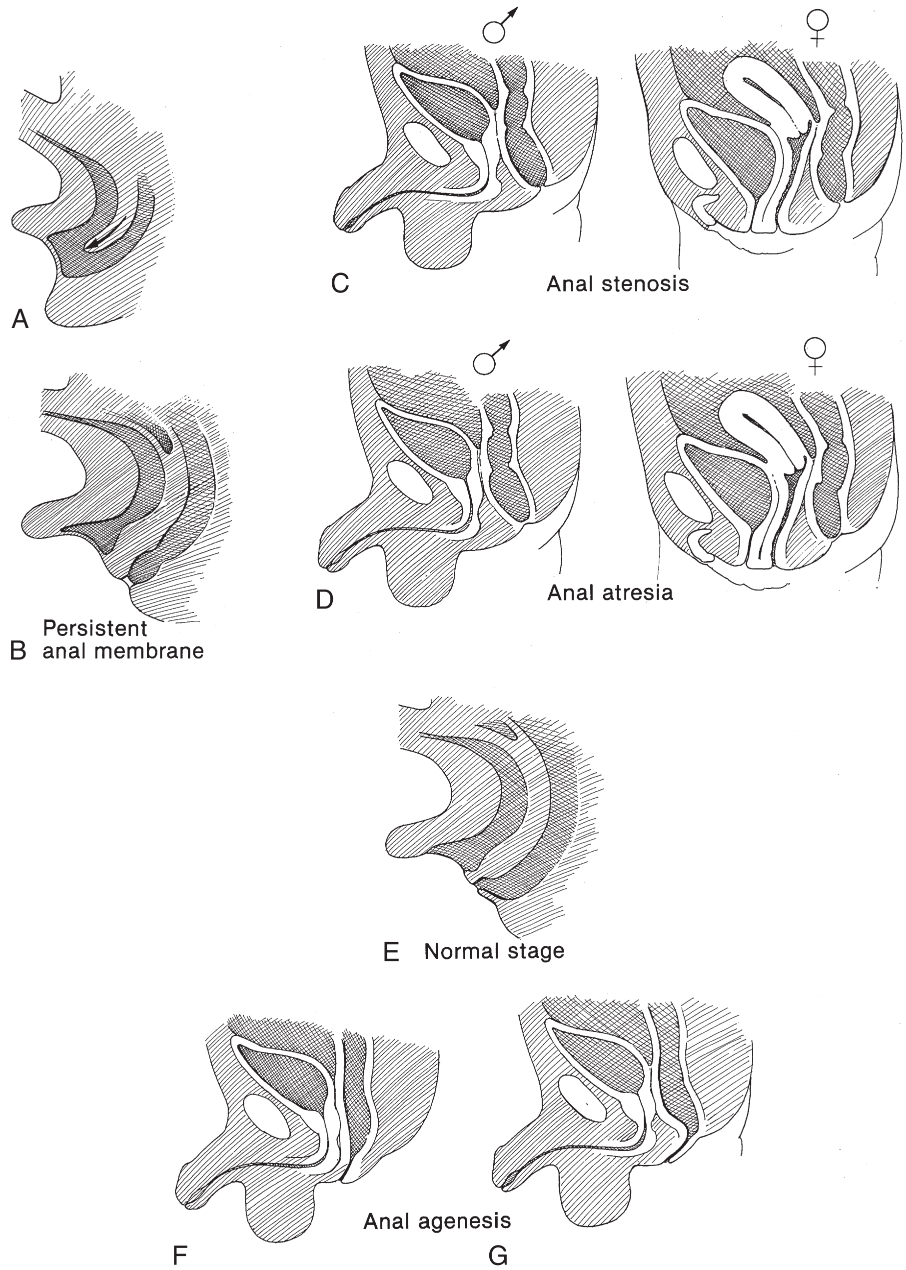


FIGURE 13-42.

Persistent Anal Membrane

When the anal portion of the cloacal membrane persists and insufficient tail gut is resorbed, the anal canal either does not open completely or ends blindly just beneath the skin, resulting in anal stenosis or anal atresia (Fig. 13-42B).

Anal Stenosis (Male and Female)

The anal portion is reduced and the anus itself may be too small (Fig. 13-42C). One of three infants is born with some constriction at the anus, a condition that usually resolves spontaneously, but the few cases with extreme stenosis may require treatment. Because the sphincteric mechanism is intact, these children will have normal fecal control.

Anal Atresia (Male and Female)

Anal atresia alone is a rare lesion. The anal membrane at the level of the anus fails to open, and the rectum ends blindly (Fig. 13-42D). The covering layer may be thin enough to allow the colored meconium to show through.

TABLE 13-2

CLASSIFICATION OF ANORECTAL ANOMALIES

LOW, INFRALEVATOR	**FIGURE 13-42**
Persistent anal membrane	B
Anal stenosis	C
Anal atresia	D
Anal agenesis	
Males	
With fistula to perineum	F, G
Without fistula	
Females	
With fistula to vulva	
With fistula to perineal body	
HIGH, SUPRALEVATOR	**FIGURE 13-44**
Anorectal agenesis	A
Without fistula	B
With fistula	C
Males	
Rectourethral fistula	D
Rectovesical fistula	F
Females	
Rectovaginal fistula	E
Rectovesical fistula	

FIGURE 13-43. Anal agenesis with perineal fistula. Meconium is trickling from the orifice of the fistula at the base of the scrotum. *(Image courtesy of Robert Parry, M.D.)*

Anal Agenesis with Perineal Fistula

If the rectal opening fails to migrate posteriorly, or if the external anal sphincter, derived from exterior mesoderm, is malformed, the relation of the rectum to the perineum is disturbed, resulting in a perineal or vestibular fistula (Figs. 13-42E–G and 13-43).

High Supralevator Rectal Anomalies

Embryogenesis of Agenesis (Fig. 13-44A)

A combination of excessive obliteration of the postanal gut (tailgut) with loss of some of the dorsal wall of the cloaca contributes to anorectal agenesis. The infolding process of the lateral walls of the cloaca as the urorectal septum descends fails to reach as far as the cloacal membrane, and the hindgut terminates above the levators. The result is agenesis without connection with the urinary tract.

Anorectal agenesis in males and females, without fistula, arises when the hindgut terminates above the levators (Fig. 13-44B). The result is agenesis of the rectum from that level (Figs. 13-45 and 13-46)

Embryogenesis of Fistulas

Should the descent of the **urorectal septum** be arrested at a higher level above the cloacal membrane and the tailgut be more completely absorbed, a fistula with the urinary tract persists (Fig. 13-44C).

Agenesis with fistula occurs when the infolding of the urorectal septum does not proceed as far as the membrane, and the folds are united only proximally and distally, and there is a persistent communication between the rectum and the urogenital tract, known as the cloacal duct of Reichel. In the male, the result is a **rectourethral fistula** (Figs. 13-44D, 13-47, and 13-48).

In the female, failure of infolding causes a **rectovaginal fistula** (Figs. 13-44E and 13-49).

Rectovesical Fistula

If union fails at a higher level, the less common rectovesical fistula is the consequence (Fig. 13-44F).

The fistulas are usually patent, although they may have such reduced caliber that they do not permit decompression of the bowel, or they may consist only of fibrous cords.

Supralevator anomalies are initiated during the sixth and seventh weeks of fetal life, when the urorectal septum is being formed. Should formation of the septum be completely arrested, the result is a *persistent cloaca.* In these cases

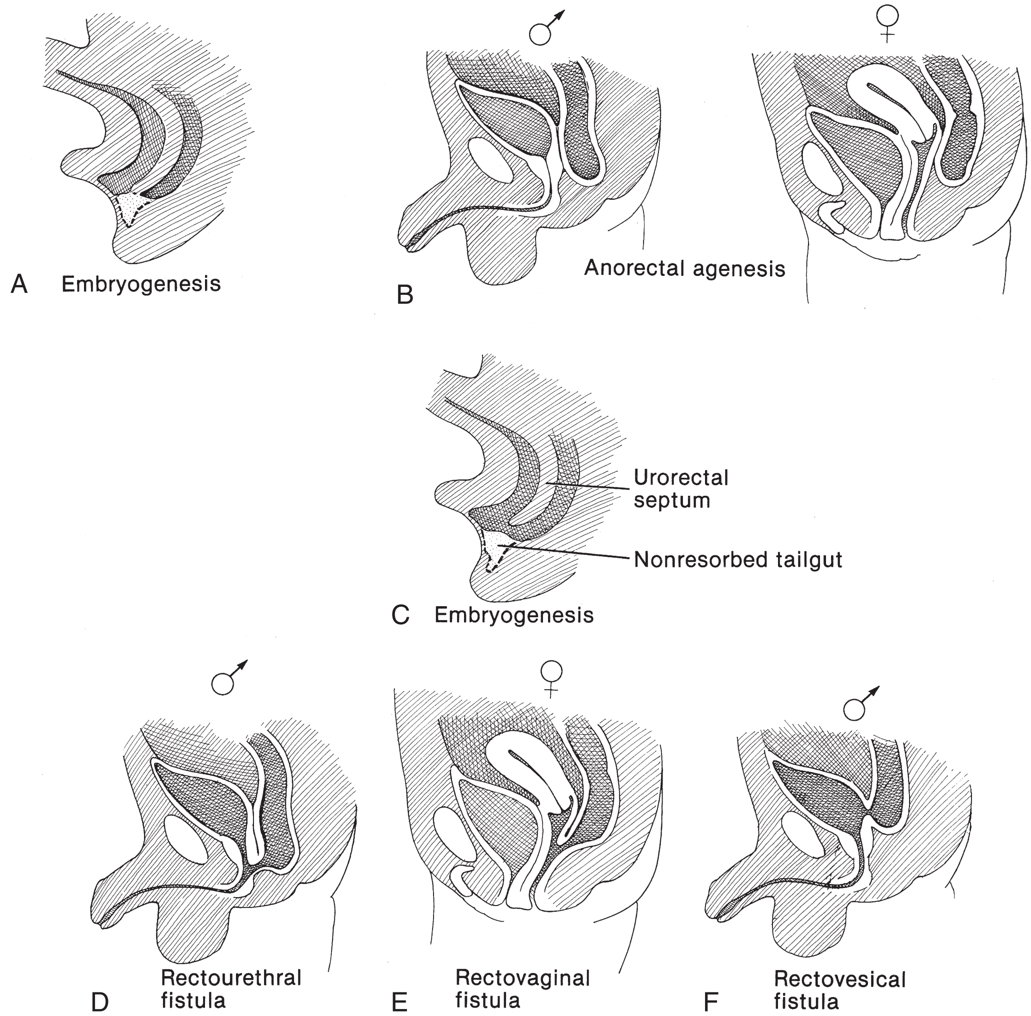


FIGURE 13-44.

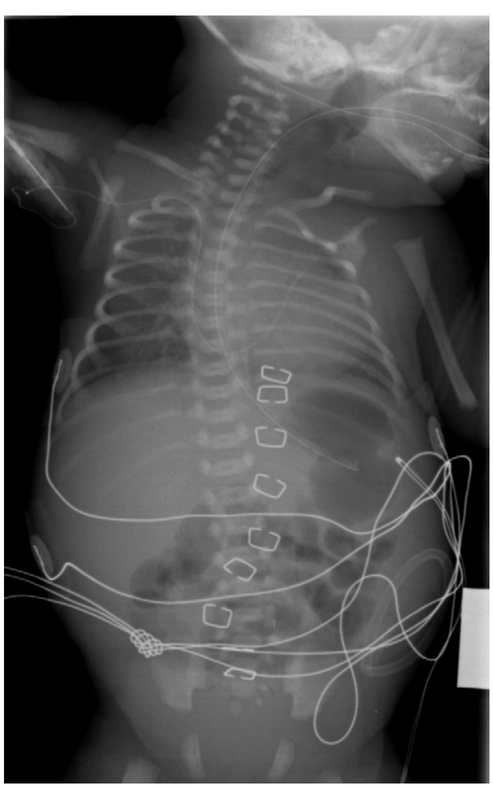


FIGURE 13-45. High anorectal agenesis. Plain radiograph shows absence of rectal air shadow. *(Courtesy of Raj Paspulati, M.D.)*

FIGURE 13-46. High anorectal agenesis. A colostomy has been created. *(Image courtesy of Nathan Wiseman, M.D.)*

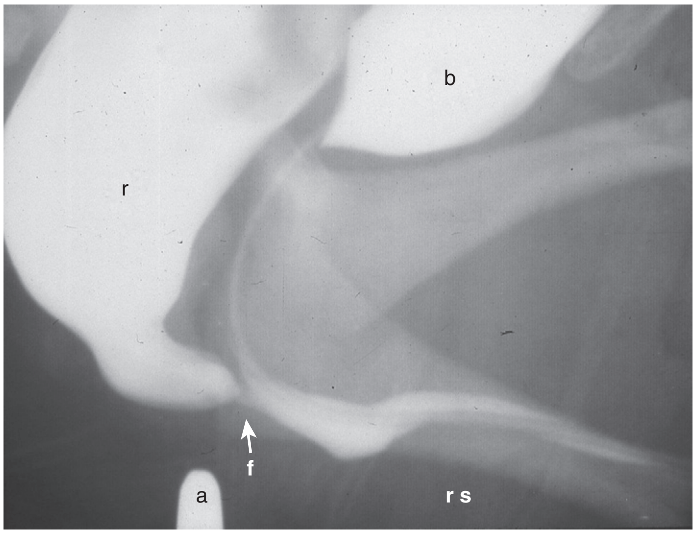


FIGURE 13-47. Rectourethral fistula. The image is labelled as follows: r, rectum; b, bladder; f, site of fistula between rectum and urethra; a, radio-opaque marker in anal dimple. *(Image courtesy of Nathan Wiseman, M.D.)*

FIGURE 13-49. Rectovaginal fistula. Meconium is trickling from the vaginal orifice. *(Image courtesy of Nathan Wiseman, M.D.)*

FIGURE 13-48. Rectourethral fistula. Meconium is trickling from the urethral meatus. *(Image courtesy of Robert Parry, M.D.)*

in the female, the urinary, genital, and intestinal tracts have a common channel leading to a single opening in the perineum.

Genitourinary anomalies are more common and more severe with supralevator lesions (54%) than with lower lesions (16%). Serious anomalies include renal agenesis, dysplasia, and ureteropelvic junction obstruction. High anorectal anomalies, because they occur earlier in fetal life, are often accompanied by other abnormalities, especially of the skeleton, which increase the chance for morbidity and mortality during repair of the rectal defect.

BLADDER AND URETEROVESICAL JUNCTION: STRUCTURE AND FUNCTION

The bladder and its connections lie in the true pelvis and are exposed surgically through incisions in the lower abdomen. Because many of the elements of the bladder, bladder neck, and ureterovesical junctions are continuous, these structures are considered together.

Pelvic Relationships of the Bladder, Posterior View

When empty, the bladder appears to have four surfaces: a superior, two anterolateral, and a smaller posterior surface that forms the base. When it is distended, the bladder becomes more spherical, with only the base remaining fixed (Fig. 13-50).

The **superior surface** apposes the peritoneal cavity. The **anterolateral surface** abuts the transversalis (endopelvic) fascia that covers the walls and floor of the pelvis. The lateral surface lies against the **obturator fascia** covering the **obturator internus** and continues inferiorly against the fascia overlying the **levator ani**. Laterally, it is in contact with the obturator nerve and a portion of the autonomic pelvic plexus, and with the **superior vesical**, obturator, **inferior vesical**, and **prostatic arteries**. More anteriorly, the retropubic space intervenes. As the bladder fills, the overlying peritoneum rises to emerge from behind the pubis to project directly onto the posterior surface of the anterior abdominal wall. The apex of the bladder terminates in the remains of the urachus, which attach it to

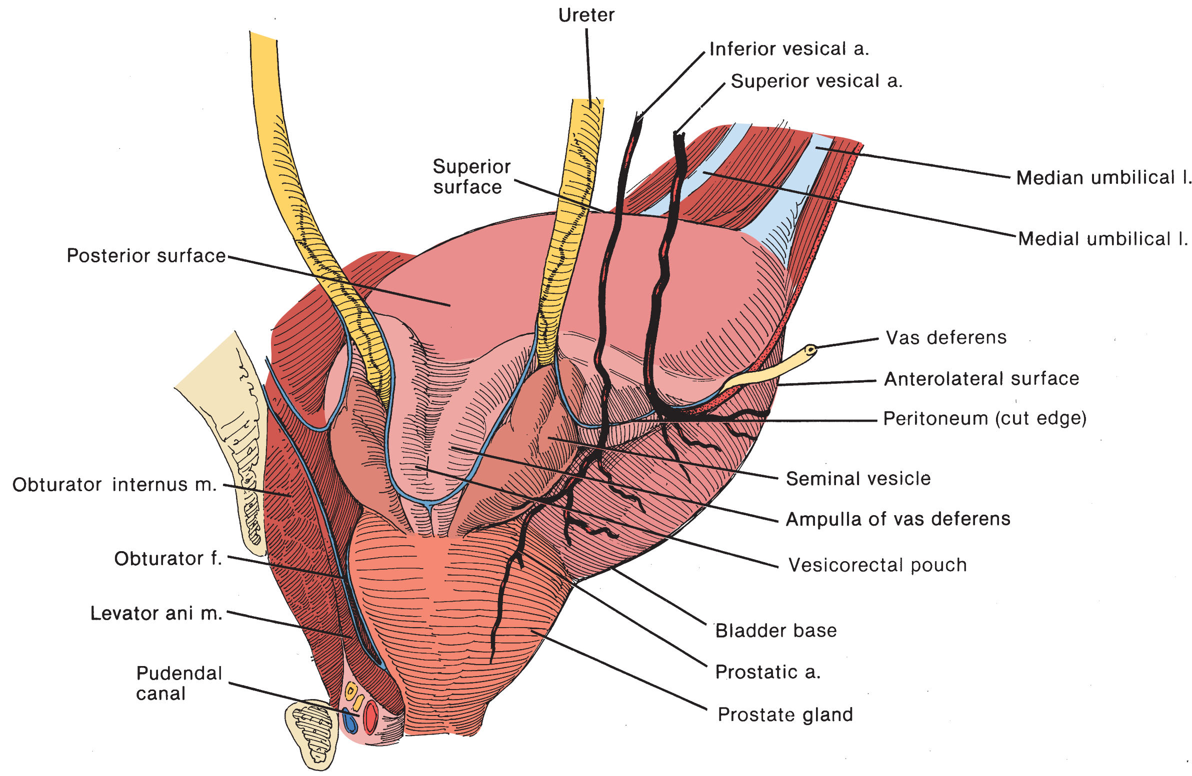


FIGURE 13-50.

the umbilicus at the **median umbilical ligament**. The obliterated umbilical arteries rise laterally to form the **medial umbilical ligaments**.

The **bladder base** is the thickest part of the bladder, is the most fixed, and has the smallest surface. It rests on the rectum and the **seminal vesicles** and **ampulla of vas deferens**, with the peritoneum of the **vesicorectal pouch** partially intervening. The base joins the vesical neck, urethra, and ureteral orifices.

Contact of the bladder with structures in the pelvis differs depending on the state of filling of bladder and rectum. With a full bladder or distended rectal ampulla, the rectovesical pouch becomes shallow, displacing the ileum, sigmoid colon, and small intestine into the abdomen.

In the female, the base is in contact with the cervix and anterior vaginal wall. Above, the uterus usually lies against the superior surface of the bladder. The uterovesical pouch corresponds to the rectovesical pouch of the male, and because there is no prostate to intervene, the female bladder neck is somewhat lower and makes greater contact with the pelvic floor.

Bladder, Transverse Section

The **prevesical space**, continuous below with the retropubic space (Retzius), lies behind the **symphysis pubis**, which forms its anterior wall (Fig. 13-51). Its floor is formed in part by the puboprostatic ligaments. The lower anterior portion of the bladder (including the prostate in the male) forms the posterior wall. Anatomic spaces are present between each of the several layers of fascia: a suprapubic space between the rectus abdominis and the **transversalis fascia;** a prefascial space between the transversalis fascia and the umbilical prevesical fascia; an interfascial space between that fascia and the umbilical vesical fascia; and the retrofascial space between the umbilical fascia and the peritoneum. Above the symphysis when the bladder is full, an area 2 to 3 cm wide is free of peritoneum and, hence, is suitable for puncture of the bladder. The contents of the deeper spaces are the prostatic and vesical venous plexuses and areolar tissue.

The bladder is bounded laterally by the **obturator fascia** (continuous with the transversalis fascia) overlying the **obturator internus** and posteriorly by the **levator ani**. The bodies of the **seminal vesicles**, the **ampulla of vas deferens**, and the **ureters** lie posterolaterally. Posteriorly, the bladder is against the **vesicorectal pouch**.

Anterolaterally, the **obturator canal** is on the outer side of the obturator internus. Posteriorly, the **pudendal canal** with its vessels and nerve is found between the obturator internus and levator ani.

Dorsal to the levator ani are the **ischiorectal fossae**, the **gluteus maximus**, and the **coccyx**.

Prostatic and Vesical Ligaments

The bladder outlet is supported from below by the **prostate**, which, in turn, is supported by the **pubococcygeus** of the levator ani system. The prostate is held in position anteriorly by the dense right and left **puboprostatic ligaments** (the two ligaments together form the medial puboprostatic ligament) that are attached to the symphysis pubis.

In the female, the bladder rests directly on the pelvic floor. The female urethra and bladder neck are supported by the pubovesical ligaments.

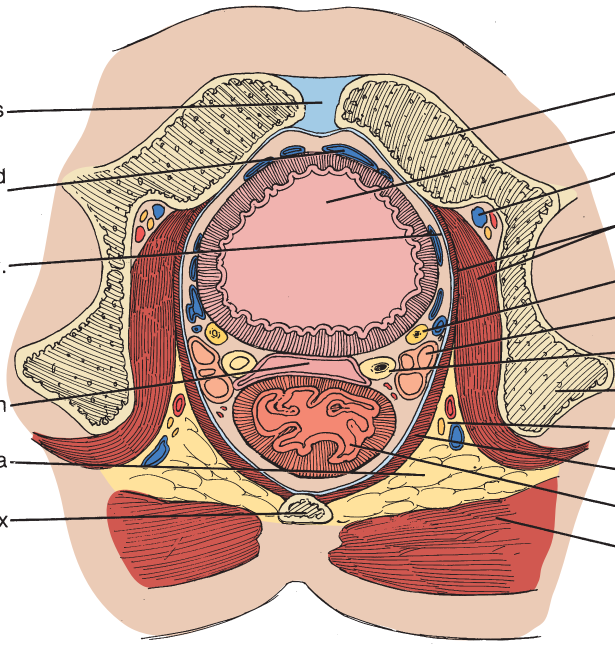


FIGURE 13-51.

The lateral aspects of the bladder are supported by the true **lateral ligaments** or pedicles of the bladder, derived from condensations of the intermediate stratum (Fig. 13-52). The ligaments connect the bladder with the **tendinous arch** of the pelvic fascia (from the outer stratum of the retroperitoneal connective tissue) and with the coccygeus and levator ani. The **median umbilical ligament** (urachal remnant) and the **median umbilical ligaments** (obliterated umbilical arteries) attach the bladder to the anterior body wall and umbilicus. The medial umbilical ligament is in continuity with the **superior vesical artery**, in keeping with its embryologic origin. Additional ligaments are the lateral false ligaments from the reflections of the peritoneum to the pelvic sidewalls and the sacrogenital folds. These form the lateral margins of the rectovesical pouch, the posterior limit of which forms the posterior false ligaments.

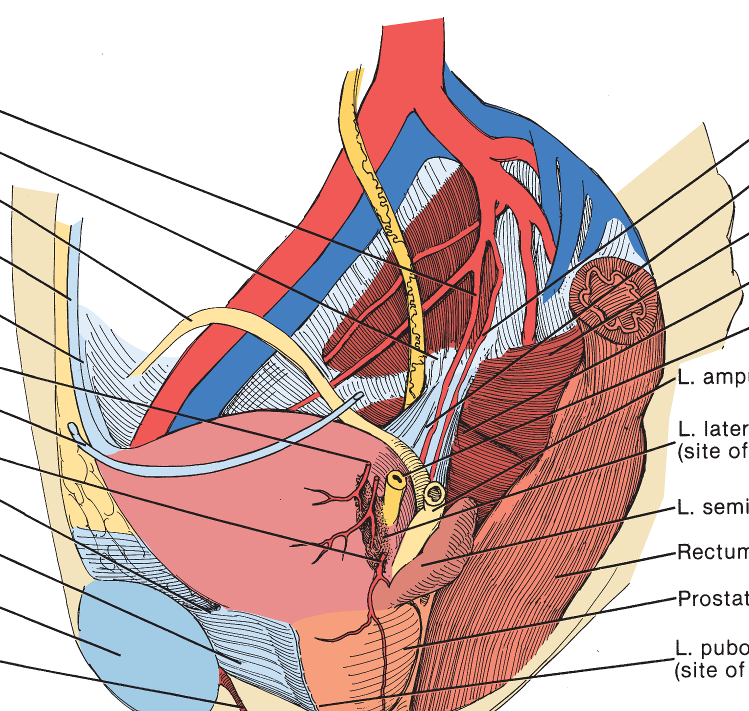


FIGURE 13-52.

Fascias Related to the Bladder

The bladder, as part of the urinary system, is contained within the intermediate stratum of the retroperitoneal fascia. Anteriorly, the umbilicovesical fascia descends to cover the dome of the bladder and join the vesical and prostatic fascias. The posterior lamina of the renal (Gerota) fascia fuses behind the bladder with the pelvic portion of the parietal (transversalis) fascia derived from the outer stratum, the same layer that covers the pelvic vessels. The anterior lamina of the renal fascia continues caudally, enclosing the ureter in a sheath before continuing as the fascial covering of the bladder.

Vesical Neck and Trigone

The *vesical neck*, which with the bladder base is the least distensible portion of the bladder, lies in a plane that passes through the top of the symphysis and the tip of the coccyx.

The trigone and posterior urethra are integral parts of the neck. The **superficial trigone** (trigonum vesicae, Lieutaud) is a smooth, relatively flat raised structure with an apex (Lieutaud uvula) extending into the vesical neck and two upper extremities encompassing the ureteral orifices (Fig. 13-53).

The trigone is bounded superiorly by the **interureteric ridge** or crest (torus uretericus or vesicalis, Mercier bar) and laterally by the **ureteral bars** (ureteric ridges or Bell muscles) (Figs. 13-54 and 13-55). The interureteric ridge is composed of transversely oriented smooth muscle fibers that connect the orifices. The ureteral bars are less distinct submucosal bands of longitudinally oriented smooth muscle fibers of the superficial trigone, which is continuous with the ureteric smooth muscle that runs from the ureteral orifices through the vesical neck. The apex of the trigone proper is at the bladder outlet, although, because of its embryologic origin, it is actually down the urethra at the end of the **urethral crest** at the **verumontanum** in the male and at the external urethral meatus in the female. The size and shape of the trigone varies, being an almost equilateral triangle in children and more elongated in adults, especially in males.

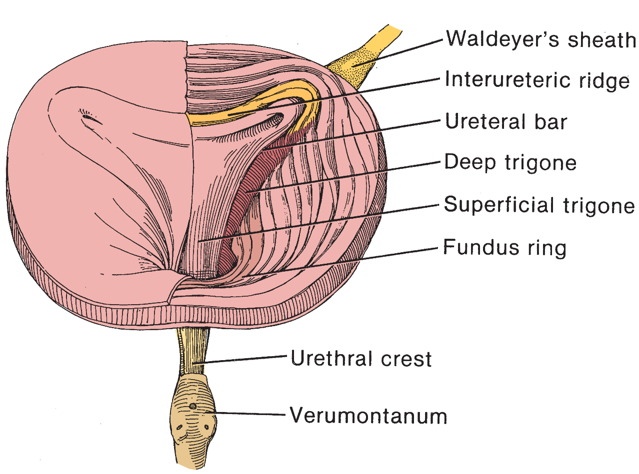


FIGURE 13-53.

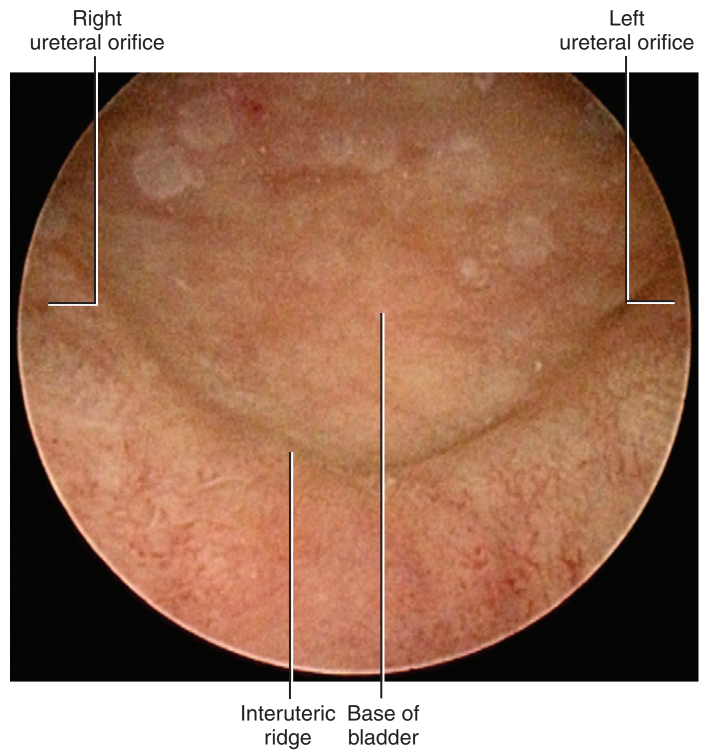


FIGURE 13-54. Cystoscopic view of the superior aspect of the trigone, including both ureteral orifices. *(Image courtesy of William Larchian, M.D.)*

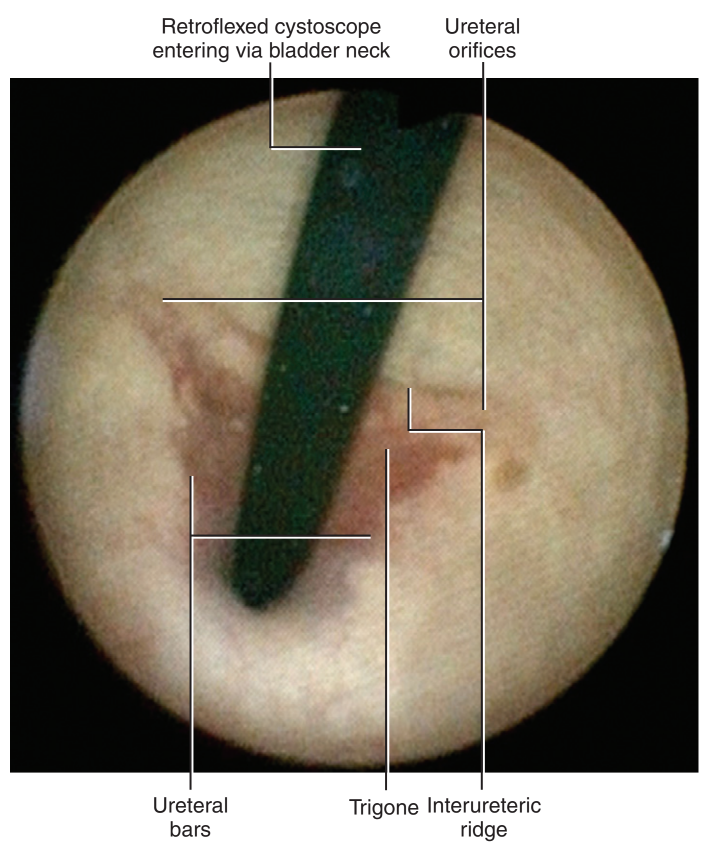


FIGURE 13-55. Retroflexed cystoscopic view of the trigone and bladder neck. *(Image courtesy of William Larchian, M.D.)*

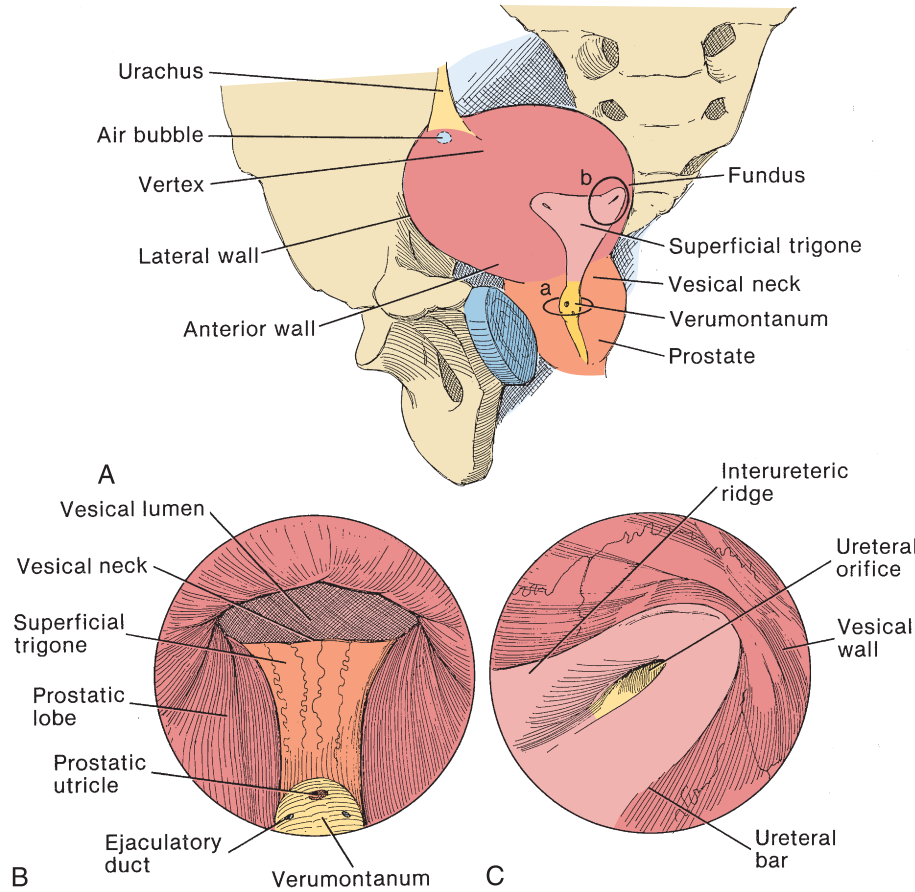


FIGURE 13-56.

Cystoscopic Anatomy

View of Bladder

Three divisions are identified when the interior of the bladder is viewed cystoscopically: (1) the **vesical neck**, (2) the **superficial trigone**, and (3) the bladder walls (Fig. 13-56A). The walls may be considered to be divided into a base or **fundus** (bas-fond) extending above the interureteric ridge, two **lateral walls**, an **anterior wall**, and a dome or **vertex** marked by an **air bubble**.

Cystoscopic View of the Bladder Neck

The **vesical neck** appears as a rounded opening in the absence of prostatic enlargement (Fig. 13-56B). The caudal extension of the **superficial trigone** is seen on the floor extending to the **verumontanum**, which contains the **prostatic utricle** and the **ejaculatory ducts** (Fig. 13-57). With benign prostatic hyperplasia, the neck assumes a triangular shape from lateral encroachment by the **prostatic lobes**.

Cystoscopic View of the Ureteral Orifice

When closed, the **ureteral orifice** appears as an oblique slit near the junction of the **interureteric ridge** and the **ureteral bar**, being held in place by the extension of the ureteral musculature, the superficial trigone (Fig. 13-56C). When ejecting urine, the longitudinal muscle fibers of the intramural ureter pull the corner of the trigone and the orifice

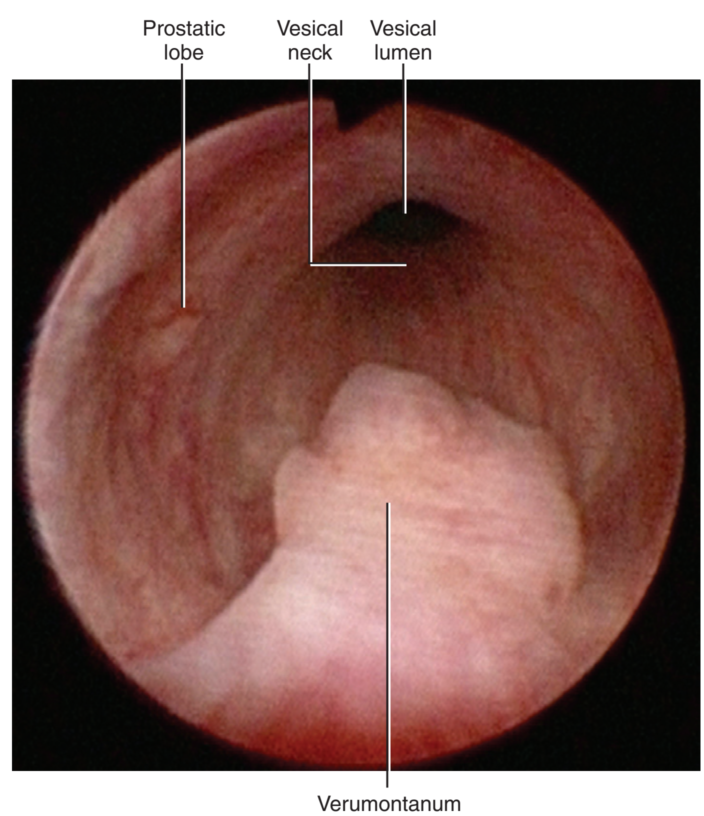


FIGURE 13-57. Cystoscopic view of prostatic urethra and bladder neck. There is no significant enlargement of the prostatic lobes. *(Image courtesy of William Larchian, M.D.)*

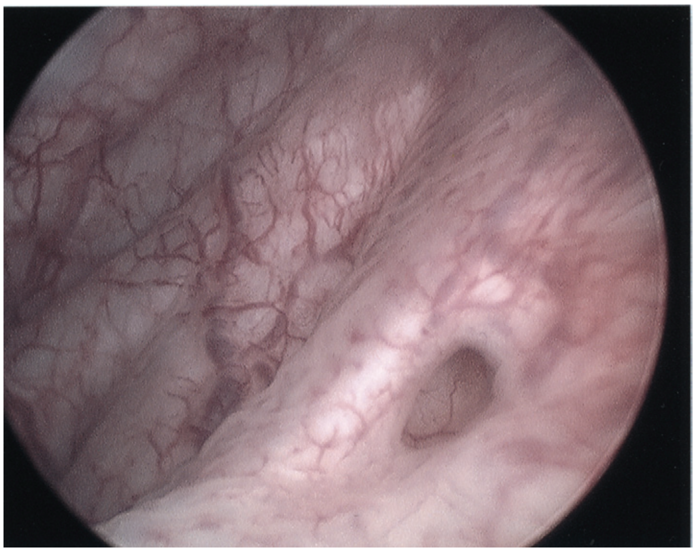


FIGURE 13-58. Cystoscopic close-up view of the left ureteral orifice. The orifice is widely patent, suggesting that urine was being ejected at the moment the photograph was taken. *(Image courtesy of William Larchian, M.D.)*

upward (Fig. 13-58). During voiding, the superficial trigone draws the orifice distally, making the course of the ureter through the **vesical wall** more oblique and, hence, more likely to resist the back flow of urine.

The lamina propria of the vesical wall, viewed through the mucosa, is seen to have fine ramifying vessels.

Structure of the Bladder Wall

The urinary bladder is a hollow muscular organ composed of several distinct layers (Fig. 13-59A). It has an inner lining of **urothelium** (also commonly called "**transitional epithelium**") three to six cell layers thick (Fig. 13-60). The surface layer of urothelium consists of large "umbrella cells" with eosinophilic cytoplasm and large, often double nuclei. The urothelial cells beneath the surface are uniform and much smaller than umbrella cells. They have modest amounts of pale or clear cytoplasm. Their nuclei are central, ovoid, uniform, and oriented roughly perpendicular to the basement membrane. The nuclei have dispersed chromatin and inconspicuous nucleoli. Between the basement membrane of the urothelium and the underlying detrusor muscle is the **lamina propria**, consisting of loose connective tissue, scattered inflammatory cells, vascular channels, and wisps of discontinuous muscularis mucosae (Fig. 13-61). The lamina propria also normally contains invaginated aggregates of urothelial cells, called von Brunn nests. On vesical distention, the urothelium and lamina propria undergo considerable flattening, but these structures are thrown into folds as the bladder empties. Lying beneath the urothelium and lamina propria are three layers of detrusor muscle: (1) **inner longitudinal**, (2) **middle circular**, and (3) **outer longitudinal** (Fig. 13-62). Small aggregates of fat may be seen normally within the detrusor muscle, and adipose tissue covers the external aspect of the detrusor muscle.

The trigone in postpubertal females is commonly covered by nonkeratinizing glycogenated squamous epithelium; this is almost certainly a normal variant (Fig. 13-63). The surface of the trigone is flat and free of folds as would be expected from its situation, because it does not appreciably change dimensions.

The **detrusor arch** (detrusor vesicae or detrusor muscle) consists of separate coarse bundles of smooth muscle (Fig. 13-59B). Over much of the bladder body, the bundles change planes and directions, and they interlace so that a single fiber may continue through all three layers. This arrangement is functionally suited to coordinate contraction in all directions to achieve uniform reduction of the surface area during voiding.

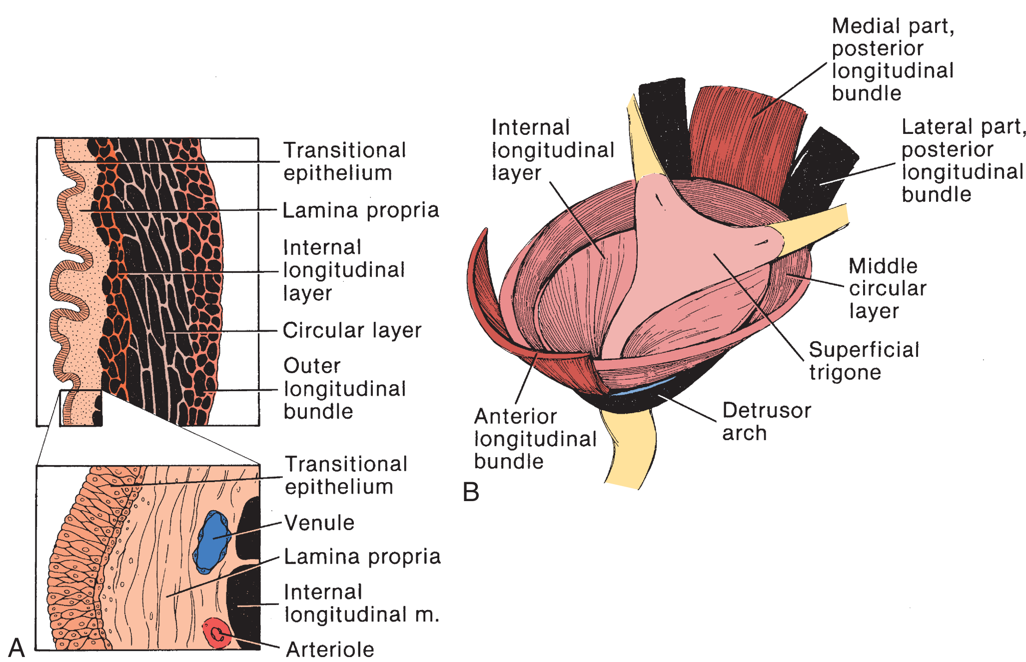


FIGURE 13-59.

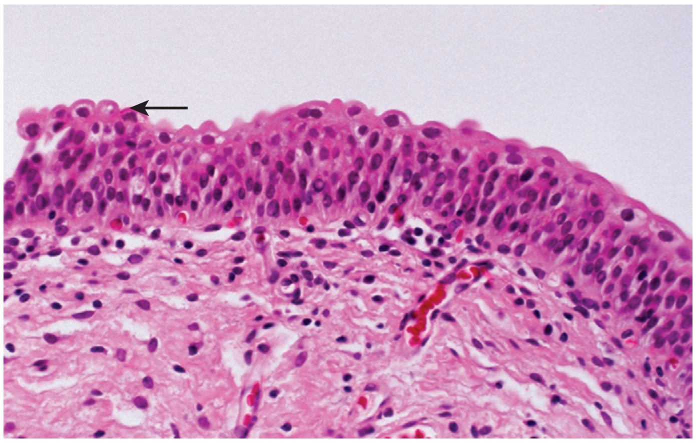


FIGURE 13-60. Normal urothelium and underlying lamina propria in the bladder. The arrow indicates a layer of umbrella cells at the surface. *(From MacLennan GT, Resnick MI, and Bostwick DG: Pathology for Urologists, 2003, with permission.)*

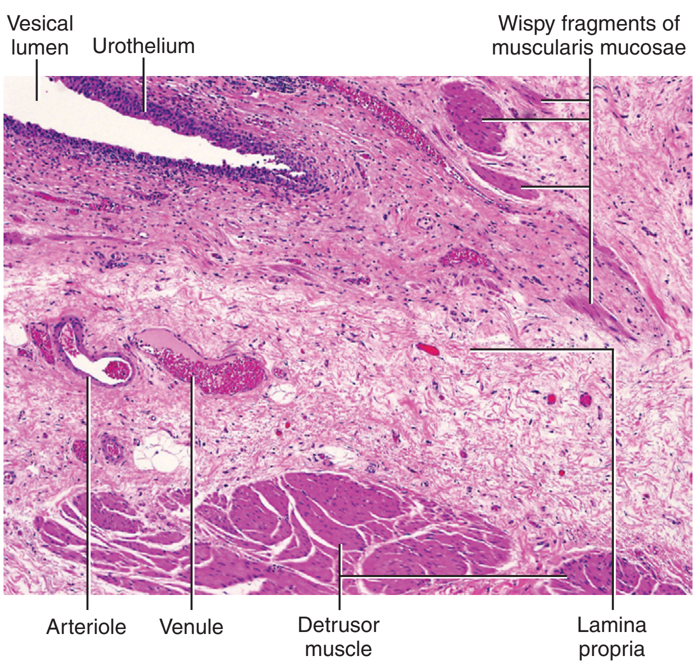


FIGURE 13-61. Section of bladder wall showing urothelium at upper left and some bundles of detrusor muscle at bottom. The space between these structures is the lamina propria, consisting of loose connective tissue containing blood vessels and wispy bundles of discontinuous muscularis mucosae.

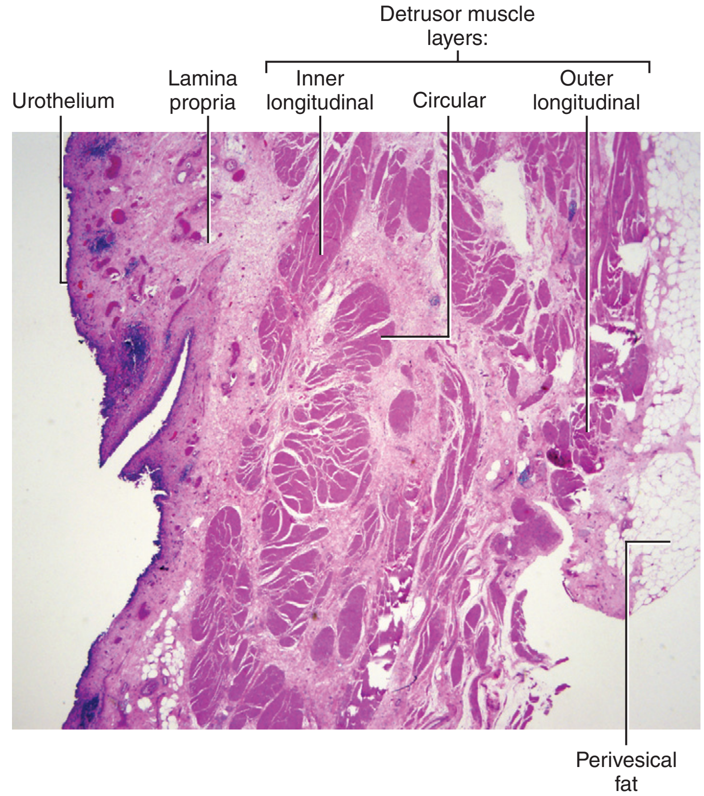


FIGURE 13-62. Full thickness section of bladder wall, including urothelium, lamina propria, detrusor muscle, and perivesical fat.

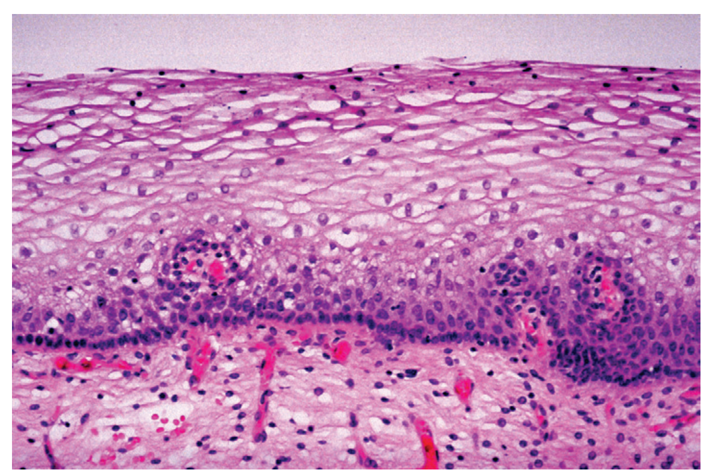


FIGURE 13-63. Normal trigone in a female. The surface epithelium is nonkeratinizing glycogenated squamous epithelium. *(From MacLennan GT, Resnick MI, and Bostwick DG: Pathology for Urologists, 2003, with permission.)*

The *outer layer* of the detrusor is found on the anterior and posterior aspects in wide bundles that run in a generally longitudinal direction; on the lateral walls, this layer is less clearly distinguishable. As the **posterior longitudinal bundle** of the outer layer approaches the bladder neck, its more central portion inserts on the apex of the deep trigone to form part of the middle circular layer. The lateral portions of the posterior bundles pass around the ureterovesical junctions and form the **detrusor arch**. The **anterior longitudinal bundle** joins the detrusor arch at the precervical arch (see Fig. 13-64).

The *middle layer* between the outer and inner layers, the **middle circular layer**, has more or less circularly oriented fibers that form rings around the bladder wall from apex to base.

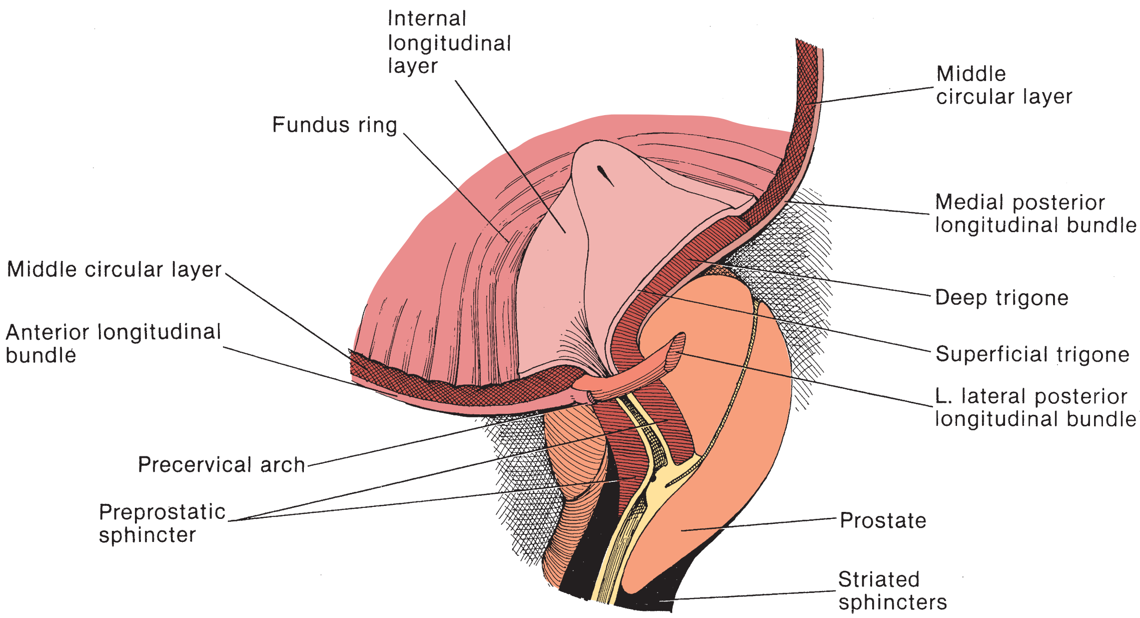


FIGURE 13-64.

The muscle bundles of the *internal layer* run as the **internal longitudinal layer** to come together at the bladder neck. The **superficial trigone** is superficial to this layer.

Trabeculation results from herniation of the mucosa and lamina propria through the spaces between the circular and longitudinal muscle bundles from increased intravesical pressure and detrusor hypertrophy.

Musculature of the Bladder Base

The bladder base is structurally distinct from the bladder body because it has the function to retain and release urine. In the male, the base also forms the most proximal part of the genital system, functioning to prevent retrograde flow of ejaculate. Whereas the motor innervation of the bladder body is principally through parasympathetic nerves, the base has a sympathetic innervation similar to that of the prostate, seminal vesicles, and ejaculatory ducts.

The bladder base has been viewed as having both a continence function and a voiding function, the former being performed by muscles and elastic tissue with sphincteric action and the latter by the dilating action of longitudinally oriented muscles. The genital functions of the bladder neck are described in Chapter 14.

The *vesical neck sphincteric system* consists of bundles of the **middle circular layer** of the detrusor that run obliquely forward and down around the urethral orifice to join the deep layer of the **anterior longitudinal bundles** of the outer coat (Fig. 13-64). This layer appears as concentric, asymmetric rings and forms what has been called the **fundus ring** or trigonal ring. In addition, the lateral portions of the **posterior longitudinal bundle** pass around either side to join anteriorly at a lower site, forming an arch that is concave posteriorly, the so-called detrusor arch (see Fig. 13-6).

The vesical neck system is in continuity with the **preprostatic sphincter**, a relationship that plays a role in maintaining continence at the level of the bladder neck. Even though the vesical neck structurally is not a true sphincter, it can be observed by cineradiography to hold urine at the bladder outlet and so is commonly called the internal sphincter. Its combined smooth muscle and elastic fibers compress the soft mucosal lining to achieve continence. The tone in this sphincter and in the preprostatic sphincter increases reflexly as the bladder fills through noradrenergic sympathetic stimulation.

A dilator system that has been postulated to open the vesical neck is formed from longitudinally oriented muscles. The middle portions of the **anterior** and **posterior longitudinal bundles** from the outer longitudinal muscle layer pass distally to fasten into the **precervical arch**, and some bundles descend to fuse with the muscle coat at the base of the prostate. A few bundles accompany the puboprostatic ligaments. The bundles in the **internal longitudinal layer** become radially oriented as they converge toward the internal urethral meatus to attach to the circular muscle or to continue down the urethra to merge with the inner longitudinal muscle layer of the preprostatic urethra (see Figure 14-52). The dilator system is innervated principally by cholinergic (parasympathetic) fibers.

In the female, the dorsal outer longitudinal layer follows a course similar to that in the male except that the fibers terminate in the vesicovaginal septum instead of in the prostate. In addition, the ventral outer longitudinal coat takes a course like the dorsal one to loop around the dorsal surface.

The effect is that of many bundles from the outer longitudinal coat encircling the urethra.

Thus the male proximal urethra and the entire female urethra may both be viewed as continuations of the bladder wall, although the elements are developmentally distinct.

Ureterovesical Junction

Five elements compose the ureterovesical junction, which allows it to both allow urine to pass into the bladder and to prevent it from refluxing back into the ureter. The elements are the **juxtavesical ureter**, the **intramural segment**, the **intravesical ureter**, the **superficial trigone**, and the bladder wall (Fig. 13-65).

Juxtavesical Ureter

The **juxtavesical ureter** ends at the adventitia of the bladder wall. It is important because of its enclosure in the Waldeyer sheath.

This section of the ureter is surrounded by a distinct adventitia, which, in turn, is enclosed in a fibromuscular **periureteral sheath** (Waldeyer sheath) derived from the detrusor. It has been erroneously called Waldeyer space; anatomically, it forms a covering for the ureter. The sheath runs proximally 3 to 4 cm from the orifice to enclose the **juxtavesical ureter**, at which level it fuses with the ureteral musculature. Distally, beyond the ureteral orifice, the fibers from the sheath spread out over the posterior bladder wall to join the deep trigone, which, in turn, is continuous with the **middle circular layer** of the detrusor muscle. Some of the fibers meet those from the opposite side to form the deep portion of the **interureteric ridge**, the superficial portion being formed from the superficial trigone. Other muscle fibers pass obliquely between the ureteral and vesical orifices to constitute the rest of the deep trigone, and the most laterally placed fibers form the deep portion of the **ureteral bars**. The bladder wall itself surrounds the ureter at its site of entry and provides a few anchoring muscle fibers to the periureteral sheath, but otherwise, the ureter passes freely through the detrusor hiatus. For anchorage to the vesical musculature, the ureter depends principally on the Waldeyer sheath and its continuation, the deep trigone, and on the adherent superficial trigone. For movement of the intramural ureter during its contraction and during contraction of the superficial trigone, the ureter depends on the loose adventitial layer under the Waldeyer sheath.

The juxtavesical ureter continues as the **intravesical** (terminal) **ureter**. This segment is about 1.5 cm in length and consists of an **intramural segment** within the bladder wall and a short **submucosal segment** under the vesical mucosa.

Intramural Ureteral Segment

The structure of the intramural ureter differs from that of the ureter above. Instead of helically oriented muscle bundles adapted for peristaltic propulsion, the muscle fibers of the intravesical segment run almost entirely longitudinally. They are embedded in a mesh of elastic fibers and collagen bundles, which are also longitudinally oriented. The balance between the muscular and elastic elements provides the needed compliance for the passage of a urine bolus through this section of the ureter. Functional obstruction (primary megaureter) may be due to the deposition of excess connective tissue that disturbs the action of the muscle and so reduces compliance.

Submucosal Ureteral Segment

After passing through the bladder wall, the ureter runs submucosally on the superficial trigone. The longitudinal muscles found in the intramural ureter continue into this segment.

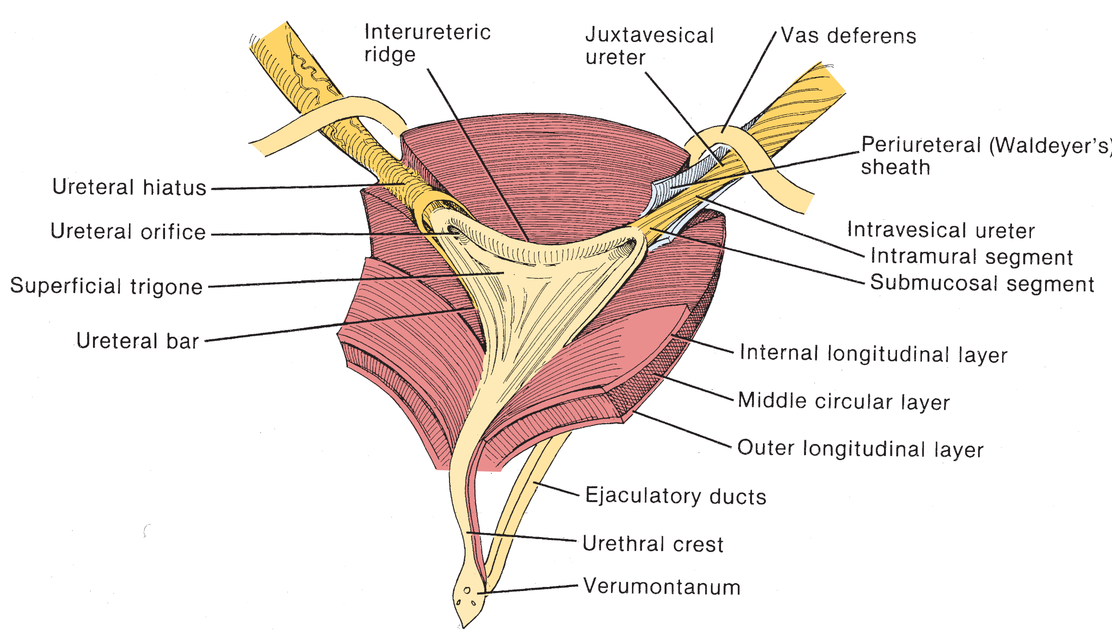


FIGURE 13-65.

Superficial Trigone

The longitudinal ureteral muscles continue into the bladder to spread out and form the **superficial trigone**, a thin layer composed of relatively small smooth muscle bundles. It is separated from the circular bundles of the deep trigone by a thin layer of connective tissue. After emerging from the ureters, the muscle spreads over the central portion of the middle circular layer that forms the deep trigone to meet in the midline. Some fibers cross transversely, but most proceed down the posterior wall of the urethra as the **urethral crest** to join the muscle of the **ejaculatory ducts**. In the female, the muscles of the superficial trigone extend the length of the urethra to terminate in a fibrous ring slightly proximal to the external meatus.

The superficial trigone probably does not help in opening the vesical neck on micturition, but it is important in preventing vesicoureteral reflux during voiding by contracting and increasing the obliquity of the intramural ureter.

Bladder Wall

As the ureter takes an oblique course through the bladder wall, it is covered by the progressively thinning layers of the bladder wall, permitting action as a flap valve. Behind it, the bladder wall progressively thickens as the orifice is approached. This provides backing, against which the ureter is compressed as intravesical pressure rises.

Reflux

It is probable that reflux is prevented by the obliquity of the ureter in its submucosal and intramural course and especially by the compressibility of its submucosal segment (flap valve). This action is supplemented by an increase in ureteral length brought about by contraction of the superficial trigone. With the bladder contents at low pressure, resting tone suffices to keep the flap of mucosa overlying the submucosal ureter closed, yet it allows passage of peristaltically driven boluses of urine. As the bladder fills and mural tension rises, the superficial trigone is stretched, pulling the intramural ureter more obliquely. Further, as voiding begins, the trigone reflexly shortens, causing the intramural ureter to assume a longer and even more oblique course, which increases the efficiency of the flap valve. For passage of a peristaltic bolus, the longitudinally oriented fibers of the intramural ureter shorten, thus enabling the helical muscular layers of the ureter above to slide over each other and be drawn into the hiatus, thereby reducing resistance to flow.

Blood Supply

The bladder has a dual blood supply that is transmitted through two pedicles of fascia, both derived from the intermediate stratum, that form the lateral and posterior vesical ligaments (Fig. 13-66).

One source of blood is the superior vesical pedicle that carries the **superior vesical artery** and its branch, the **vesiculodeferential artery** (or uterine artery in the female). These vessels from the **internal iliac artery** are actually branches of the embryonic umbilical artery, which, at birth, becomes the **obliterated hypogastric artery** in the **medial umbilical ligament**. The superior vesical artery may be single but usually has two or three branches that supply the dome and posterior aspect of the bladder. The branches have a tortuous configuration to accommodate to changes in vesical size with distention. The vesiculodeferential artery provides small branches to the fundus and a **ureteral branch** to the terminal ureter, although the arrangement is variable.

The second source of blood supply is through the inferior vesical pedicle that contains the **inferior vesical artery**. This artery usually arises from the **internal pudendal** or the **internal iliac artery**, but it often comes from the **inferior gluteal artery**. Other sources are the residual portions of the umbilical artery or a common trunk with the vesiculodeferential artery (see Figure 14-40). The inferior vesical artery supplies the bladder base, the proximal urethra, and the prostate, often receiving contributions from the obturator arteries. In the female, the uterine and vaginal arteries also provide some supply to the bladder (see Fig. 15-14).

Venous Drainage

Instead of following the arteries, the veins of the bladder drain into the **lateral plexuses** about the ureters and into the **prostatovesical plexus** (pudendal plexus, Santorini) along with the **deep dorsal vein of the penis** and the **cavernous vein** (Fig. 13-67). From the plexus, the veins run in the lateral prostatic ligaments to empty into the **internal iliac veins**.

Innervation of the Bladder, Diagrammatic

Sympathetic nerves arise as preganglionic fibers (solid line), at spinal levels **L1** and **L2**, pass through the **sympathetic trunk**, then run as the **hypogastric nerve** to the **inferior hypogastric (pelvic) plexus**, where they synapse (Fig. 13-68). As postganglionic fibers (dashed line), they pass through the **vesical plexus** to innervate the bladder neck and through the **prostatic plexus** to innervate the preprostatic sphincter and **prostate**. Synapses with the parasympathetic nerves provide modulation.

Parasympathetic nerves exit from sacral nerves **S2, S3**, and **S4**, and, as the **pelvic (splanchnic) nerves** composed of *preganglionic fibers* (dotted lines), they pass through the **inferior hypogastric (pelvic) plexuses** and **vesical plexuses** to the substance of the detrusor to terminate in ganglia, from which the bladder muscle is innervated by *postganglionic nerves* (heavy line).

The detrusor is very well supplied with motor cholinergic terminals; each smooth muscle cell of the detrusor is innervated by at least one such parasympathetic terminal. Because only a few sympathetic noradrenergic nerves are found and they are involved with the blood vessels, modulation of detrusor activity is probably accomplished by influencing ganglionic transmission through parasympathetic cell bodies in the inferior hypogastric plexus. It may be that other agents, such as vasoactive intestinal peptides, act on the detrusor through a second type of motor nerve.

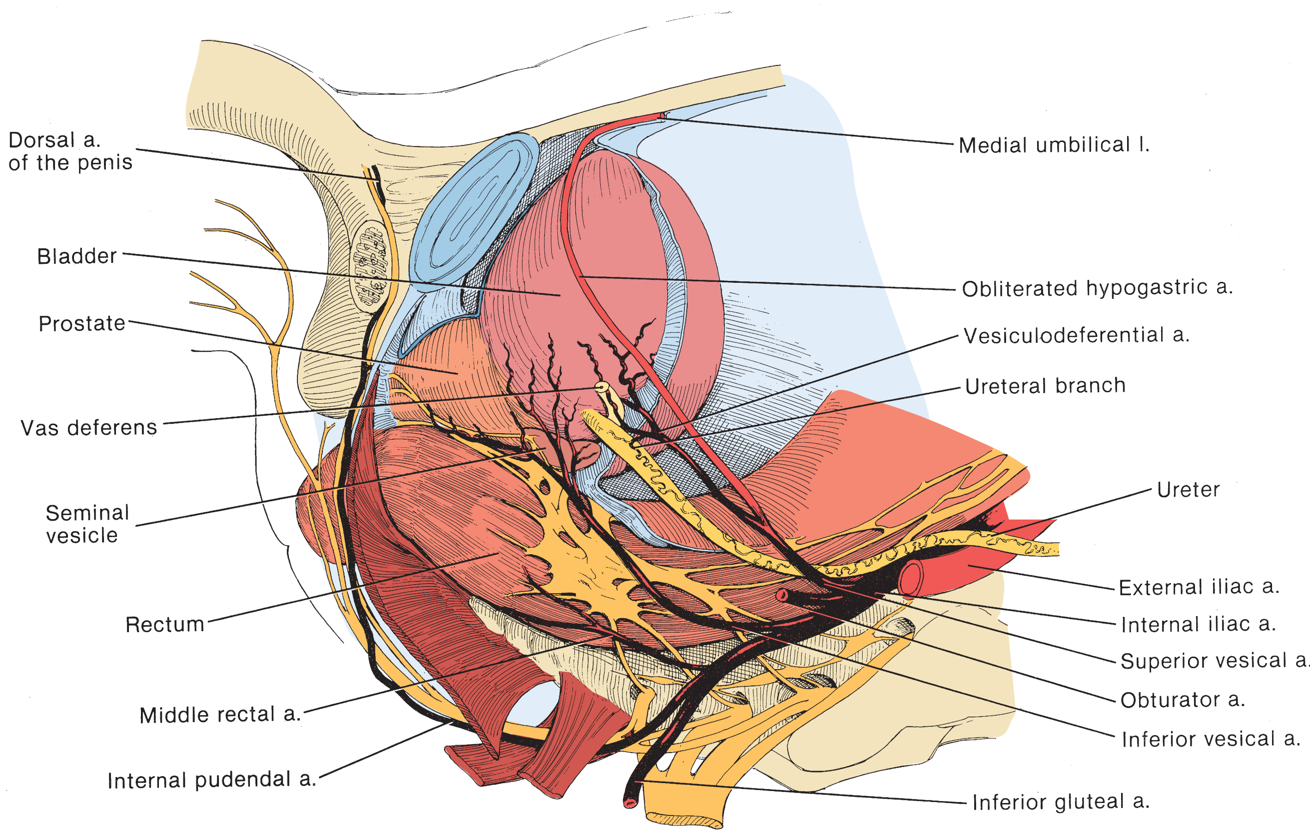


FIGURE 13-66.

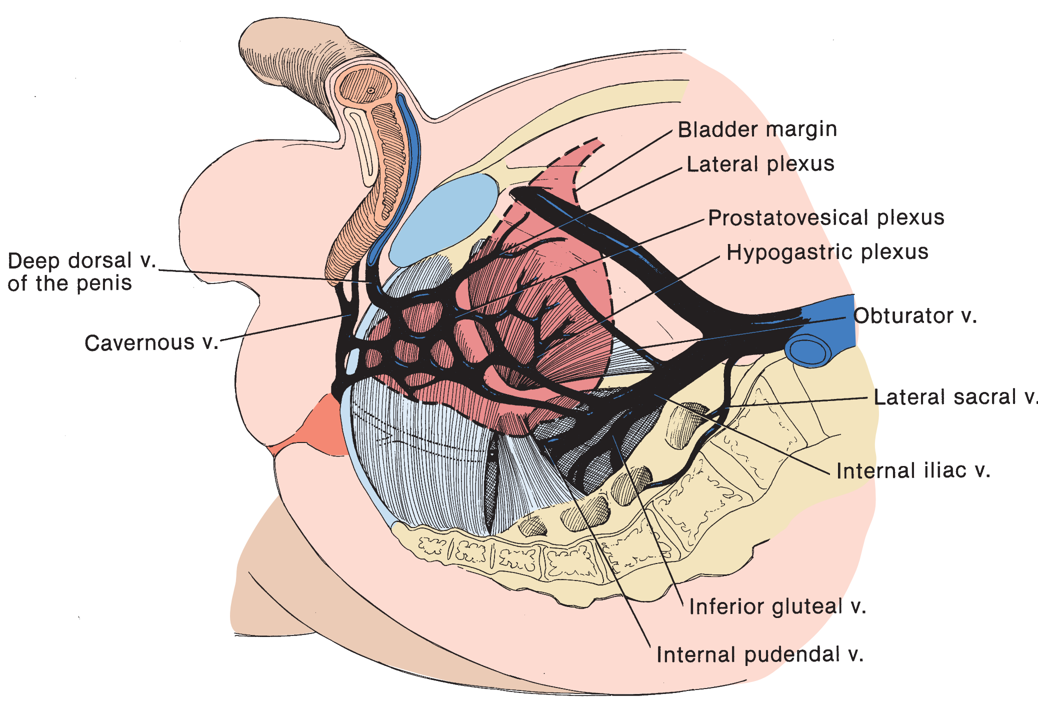


FIGURE 13-67.

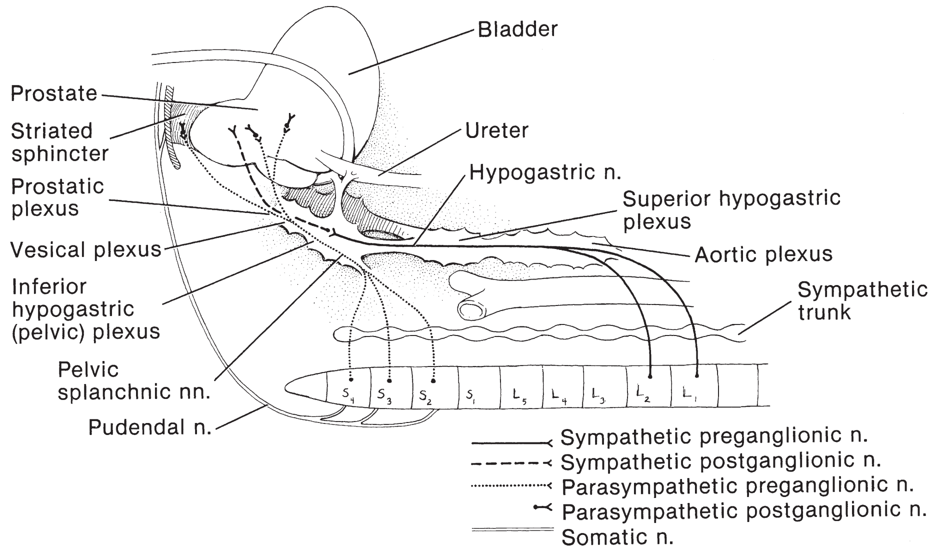


FIGURE 13-68.

The innervation of the bladder neck is from the sympathetic nervous system and, as part of the vesical neck–prostatic complex, is described in Figure 14-55.

Course of the Nerves to the Bladder

From each side of the **superior hypogastric plexus**, the right and left **hypogastric nerves** descend medial to the internal iliac artery and anterior to the **sacral sympathetic chain**. They join the right and left inferior hypogastric (pelvic) plexuses that lie adjacent to the bladder base, the prostate, and the seminal vesicles (Fig. 13-69). The bladder is innervated through the **vesical plexus** on the posterolateral surface of the bladder. This plexus is derived from the anterior portion of the inferior hypogastric plexus, and it joins the **prostatic plexus** inferiorly. The inferior hypogastric plexus and its derivatives give off branches to the ureteric and testicular plexuses. The **1st** to **3rd sacral (splanchnic nerves)** contribute parasympathetic fibers to the plexuses.

The nerves from the vesical plexus run with the arteries to the bladder at its base. The anterior part of each inferior hypogastric plexus constitutes the vesical plexus. The parasympathetic nerves from the prostatic plexus may provide some supply to the external urethral sphincter (see Figure 14-45B).

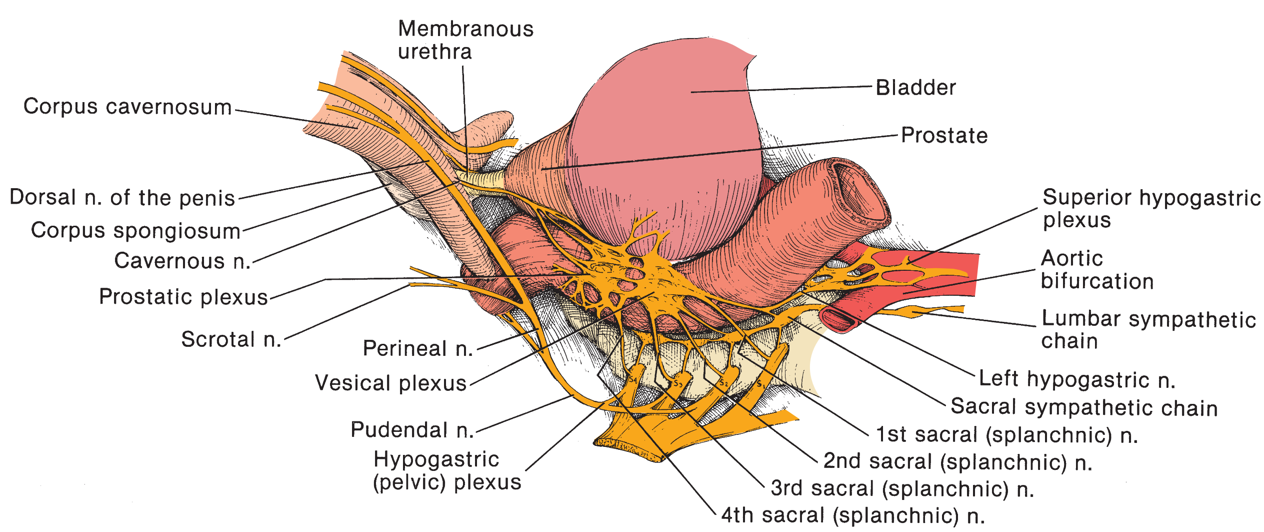


FIGURE 13-69.

Lymphatic Drainage

Three levels of lymphatic vessels drain the bladder wall: (1) submucosal, (2) muscular, and (3) perivesical. The vessels in the **submucosal plexus** merge with the rich muscular network, which, in turn, joins larger vessels in the **muscularis plexus** to drain into the collecting trunks of the **adventitial collectors** at the surface (Fig. 13-70A).

The lymph collectors from the bladder drain into the **external iliac nodes** through one of three different courses, depending on their site of origin. The lymphatics from the *vesical neck, trigone*, and *bladder base* originate from the bladder wall between the vasa deferentia in the male and the ureters in the female. They run cephalad and laterally toward the inferior vesical pedicle, staying anterior to the insertion of the ureter. Some lymph from the base may pass directly to **internal iliac** and **common iliac nodes**, and some from the neck may go directly to the **sacral nodes** (Fig. 13-70B). Those lymphatics from the *posterior wall* run in two or three trunks in front of the ureter to cross the obliterated umbilical artery and reach the internal iliac nodes. Those from the *anterior wall* meet sets of collectors from the prostate and adjacent organs and end in the middle chain of the external iliac group. Small intercalary nodes appear in the course of these channels, especially in front of the bladder. Alternate drainage sites from the anterior wall are the femoral (Cloquet) node and the internal iliac or common iliac nodes.

Some lymphatic drainage is intercepted by perivesical and intercalating nodes that lie along the vesical, deferential, and prostatic branches of the inferior vesical and middle hemorrhoidal arteries.

Clinically, metastases from bladder carcinoma have been found to spread principally to the obturator and the external iliac nodes, although the sacral nodes are involved in more than a fifth of cases.

Urachus and the Umbilical Ligaments

The urachus, a remnant of the ventral end of the vesicourethral canal, is embedded in the peritoneum in the midline to form the urachal or **median umbilical ligament**. The initial part of the urachus lies in the space of Retzius, and the remainder runs between the peritoneum and the transversalis fascia within the umbilicovesical fascia (middle stratum). This layer extends laterally as the **medial umbilical ligaments** to enclose the **obliterated umbilical arteries** that run from the superior vesical artery to the umbilicus (Fig.13-71). Inferiorly, the umbilicovesical fascia fuses with that over the **bladder** and prostate.

The urachus does not usually reach the umbilicus in the adult; rather, it may terminate adjacent to one of the obliterated hypogastric arteries, or it may join both arteries, or it may be short and partially degenerate into the subumbilical *fibrous plexus of Luschka* (see text introducing Fig. 13-32). The wall of the urachus consists of an adventitia, an outer smooth muscle coat that is more fully developed near the bladder, a submucosal layer of connective tissue, and an inner epithelial layer with either transitional or, less often, cuboidal epithelium (see Fig. 13-36).

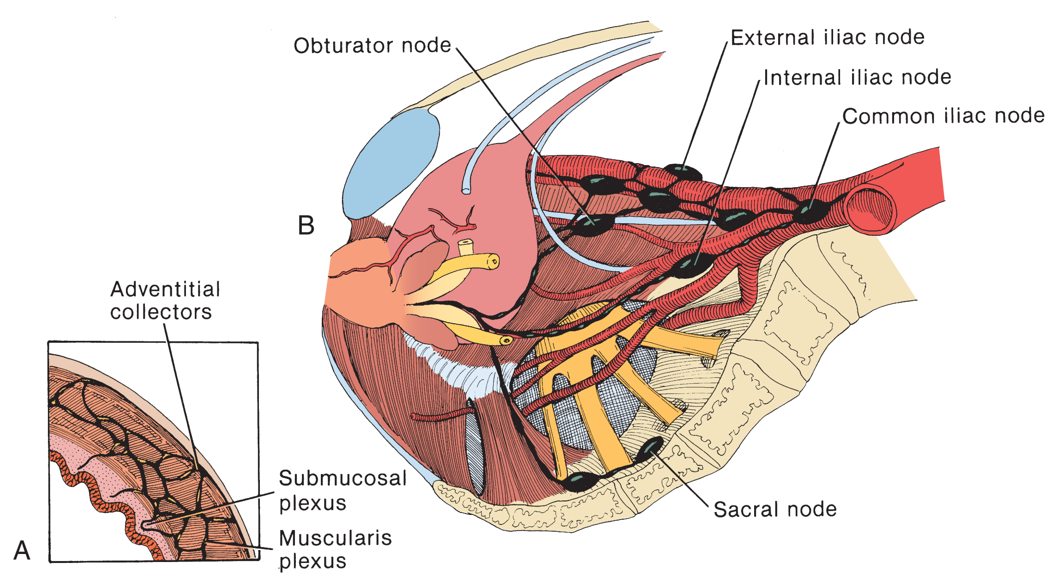


FIGURE 13-70.

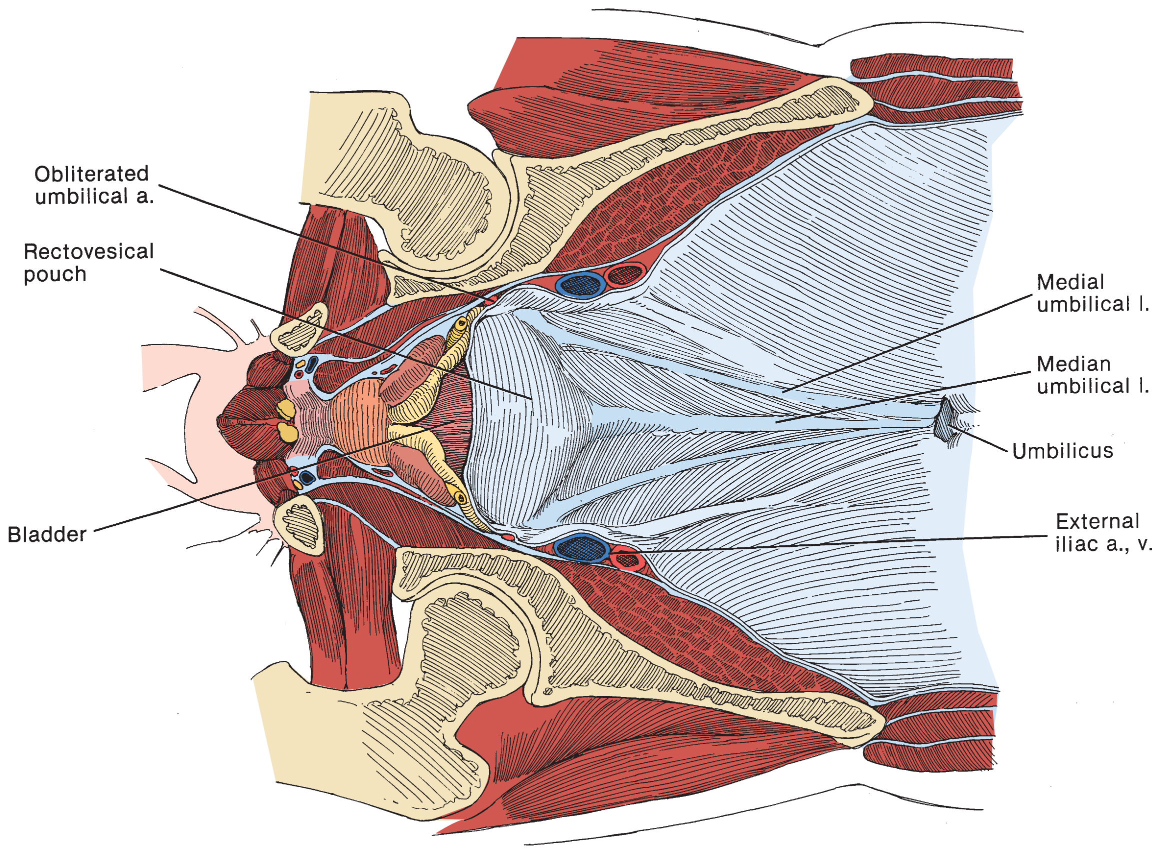

Obliterated umbilical a.
Rectovesical pouch
Bladder
Medial umbilical l.
Median umbilical l.
Umbilicus
External iliac a., v.

FIGURE 13-71.

Chapter 14

Prostate and Urethral Sphincters

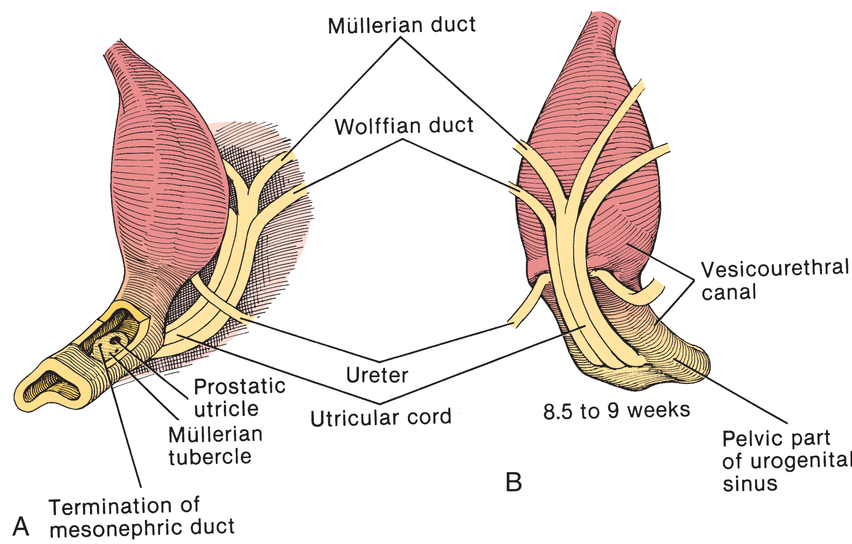


FIGURE 14-1. (A) Anterolateral view. (B) Posterolateral view.

In shape the prostate resembles a Spanish chestnut.
Todd's Cycl. Anat., IV, *146/1, 1847–9*

Very little is known as to the uses of the prostatic body.
Todd's Cycl. Anat. II, *459/1, 1836–9*

DEVELOPMENT OF THE PROSTATE, SEMINAL VESICLES, AND URETHRAL SPHINCTERS

Prostate

The prostate is formed after differentiation of the urogenital sinus and the development of the wolffian structures (see Fig. 13-9).

The Utricular Cord; the Müllerian and Wolffian Ducts

The **müllerian** (paramesonephric) **ducts** fuse in the midline to form the solid **utricular cord** between the **wolffian ducts** (Fig. 14-1). The cord impinges on the wall of the urogenital sinus at the junction of the **vesicourethral canal** (the portion that will become the bladder) and the **pelvic portion of the urogenital sinus** (that will form the prostatic urethra).

Formation of the Müllerian Tubercle

The **utricular cord** becomes canalized (Fig. 14-2A).

Where the cord impinges on the dorsal wall of the **urogenital sinus,** forming the **müllerian** (sinus) **tubercle,** the endodermal lining of the sinus is stimulated and extrudes to form the **sinoutricular cord** with the mesoderm of the **utricular cord** (Fig. 14-2B, see also Fig. 13-9).

As the müllerian ducts atrophy, the fused residual, distal portion and the attached sinus portion of the sinoutricular cord become canalized (Fig. 14-2C). It has been shown that the utricle forms as an ingrowth of specialized cells from the dorsal wall of the urogenital sinus as the caudal müllerian ducts regress. The müllerian tubercle remains as the **verumontanum** or colliculus seminalis.

In the female, the sinus forms the introitus and the utricular cord forms the vagina, as described in Fig. 15-6.

Preprostatic and Posterior Urethra

The primary or **preprostatic urethra** originates from the **vesicourethral canal,** which is that part of the urogenital sinus lying above the **müllerian tubercle** (verumontanum) (Table 14-1). This section examines the entire urethra in the female.

The **posterior urethra** proper is formed from the **pelvic part** of the **urogenital sinus** (Fig. 14-3A).

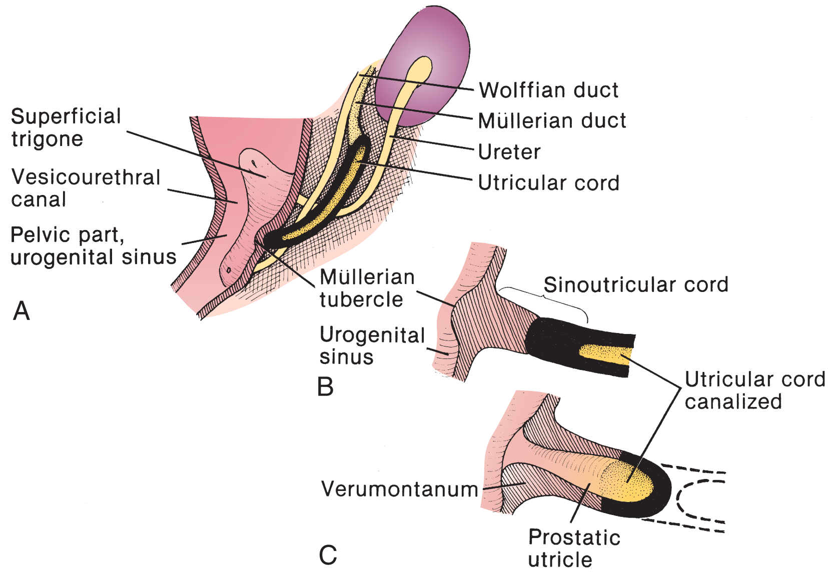


FIGURE 14-2.

DIVISIONS OF THE MALE URETHRA

TABLE 14-1

PREPROSTATIC URETHRA
From portions of urogenital sinus. Extends from above entrance of müllerian and wolffian ducts to junction with bladder.

POSTERIOR URETHRA
From the pelvic part of the urogenital sinus. Extends from above the level of the duct openings to urogenital membrane.

DISTAL URETHRA
From the phallic part of the urogenital sinus as a groove between the urethral folds, elongating with growth of genital tubercle.

It begins immediately above the level of the openings of the wolffian and müllerian ducts and extends to the urogenital membrane. Epithelial extensions from the proximal portion will form the prostatic lobes. The phallic part of the urogenital sinus forms the bulbar and penile sections of the urethra (see Fig. 16-3).

In the adult, the **prostatic utricle** is a shallow depression on the **verumontanum,** which is flanked distally by the openings of the ejaculatory ducts (Fig. 14-3B). The **collicular folds** (seminal colliculi) lie on either side of the verumontanum, closely associated with the openings of the sets of **prostatic ducts.** The folds are derived from wolffian elements and appear as paired longitudinal striations in the lateral wall of the more proximal portion of the urogenital sinus (see Fig. 13-11). They extend distally from the müllerian tubercle to the site of origin of the bulbourethral glands, which in early development are situated anteriorly. Later, as the wolffian ducts regress and move more proximally, the folds move with them, fostered by regression of their most distal portions. They also move laterally by growth of the urethra.

The epithelium of the collicular folds differs from that of the rest of the urethra. It contains appreciably less prostatic acid phosphatase than the rest of the prostatic urethra.

Formation of the Prostatic Ducts

The primitive prostatic ducts develop under the influence of wolffian duct mesenchyme in close association with the wolffian duct in the prostatic urethra.

Fetal androgens produced by the testis beginning in the eighth week are a prerequisite to this mesenchymal activity. As Leydig cells differentiate, androgen levels in testicular tissue rise. The enzyme 5-alpha reductase is produced in the end-organ to convert testosterone into dihydrotestosterone.

Between the 11th and 12th weeks, the *mesenchyme* surrounding the prostatic urethra is stimulated by androgens to induce proliferation of the *epithelium,* evidenced first by the budding of the primary ducts, then by the formation of branches from the urethral epithelium. At this time, the ducts appear as solid epithelial outgrowths within an area of smooth muscle fibers and dense connective tissue both proximal to the entrance of the wolffian duct (in the preprostatic urethra) and distal to it (in the urogenital sinus) in an area that is demarcated from the surrounding mesenchyme. The ducts develop principally on the dorsal wall, less densely on the lateral wall, and rarely in a ventral position. Lowsley counted 63 branches in a 13-week-old fetus. The ducts are solid at first; after 30 weeks, they acquire lumens. At first, small collections of cellular buds develop, then acinar structures appear. Later, lobular clusters of acinotubular structures develop as the ducts invade the mesenchyme surrounding them.

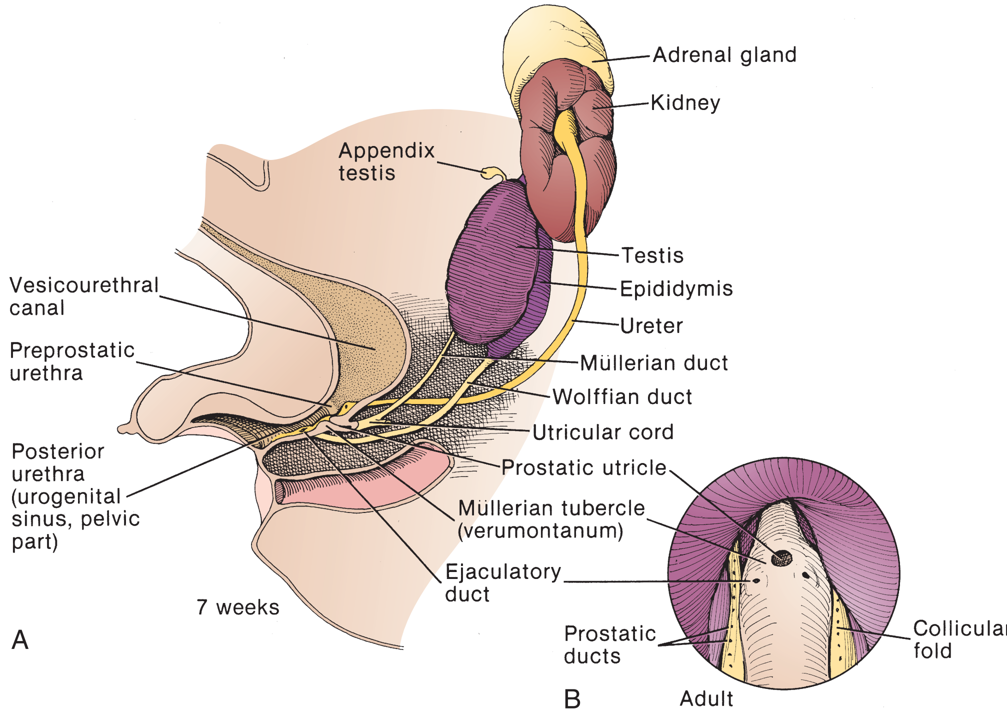


FIGURE 14-3.

Zonal Distribution

The ducts arise from three areas in the epithelium and contiguous mesenchyme of that part of the urogenital sinus destined to become the floor of the prostatic urethra (Fig. 14-4). Each of the three sets of ducts will drain one of the three zones of the prostate (see also Figs. 14-24, 14-27, 14-29, 14-30, 14-31, and 14-32).

The earliest set buds distal to the verumontanum and becomes the **peripheral zone** of the prostate.

A second set branches from the urethra in two rows that lie beside and above the site of exit of the ejaculatory ducts in the verumontanum in an area populated by epithelium from the wolffian ducts. This set will become the **central zone** of the prostate in the male and will form the paraurethral glands in the female.

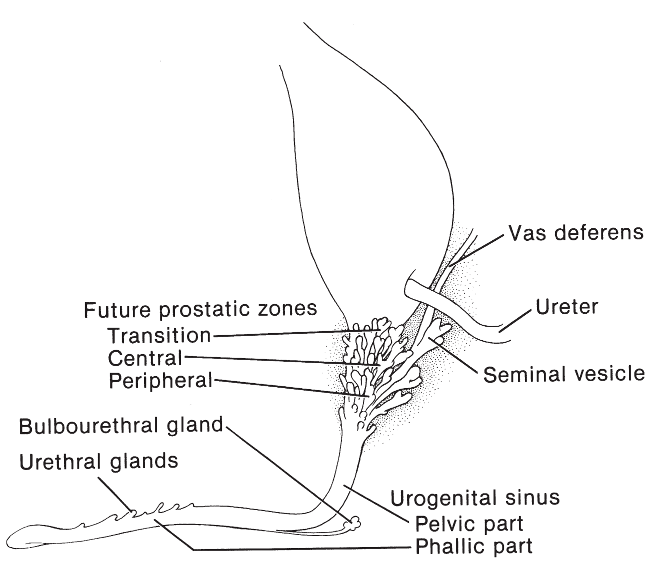


FIGURE 14-4.

The ducts of the peripheral zone are thought to arise from the tissue of the urogenital sinus, whereas those of the central zone come from the intrusion of wolffian duct material into the tissue of the urogenital sinus.

A third set of buds, situated most proximally in the vesicourethral canal, will proliferate within an inner submucosal zone to form the ducts and glands of the **transition zone** in the male, homologues of the urethral glands in the female. These glands remain small in size and uncomplicated in structure and do not develop intrinsic musculature.

For the *transition zone,* well-differentiated acini develop; at first, periurethrally along the preprostatic urethra on the luminal side of the preprostatic sphincter proximal to the site of the future peripheral and central zones. The sphincter becomes thinner as it approaches the proximal end of the peripheral zone near the verumontanum. This allows a special group of larger and more complex periurethral glands to expand peripherally and centrally to form the transition zone. Their ducts at first run parallel to the urethra and then turn medially when they reach the distal end of the preprostatic sphincter.

In this zone, both sinus and wolffian tissues are probably involved in competition for the space between the urethral lining and the musculature of the urethral wall (preprostatic sphincter). The result of such interposition is a somewhat unstable embryologic development. With aging, this area reverts to a more elemental state in which the stroma proliferates and induces glandular formation, resulting in benign prostatic hyperplasia.

Histologic Characteristics. The three zones have different cellular characteristics and show different responses to hormonal stimulation (see Figs. 14-33, 14-34, and 14-35). The distal two zones might be considered analogous to the double set of prostate glands of subhuman primates. The central zone develops more rapidly than the peripheral zone during early puberty and atrophies later with aging, suggesting that it is less dependent on androgens. Perhaps the transition zone should not be considered part of the prostate proper because the glands are essentially periurethral, have a different mode of origin at a different site, and have a different response to aging and neoplasia. Benign prostatic hyperplasia develops only from this zone; carcinoma begins here less often than it does in the other zones.

Prostate-specific antigen, appearing at 28 weeks, shows a weaker reaction in all areas of the developing prostate than in the mature prostate. Prostatic acid phosphatase activity appears at the same time as prostate-specific antigen and is variable in its activity, being highest in the lateral areas of the peripheral zone.

The subcervical glands (Albarrán) develop about the 16th week from the urethral floor at and below the level of the internal sphincter. Hyperplasia of these glands may produce a distinctive exophytic nodule of prostatic tissue at the bladder neck, projecting into the vesical cavity, often referred to as median lobe hyperplasia (Fig. 14-5). A few subtrigonal glands are found in the 20th week.

The **bulbourethral glands** (Cowper) form as epithelial buds from the pelvic part of the urogenital sinus and grow through the mesenchyme of the corpus spongiosum (Figs. 14-6 and 14-7; see also Fig. 14-56). Once past this tissue, they branch and develop lumens. The greater vestibular glands (Bartholin) are the homologous structures in the female. The forerunners of the **urethral glands** (Littré) appear successively, starting anteriorly as endodermal buds around the walls of the phallic part of the urogenital sinus.

The *ejaculatory ducts* develop as the termination of the wolffian duct. The deferential branches from the vesicodeferential arteries pass through the posterior surface of the prostate between the central and peripheral zones on the way to supply part of the verumontanum.

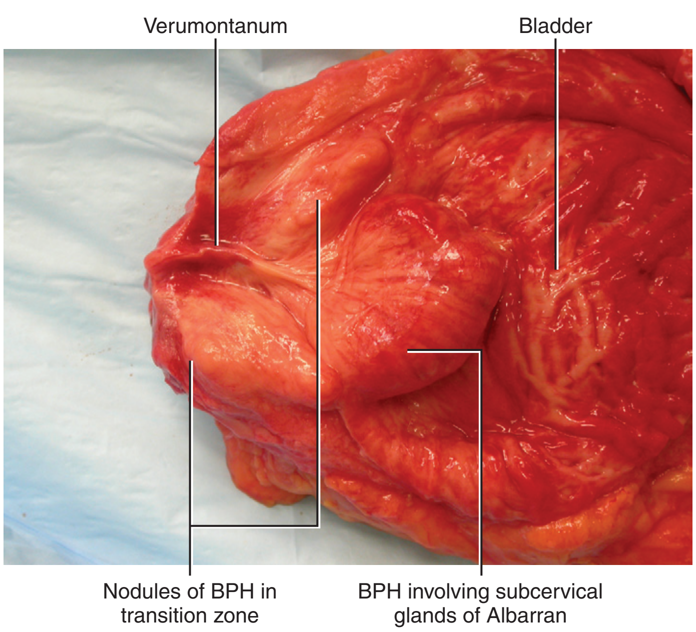


FIGURE 14-5. Median lobe hyperplasia. Benign prostatic hyperplasia forming periurethral nodules and also arising in the subcervical glands of Albarran to form an exophytic nodule protruding into the vesical cavity. *(Image courtesy of Lisa Stempak, M.D.)*

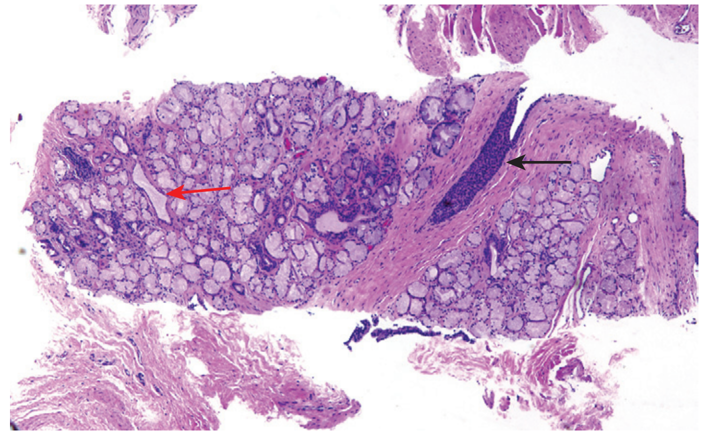


FIGURE 14-6. Cowper's gland. Cowper's glands, which are small, paired bulbomembranous urethral glands, are occasionally sampled inadvertently during prostatic needle biopsy. Circumscribed lobules of closely packed uniform acini lined by cytologically benign mucin-producing cells surround a central duct (red arrow). Urethral urothelium is included in the biopsy core (black arrow). *(From MacLennan GT, Resnick MI, Bostwick DG: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

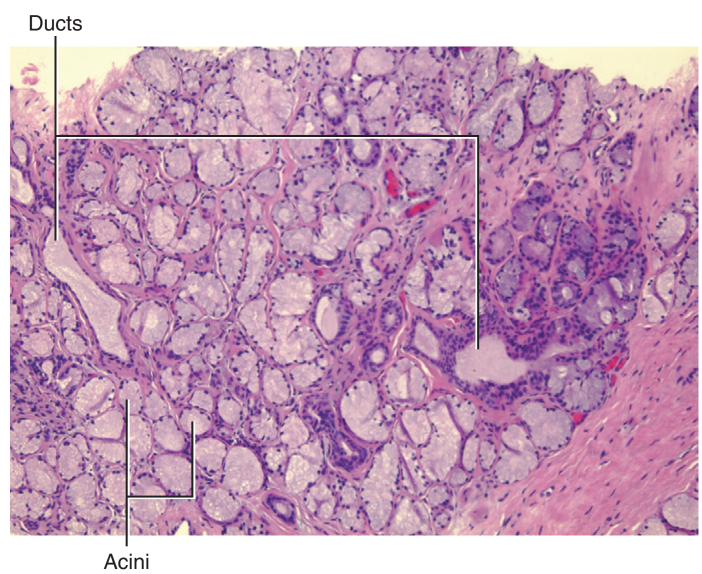


FIGURE 14-7. Cowper's gland. Acini are clustered around central ducts and are lined by cytologically benign mucin-producing cells with small nuclei, inconspicuous nucleoli, and abundant apical mucinous cytoplasm.

Squamous metaplasia develops in regions derived from the müllerian ducts. It is uniformly present about the prostatic utricle, common in the ejaculatory ducts, and less common in the posterior urethra.

The prostatic ducts proliferate and show signs of secretion between 5 and 6 weeks' postpartum. Alveoli are subsequently formed. The metaplasia of the alveolar epithelium and verumontanum that had been induced by maternal hormones is reversed and the prostate remains essentially unchanged until puberty. During the 6 or 7 years after puberty, the gland rapidly enlarges to reach its mature size. Later in life, the epithelial complexity decreases at the same time that the periurethral glands of the transition zone are induced by the stroma to differentiate and form benign hyperplasia.

Smooth Muscle Sphincters

Development of the Preprostatic and Urethral Smooth Muscle Sphincters

The smooth muscle of the bladder outlet and that of the preprostatic urethra are formed independently but become continuous during subsequent development. Muscle fibers differentiate in layers from mesenchymal cells with the same orientation. Thus, very early in fetal life, three smooth muscle systems can be detected: (1) the musculature of the bladder base, (2) the smooth urethral musculature, and (3) the prostatic smooth musculature, which develops independently of the other two (Fig. 14-8).

The *bladder base segment* is composed of the deep and superficial trigonal systems. The circular fibers forming the **deep trigone** develop first at 3 weeks to form the **trigonal ring.** A week later, the longitudinal fibers of the **superficial trigone** related to the ejaculatory ducts and the ureteral musculature appear and extend from the verumontanum to the ureteral orifices (see Figs. 13-11 and 13-12).

The *urethral smooth muscle* that will form the **preprostatic sphincter** appears around 5 weeks of gestation as two layers: (1) an inner longitudinal and (2) an outer more or less obliquely oriented circular layer. These layers arise separately from those of the bladder and are not connected to the detrusor at this stage. Only later and secondarily do they become continuous with the corresponding longitudinal and circular muscles of the bladder neck.

Ultimately, they form both the preprostatic sphincter and the passive prostatic sphincter. The preprostatic sphincter, as noted, is closely related to the formation of the adjacent transition zone.

The *prostatic musculature* develops in the outer stromal layer of the primitive **prostate** synchronously with that of the bladder neck. The slender fibers are distinguishable from the coarser smooth muscle of the trigone and the urethra as they surround the urethra except for the dorsomedial wall.

Striated Sphincters

Early Development of the Striated Sphincter

At 5 weeks, before the primitive prostatic ducts are formed, the primordium of the external striated urethral sphincter is in place over the transverse bundles of smooth muscle of the ventral wall of the prostatic urethra. Now clearly striated, the primordium develops dorsally and makes contact with the rectal musculature at the site where the rectourethralis will develop.

By 9 weeks, the **striated sphincter**, which will differentiate into the prostatic striated sphincter and the membranous urethral sphincter, covers the ventral side of the urethra all the way to the bladder neck (Fig. 14-9). On the dorsal side, the muscle coat is incomplete because the entry of the **müllerian** and **wolffian ducts** limits its proximal distribution. Here, the muscle has the shape of a horseshoe, becoming doughnut-shaped distally as it encircles what will become the membranous urethra. Cranially, the bundles insert into the prostate and their free ends attach to the **dorsal raphe.**

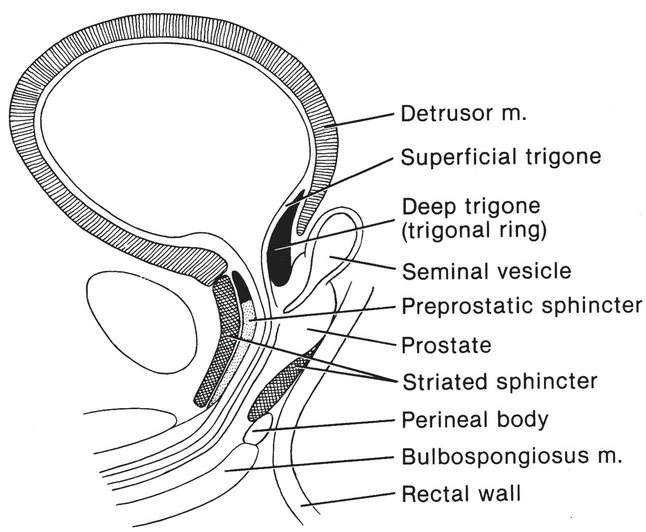


FIGURE 14-8.

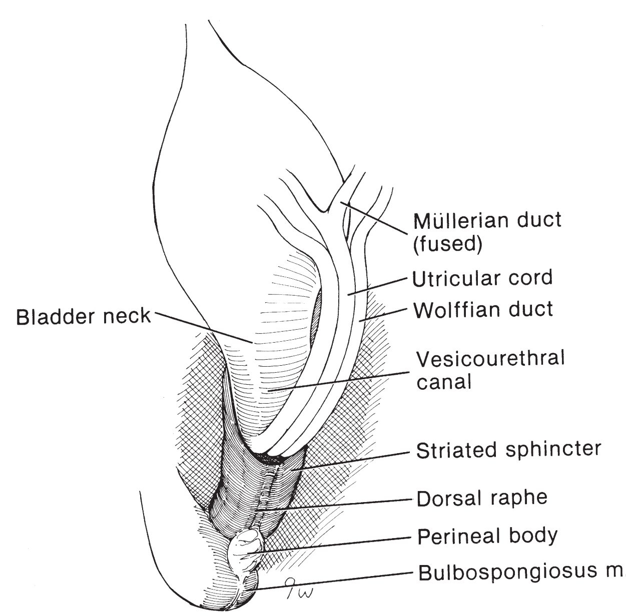


FIGURE 14-9.

Glandular Development

The mucosal buds expand from the dorsum of the urethra on both sides and develop into lobes as they intrude against the striated musculature. The two lateral portions of the developing prostate fuse in the midline anteriorly, forming the anterior commissure, which is complete proximally but may be incomplete distally. The growth of the prostate thins the muscle surrounding the prostatic urethra ventrally and laterally.

The striated sphincter not only covers the smooth urethral musculature and immature prostate but also inserts into the prostatic substance in the capsule and is in contact with the circular muscle of the fundus ring.

Development of the Striated Sphincter after Birth

At term, the prostatomembranous sphincter extends along the urethra from the **bladder neck** to the **perineal membrane**. The proximal portion of the sphincter, called the **prostatic striated sphincter,** is most developed over the central part of the prostate, where it extends three-quarters of the way around (Fig. 14-10). At the caudal end, where the distal portion of the sphincter meets the pelvic floor, the **membranous striated sphincter** lies above the perineal membrane between it and the so-called superior layer of the urogenital diaphragm. Here, the muscle is distributed more uniformly around the urethra but is still relatively deficient dorsally. As the **prostate** develops bilaterally around the urethra to meet in a ventral commissure, the fibers of both prostatic sphincters are displaced and thinned. These changes account for the difficulties that have been encountered in describing them accurately. Moreover, the prostatic lobes may not join distally at the commissure, thus allowing direct contact between sphincter and urethra.

By 4 years of age, the striated sphincter has extended from the trigonal ring to a point slightly beyond the transverse perineal muscle. Evidence that a true urogenital diaphragm does not form is that the sphincters do not lie above it.

Development of the Prostatic Sheath and Denonvilliers' Fascia

Prostatic Sheath

The prostate and seminal vesicles are enclosed in a loose fascial coat developed from the middle stratum of the retroperitoneal connective tissue as part of the umbilicovesical fascia, the same fascia that forms the puboprostatic ligaments.

Denonvilliers' Fascia, Anterior Lamella

During early development, after the descent of the urorectal septum, the peritoneal cavity separates the urogenital sinus from the hindgut, so that the posterior surfaces of the bladder, seminal vesicles, and prostate are covered with a double layer of fusion-fascia derived from the two layers of peritoneum that lined the rectovesical pouch. The two apposed peritoneal coats have fused distally to proximally, and the mesothelium is subsequently resorbed, leaving as fusion-fascia the two underlying layers of the inner stratum of retroperitoneal connective tissue to constitute the anterior lamella of Denonvilliers' fascia (see Fig. 14-25). The periprostatic tissue (prostatic sheath), derived from the intermediate stratum of the retroperitoneal connective tissue, is anterior to this fascia.

Denonvilliers' Fascia, Posterior Lamella

The loose mesenchymal tissue of the inner stratum of retroperitoneal tissue over the rectum becomes organized into a sheet covering the anterior and lateral surfaces of the rectum after the descent of the urorectal septum into the pelvis (migration fascia). This sheet, the rectal fascia, forms the posterior lamella of Denonvilliers' fascia.

Thus, embryologically, four layers are formed between prostate and rectum: one from the intermediate stratum that forms the prostatic sheath, two layers associated with the peritoneal mesothelium that fuse to form the anterior

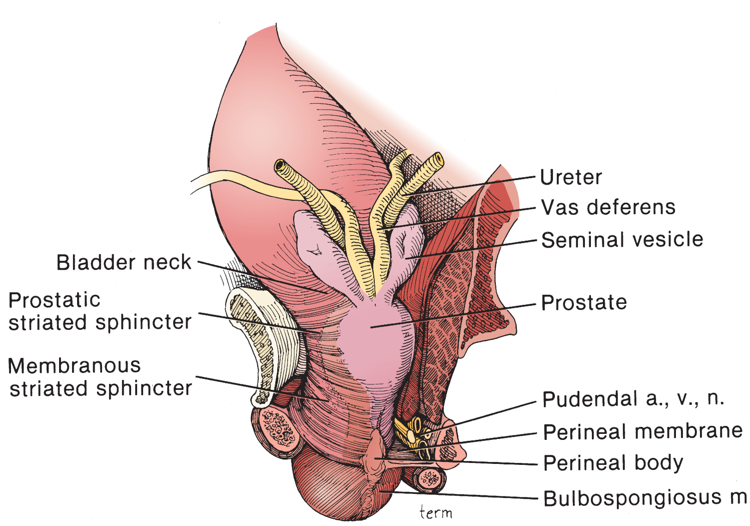


FIGURE 14-10.

lamella of Denonvilliers' fascia, and one from the inner stratum, the posterior lamella of Denonvilliers' fascia.

An alternative explanation that does not invoke peritoneal fusion and accounts for the smooth muscle fibers in Denonvilliers' fascia is that the apparent upward migration of the rectovesical pouch occurs by condensation of the loose areolar tissue overlying the rectum. Other opinions exist for the origin of Denonvilliers' fascia, for example, that it is a wolffian derivative.

Development of the Seminal Vesicles

In the sixth month, the seminal vesicles and ampullae become very large at the same time that the growth of the prostatic tubules is accelerated.

A mound rises at the juncture of the **wolffian duct** with the derivatives of the urogenital sinus at the end of the third month, at the time of degeneration of the **müllerian ducts** (Fig. 14-11A). This swelling will form the seminal vesicles and the ampulla of the vas. As the remains of the wolffian ducts, the vasa deferentia appear as two small tubular structures under the bladder between the ureters. They are contained in a thick muscular and connective tissue coat. The coats between the vasa merge beneath the vesical neck, where the vasa are very large. **Lateral branches** appear on each vas, signally the initial development of the seminal vesicles (Fig. 14-11B). After becoming demarcated from the ampullary portion, the seminal vesicle elongates, acquires a distinct duct, and develops sacculations in the wall (Figs. 14-11C-F). In time, as the first branches grow dorsolaterally, they become tortuous and each produces up to four similarly tortuous branches. The vesicular ducts are connected with the vasa deferentia within the substance of the prostate.

Distal to the vesicular branches, the **vas deferens,** as the **ejaculatory duct,** has a smaller lumen surrounded by less abundant tissue as it fuses with the muscular coat of the urethral wall (Fig. 14-11F).

At the same time, above the site of vasal fusion, the fused müllerian ducts retain a small lumen within a delicate

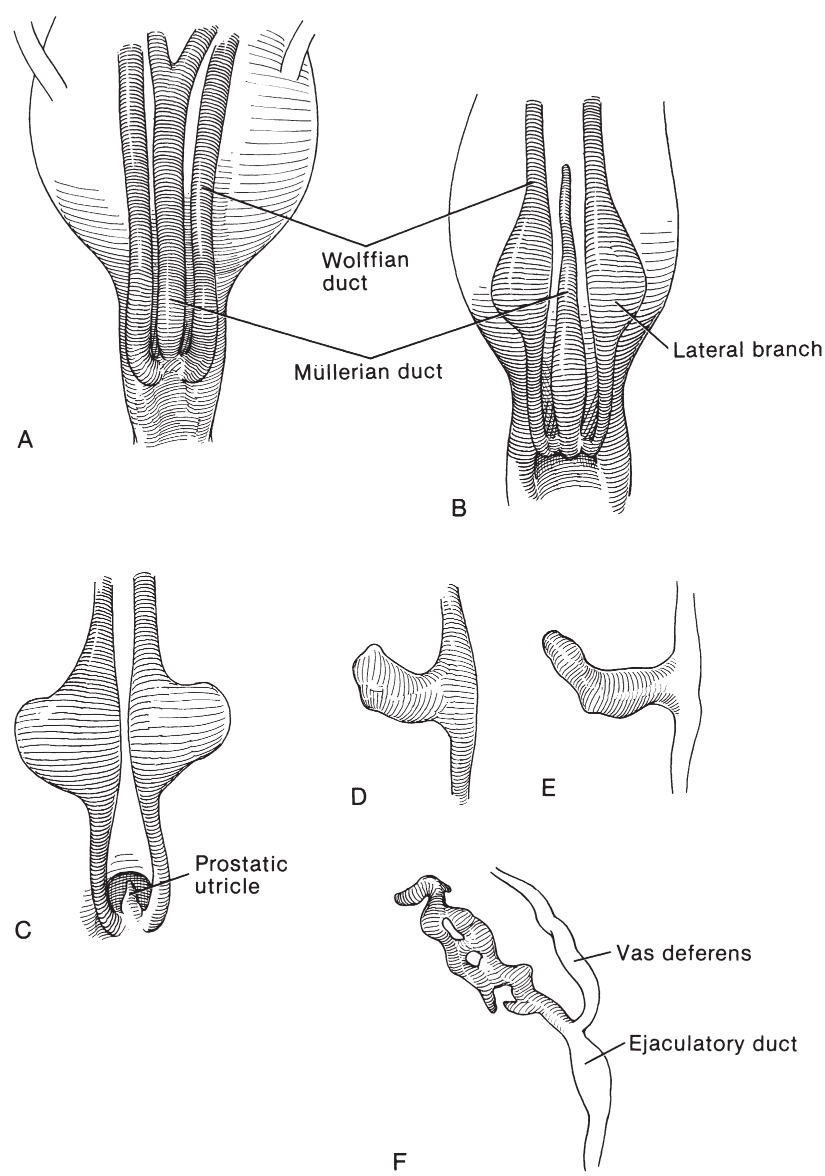


FIGURE 14-11.

connective tissue cover. Distally, the lumen becomes greatly enlarged to form the prostatic utricle, but it subsequently contracts so that after the 22nd week, it can be found only as a pocket (the **prostatic utricle**) just below the openings of the prostatic ducts (Fig. 14-11C).

Anomalies in the Male

The anomalies associated with the abnormal development of the müllerian and wolffian ducts are listed in Table 14-2. All of them are rare and, except for absence of wolffian derivatives, are of little clinical significance.

Congenital Urethral Valves

Abnormalities of the collicular folds, the wolffian derivatives that arise as longitudinal striations in the posterolateral wall of the more proximal portion of the urogenital sinus below the verumontanum, are responsible for most urethral valves (see Fig. 14-3B).

Three types of valves are recognized (Fig. 14-12). Type I valves are sail-like exaggerations of the collicular folds that extend from the müllerian tubercle to the site of origin of the bulbourethral glands distal to the verumontanum (Figs. 14-13 and 14-14). Because the folds are attached on

TABLE 14-2

ANOMALIES OF THE PROSTATE AND SEMINAL VESICLES

Anomaly	Age (Weeks)	Time of Appearance
Müllerian and mesonephric remnants in the male:		
Torsion of the appendix		Adolescence
Testis or appendix		
Epididymis		
Absence of wolffian derivatives in the male:		
Complete absence	4	Birth
Partial absence	After 4	Adulthood
Duplication of the ductus deferens	Late 4	None
Absence of the seminal vesicle	Before 12	Adulthood only if bilateral
Duplication of the seminal vesicle	12	Never
Anomalies of the prostate gland:		
Absence of the prostate	12	Adulthood

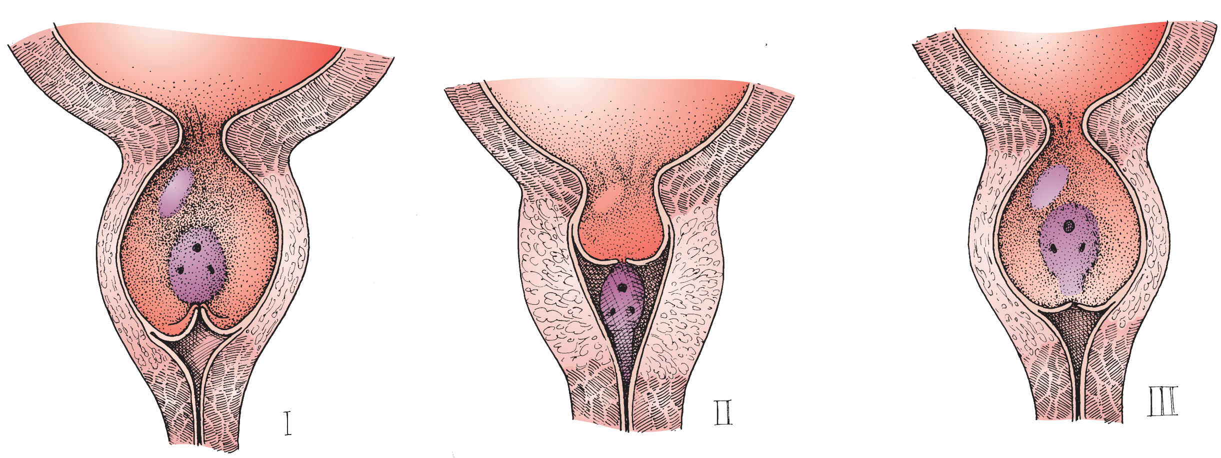


FIGURE 14-12.

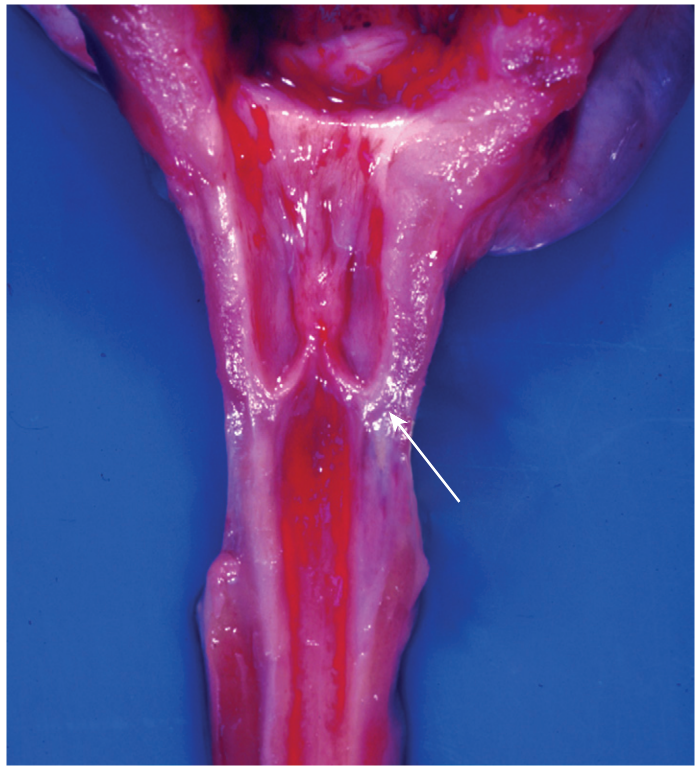


FIGURE 14-13. Posterior urethral valves. Posterior urethral valves are the most common cause of congenital urethral obstruction. Various types occur, the most common of which are a bivalvular form as shown in this photograph, and a diaphragm with a central pinhole, as shown in Fig. 14-15. Posterior urethral valves can cause marked or even life-threatening bladder outlet obstruction, with upper tract deterioration. *(From MacLennan GT, Resnick MI, Bostwick DG: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

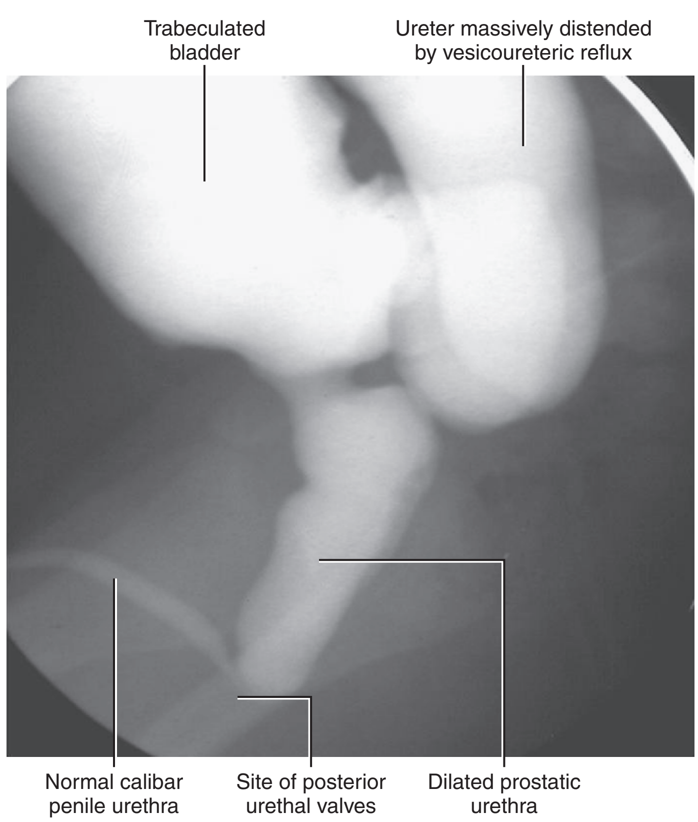


FIGURE 14-14. Posterior urethral valves. Voiding cystourethrogram showing thickening of the bladder wall, with trabeculation, and a ureter distended by massive vesicoureteric reflux. The prostatic urethra is markedly dilated; the urethra distal to the valves is of normal caliber. The changes are secondary to longstanding bladder outlet obstruction by the valves. *(Image courtesy of Raj Paspulati, M.D.)*

the anterolateral walls of the urethra, when fully developed, they may effectively block the passage of urine as they are filled by the flow of urine. The rare Type II valves run from the verumontanum toward the bladder. Both Types I and II may be the result of abnormal insertion and failure of cephalad regression of the wolffian ducts, leaving the collicular folds to assume an abnormal shape. The Type III valve is actually a diaphragm with a small opening in the center that lies either above or below the verumontanum (Figs. 14-15 and 14-16). It probably represents the residua of the urogenital membrane.

Enlarged Prostatic Utricle

The prostatic utricle forms as an ingrowth of specialized cells from the dorsal wall of the urogenital sinus as the caudal müllerian ducts regress. Its size usually diminishes in the ninth week, but in some cases of hypospadias and intersexuality a deep utricle is found; its size is generally inversely proportional to the degree of hypospadias. Cystic dilatation of the utricle may occur, and in some cases of this entity there is a direct connection between the cavity of the utricle and the urethra; absence of such a communication results in a prostatic utricular cyst.

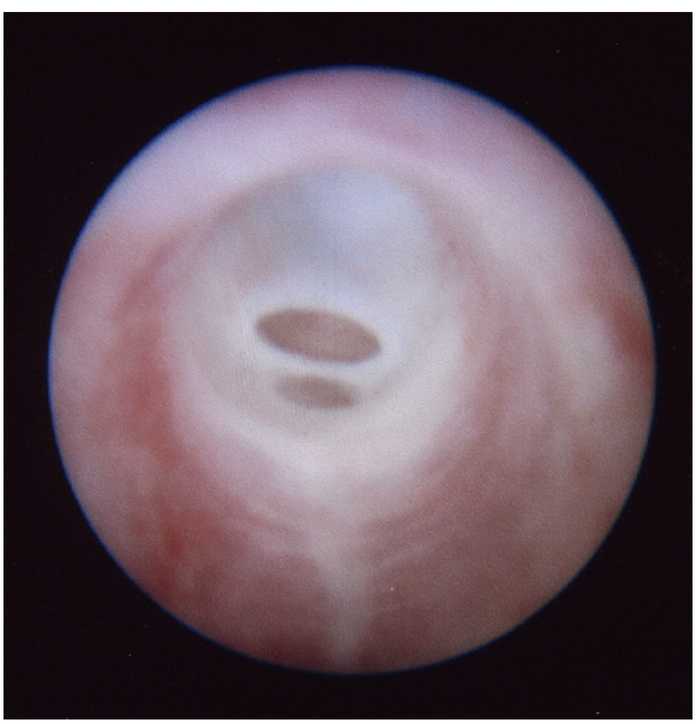


FIGURE 14-15. Posterior urethral valves, type III. Endoscopic view showing a diaphragm obstructing the prostatic urethra. The smaller inferiorly placed luminal structure was thought to be related to previous catheterization. *(Image courtesy of Lynn Woo, M.D.)*

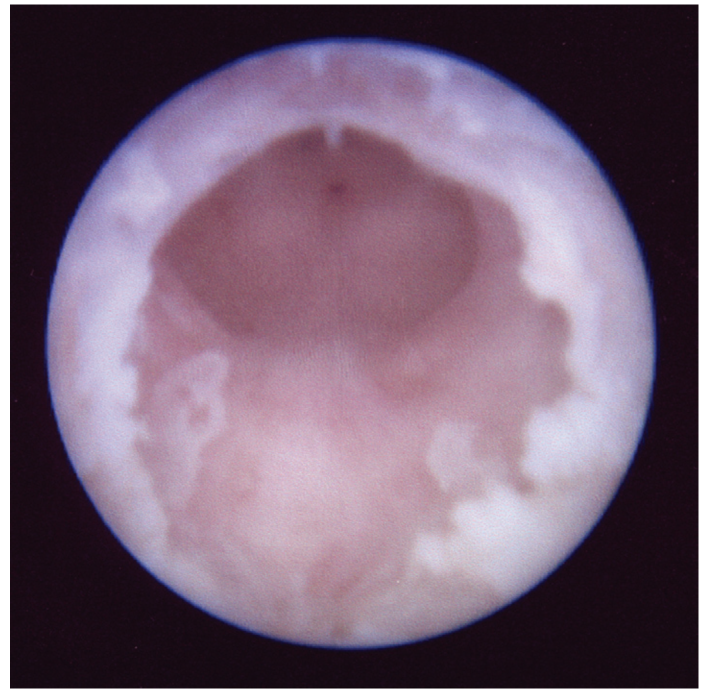


FIGURE 14-16. Posterior urethral valves, type III. The diaphragm shown in Fig. 14-15 has been endoscopically obliterated. *(Image courtesy of Lynn Woo, M.D.)*

PROSTATE, URINARY SPHINCTERS, AND SEMINAL VESICLES: STRUCTURE AND FUNCTION

Prostate

Prostatic Relationships

The **prostate** has a somewhat pyramidal shape, with a **base** against the bladder and an **apex** joining the membranous urethra. The posterior surface is flattened and slightly depressed in the midline, which is evidence of the bilobar character of the gland. This surface lies against the **rectal ampulla,** with the two lamellae of **Denonvilliers' fascia** intervening. More laterally, the prostate rests on the anterior projections of the **levator ani** that form the **pubococcygeus muscles,** which, with the **puborectalis** and **iliococcygeus,** overlie the **obturator internus** (Fig. 14-17).

Surgical exposure is not easy because the prostate lies deep in the pelvis behind the **pubic symphysis,** wedged between the levators.

Prostate and Adjacent Structures, Sagittal Section

The base of the **prostate** abuts the **bladder base** superiorly. Posteriorly, in company with the seminal vesicles and **ampullae of the vasa,** it rests on the surgically important **anterior lamella of Denonvilliers' fascia** (Figs. 14-18 and 14-19).

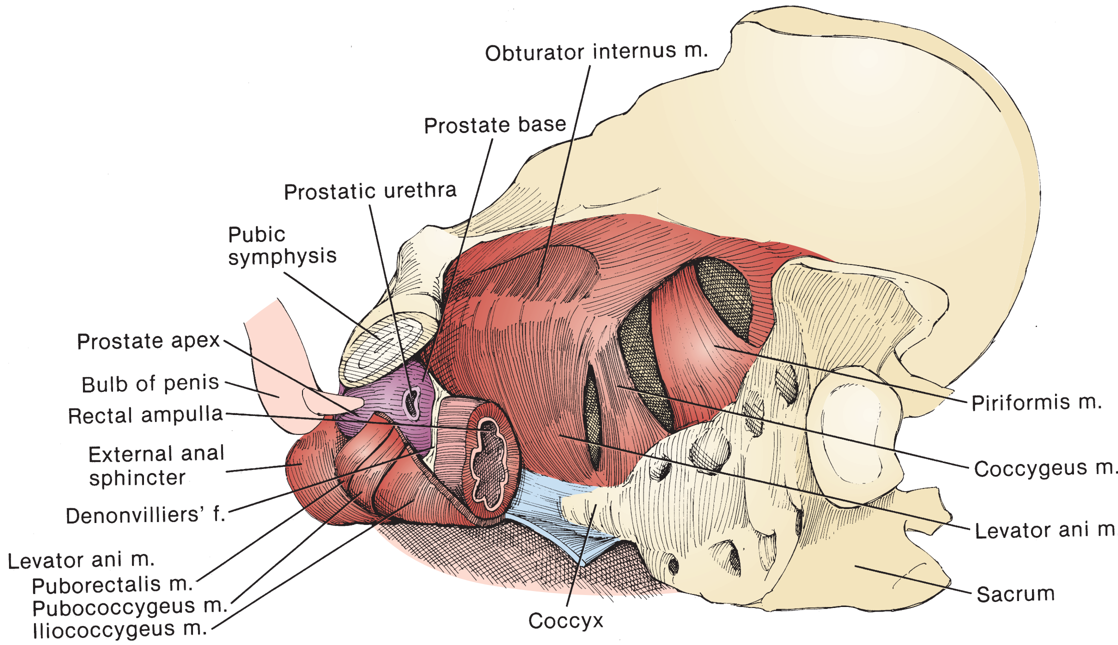


FIGURE 14-17.

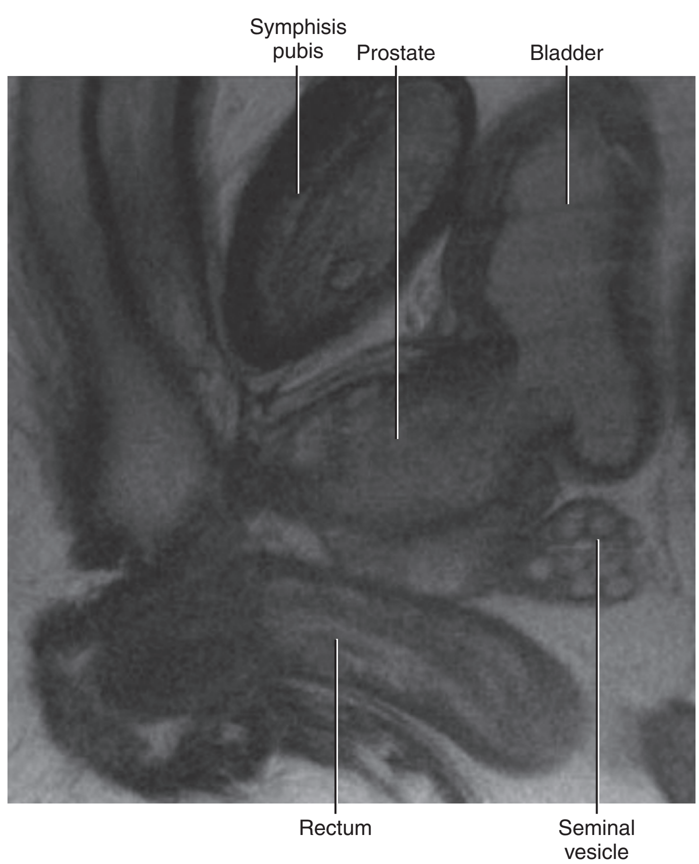


FIGURE 14-18. Magnetic resonance imaging (MRI) study showing a sagittal section of the prostate and adjacent structures. *(Image courtesy of Raj Paspulati, M.D.)*

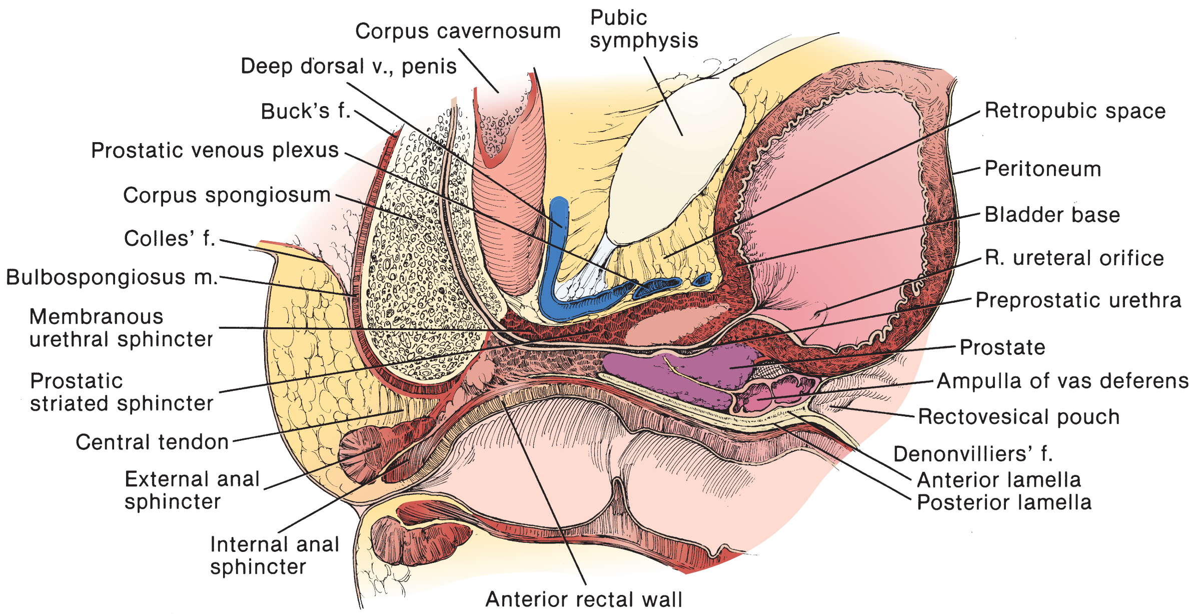


FIGURE 14-19.

Beneath this fusion-fascia is the **posterior lamella of Denonvilliers' fascia,** a layer of rectal fascia.

The deepest extension of the **rectovesical pouch** in the adult lies about 6 cm above the anus; it always ends above the tip of the coccyx, opposite the fourth or fifth part of the sacrum and well above the base of the prostate gland.

Denonvilliers' fascia covers the posterior wall of the prostate as a loose layer of connective tissue dispersed about areolar spaces filled with fat, vessels, and nerves. This description is contrary to that in most reports, which present a dense two-layered system. When exposed perineally, Denonvilliers' fascia appears as a white surface, but on microscopic inspection, it is seen to be composed mainly of areolar tissue. However, it is an identifiable surgical layer and does form a barrier between prostate and rectum, because rarely do neoplasms extend from one organ to the other.

The apical portion of the prostate and the first part of the membranous urethra are firmly attached by the rectourethralis muscle to the lower **anterior rectal wall.**

The **prostatic striated sphincter** partially covers the anterior surface of the prostate; it is continuous distally with the **membranous urethral sphincter.** The prostate is separated from the posterior surface of the pubis by the rather deep retropubic space (Retzius), containing the **prostatic venous plexus** (Santorini). The plexus is in continuity with the **deep dorsal vein** of the penis.

The **preprostatic urethra** and the prostatic urethra traverse the prostate in succession from the vesical neck to the apex. The urethra then passes through the membranous urethral sphincter and the two poorly characterized layers of the so-called urogenital diaphragm to join the bulbous urethra.

Structures Related to the Prostate, Coronal-sagittal View

The **prostatic venous plexus** is embedded in the **periprostatic fascia,** a layer derived from the intermediate stratum, shown here reflected from the anterior surface of the **prostate** (Fig. 14-20). The plexus lies over the **anterior fibromuscular stroma** and some of the lateral surface of the prostate. The prostate is separated laterally by a few millimeters of connective tissue sheath from the pelvic portion of the outer stratum of the retroperitoneal connective tissue, called the **endopelvic (lateral pelvic) fascia.** This fascia, overlying the **pubococcygeus,** is continuous with the **obturator fascia** covering the **obturator internus**. Superiorly, the base of the prostate joins the vesical neck. The **bulbourethral glands** (Cowper) lie above the **perineal membrane** (inferior layer of the urogenital diaphragm). The **pudendal vessels** and **nerve** pass through the **pudendal canal** (Alcock) inferolateral to the **prostatic striated sphincters.**

Puboprostatic Ligaments and Dorsal Vein Complex

Viewed from above, the anterior surface of the **prostate** is held behind the pubic symphysis by the paired **puboprostatic ligaments** (median puboprostatic ligaments) (Fig. 14-21). Each ligament is 4.5 mm wide and is attached to the perichondrium near the inferior border of the **symphysis pubis** lateral to the synchondrosis, and each deviates slightly medially before becoming continuous with the fascial sheath overlying the prostatovesical junction. In prostates enlarged by benign hyperplasia, the ligaments become thin and less well-defined, and are attached more distally to the prostatic sheath and capsule. Branches of the deep dorsal vein that drains the penis run beneath and between the puboprostatic ligaments, forming the **dorsal vein complex,** the distal part of the prostatic venous plexus. The deep dorsal vein also provides connections with the lateral part of the prostatic venous plexus, which, in turn, empties into the vesical plexus to terminate in the middle hemorrhoidal and inferior vesical veins.

The dorsal vein complex and the veins of the prostatic plexus cushion the prostate against the symphysis. The puboprostatic ligaments contain smooth muscle that provides a flexible attachment for the prostate so that it, with its

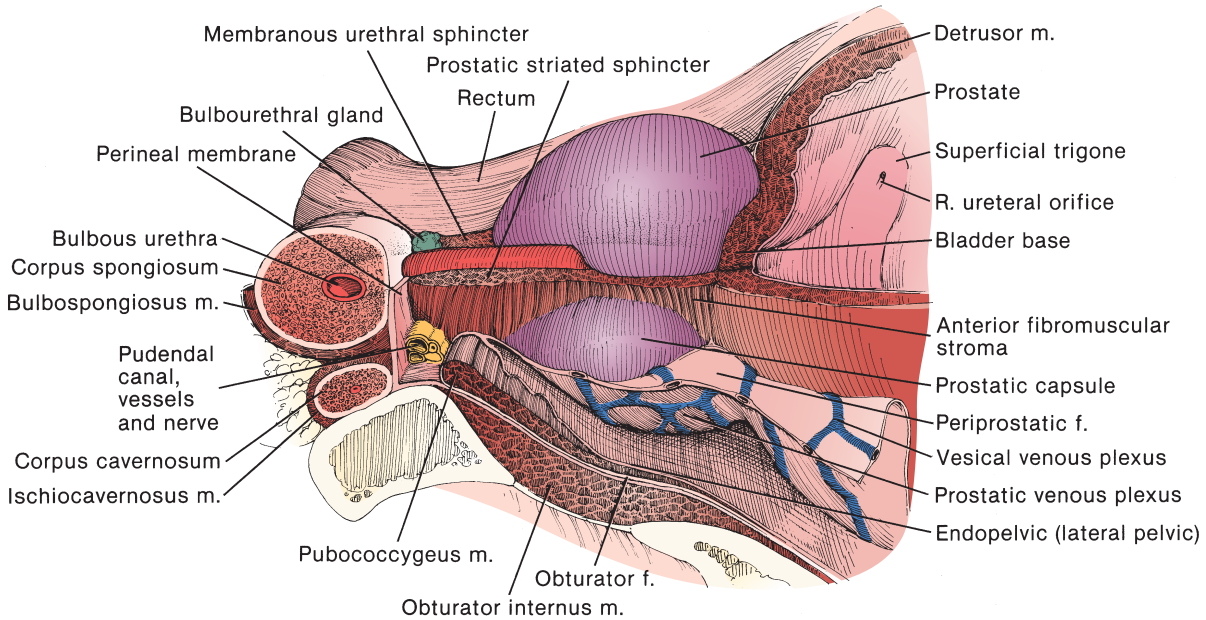


FIGURE 14-20.

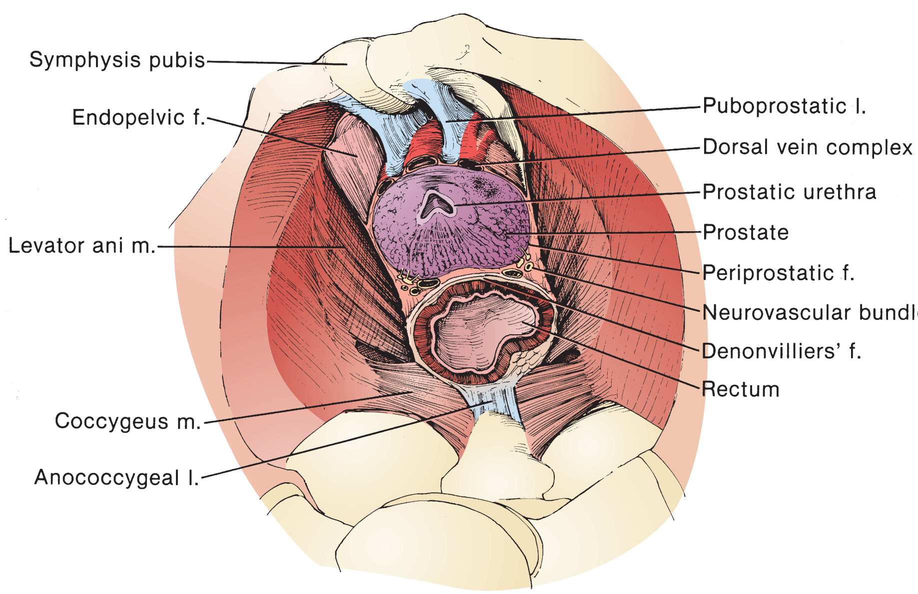


FIGURE 14-21.

sphincters, is free to descend during relaxation of the pelvic floor before micturition.

Posteriorly, the rectourethralis forms a connection between the rectum and the prostatic apex.

Prostatic Urethra

The urethra traversing the prostate is between 3 and 4 cm long, extending from the vesical neck to the **membranous urethra**. It is not straight because the urethra above the verumontanum is tilted anteriorly at a 45-degree angle from the vertical plane. The most proximal part of the urethra lies in the anterior portion of the prostate, its course running deeper into the prostatic substance as it descends to the verumontanum (see Fig. 13-57).

Although the prostate is thought of as a single organ, it is actually dual, perhaps homologous with the two distinct prostates found in nonhuman primates. Because of differences in development and function, the prostate has been divided into two regions (Fig. 14-22). One is the *preprostatic region,* involved with the transition zone of the prostate. This region extends from the vesical neck to the entrance of the ducts that drain this zone lying immediately above the openings of the ejaculatory ducts. The other is the *prostatic region* that extends to the apex at the membranous urethra. This region involves the majority of the prostatic tissue with its ducts emptying lateral to the ejaculatory ducts.

The **preprostatic urethra** (preprostatic segment of the prostatic urethra) is different in structure from the rest of the prostatic urethra because it is lined with transitional

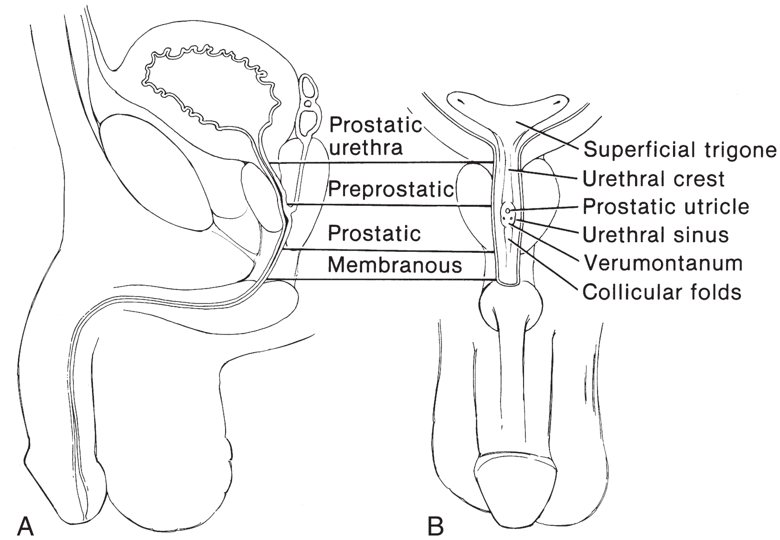


FIGURE 14-22. (A) Sagittal section. (B) Coronal view.

epithelium similar to that in the bladder, and it is also different in function because the periurethral and not the true prostatic glands drain into it. Developmentally, it is in continuity with the bladder musculature (see Fig. 14-3).

The **prostatic urethra** (prostatic segment of the prostatic urethra) runs through the distal half of the prostate, lying below the entrance of the ejaculatory ducts. It is about 2 cm long and is the portion surrounding and lying distal to the verumontanum. Most of the prostatic acini that produce secretions for sperm transport during ejaculation empty into it. It is lined by pseudostratified or stratified columnar epithelium that is continuous with the lining of the membranous urethra and of the penile urethra as well. Cells that secrete mucus are interspersed among the lining cells.

An elevated ridge along the dorsal wall of the prostatic urethra, the **urethral crest,** contains longitudinal smooth muscle fibers that are continuous proximally with the **superficial trigone** and distally with the smooth muscle of the ejaculatory ducts.

The ejaculatory ducts empty into the urethra at the **verumontanum** (colliculus seminalis), which is situated midway along the crest. The shallow **prostatic utricle** (vagina masculina) opens on its summit, usually proximal to the entry of the ducts. The **urethral** (prostatic) **sinuses** are recesses beside the urethral crest on the floor on either side of the utricle. The orifices of the prostatic ducts that drain the three prostatic zones are distributed along the sinuses. Those from the transition zone are found proximal to the ejaculatory duct openings, those from the peripheral zone are distal to them, and ducts from the central zone enter between.

A variable number of small *periurethral glands* develop in the submucosa superficial to the preprostatic sphincter. These are small structures consisting of many simple ducts with small acini that are not encased in muscle. Confined by the sphincteric muscular coat surrounding the layer in which they lie, they are limited in development. They run for short distances parallel to the urethra to drain into the preprostatic urethra. These glands have been estimated to represent less than 1% of the prostate mass. A form of stromal hyperplasia may occur about them.

Prostate in Situ, Transverse Section

The terms surgical capsule and anatomic capsule require definition. The surgical capsule is called "surgical" because it is the compressed prostate gland that remains after resection or enucleation of the fibroadenomyoma in the transition zone. The anatomic capsule is the outer margin of the prostate gland itself.

The stromal tissue of the prostate that is distributed over its surface serves as an **anatomic prostatic capsule**. The anatomic capsule is not a discrete structure like an apple skin, but forms the outer aglandular fibromuscular portion of the prostatic parenchyma, tissue that is continuous with the trabeculae between the acini. The glandular tissue may lie so near the surface in some areas that a distinct capsular covering may not be demonstrable histologically. The capsule consists of prostatic fibromuscular tissue 2 to 3 mm in thickness. Although it grossly appears to delimit the parenchyma from the surrounding connective tissue of the prostatic sheath, microscopically it is seen as an integral part of the prostate gland and cannot be separated from it. Moreover, the outer surface of this capsule has an indistinct margin, from which fibromuscular strands mingle with the periprostatic connective tissue of the prostatic sheath.

The anatomic capsule contains relatively few muscle fibers and so contributes little to prostatic contraction during ejaculation. Expulsion of prostatic secretions is accomplished by smooth muscle distributed around the acini and ducts throughout the prostate.

The anatomic capsule is encased in a loose **prostatic sheath** derived from the intermediate stratum of retroperitoneal connective tissue (Figs. 14-23 and 14-24). The sheath and the surrounding fibroareolar tissue form the **periprostatic fascia**, which extends from the anterior surface of the prostate, where it encloses the dorsal vein complex, to the posterolateral area, where it encases the neurovascular bundle before it joins the tongue of Denonvilliers' fascia,

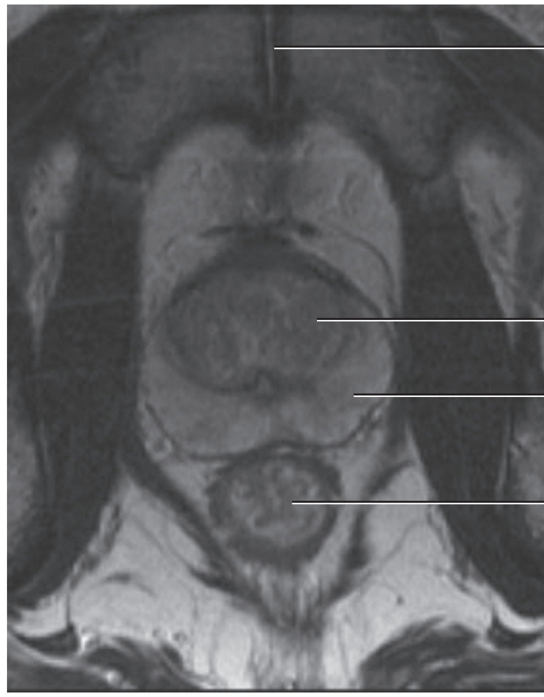


FIGURE 14-23. Magnetic resonance imaging (MRI) study showing an axial transverse section of the prostate and adjacent structures. *(Image courtesy of Raj Paspulati, M.D.)*

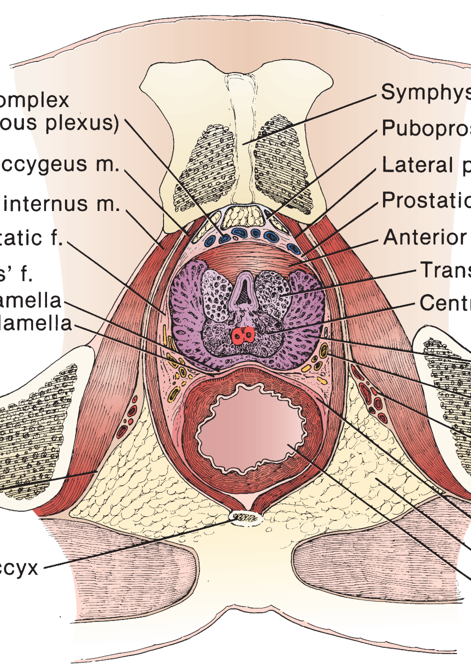


FIGURE 14-24.

which extends laterally behind the prostate. The thickness of these connective tissue layers separating the prostate from the surrounding structures varies from 1 to 3 mm. Thus, the prostate is very closely confined within the **pubococcygeus portion** of the levators ani.

The **dorsal vein complex** lies medially inside a bridge of the periprostatic fascia and collects from the dorsal vein in the midline. The **neurovascular bundle** that supplies part of the prostate and penis runs within the periprostatic fascia at the junction of the lateral and posterior portions of the endopelvic (lateral pelvic) fascia. It is separated from the prostate by a distance of 1.5 mm at the base and 3 mm at the apex. Although it is closely applied to the prostate because of its posterolateral position, the neurovascular bundle can be dissected from the gland by entering the periprostatic fascia laterally.

The prostate is also tethered at the base by lateral vascular pedicles that arise from the inferior vesical vessels and run on the lateral surface of the seminal vesicles, as well as by veins that enter it laterally just proximal to the apex and by the accompanying nerves.

The **internal pudendal vessels** lie outside the levator muscles, passing between the pubococcygeus and the obturator internus.

Configuration of Denonvilliers' Fascia

The **anterior lamella of Denonvilliers' fascia** arises by the distal-to-proximal fusion of the mesothelial layers of the inner stratum of the retroperitoneal connective tissue that had formed beneath the two layers of pelvic peritoneum in the retrovesical pouch. The resulting lamella is a single layer of fusion-fascia. The **posterior lamella of Denonvilliers' fascia** is the rectal fascia that overlies the anterior and lateral walls of the rectum. The anterior and posterior lamellae are closely applied to each other but can be separated during dissection in cadavers (Fig. 14-25A). The anterior lamella is also adherent to the posterior surface of the prostate, where the periprostatic fascia is deficient.

The subperitoneal connective tissue extension from the vesicorectal pouch that forms the **anterior lamella of Denonvilliers' fascia** is relatively narrow because it is confined laterally by the pelvic wall. Its lateral margins merge with the intermediate stratum of retroperitoneal fascia that forms the lateral periprostatic fascia as part of the prostatic sheath with its contained nerves and vessels and also merges with the **endopelvic** (lateral pelvic) **fascia** (Figs. 14-25B and C).

It should be noted that the term endopelvic fascia is used almost universally for that part of the transversalis fascia forming the deep fascia of the pelvis, but the term is also used interchangeably with the lateral pelvic fascia in the vicinity of the prostate. For clarity, endopelvic fascia may properly be limited to the collars of fascia from the outer stratum (transversalis fascia) that surround the prostate or vagina and the rectum, where they exit from the pelvis. These collars provide fixation for the inner and intermediate strata that accompany these structures. The lateral pelvic fascia, then, is that portion of the endopelvic fascia that provides lateral fixation for the prostate and, along with the periprostatic fascia, protects the neurovascular bundles.

The anterior lamella of Denonvilliers' fascia extends laterally for a limited distance beyond the margins of the posterior surface of the prostate. The relationship may be visualized by imagining four fingers of an opened hand pushed down inside the pelvic peritoneum in the rectovesical pouch so that the peritoneum is carried distally with the fingers as a flattened sac, whose inner surfaces will subsequently fuse to form the anterior lamella. Because the fused layers extend laterally for a limited distance, the anterior lamella of Denonvilliers' fascia resembles a shield, with its base on the posterior surface of the bladder at the bottom of the rectovesical pouch and its apex descending to reach the apex of the prostate.

The **posterior lamella of Denonvilliers' fascia**, the rectal fascia, is derived from the inner stratum of the retroperitoneal connective tissue, the layer that is associated with the gastrointestinal tract (see Fig. 10-11).

Such inner fascial coverings persist even when a section of intestine initially covered by peritoneum has lost its peritoneal coat. On the rectum, this inner layer persists as

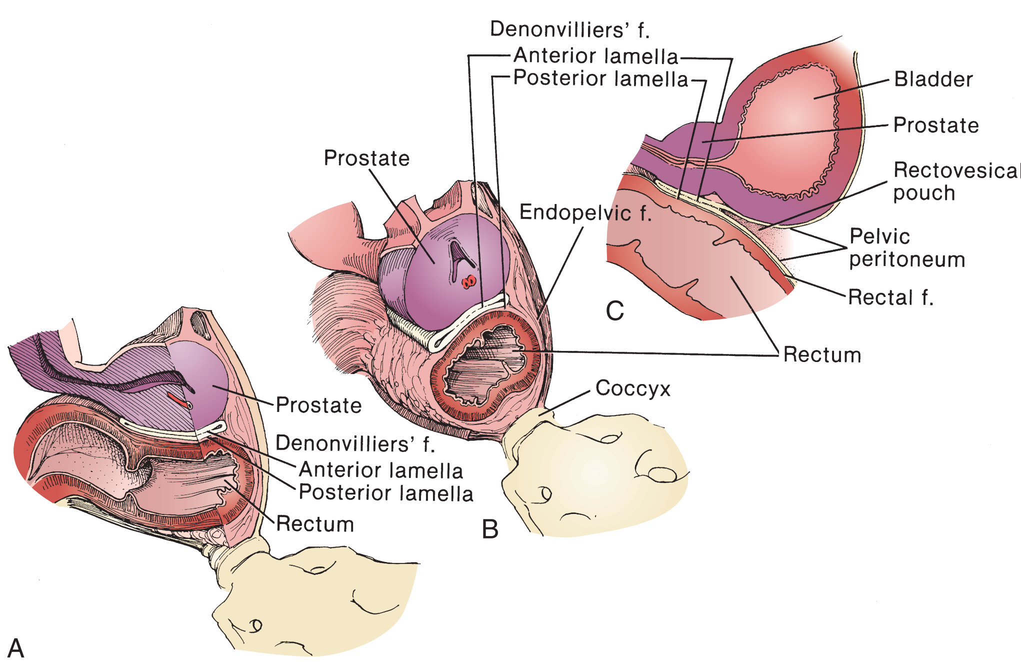


FIGURE 14-25. (A) Combined sagittal and transverse section. (B) Transverse section. (C) Sagittal section.

the rectal fascia. It covers the anterior and anterolateral surfaces of the rectum as it overlies the lamina propria of the rectal musculature.

From a retropubic approach, to elevate the prostate from the rectum, the combined fascial layer made up of periprostatic fascia and the lateral extensions of both lamellas of Denonvilliers' fascia must be divided through the lateral leaf of the periprostatic fascia that conceals the neurovascular bundle, so that both lamellas are taken with the specimen.

When the approach is perineal, separation of prostate from rectum is hindered by the rectourethralis muscle, which tents the rectum anteriorly just below the prostatic apex (see Fig. 11-10), encouraging inadvertent entry into the rectum. The posterior lamella of Denonvilliers' fascia is encountered first (Fig. 14-26). If it is entered through a vertical incision and mobilized laterally in company with the anterior lamella. the neurovascular bundle will be carried laterally and spared injury.

Retrovesical Pouch in the Female

In contrast to the formation of fusion-fascia in the male, in the female the inner stratum beneath the peritoneum lining the rectouterine pouch (pouch of Douglas) does not fuse; the overlying peritoneal surface remains in two

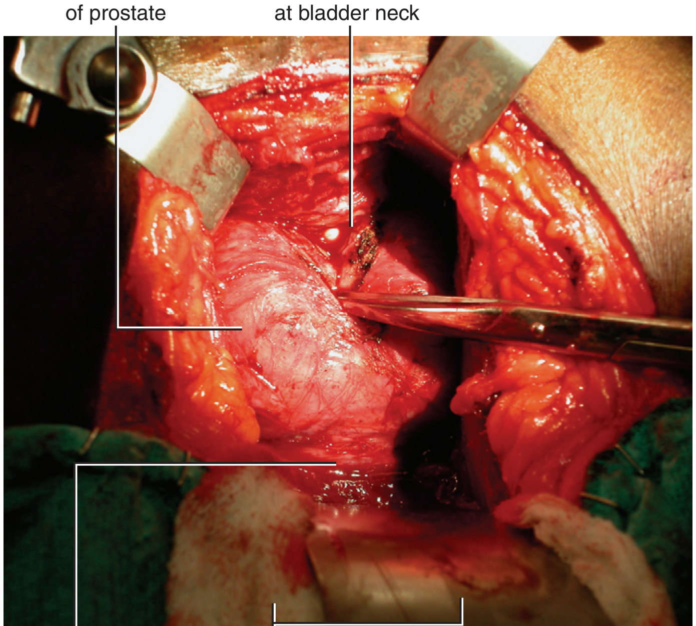


FIGURE 14-26. Radical perineal prostatectomy. Rectum, covered by a gauze and retractor in this image, has been separated from the prostate. An incision has been made at the apex of the prostate, partially exposing a catheter. *(Image courtesy of Nehemiah Hampel, M.D.)*

layers (see Fig. 10-10). The distal portion of the pouch is homologous with the fused layers forming the anterior lamella of Denonvilliers' fascia in the male.

Mid-prostate, Axial Section

Prostatic Sheath and Capsule

A loose sheath derived from the intermediate stratum of retroperitoneal fascia and the enclosed areolar tissue encases the prostate. In the surgical literature, this fascial layer has been called the prostatic sheath or **periprostatic fascia**. This fascia fuses anterolaterally with the endopelvic fascia (lateral pelvic fascia) and is continuous with the obturator fascia of the pelvic wall and with the transversalis fascia, all derived from the outer stratum of the retroperitoneal fascia.

Three parts of the periprostatic fascia are recognized (Fig. 14-27). The lateral leaf is the most important surgically. It extends from the anterolateral surface of the prostate to the posterolateral area, where it encases the neurovascular bundle. It fuses anterolaterally with the endopelvic fascia. The anterior leaf is a continuation of the lateral leaf and encloses the **dorsal vein complex** or prostatic venous plexus (Fig. 14-28). The posterior leaf extends from the neurovascular bundle around the posterolateral surface before joining the tongue of the anterior lamella of Denonvilliers' fascia behind the prostate, which is composed of somewhat similar loose fibroareolar tissue.

Posterolaterally and inferiorly, the periprostatic fascia fuses with **Denonvilliers' fascia**. The junction is indistinct because both fascias are composed of such loose areolar tissue, Denonvilliers' fascia being the more condensed.

Prostatic Zones

The prostate is customarily examined clinically as an individual organ and so is referred to by planes independent of those of the body. Sonographically, these are the sagittal plane and the transverse (axial) plane of the gland, corresponding to their relation to the probe in the rectum. Because the urethra turns anteriorly at the verumontanum, proximal sections are not strictly axial to it. The same is true for specimens examined pathologically after total prostatectomy. Emphasis will be placed here on these two surgically important planes to provide for visual reconstruction of the prostate, even though for computed tomography and magnetic resonance imaging, the classic body planes must be used.

In Fig. 14-27, the three zones of the prostate are shown in an axial section proximal to the level of the verumontanum and the entrance of the ejaculatory ducts. The transition zone lies on either side of the urethra; the central zone and peripheral zone lie principally dorsal to it. The anatomic relationships between the urethra and the prostatic zones are further illustrated in Figs. 14-29 and 14-30. The zones can be appreciated to a limited extent on gross

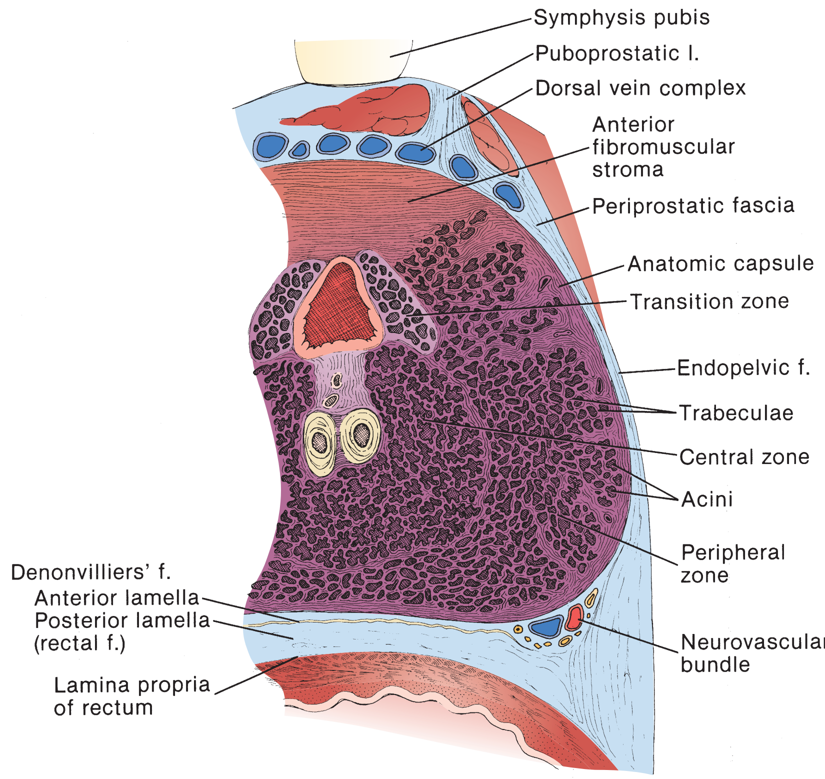


FIGURE 14-27.

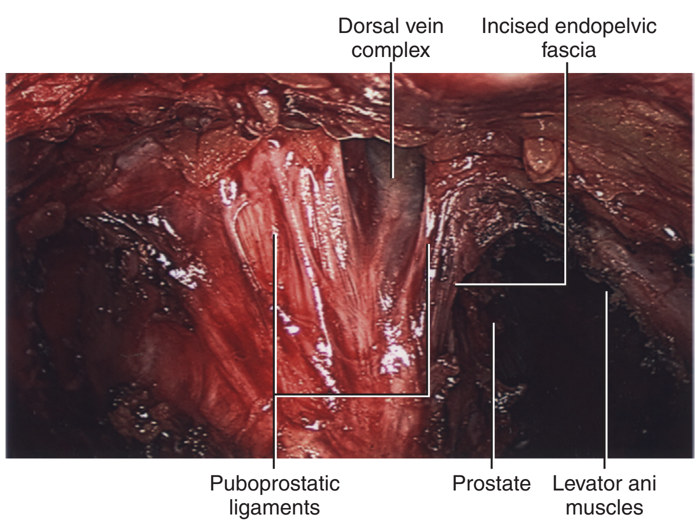


FIGURE 14-28. Laparoscopic radical prostatectomy. The dorsal vein complex and the puboprostatic ligaments have not yet been divided. *(Image courtesy of Lee Ponsky, M.D.)*

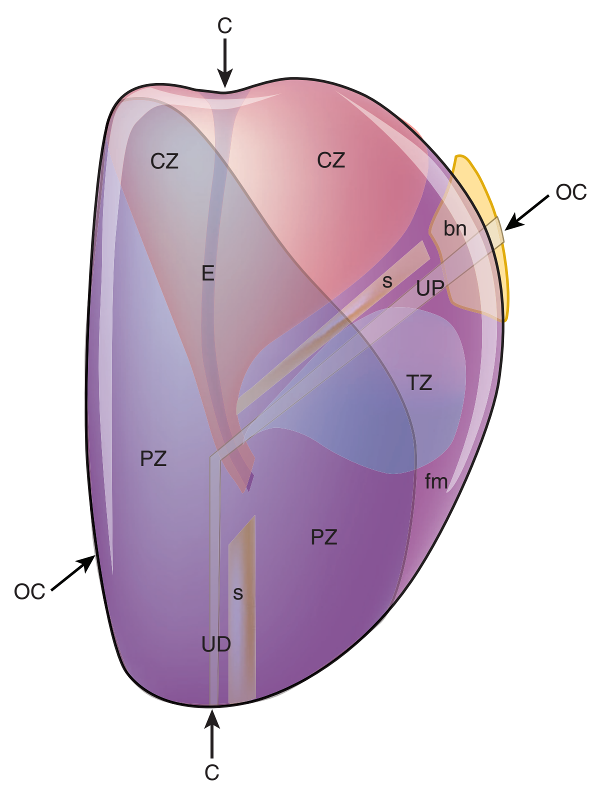


FIGURE 14-29. Prostate, sagittal section, showing distal prostatic urethra (UD), proximal prostatic urethra (UP), ejaculatory ducts (E), bladder neck (bn), anterior fibromuscular stroma (fm), preprostatic sphincter (s) and distal striated sphincter (s), and their relationships to three-dimensional representations of the central zone (CZ), peripheral zone (PZ), and transition zone (TZ). Arrows delineate the coronal (C) and oblique coronal (OC) planes. *(From McNeal JE, Bostwick DG: Anatomy of the prostate: implications for disease. In: Bostwick DG, ed. Pathology of the Prostate. New York, Churchill Livingstone, 1990, 2.)*

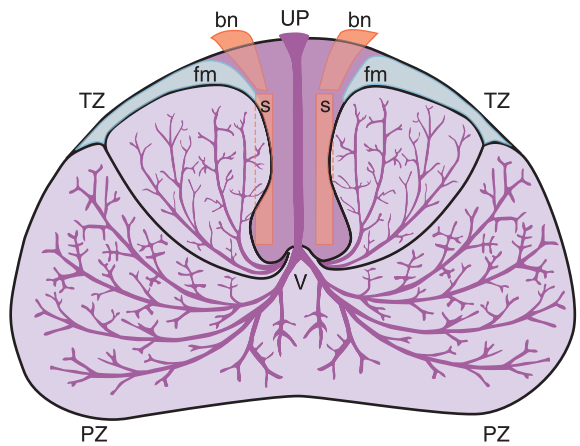


FIGURE 14-30. Diagram of an oblique coronal section of prostate illustrating locations of the peripheral zone (PZ) and transition zone (TZ) with respect to the proximal urethral segment and periurethral glands (UP), verumontanum (V), preprostatic sphincter (s), bladder neck (bn), and periurethral region, as well as the branching pattern of the prostatic ducts. *(From McNeal JE, Bostwick DG: Anatomy of the prostate: implications for disease. In: Bostwick DG, ed. Pathology of the Prostate. New York, Churchill Livingstone, 1990; 2.)*

inspection (Fig. 14-31) and are more readily discerned in a whole-mounted histologic preparation (Fig. 14-32).

Transition Zone. Peripheral to the small superficial periurethral glands (not illustrated here) are larger and more complex glands that have a similar origin but develop differently (see Fig. 14-4). These glands will form the **transition zone**, a distinct subset of the periurethral glands (Fig. 14-33). Their ducts at first run parallel to the preprostatic urethra and then turn medially when they reach the distal end of the preprostatic sphincter. There, proximal to the verumontanum, they empty into the urethral sinuses on either side of the urethral crest. As mentioned previously, the transition zone may be considered preprostatic rather than prostatic and, as a development of the periureteral glands, is actually not part of the prostate gland.

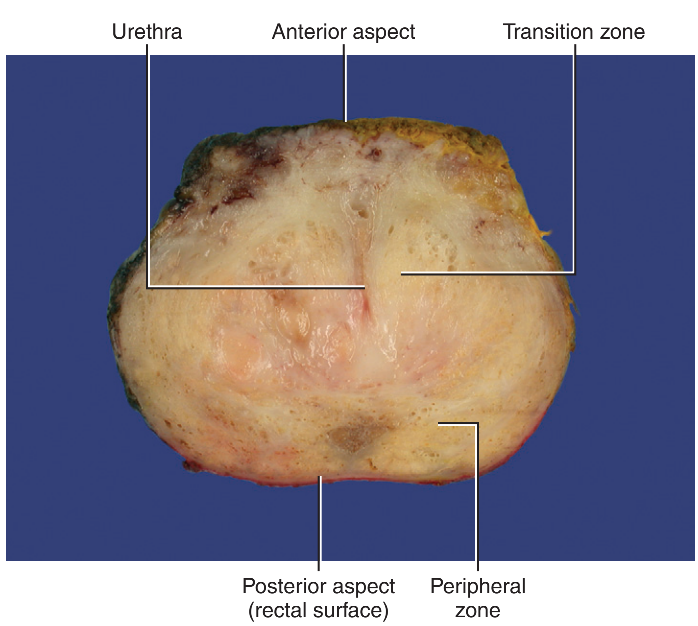


FIGURE 14-31. Prostate, gross whole-mount section from a radical prostatectomy specimen. The peripheral zone and transition zone are discernible, although the boundary between them is indistinct. The transition zone exhibits a modest degree of benign prostatic hyperplasia. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. Springer-Verlag London Limited, 2011, with permission.)*

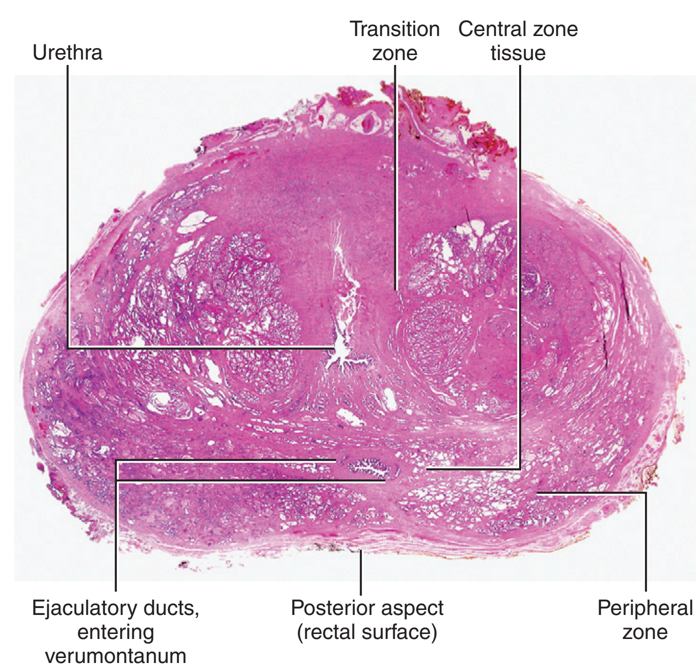


FIGURE 14-32. Prostate, histologic whole-mount section from a radical prostatectomy specimen. The boundaries between the peripheral zone and transition zone are more clearly discernible. A small amount of central zone tissue is present in this section, surrounding the ejaculatory ducts. The transition zone exhibits a modest degree of benign prostatic hyperplasia. *(From MacLennan GT, Cheng L: Atlas of Genitourinary Pathology. Springer-Verlag London Limited, 2011, with permission.)*

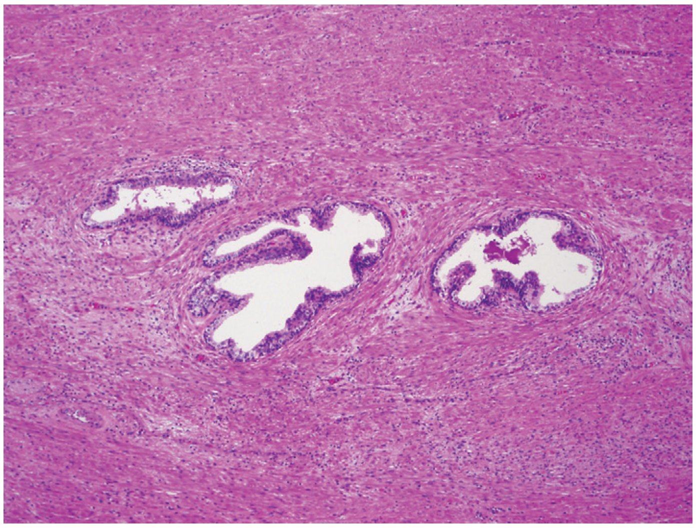


FIGURE 14-33. Transition zone of prostate. Simple acini are arrayed in compact stroma. The epithelium is cuboidal or low columnar.

Even though the transition zone occupies only 5 to 10% of overall prostatic volume, it is an important component because benign prostatic hyperplasia develops from its glands.

Central and Peripheral Zones. The prostate proper is composed of paired regions, the **central zones** and the **peripheral zones** each characterized by subtle histologic differences (Figs. 14-34 and 14-35).

These regions were called zones by McNeal to avoid the confusion that had arisen over the terminology of lobes. That two such zones would develop might be predicted by the embryologic origin of the prostate from two sets of buds on each side of the future prostatic urethra (see Fig. 14-4). Those emptying just above the verumontanum drain the central zone, and those below drain the peripheral zone. In addition, the central zone is traversed by the ejaculatory ducts.

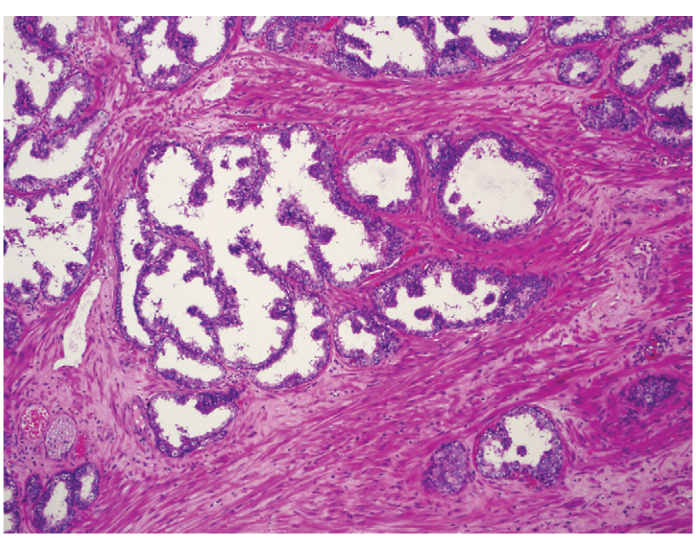


FIGURE 14-34. Central zone of prostate. Acini are large and are arrayed in stroma that is largely compact smooth muscle. The glandular elements exhibit complex intraluminal ridges and epithelial arches.

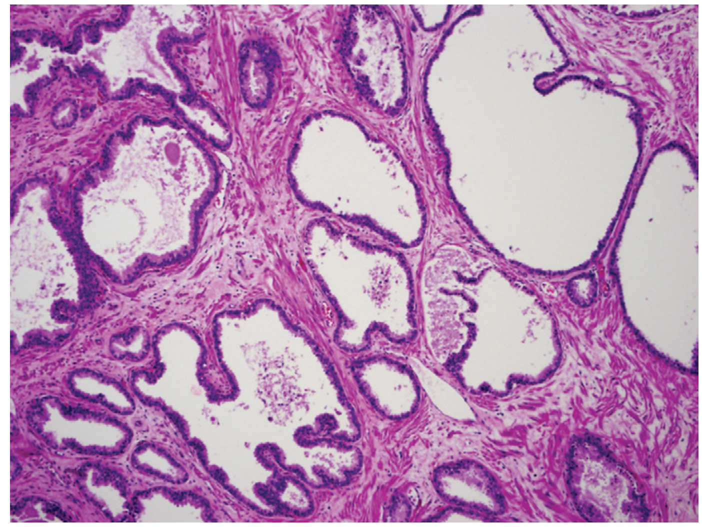


FIGURE 14-35. Peripheral zone of prostate. Simple acini are arrayed in loosely packed smooth muscle and collagen stroma. The epithelium is cuboidal or columnar.

Anterior Fibromuscular Stroma. The **anterior fibromuscular stroma** occupies the anterior and anterolateral part of the prostate and is usually free of glandular tissue. It forms the anterior part of the **anatomic capsule**, becoming thinner laterally as it joins the glandular part of the prostate.

Denonvilliers' fascia can be seen as a rather loose connective tissue layer containing some smooth muscle fibers but with little evidence of its bipartite origin. Beneath it is the loose **periprostatic fascia** of the prostatic sheath that overlies the **anatomic capsule** of the prostate, which, in turn, is continuous with the **trabeculae** between the prostatic **acini**.

At operation, Denonvilliers' fascia is usually found as a definite fascial layer over the posterior surface of the prostate. It may be attenuated, becoming especially areolar laterally and superiorly over the seminal vesicles. Because the combined layers of Denonvilliers' fascia appear glistening white when exposed perineally and herald safe passage past the rectum, the fascia was called the pearly gates by Hugh Young. It is probable in many cases, however, that the glistening white layer exposed perineally is the capsule of the prostate rather than the anterior lamella. In any case, for complete removal of the prostate, it is necessary that the fascia be removed with the specimen down to the lamina propria of the rectum because there is no surgically separable plane between the two layers of Denonvilliers' fascia. A plane can be entered beneath Denonvilliers' fascia that is between it and the prostatic capsule, but such a dissection enters the periprostatic space with its container vessels and lymphatics.

Axial Sonographic Image

Prostate tissue is echogenic because sound waves reflect from the multiple interfaces between acini and stroma (Fig. 14-36). The strength of the echoes varies with the size

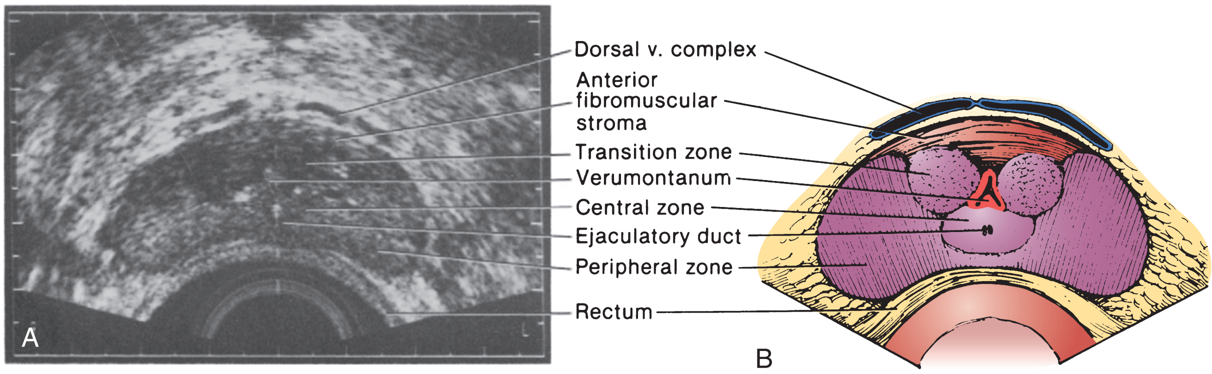


FIGURE 14-36.

of the acini and their proportion relative to the stroma so that the image differs among the several prostatic zones, as well as between the normal prostate and carcinomatous tissue. The **central zone** and, to a slightly lesser extent, the **peripheral zone** have a reticular structure and a uniform distribution of acini among the stromal elements. For these zones, the resulting echoes are of midrange amplitude (isoechoic). The **transition zone**, with its coarser fibromuscular stroma, larger septated acini, and more complex epithelium, may be distinguished from the central and peripheral zones by its hyperechogenicity. In contrast, the **anterior fibromuscular stroma**, and also prostatic cancer, are hypoechoic because of their more homogeneous structure. Although the prostatic capsule is not seen as a well-defined layer relative to the acini, the prostate itself is delimited ultrasonically by the high echogenicity of the fat in the periprostatic tissue.

Sagittal Sonographic Image of Central and Peripheral Zones

The **prostatic urethra** may be seen as an anechoic cone at the **bladder neck** (Fig. 14-37). At the apex, the hypoechoic muscle of the external sphincter appears posterior to the even more hypoechoic **dorsal vein**. The **ejaculatory duct** is visualized as a hypoechoic stripe traversing the prostate through the **central zone**. The hypoechoic **seminal vesicle** lies behind the muscle of the vesical neck, surrounded by hyperechoic layers of the perivesicular fat. The **peripheral zone** lies nearest the probe.

The *central zone* makes up about a quarter of the prostatic parenchyma. It surrounds the ejaculatory ducts and is shaped like a pyramid, with the base toward the bladder and the apex extending to the verumontanum. Its ducts open into the floor of the prostatic urethra lateral to the verumontanum. The ampulla of the vas and the duct of the seminal vesicle, entering the prostate posteriorly near the base, join together as the ejaculatory duct to terminate in the verumontanum.

The *peripheral zone* occupies three-quarters of the glandular prostate. It surrounds the posterolateral surfaces of the distal portion of the central zone that lie above the verumontanum. Below that point, the zone extends anteriorly around both sides of the urethra as far as the anterior fibromuscular layer. Its ducts, approximately 20 in number, empty into the urethra in two rows below the verumontanum.

Sagittal Cuts Through the Prostate

The axial vignette to the right shows the sites of the three cuts from which the drawings of sonographic sagittal images were made.

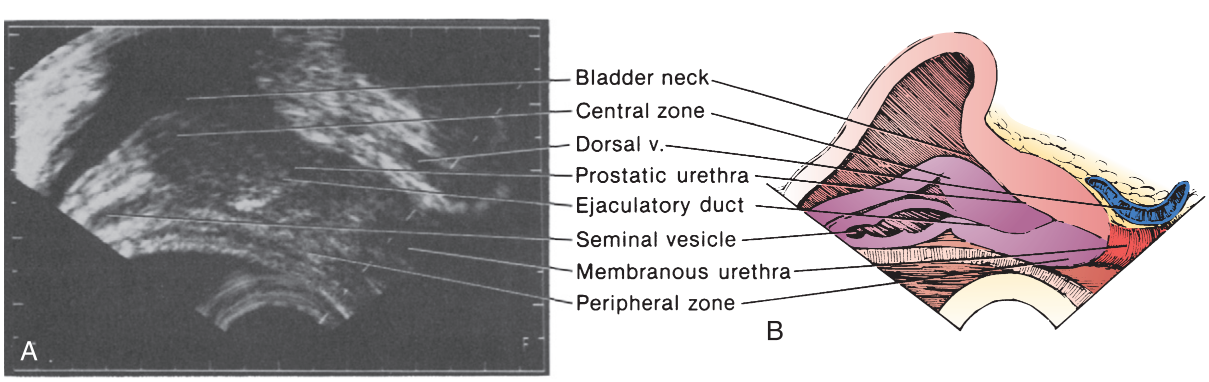


FIGURE 14-37.

A near-centerline section (Fig. 14-38A) shows the **anterior fibromuscular stroma** and the **peripheral zone**. The **ejaculatory duct** passes from the **ampulla of the vas** to the **verumontanum**.

A section 1 cm from the centerline (Fig. 14-38B) shows the relation among the **transition, central**, and **peripheral zones**.

A section 2 cm from the midline (Fig. 14-38C) passes through the bulging **peripheral zone** and a small amount of **anterior fibromuscular stroma**.

Zonal Relationships

The prostate is depicted by combining sagittal and axial sections to permit visualization of the distribution of the zones in two planes simultaneously. A transparent diagram shows the planes of the axial cuts, **X** cut proximally and **Y** cut distally.

A midline sagittal section (left) is combined with an axial section (right) cut proximally in plane **X** (Fig. 14-39A). The **anterior fibromuscular stroma** is prominent and the **preprostatic sphincter** is seen to surround the urethra. The **transition zone** beneath the sphincter continues anteriorly, lying medial to the **central zone**. Only a small portion of the **peripheral zone** extends this far proximally. The **neurovascular bundle** is shown in its posterolateral path.

A combined section slightly proximal to the verumontanum is exposed by an axial cut distally at **Y** (Fig. 14-39B). Here, the **transition zone** is smaller and the **central zone** is more prominent. The proximal part of the **peripheral zone** surrounds the central zone anteriorly and posteriorly. The **ejaculatory duct** enters the **verumontanum** between the central and peripheral zones. The **dorsal vein complex** is seen anteriorly and the **neurovascular bundle** posterolaterally.

Arterial Supply of the Prostate, Seminal Vesicles, and Vasa

The **prostatovesical artery** provides the major portion of the blood supply to the prostate. Most commonly, it arises from the **gluteopudendal trunk** of the **internal iliac artery**, although it may come from the **superior vesical artery**, from a common trunk in company with the vesiculodeferential artery, or even from the **internal pudendal** or **obturator arteries**. It runs medially on the surface of the levator ani to the bladder base. There, the prostatovesical artery divides into the **inferior vesical artery** to supply the base of the bladder and lower part of the ureter and the **prostatic artery** to supply the prostate. The prostatic artery, in turn, divides at the base of the prostate to form a major **posterolateral branch** supplying most of the gland and an **anterior branch** supplying only the anterolateral portion (Fig. 14-40).

The vas deferens and seminal vesicle receive blood from the superior vesical artery through the **vesiculodeferential artery**. Distally, this vessel makes a connection with the testicular artery to provide additional blood to the testis and epididymis.

The prostate, seminal vesicle, and vas are also supplied by small accessory arteries from the middle hemorrhoidal

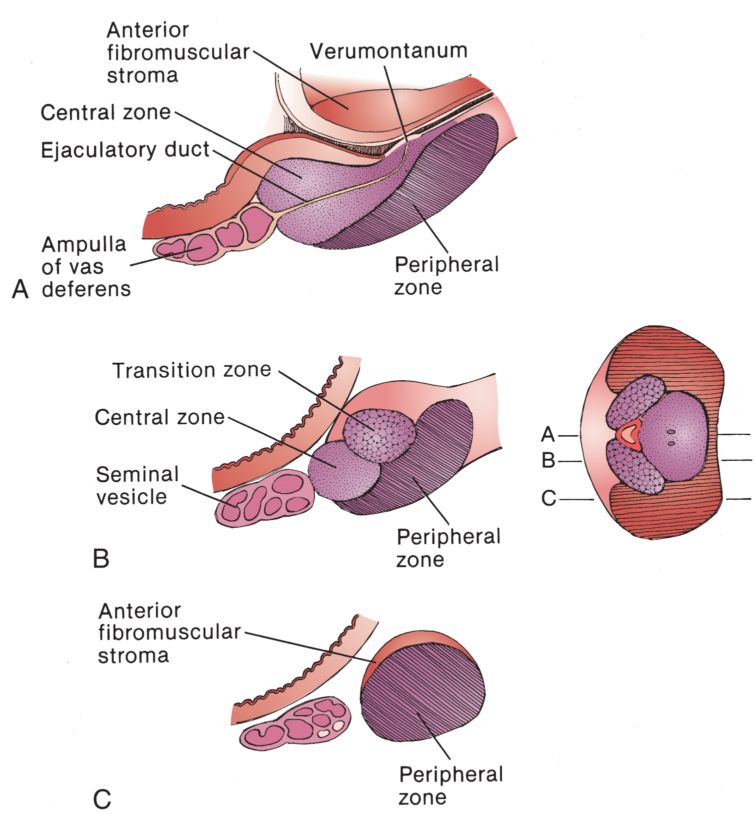


FIGURE 14-38.

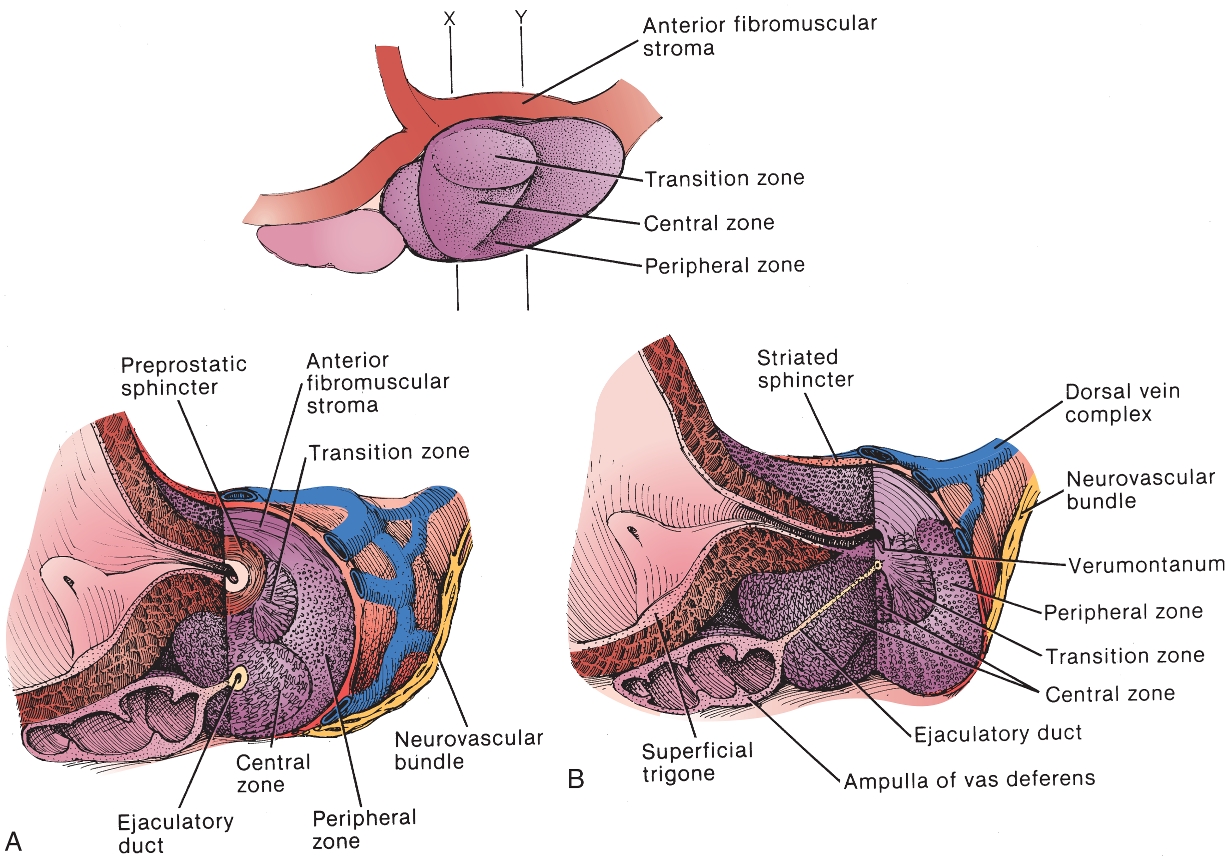


FIGURE 14-39.

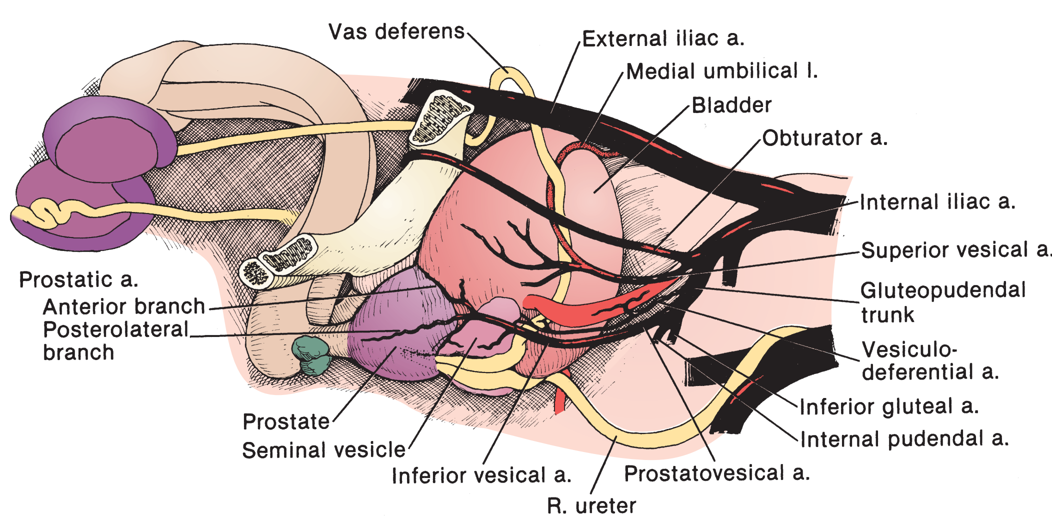


FIGURE 14-40.

artery, and the inferior portion of the prostate receives some blood from the (inconstant) prostatovesical branch of the internal pudendal artery. The arteries may communicate with vessels from the opposite side.

The superior rectal artery, a branch of the inferior mesenteric artery, often provides blood to the upper lateral portion of the prostate. It turns at the lower end of the rectum to join the middle rectal artery, which may also supply the prostate.

Distribution of Blood to the Prostate, Posterior View

From the **gluteopudendal trunk**, the **prostatovesical artery** branches to form the **inferior vesical artery** and the **prostatic artery** (Fig. 14-41). The prostatic artery, in turn, provides branches that first course tortuously in the loose periprostatic tissue of the prostatic sheath and then penetrate the condensed fibromuscular tissue of the prostatic capsule. Their subsequent course depends on the level at which they

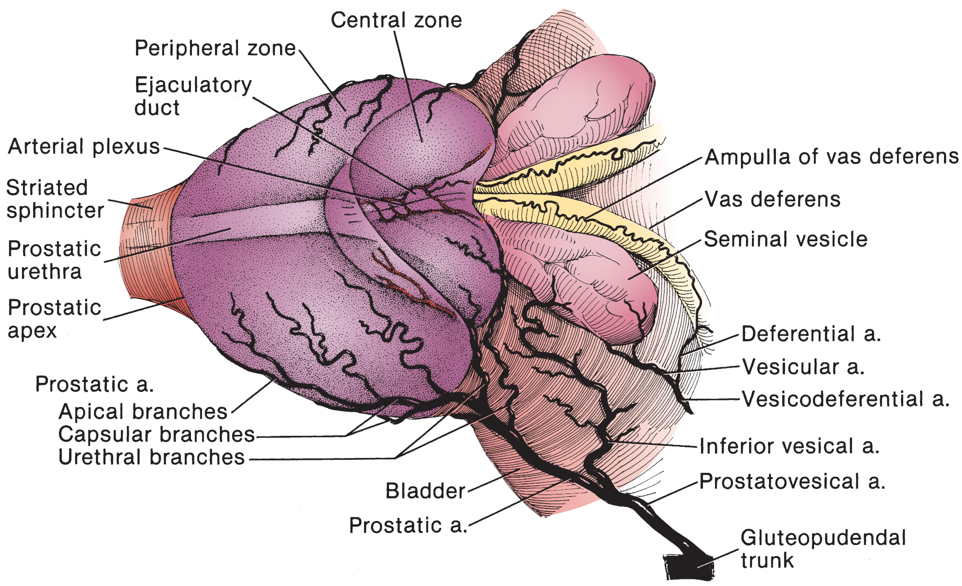


FIGURE 14-41.

enter. The penetrating or **urethral branches** are the proximal branches that enter through the prostatic capsule posterolaterally, just distal to the bladder neck. These run concentrically, parallel to the urethra in the preprostatic sphincter to supply the transition zone. With the development of benign prostatic hyperplasia, they become very large. The **capsular branches**, as posterolateral offshoots, enter the prostate more distally and peripherally than the urethral group. They supply the **central** and **peripheral zones** that normally make up more than two-thirds of the prostate mass. These vessels send branches obliquely and more or less radially into the substance of the gland. One usually distinct branch from the prostatic artery passes between the central and peripheral zones, giving evidence of their embryologic individuality. Small branches supply the apex. In addition, a small portion of the prostate is supplied by a well-vascularized **arterial plexus** around the ejaculatory ducts and prostatic utricle that is formed in conjunction with the artery from the other side. This plexus supplies the ducts, colliculus, and part of the prostatic urethra.

Bleeding during transurethral resection can be reduced by early control of the urethral group of vessels that supply the hypertrophic tissue of the transition zone. They enter at the 4 and 8 o'clock positions near the vesical neck. After they have been transected and controlled, the remainder of the hypertrophic tissue may be removed with minimal loss of blood.

Postoperative bleeding results from incompletely resected tissue in the fossa that has been rendered partially ischemic by division of the urethral branches from the base that form their main supply. Because the tissue of the transition zone obtains only a little blood from the vessels going to the central and peripheral zones, bleeding occurs later as the tissue sloughs.

Branches from the **inferior vesical artery** also supply the **seminal vesicle**. The **vesiculodeferential artery** supplies the **ampulla of the vas** and the **seminal vesicle** by way of the **vesicular artery**. A branch, the **deferential artery**, goes to the **vas deferens** and **ejaculatory duct**.

Venous Drainage

Venules within the parenchyma join veins entering the **prostatic venous plexus** (dorsal vein complex) (Fig. 14-42). This plexus of thin-walled veins that are free of valves lies between the puboprostatic ligaments behind the lower part of the **symphysis pubis** within the **periprostatic fascia**. The **deep dorsal vein** of the penis that provides the principal input to the plexus exits from beneath the **symphysis** centrally between the **dorsal penile arteries** to divide into right and left branches before joining the plexus, which also receives some blood from the anterior surface of the prostate and the adjacent bladder wall. The prostatic venous plexus drains partially through the **vesical venous plexus** into the internal pudendal veins, but most of the blood passes more directly into the **inferior vesical veins** and the internal iliac veins. The deep veins of the entire pelvis intercommunicate with the prostatic plexus; material injected into the deep dorsal vein reaches virtually all of the pelvic veins and their branches, including the vertebral veins (see Figs 2-18 and 2-19).

The **prostatovesical artery** and its branches, the **pudendal vessels** and **nerve** and the **dorsal penile artery**, are viewed from the lateral aspect. The **pelvic** autonomic **plexus** supplies the **superior** and **inferior prostatic nerves** and the **cavernous nerve** to the penis through the **neurovascular bundle**.

Lymphatic Drainage from the Prostate

Lymph capillaries arise from fine lymphatic vessels that run through the fibrous stroma intervening among the muscle cells, between the muscle bundles and with the acini, although such vessels are not found in the subepithelium. The capillaries anastomose with their neighbors to form a perilobular network of irregular channels that increase in size as they approach and pass through the capsule (Fig. 14-43). They form a periprostatic lymphatic network within the prostatic sheath. Vessels from the prostatic urethra and ejaculatory ducts contribute to the network. Three lymphatic routes, marked **1, 2,** and **3** in the figure, may be taken by invasive cells.

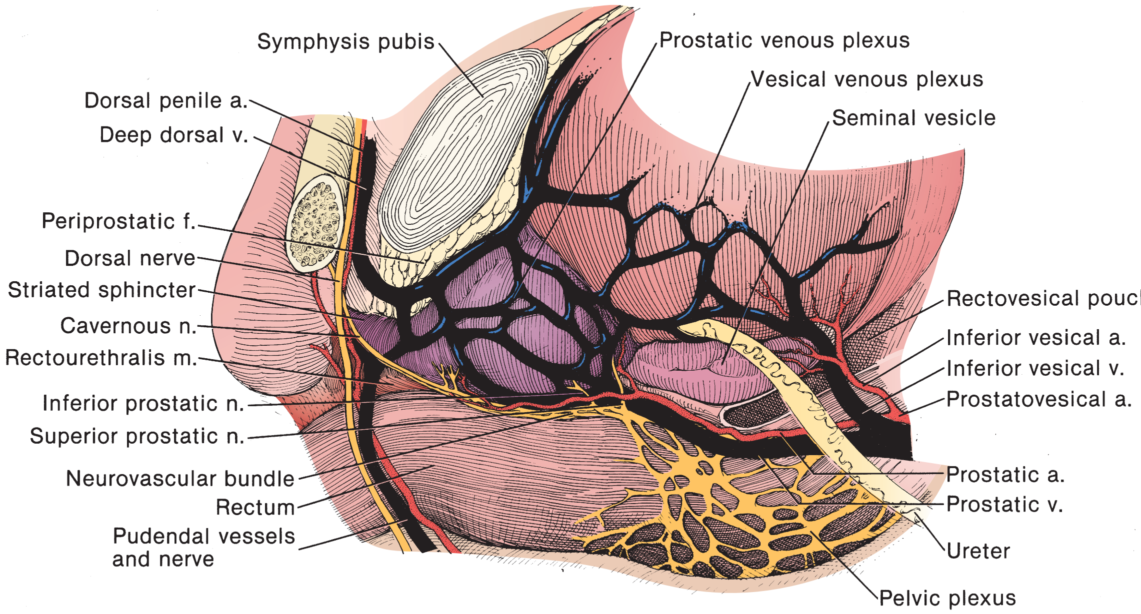


FIGURE 14-42.

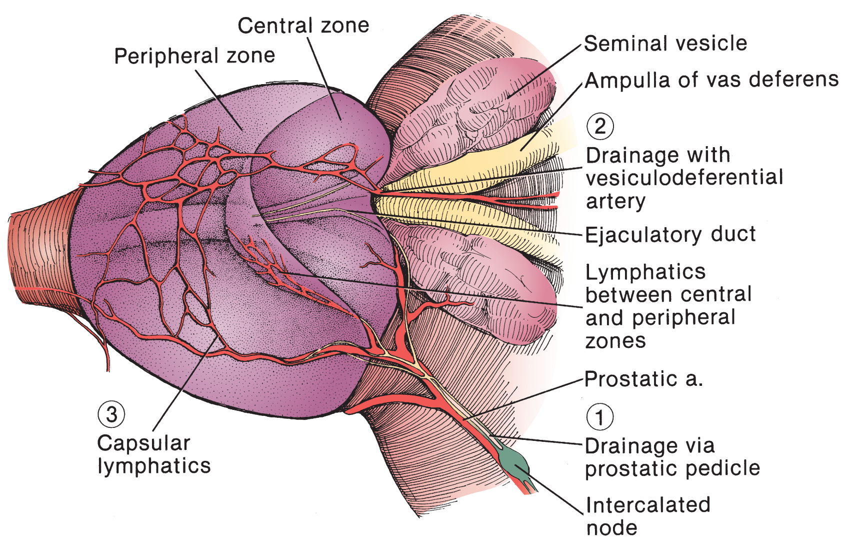


FIGURE 14-43.

Route 1

Major lymphatic vessels leave the prostate with the branches of the prostatic artery in the prostatic pedicle. These vessels are important for metastatic spread of prostatic carcinoma. Lymphatics also accompany penetrating urethral branches of the prostatic artery as they pass between the central and peripheral zones. Here, they may acquire tumor cells that have reached the boundary between these zones.

Route 2

The lymphatics accompanying the **vesiculodeferential artery** pass through the **central zone** with the **ejaculatory duct**. The ejaculatory duct and vessels enter the substance of the prostate within a tongue of tissue that is an extension of the prostatic sheath superficial to the prostatic capsule.

Because on microscopic section and by ultrasonography the prostatic capsule appears to be invaginated by these vessels, this continuation of the sheath about the ducts may be viewed as its intrusion into the prostatic substance. This encroachment creates one more capsular boundary, one that lies deep within the prostate. The sleeve of sheath within the prostate can be broached by a neoplasm growing at the boundary of the zone before the tumor has reached the peripheral capsule. Thus cells from a tumor growing in the central zone may be picked up by the lymphatics accompanying the vasal arteries and spread outside the prostate even though the pathologic findings indicate that the tumor is still confined, because on section, none are found outside the peripheral prostatic capsule.

Route 3

Collecting vessels arise from the **capsular lymphatic network** beneath the sheath of periprostatic tissue and exit with the main arteries of the prostate. These are superiorly, the vesiculodeferential artery; laterally and posteriorly, the prostatic and middle hemorrhoidal artery; and anteriorly, the prostatovesical branch of the internal pudendal artery.

Regional Lymph Nodes

Considerable variation in the drainage routes to the pelvic nodes has been found in studies by injection techniques and among individual subjects. The most generally applicable description is that the prostate drains into the pelvic lymphatic chains by one of the three sets of collectors from the prostate that are depicted in Fig. 14-43.

The first drainage route is along the prostatic artery in the vascular pedicle, with one trunk from the posteroinferior portion of the prostate that runs with the middle hemorrhoidal artery to the **obturator and internal iliac nodes** (Fig. 14-44). The second is through six or eight small collectors arising from the base and the proximal posterior portion of the prostate. These vessels combine to form three or four trunks that run along the medial border of the seminal vesicle and over the ureter to drain into the **external iliac nodes**. The third collector drains lymph into the **sacral nodes** from the capsular lymphatics on the posterior part of the prostate in the region covered by Denonvilliers' fascia. An additional but less constant route is through a single trunk from the anterior portion of the prostate that runs with the internal pudendal artery to an **internal iliac node** near the origin of the artery. There are, however, many intercalated nodes along these four main channels, and frequent anastomoses are found between the prostatic lymphatics and those of the bladder, seminal vesicles, vasa deferentia, and the rectum.

From surgical experience, the primary sites for drainage of the prostate are considered to be the obturator and external iliac nodes. The **obturator lymph nodes**, related to the internal iliac nodes, lie adjacent to and within the obturator canal. The external iliac lymph nodes, 8 to 10 in number, are divided into lateral, medial, and anterior groups. The medial group is the most important; the lateral group is not consistently present. In addition to draining the posterior surface of the prostate, these nodes receive lymph from the lower abdominal wall, the penis and membranous urethra, and the bladder base. The internal iliac nodes drain not only the anterior surface of the prostate but also the perineum and the organs within the pelvis. Less important as initial sites for prostatic drainage are the presacral and presciatic nodes; moreover, they will be missed during node sampling or dissection.

Innervation of the Prostate

The prostate receives nerves from both the sympathetic and parasympathetic systems, as well as neural input via other transmitters.

Schematic View (Fig. 14-45A)

Sympathetic Nerves

The prostate is supplied from spinal levels **L1** and **L2** by preganglionic nerves (solid line) that run through the **superior hypogastric plexus**. The prostatic musculature is innervated by postganglionic fibers (dashed line) from the sympathetic trunks whose cell bodies lie in the **inferior hypogastric (pelvic) plexus** lateral to the bladder and prostate. These nerves contain noradrenalin and neuropeptide Y.

Parasympathetic Nerves

The function of the prostatic epithelium is controlled by nerves from the preganglionic fibers of the **pelvic (splanchnic) nerves** from spinal nerves **S2, S3**, and **S4** via the **inferior hypogastric (pelvic) plexus** (dotted line). They synapse in the **prostatic plexus** before they distribute in the prostate as postganglionic fibers (short solid line). These are cholinergic nerves, but some peptidergic nerves containing the neuropeptide VIP are distributed to the prostate and the external sphincter.

Somatic Nerves

Somatic nerves (double line) from sacral nerves **S2, S3,** and **S4** supply the external sphincters via the **pudendal nerve**.

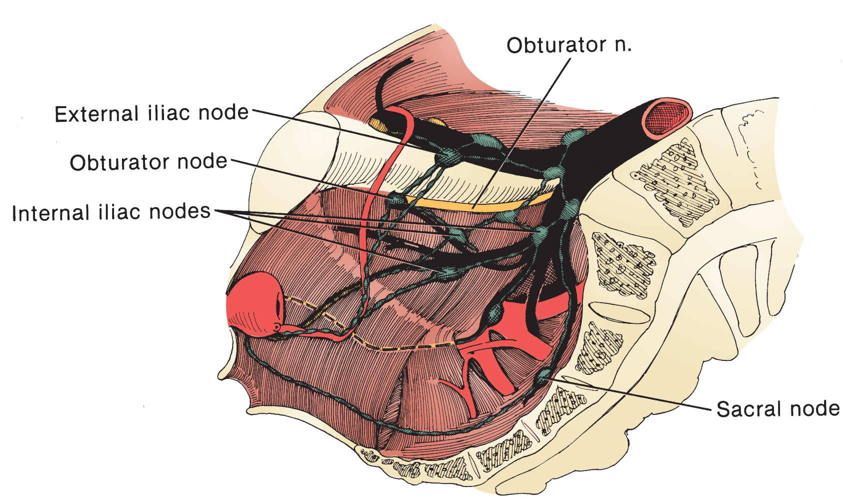


FIGURE 14-44.

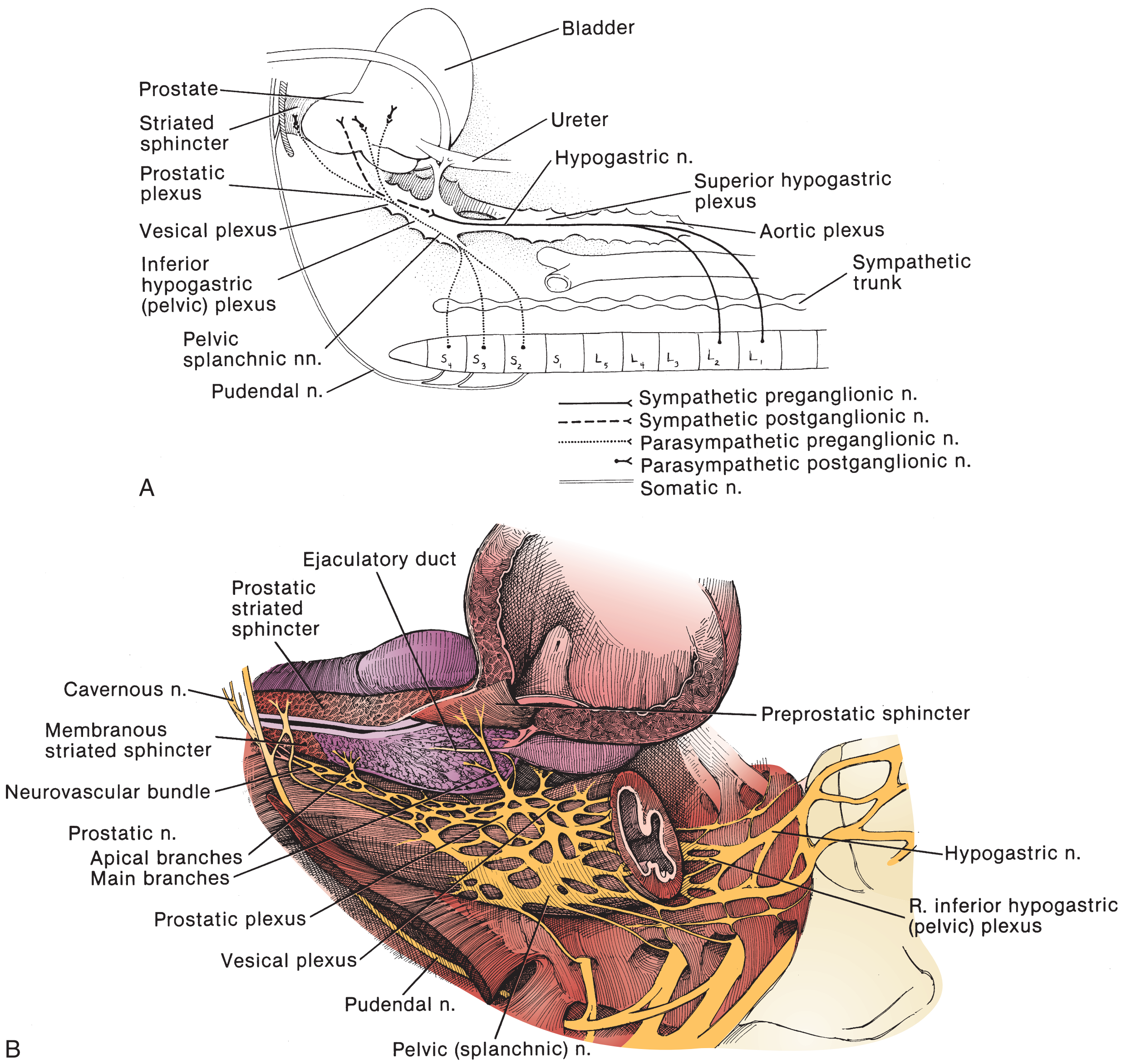


FIGURE 14-45.

Distribution of Nerves (Fig. 14-45B)

The **hypogastric nerve** supplies the **inferior hypogastric (pelvic) plexus,** from which sympathetic nerves are distributed to the **vesical** and **prostatic plexuses**. The parasympathetic nerves from sacral nerves S2, S3, and S4 join the **pelvic (splanchnic) nerve** and proceed to the prostatic plexus. The ganglia of the sympathetic nerves and their postganglionic fibers pass from the prostatic plexus into the loose fascial prostatic sheath.

At the entrance of each **ejaculatory duct** into the substance of the prostate, the nerves are more numerous and are concentrated into ganglionic clusters that are connected with each other to form the **prostatic plexus** that lies between the seminal vesicles and the prostate. Each ganglion contains approximately 20 nerve cell bodies. Such ganglia are also distributed in the connective tissue between the prostate and bladder as the **vesical plexus** and contribute fibers to the detrusor.

A large nerve trunk that will form part of the **neurovascular bundle** and end as the **cavernous nerve** emerges posterolaterally where the lateral pelvic fascia and the anterior layer of Denonvilliers' fascia meet.

The fibers of the **prostatic nerve** are distributed principally over the posterior surface of the superior half of the prostate (**main branches**), except for a few fibers that enter the prostate accompanying the **ejaculatory ducts.** The fibers pass along and through the sheath to enter the capsule in close association with the prostatic capsular vessels. Near the apex, a somewhat separate small group of **apical branches** travels only a short distance in the sheath before penetrating the prostatic capsule.

During sexual activity, parasympathetic stimulation increases secretion from the prostatic acini. Sympathetic stimuli close the preprostatic sphincter and contract the prostatic smooth muscle to force the secretion into the prostatic urethra (emission). The somatic nerves to the striated musculature of the bulbospongiosus produce contractions to force the semen out through the urethra (ejaculation).

Neurovascular Bundle

The course of the cavernous nerve in relation to the prostate is of importance in total prostatectomy (Fig. 14-46). After the fibers pass through the prostatic plexus, the cavernous nerve is carried in the so-called neurovascular bundle in company with the nerves and vessels that supply the prostate (see Fig. 16-41). The arteries in the bundle are branches of the prostatovesicular artery that not only go to the posteroinferior margin of the seminal vesicle and the prostatovesical junction but continue as the urethral and capsular branches running in the loose periprostatic tissue before they penetrate the prostatic capsule. The capsular arterial branches, running posterolaterally to supply the majority of the prostate mass, are accompanied by most of the nervous tissue and thus constitute the neurovascular bundle (Fig. 14-47). The bundle runs posterolateral to the prostate in the intermediate stratum of retroperitoneal connective tissue but medial to the outer stratum, the endopelvic fascia.

During retropubic prostatectomy, the endopelvic fascia (lateral pelvic fascia) must be divided where it is adherent to the intermediate fascia to allow lateral displacement of the neurovascular bundle. In contrast, during perineal prostatectomy, after Denonvilliers' fascia has been split posteriorly, the plane of dissection continues within the endopelvic fascia, also displacing the neurovascular bundle laterally.

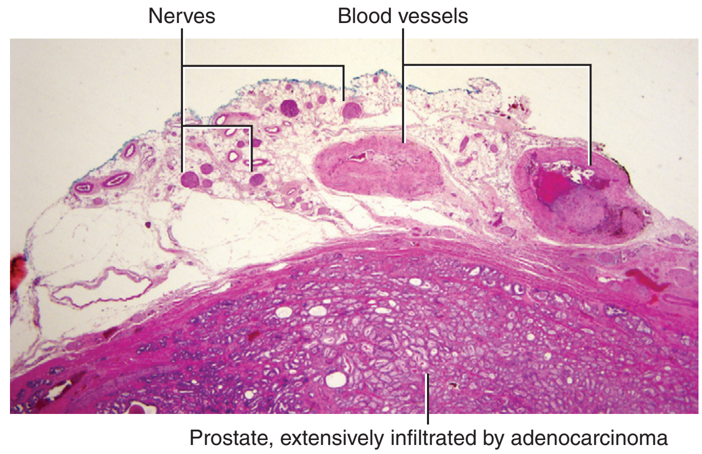


FIGURE 14-47. Neurovascular bundle. In this section from a whole-mounted radical prostatectomy, cancer occupies most of the prostatic tissue, but is confined within the capsule. The neurovascular bundle on this side has been included in the specimen.

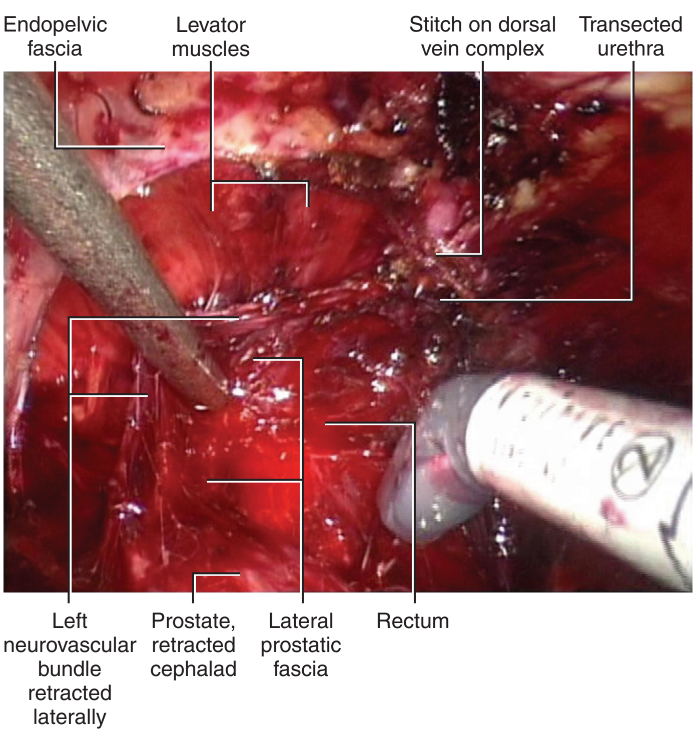


FIGURE 14-46. Neurovascular bundle. The image is from a robotic radical prostatectomy procedure. The dorsal vein complex and the urethra have both been divided. The left lateral prostatic fascia, containing the left neurovascular bundle, has been separated from the body of the prostate and retracted laterally. The prostate has been separated from the rectum, drawing it in a cephalad direction, exposing the rectum beneath. *(Image courtesy of Rabii Madi, M.D.)*

Intraprostatic Nerve Distribution

The **prostatic nerve** is part of the **neurovascular bundle.** It divides into **main branches** to the body of the prostate and into **apical branches,** with a separate branch accompanying the **ejaculatory duct** into the prostate (Fig. 14-48). After the nerves enter the prostate, they run under the condensed smooth muscle and connective tissue of the prostatic parenchyma that constitutes the **prostatic capsule** and then divide into small **acinar branches** to be distributed along the fibromuscular trabeculae among the acini. In addition to nerve fibers, parasympathetic ganglia are present in the prostatic substance, enabling synapses with the postganglionic secretory nerves (Fig. 14-49). No difference has been found in nerve distribution between the peripheral and the transition zones.

Perineural Space

Within the peripheral nerves, the **nerve fibers** are surrounded by a fine connective tissue network, the **endoneurium,** that, in turn, is continuous with septa derived from the **perineurium,** which binds groups of nerve fibers into **fascicles** (Fig. 14-50). The **perineural space** is distributed among the septa, where it surrounds the nerve fibers. The perineurium itself consists of layers of flat cells spread concentrically around the nerve fascicles, with more layers on large fascicles. These cells have cytoplasmic extensions that interdigitate with adjacent cells that act as barriers. However, the cellular layer of the perineurium is reduced to a single layer and ends as an open cuff near the end of each nerve fiber.

Indirect invasion by malignant prostatic cells may occur through the termination of the nerve fibers, but direct

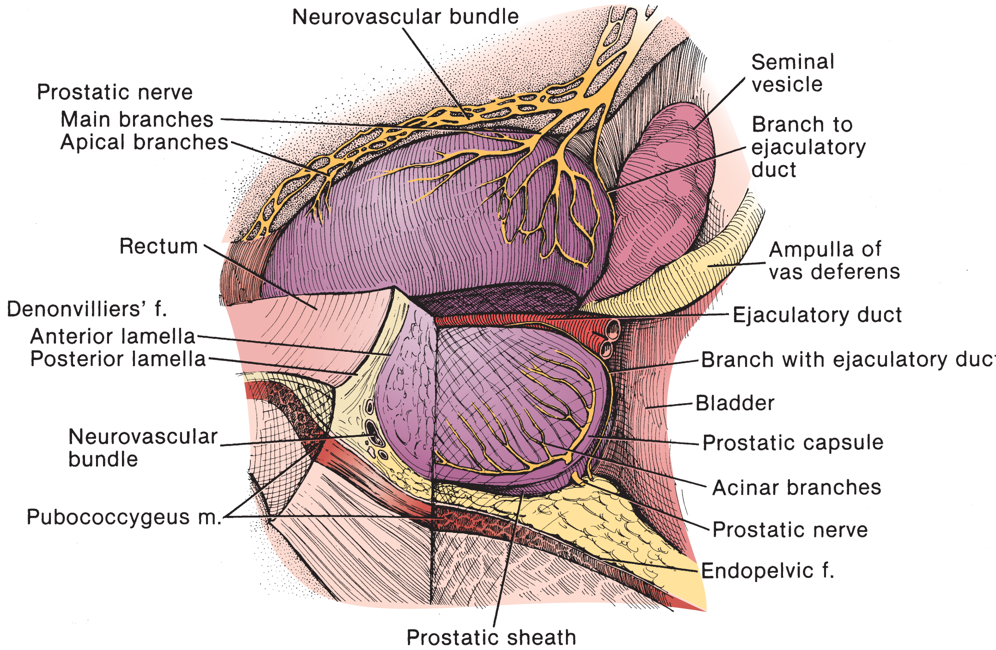


FIGURE 14-48.

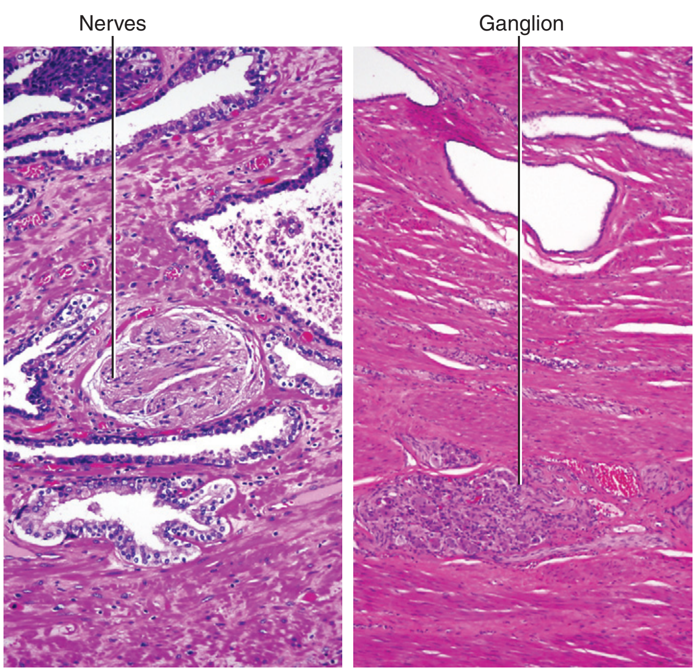


FIGURE 14-49. Intraprostatic nerves (left side of image) form a network of nerve twigs that are often seen in close proximity to acini or ducts. Capsular ganglia (right side of image) are identifiable in about half of radical prostatectomy specimens; they are commonly found at the posterolateral aspect of the base of the prostate.

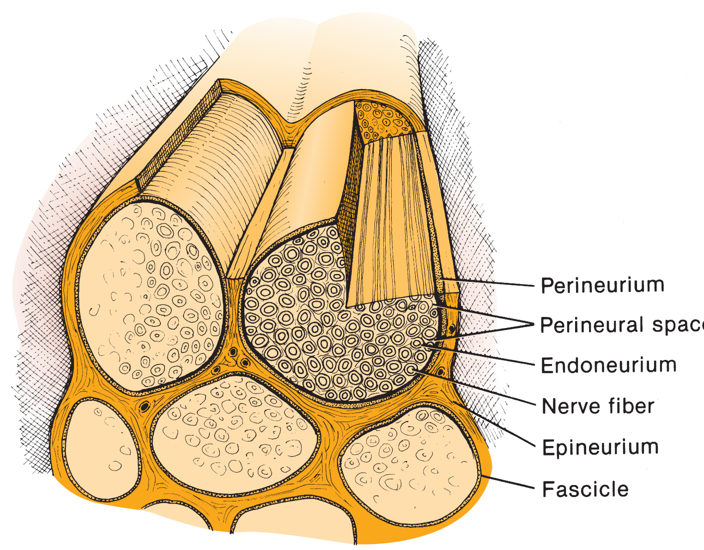


FIGURE 14-50.

invasion through the perineurium into the perineural space is common despite the structural barrier, apparently aided by its low resistance to invasion by tumor cells. The malignant cells are found as solid sheets or are seen forming small glands about the nerve fibers within the perineural space. After the cells reach the perineural space, a pathway is provided for spread of cells through the prostatic capsule within the fascicles into the periprostatic tissue and beyond. Lymphatics are not found within these nerve channels, so the term perineural lymphatics used in this connection has been in error.

Spread of tumor cells is by permeation involving a continuous growth of cells; embolism is less common. Because of their shortness and proximity to the sphincters, the nerves that enter the apex play an especially significant role in the spread of tumor cells through the capsule along the perineural spaces. In summary, extraprostatic spread does not necessarily occur where the tumor breaks through the capsule, but it may take place where the nerve trunk supplying the tumor area leaves the gland.

Urinary Sphincters

Although many anatomists have studied and described the male sphincteric mechanisms, it is still difficult to form a unified construction from the various interpretations. The sphincteric muscles are closely interrelated both structurally and functionally, accounting for the problem of separating them by an anatomic approach. Not only are the arrangements of the various sets of muscle fibers complicated, but their individual innervation is complex as well, because the nerve supply must control both urination and ejaculation.

The internal sphincter that holds urine above the prostate is described as part of the vesical neck sphincteric system in Fig. 13-64.

Components

Most studies identify some or all of at least five components of the prostatic sphincter mechanism, although by many different names (Table 14-3).

The greatest anatomic support is found for two smooth muscle sphincters—the preprostatic sphincter and the passive prostatic sphincter—and three striated muscle sphincters—the prostatic striated sphincter, the membranous urethral sphincter (together termed the prostatomembranous urethral sphincter), and the periurethral striated sphincter. The prostate itself functions to maintain the shape of the bladder neck and allow the preprostatic sphincter to assume its role in maintaining continence.

Smooth Muscle Sphincters

Preprostatic Sphincter and Vesical Neck

The **preprostatic sphincter** is in continuity with the **middle circular layer** of the bladder that forms the **fundus ring** but is embryologically, morphologically, and functionally quite different. It consists of a cylinder of smooth muscle with circularly oriented fibers that lies beneath the urethral mucosa inside the transition zone of the prostate. It encircles the urethra for a distance of 1 to 1.5 cm and ends at the upper margin of the **verumontanum,** where the preprostatic urethra terminates (Fig. 14-51). The proximal portion surrounds the bladder neck and extends into the base of the prostate, where it becomes continuous with the smooth muscle of that organ. Thus a single sphincteric aggregation of smooth muscle is found that consists of a part of the vesical neck musculature and the preprostatic sphincter in continuity distally with the passive prostatic musculature.

The fibers of the preprostatic sphincter are distinctly different morphologically and functionally from those of the adjacent detrusor. Not only are they smaller in size and mixed with elastic fibers and collagen, but they have a separate innervation composed of sympathetic noradrenergic terminals. The function of this complex is to maintain continence at the vesical neck and to prevent retrograde seminal ejaculation.

Superficial Trigone

Considered a part of the preprostatic sphincter, the portion of the **superficial trigone** in the urethra is a longitudinal band of fine bundles of small diameter smooth muscle cells. Running on the posterior wall within the circular coat of the preprostatic sphincter, the band extends from its origin in the superficial trigone to the region of the verumontanum, where it becomes continuous with the musculature of the ejaculatory ducts.

Nerve Supply

Motor Nerves. The preprostatic sphincter is innervated by noradrenergic nerves from the sympathetic system similar to those supplying the smooth muscle of the prostate. This

TABLE 14-3

NOMENCLATURE OF THE URINARY SPHINCTERS

SMOOTH MUSCLE SPHINCTERS

Preprostatic sphincter involuntary sphincter, vesical neck sphincter, prostatic smooth muscle sphincter, internal sphincter

Passive prostatic sphincter passive sphincter, passive smooth sphincter

STRIATED MUSCLE SPHINCTERS

Prostatomembranous striated sphincter

Prostatic striated sphincter external striated sphincter, striped compressor of the prostatic urethra (Haines), compressor prostatae (Albinus), sphincter urethrae prostaticae (Kohlrausch), sphincter externe de la vessie (Cadiat)

Membranous urethral sphincter external sphincter, external voluntary sphincter, distal intrinsic urethral sphincter (Gosling), intrinsic external sphincter, intramural external sphincter

Periurethral striated sphincter (pubococcygeus) external intrinsic striated urethral sphincter, distal intrinsic striated urethral sphincter, extrinsic periurethral musculature, periurethral striated muscle, periurethral levator ani muscle

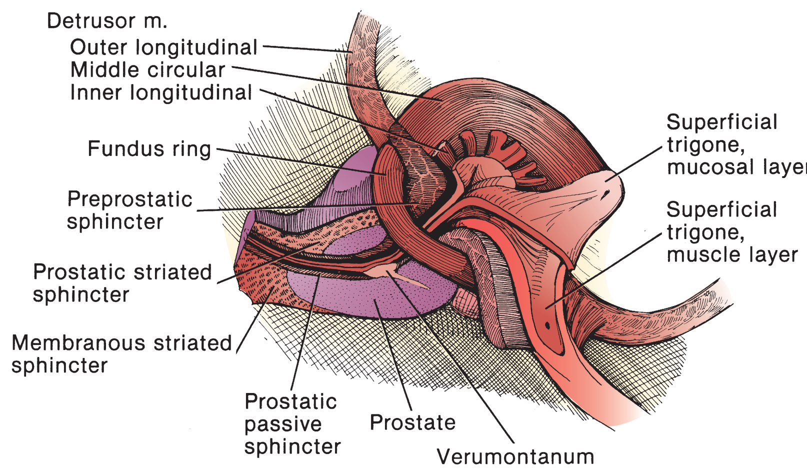


FIGURE 14-51.

is in contrast to the nerves of the bladder and bladder neck, which contain very few noradrenergic nerves but are generously supplied with parasympathetic nerves.

Sympathetic nerve stimulation not only empties the prostatic acini but, by closing the preprostatic sphincter, also prevents retrograde flow of ejaculate at the time of contraction of the prostatic musculature. In the presence of sympathetic hyperactivity, the sphincter may not open reflexly on detrusor contraction, resulting in obstruction to voiding.

Sensation. Sensory input from the vesical outlet enters through the sympathetic and parasympathetic nerves in the inferior hypogastric (pelvic) plexus through the inferior mesenteric ganglia and also through the pelvic nerves via dorsal nerve roots into the dorsal columns of the lumbar and sacral cord.

Passive Prostatic Sphincter

In the male, in addition to the activity of the preprostatic sphincter, continence is aided by a more distal passive sphincter that lies in the prostatomembranous urethra. It is composed of compact fibers of smooth muscle combined with fibroelastic tissue and is distributed semicircularly along the inframontane urethra. These muscle fibers are similar to those found more proximally in the preprostatic sphincter but are intimately related to the striated muscle bundles of the adjacent prostatomembranous sphincter. In addition, an inner longitudinal layer of smooth muscle distal to the verumontanum is continuous with the bundles of the preprostatic sphincter.

The deeper layer of semicircular fibers of the passive sphincter becomes more dense distally near the membranous urethra. Here, the muscle fibers form a ring around the urethra between the inner longitudinal smooth muscle layer and the prostatic striated sphincter external to it. The circular smooth muscle fibers are found mixed with circularly oriented striated fibers. The smooth muscle fibers thin out within the membranous urethra but are still present at the entrance to the bulbar urethra.

The smooth muscle in the passive prostatic sphincter does not appear to have a specific sphincteric organization but acts throughout the entire distal prostatic urethral segment as a supplement to the closure capabilities of the passive continence mechanism that is provided by the slow-twitch fibers of the prostatic striated sphincter with which it intermingles. During voiding cystography after prostatic adenomectomy, although on the command to "hold," the urinary stream can be seen to be at first cut off sharply by voluntary activity at the level of the membranous urethral sphincter, the site of urethral closure is seen to gradually move proximally because of the tone of the passive sphincter.

Striated Muscle Sphincters

The voluntary external sphincter mechanism consists of two separate muscular components. One is an intramural prostatomembranous sphincter that itself may be considered to have two parts: a prostatic striated sphincter and a membranous urethral sphincter. The other sphincter is extramural: the periurethral striated sphincter. Several of the different names and combinations for these sphincters are listed in Table 14-3.

Prostatomembranous Striated Sphincter

The prostatomembranous striated sphincter may be divided into a *prostatic striated sphincter* and a *membranous urethral sphincter*. Actually, these two sphincters are anatomically and functionally so similar that they may be best considered as the prostatic and membranous portions of a prostatomembranous sphincter. However, each influences a different part of the prostatic urethra, making a distinction necessary.

Prostatic Striated Sphincter

The proximal, prostatic part of the prostatomembranous sphincter consists of striated muscle fibers that cover the anterior and lateral surfaces of the prostate, forming the **prostatic striated sphincter** (Fig. 14-52). The muscle layer is especially thick over the anterior surface of the prostate, becoming thinner as the fibers sweep around laterally and dorsally. The muscle bundles fuse with the anterior fibromuscular stroma, and only with difficulty can they be dissected

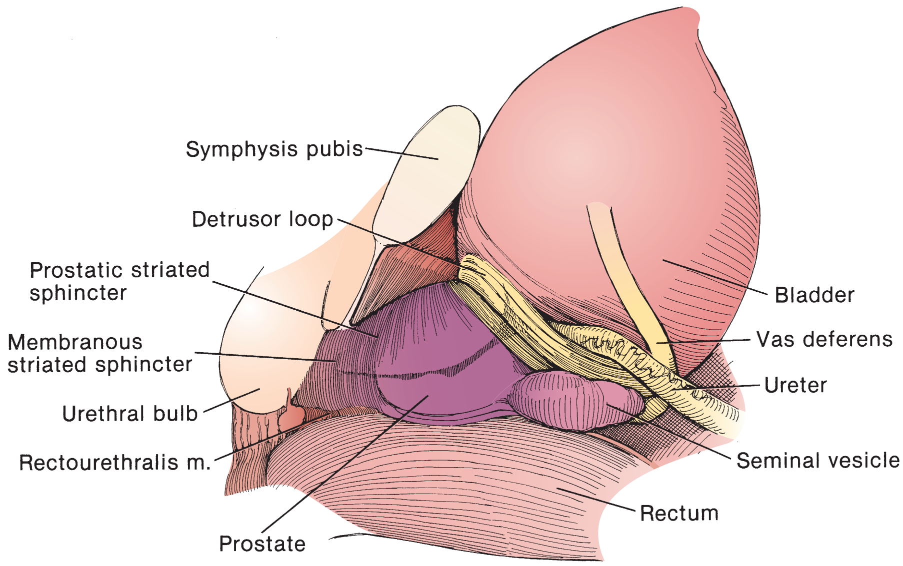


FIGURE 14-52.

from the prostate. Near the bladder neck, the muscle fibers often lie posterolateral to the prostate in continuity with the vesical neck fibers and the deep trigone. Distal to the neck, they run obliquely forward over the lateral surfaces of the prostate. About halfway between the bladder neck and the prostatic apex, they become transversely oriented and envelop the anterior surface of the prostate, whereas more distally, the striated muscle sheet almost completely surrounds the apex of the prostate except for a posterior gap.

Distally, the anterior extension of the prostatic striated sphincter merges with the membranous urethral sphincter. The longitudinally oriented puboprostatic muscle, an extramural muscle from the levator system, lies on either side of the prostatic striated sphincter. Although a separate structure, it reinforces the activity of the prostatic sphincters.

If prostatic development about the anterior commissure is deficient, the prostatic portion of the prostatic striated sphincter may lie in direct contact with the urethra at a point distal to the prostatic apex. The intervening smooth muscle layer of the passive sphincter would also be lacking, leaving the striated sphincters exposed to injury during total retropubic prostatectomy.

Membranous Urethral Sphincter

The membranous portion of the striated sphincter lies distal to the prostatic portion (Fig. 14-53). It may be as long as 2 cm and as thick as 0.6 cm. The fibers are more circularly oriented than those of the prostatic striated sphincter so that they completely surround the urethra from the anterior decussation of the fibers of the prostatic portion of the sphincter to the level of the perineal membrane and the bulbous urethra. The perineal body provides a point of insertion.

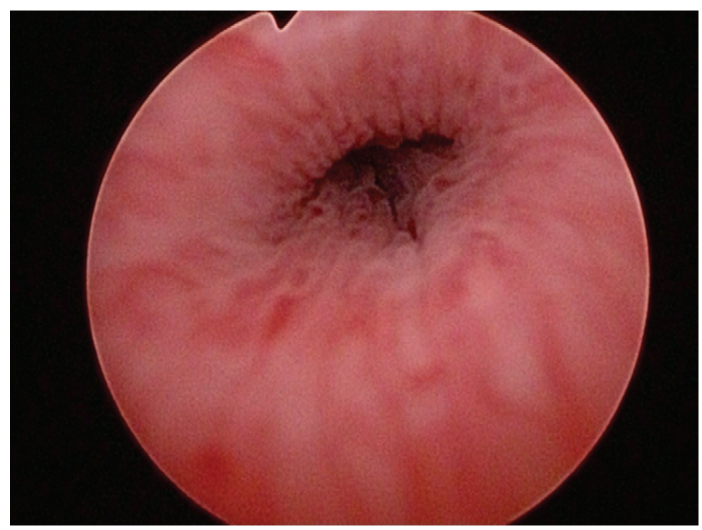


FIGURE 14-53. Endoscopic view of the membranous urethral sphincter. *(Image courtesy of William Larchian, M.D.)*

Muscle Types

The muscles of the prostatomembranous striated sphincter differ from the skeletal muscle of the periurethral striated sphincter, a part of the pubococcygeus. Many of its fibers are one-third as large as those of the pubococcygeus and are fatigue-resistant, slow-twitch fibers that typically have a high content of lipid and mitochondria (Type I fibers). These fibers have a different response to repeated stimulation. They are not only slower to fatigue and thus can maintain tone in the posterior urethra for long periods to maintain continence, but they are also adapted for sustained contraction.

Nerve Supply

The prostatic and membranous striated sphincters are innervated solely by motor somatic fibers; there is no autonomic contribution to the striated musculature in humans. The somatic supply comes from the ventral root of S3, with some contribution from S2. It continues in branches of the pelvic (splanchnic) nerve and passes to the pelvic (inferior hypogastric) plexus. This innervation of the intrinsic striated urethral sphincters is in contrast to the supply to the periurethral striated sphincter (pubococcygeus) that is transmitted over the pudendal nerve, principally from the ventral root of S2. Thus pudendal nerve block does not affect function of the intrinsic striated sphincters; it only halts the activity of the periurethral striated sphincter and the pelvic floor.

Sensation from the striated musculature of the urethral sphincters travels through the pudendal nerves via S2, and to a lesser extent S3, to be correlated centrally in the node of Onuf.

Periurethral Muscle of the Levator System

The **periurethral striated sphincter** is formed from the medial portions of the **pubococcygeus** (Fig. 14-54). It is distinct from the prostatic and membranous striated sphincters neurologically and also anatomically, being separated from the **membranous urethral sphincter** by a continuous connective tissue septum.

The muscle fibers are a mixture of slow and fast twitch. Many are of greater diameter than those of the more proximal sphincters and contain the larger Type II fast-twitch fibers. These fibers increase the force and speed of closure when they are recruited to assist the prostatomembranous sphincter during coughing and straining and during voluntary cessation of micturition. The majority of fibers, however, are slow-twitch fibers that are concerned with the tone required to maintain elevation of the prostate, bladder, and rectum so that the other sphincteric mechanisms may be effective. This is the main function of the periurethral striated sphincter in combination with the rest of the pubococcygeus and other parts of the levator ani. This function accounts for the continuous background electromyographic activity obtained from the pelvic floor, activity that ceases before voiding. Voluntary relaxation of the pubococcygeus lowers the prostate and bladder and acts as the signal for reflex contraction of the detrusor. Voluntary contraction will stop urination and reverse detrusor contraction. Reflex elevation occurs during straining and coughing. In addition, the periurethral muscle acts as a sphincter, supplementing the action of the striated prostatic sphincters in maintaining urethral closure.

The periurethral striated sphincter, as part of the levator ani system, is innervated principally from the ventral root of spinal nerve S2 by the pudendal nerve.

The difference in the nerve supply to the prostatomembranous and the periurethral striated sphincters has implications for the determination of striated sphincter activity during the evaluation of candidates for a bladder pacemaker. Incorrect interpretation of electromyograms results when electrodes are not placed accurately within the prostatic striated sphincter.

Innervation of the Urinary Sphincters

Nerve Supply to the Prostatic Sphincters

Autonomic Nerves

The nerves to the smooth muscle of the preprostatic sphincter and the prostatic smooth musculature are supplied by sympathetic spinal nerves L2 and L3, passing through the ganglia of the sympathetic chain and along the third and fourth lumbar splanchnic nerves to the **superior hypogastric plexus** and the **right** and **left hypogastric nerves** (Fig. 14-55) (for schematic representation, see Fig. 14-45A). These are preganglionic neurons that synapse with short alpha-adrenergic sympathetic postganglionic nerves whose cell bodies lie in the **pelvic** (inferior hypogastric) **plexus** lateral to the rectum, bladder, prostate, and seminal vesicles.

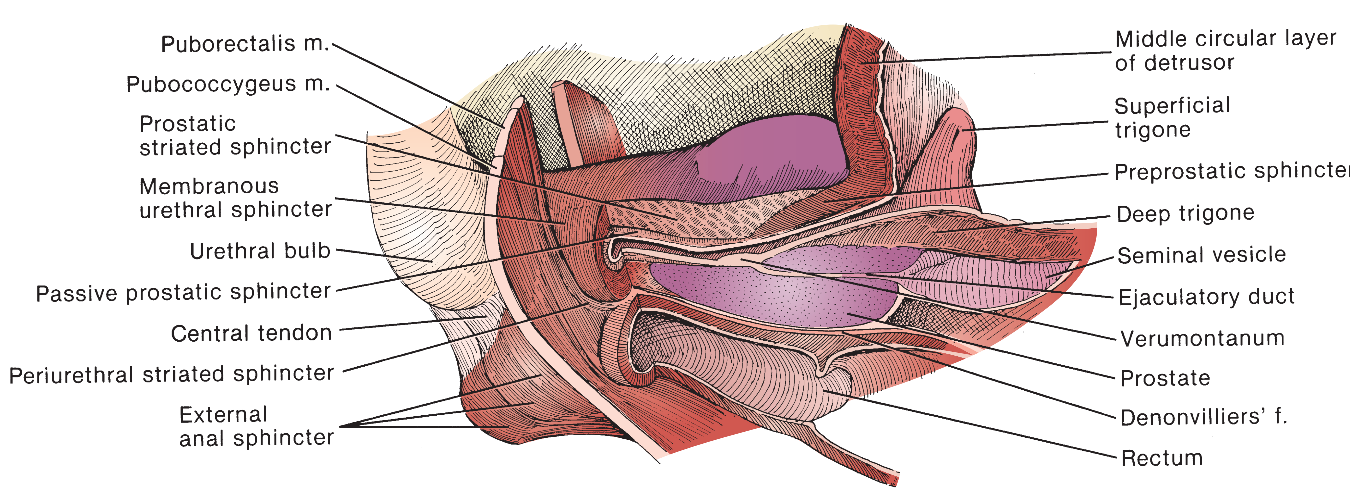


FIGURE 14-54.

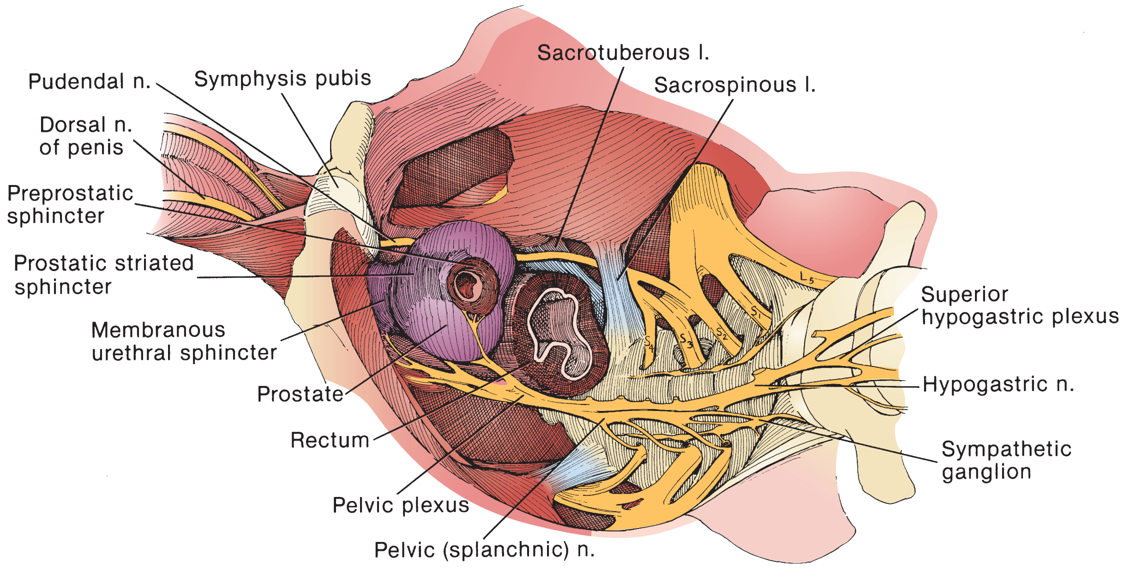


FIGURE 14-55.

Somatic Nerves

The nerves to the striated **prostatic** and **membranous sphincters** come from spinal nerves S2 and S3 in branches of the **pelvic (splanchnic) nerve** through the **pelvic plexus**. Nerve supply to the periurethral striated sphincter (pubococcygeus) arises from spinal root S2 and runs in the **pudendal nerve**.

Urinary Continence

Urine is held at the bladder neck by the internal vesical sphincter under noradrenergic sympathetic control. It is probable that some of the longitudinal fibers of the urethral smooth muscle are similarly innervated. With loss of the bladder neck musculature, as occurs after prostatic resection, the circular smooth muscle of the urethra, also controlled by noradrenergic nerves, contracts to act as the passive sphincter. The prostatomembranous sphincter contains both slow-twitch and fast-twitch fibers, the slow-twitch fibers allowing somatic innervation to act somewhat passively. The periurethral striated sphincter is somatically innervated and provides for voluntary cessation of urination.

A continence function can be ascribed to each of these sphincteric mechanisms. In addition, a vesical neck system that is continuous with the preprostatic sphincter may play a role in maintaining continence at the bladder neck. Even though, structurally, the vesical neck sphincter system is not a true sphincter, it is observed to function to hold the urine at that level, at what is commonly called the "internal sphincter." It is composed of smooth muscle and elastic fibers that compress the soft mucosal lining together for continence. The tone in this "sphincter," along with that of the preprostatic sphincter, increases reflexly as the bladder fills. The main function of the preprostatic sphincter, however, through alpha-adrenergic stimulation, is to close the posterior urethra at the time of ejaculation and prevent retrograde seminal flow.

The prostatomembranous striated sphincter apposes the anterior to the posterior wall of the prostatic urethra, providing more effective sphincteric action of the membranous portion. This mechanism works in concert with the periurethral striated sphincter of the pelvic floor that is actuated by the levator ani system. Contraction of the pelvic floor not only raises the bladder base and lengthens the urethra, but probably also constricts the membranous urethra. Contracting it also blocks bladder contractions by reflexively inhibiting the detrusor motor nucleus through pelvic short neurons. Volitionally relaxing the pelvic floor initiates a reciprocal detrusor contraction.

Seminal Vesicles, Ejaculatory Ducts, and Vasa Deferentia

Seminal Vesicles and Associated Ducts

The **seminal vesicles** behind the bladder are low enough for a portion of them to be felt rectally (Fig. 14-56). Although they are usually about 5 cm in length overall, their tips may extend as high as the termination of the ureters and reach the peritoneum. Each vesicle is a tube that, unfolded, is about 12 cm long; it has a capacity of 3 to 4 ml (Fig. 14-57). The tube is held as a coil by a fibrous matrix, and it contains saccules (diverticula) with short, wide necks (Fig. 14-58). Several types of seminal vesicles have been described, depending on the configuration of the main canal and of the saccules.

The lumen of the vesicle, encased in a fibromuscular sheath, narrows as it is joined at an acute angle by the more medially lying **ampulla of the vas deferens** (Fig. 14-59). Together, they become the **ejaculatory duct,** which has a length of 2.2 cm. This duct enters the prostate gland though a posterior cleft at the base, accompanied by vessels, lymphatics, and nerves. The *ejaculatory ducts* have smooth muscle in their walls (Fig. 14-60). At their termination on the verumontanum, circular and oblique fibers may be found in the sheath, presumably to prevent regurgitation. The ejaculatory ducts converge with one another and terminate in the urethra on the verumontanum (Fig. 14-61).

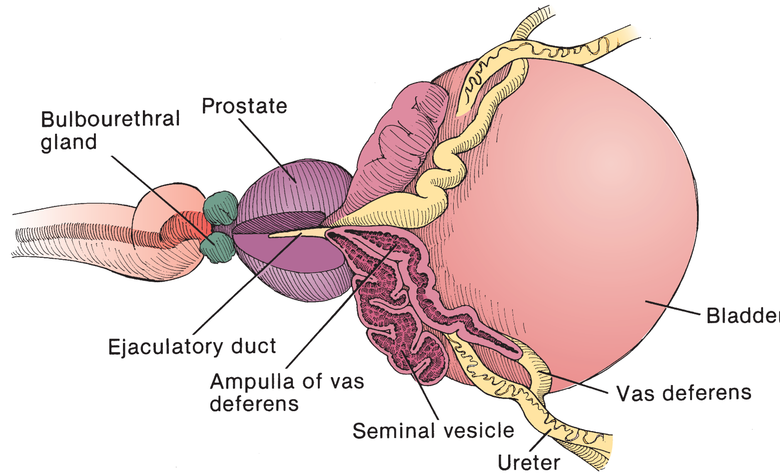


FIGURE 14-56.

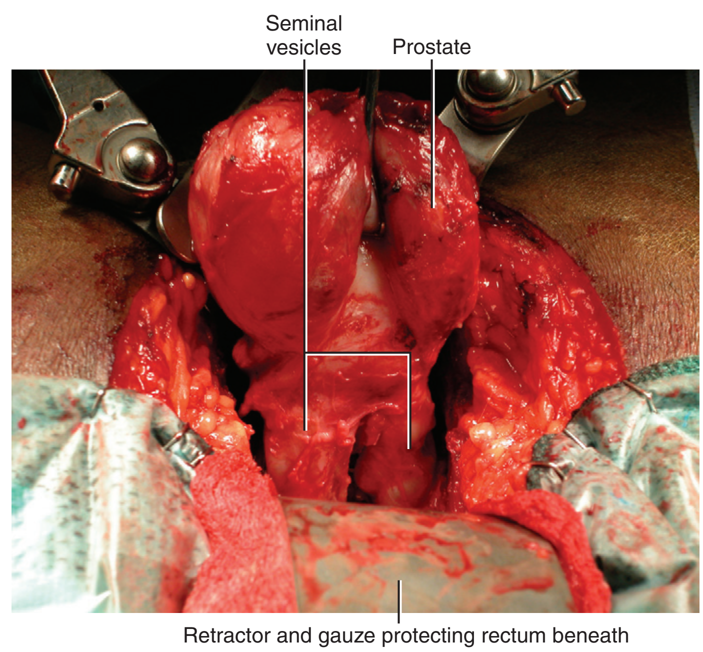


FIGURE 14-57. Radical perineal prostatectomy, nearing completion. Seminal vesicles are being dissected free of their surrounding attachments. *(Image courtesy of Nehemiah Hampel, M.D.)*

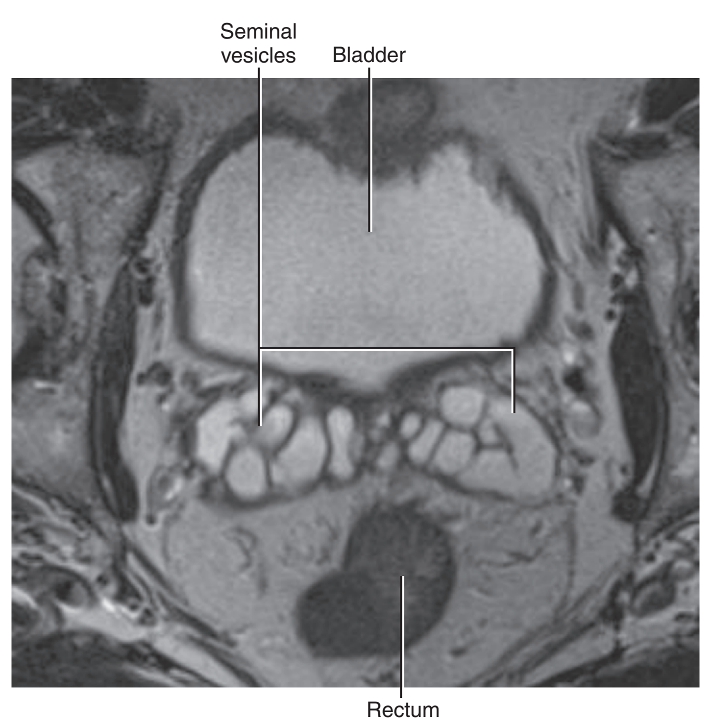


FIGURE 14-58. Magnetic resonance imaging (MRI) study, axial transverse section, showing the relationship of the seminal vesicles to the bladder and rectum. *(Image courtesy of Raj Paspulati, M.D.)*

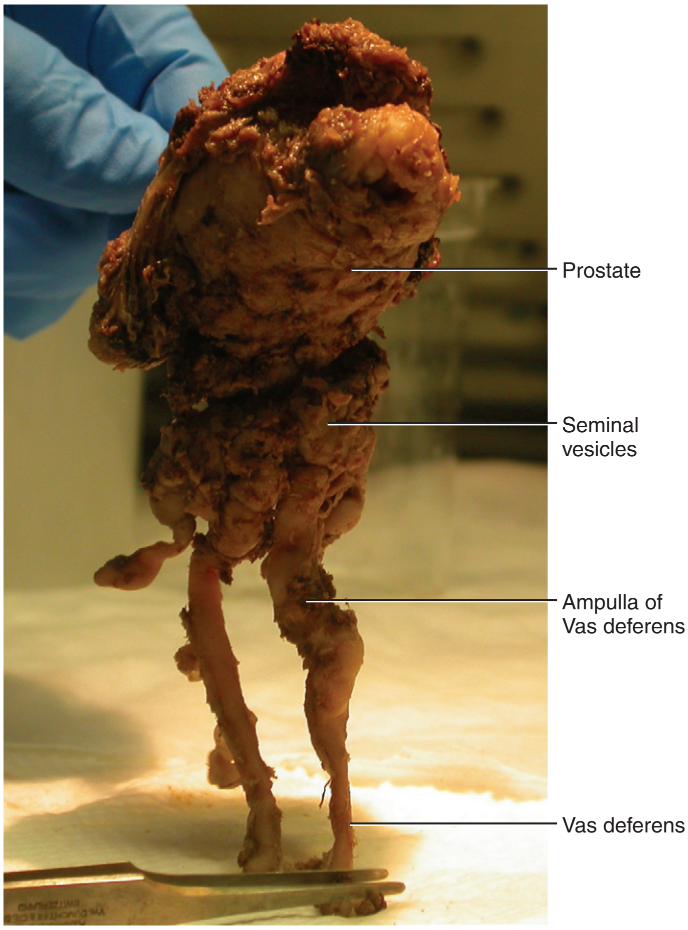


FIGURE 14-59. Radical prostatectomy specimen, following formalin fixation, and before whole-mounting for histologic evaluation. This image shows the relationships of vas, ampulla of vas, seminal vesicles, and prostate. *(Image courtesy of Annette Trivisonno.)*

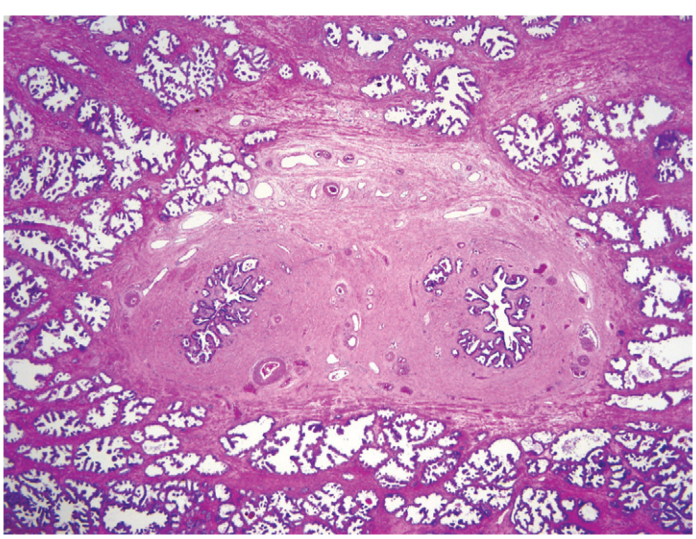


FIGURE 14-60. Ejaculatory ducts. Paired ejaculatory ducts are embedded within central zone prostatic parenchyma. The ducts are surrounded by attenuated thin muscular walls. The epithelial lining of the ejaculatory ducts is similar to that of the seminal vesicles.

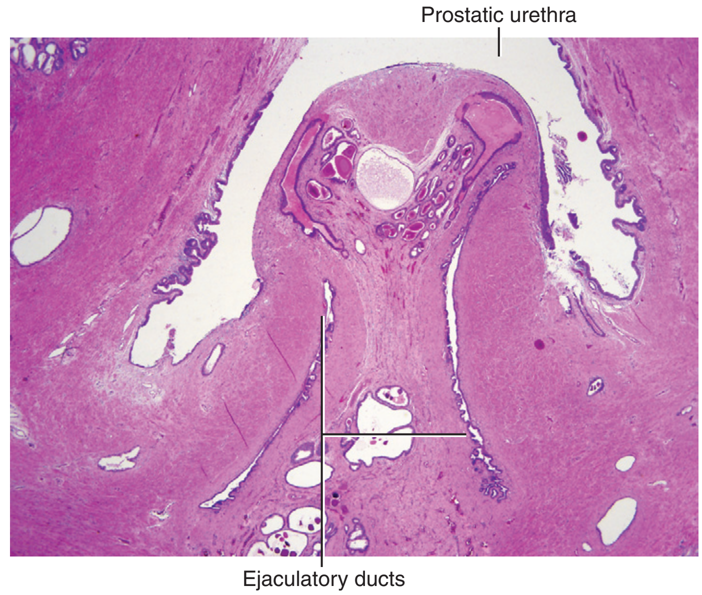


FIGURE 14-61. Verumontanum. The verumontanum appears as an elevation or protuberance in the prostatic urethra where the ejaculatory ducts enter the prostatic urethra.

The ejaculatory duct makes a gradual curve from the base of the prostate. As it approaches the urethra, it runs parallel with the axis of the urethral lumen, an arrangement that may act as a valve mechanism for closure during micturition because no distinct sphincter has been found at the junction with the urethra. The ducts open on the verumontanum within a collapsible fold of mucosa, which may prevent retrograde filling by itself.

The *seminal vesicles* have three coats: (1) areolar, (2) muscular, and (3) mucosal. As with the vas deferens, the muscular coat has an external longitudinal and an internal circular layer (Fig. 14-62). It is active just before ejaculation. The secretion of the columnar epithelium and goblet cells of the mucosa forms the principal part of the ejaculate (Fig. 14-63). It contains fructose for nutritional support of spermatozoa and a coagulating enzyme.

Spermatozoa pass from the epididymis into the ampulla of the vas partly by muscular activity of the vas. At the time of ejaculation, spermatozoa are actively passed through the ejaculatory ducts into the prostatic urethra, accompanied by the stored secretions from the contracting seminal vesicles.

The *blood supply* to the seminal vesicle is from the vesiculodeferential artery (see Fig. 14-40). This artery arises from the superior vesical artery or, more frequently, from the site where the internal iliac artery takes off from the umbilical artery. As it passes anterior to the ureter, it provides branches to that structure. At the seminal vesicle, it divides into three branches: (1) one to the bladder, (2) one to the vas, and (3) the largest to the anterior surface of the vesicle. This anterior vesicular artery divides on the surface of the vesicle to supply its anterior part. A second source of blood is the posterior vesicular artery, which may come either from the prostatovesical artery or directly from the gluteopudendal

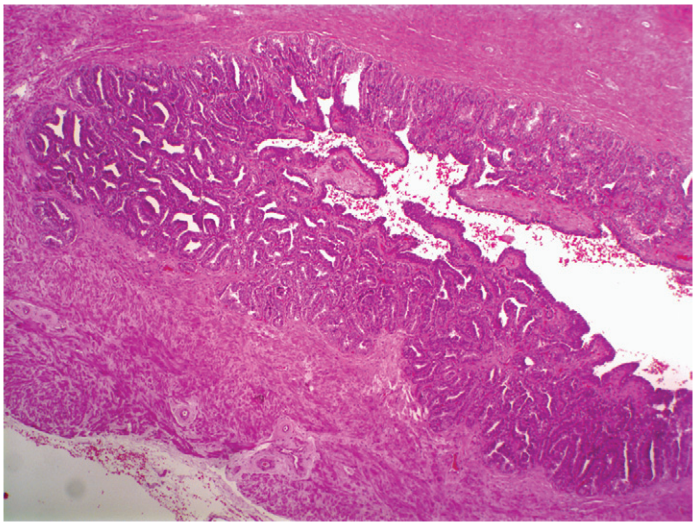


FIGURE 14-62. Seminal vesicle. This low power view of a normal seminal vesicle demonstrates a thick muscular wall surrounding complex tubulopapillary structures, bordering a large central lumen. *(From MacLennan GT, Resnick MI, Bostwick DG: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

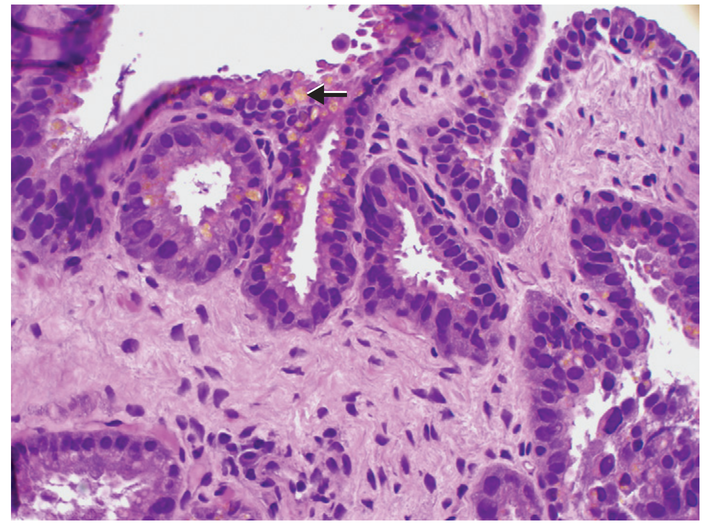


FIGURE 14-63. Seminal vesicle. Many cells exhibit intracytoplasmic bright golden lipofuscin granules (arrow). Seminal vesicle cells may show alarmingly atypical cytologic features, including nuclear hyperchromasia, nuclear pleomorphism, intranuclear inclusions, multinucleation, and nucleomegaly, but they lack nucleoli and mitotic activity. *(From MacLennan GT, Resnick MI, and Bostwick DG: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

trunk. Its small branches supply the posterior portion of the vesicle and anastomose with branches of the anterior vesicular artery. *Venous drainage* is through veins that accompany the arteries, draining into the internal iliac veins by way of the prostatic plexus.

The *vas deferens* is tortuous as it leaves the tail of the epididymis, but it straightens out as it ascends behind the testis on the medial side of the epididymis. It assumes a position in the posterior portion of the cord before passing through the inguinal canal. At the internal inguinal ring, it separates from the vascular portion of the cord to pass lateral to the inferior epigastric vessels. After crossing the external iliac vessels, it becomes subperitoneal and runs toward the midline superficial to the obliterated umbilical artery, the obturator vessels and nerve, and the vesical pedicles. At the medial side of the ureter, the vas turns caudally and passes behind the bladder and anterior to the upper half of the seminal vesicle. Midway along the vesicle, the vas widens and becomes tortuous (the ampulla) as it assumes a more medial position. It approaches the opposite vas behind the base of the prostate, where the duct of the seminal vesicle joins it to become the ejaculatory duct.

The vas deferens is covered with a superficial areolar layer. The wall itself is thick and muscular, with poorly defined external longitudinal and internal circular layers of muscle. The lumen is small and lined with columnar epithelium (see Figs. 17-35 and 17-36).

Lymphatic Drainage of the Seminal Vesicles and Vas Deferens

The mucous membrane and the muscular coat of the seminal vesicles are initially drained by separate systems, but on reaching the surface, they anastomose into a large plexus consisting of many large lymphatic vessels possessing valves. The plexus drains into the median chain of the external iliac nodes and into the internal iliac nodes after being joined by channels from the prostate. Many anastomoses connect these channels with those from the vas deferens as well as those from the prostate, bladder, and rectum.

The small lymphatics from the vas deferens pass into collectors that accompany the deferential artery to empty into the external iliac nodes. Anastomoses occur distally with vessels from the epididymis and more proximally with those from the prostate and bladder.

Chapter 15

Female Genital Tract and Urethra

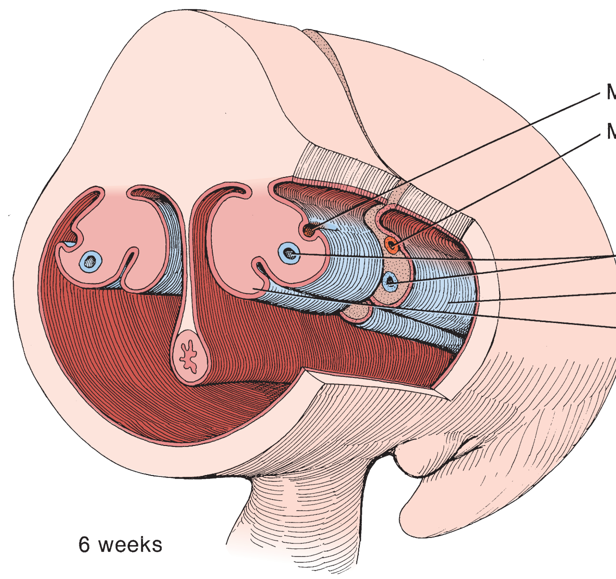


FIGURE 15-1.

The organs of generation . . . consist in each muscle of two ovaries, which are the female parts of its furniture.

GOLDSMITH
Nat. Hist. VII. 42, 1774.

. . . in wymmen ye neck of ye bladder is schort and is maad fast to ye cunte . . .

LANFRANC
1400.

DEVELOPMENT OF THE FEMALE GENITAL TRACT AND URETHRA

Many male-female homologies of the urogenital tract are described in Chapter 14. Here, the discussion is limited to those developmental and structural characteristics that are particularly female.

Female Genital Tract

Müllerian Ducts

Epithelial-lined grooves develop from the cephalad end of the **mesonephros** late in the sixth week of gestation (Fig. 15-1). The **müllerian grooves** that form in the nephrogenic blastema posterior to the **wolffian** (mesonephric) **ducts** become tubes as the margins close, forming the **müllerian** (paramesonephric) **ducts**.

Relation of the Müllerian to the Wolffian Ducts

The unattached cranial portion of the **müllerian duct** is the primordium of the uterine tube. The **ovary** develops medial to the duct (Fig. 15-2A). The **metanephros** now is formed into a kidney, attached by the **ureter** to the **urogenital sinus**.

The **kidney** "ascends," covered by the **adrenal gland** (Fig. 15-2B). The **round ligament** joins the **müllerian duct** to the inguinal canal.

The fused caudal part of the **müllerian ducts** forms the **uterovaginal canal,** later to become the uterus and vagina (Fig. 15-2C). The open end of the müllerian duct will form the **infundibulum** of the uterine tube and will descend with the **ovaries** enclosed in a peritoneal fold, the broad ligament.

The growing tip of the fused müllerian ducts lies medial to the wolffian duct. Both systems empty into the **urogenital sinus** on the **müllerian tubercle** (Müller's hillock). The two ducts are intimately related; experimental arrest of the wolffian duct blocks further development of the müllerian duct.

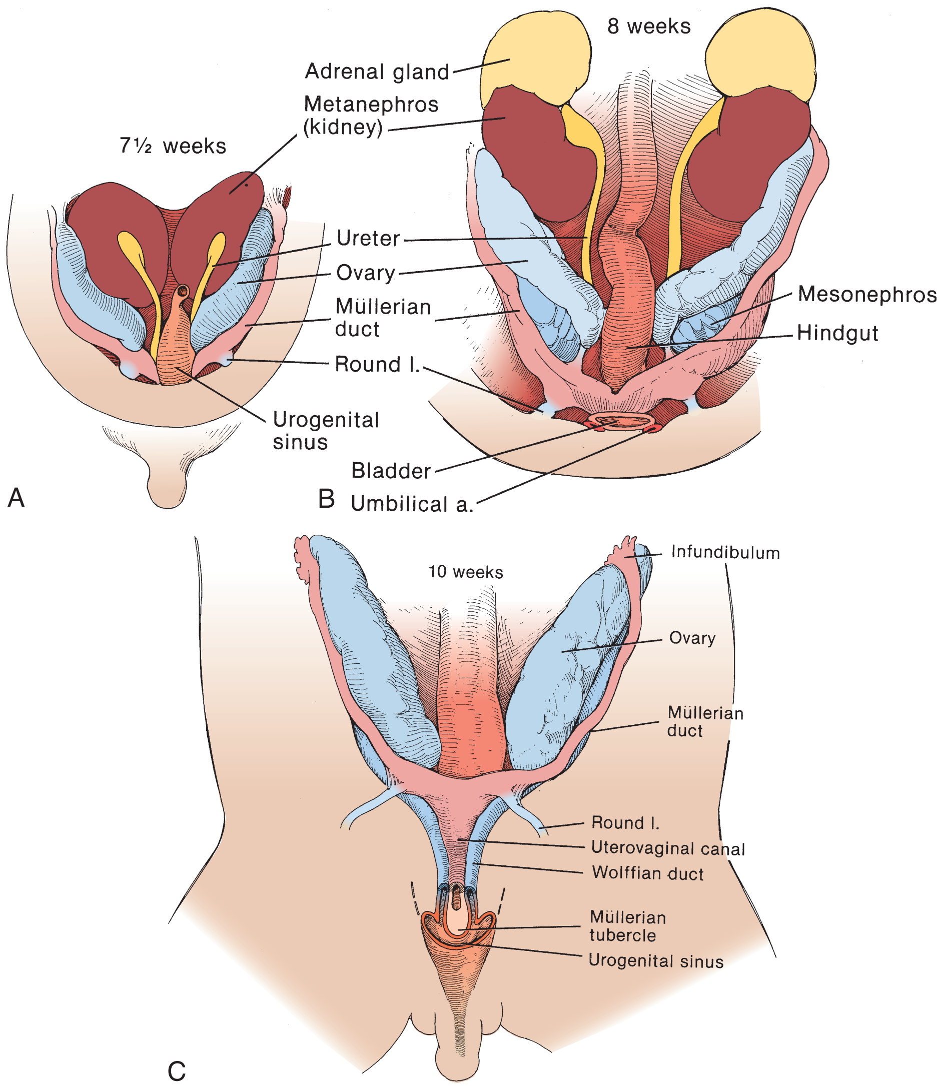


FIGURE 15-2.

Müllerian Tubercle

The **müllerian ducts** fuse to form the **utricular cord,** which subsequently becomes canalized (Fig. 15-3A). The cord impinges on the dorsal wall of the **urogenital sinus** at the junction of the vesicourethral canal and the pelvic part of the urogenital sinus.

The lining of the urogenital sinus proliferates locally and joins with that of the utricular cord to form the **sinoutricular cord,** which is composed of a mixture of sinus endoderm and the epithelial linings of the wolffian and müllerian ducts (Fig. 15-3B). This combination forms the **müllerian** (sinus) **tubercle** (see Figure 14-3). The utricular cord will form the vagina, and the sinus will form the introitus.

The openings of the wolffian ducts become sealed, and the ducts subsequently regress.

As the urinary tract separates from the hindgut and the urogenital membrane becomes perforated to form the urogenital orifice, the urogenital sinus above the membrane shortens. This exposes the separate openings of the vagina and the urethra. The rectum and anus are displaced posteriorly to make room for the separate vaginal opening.

Near the urogenital sinus, between the bladder and the rectum, the wolffian ducts fuse to form the genital cord, a structure that divides the pelvis coronally, forming a fossa in the peritoneal cavity behind the bladder. In the female, this space persists as the uterovesical pouch; it becomes obliterated in the male.

Uterovaginal Development

The uterus and cervix develop from the tubular portion of the fused müllerian ducts. The müllerian primordium itself will become the lining of the uterus, and the adjacent mesenchyme will form the endometrial stroma and

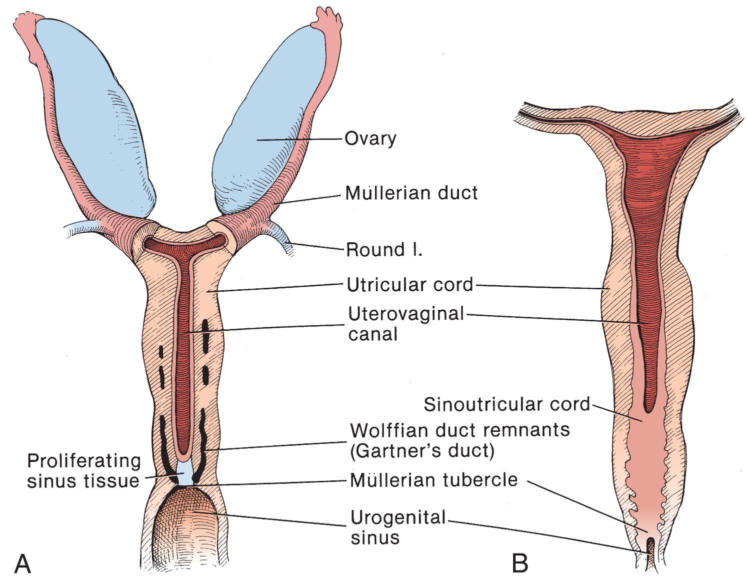


FIGURE 15-3.

myometrium. Should müllerian fusion be incomplete, uterus didelphys with septate vagina may result (Figs. 15-4 and 15-5).

The cervix becomes twice the size of the uterine body by the time of birth, after which both structures regress by 66% and 33%, respectively.

The cranial unfused portions of the müllerian ducts develop as the wolffian ducts regress. The pelvis widens during maturation so that the ducts assume a more transverse position as they develop into uterine tubes. The müllerian ducts fuse, but the proximal portion remains patent as the **uterine canal** (Fig. 15-6A). The enlargement of the pelvis pulls the urogenital sinus away from the uterine portion, allowing space for development of the **vagina**.

The vagina passes through a solid stage by invasion of mesenchyme and by internal proliferation of epithelium that form a solid epithelial **utricular cord.**

Subsequently, spaces appear within the **utricular cord** by regression of the **epithelial lining,** so that by the 20th week, the **vagina** has a complete lumen (Fig. 15-6B).

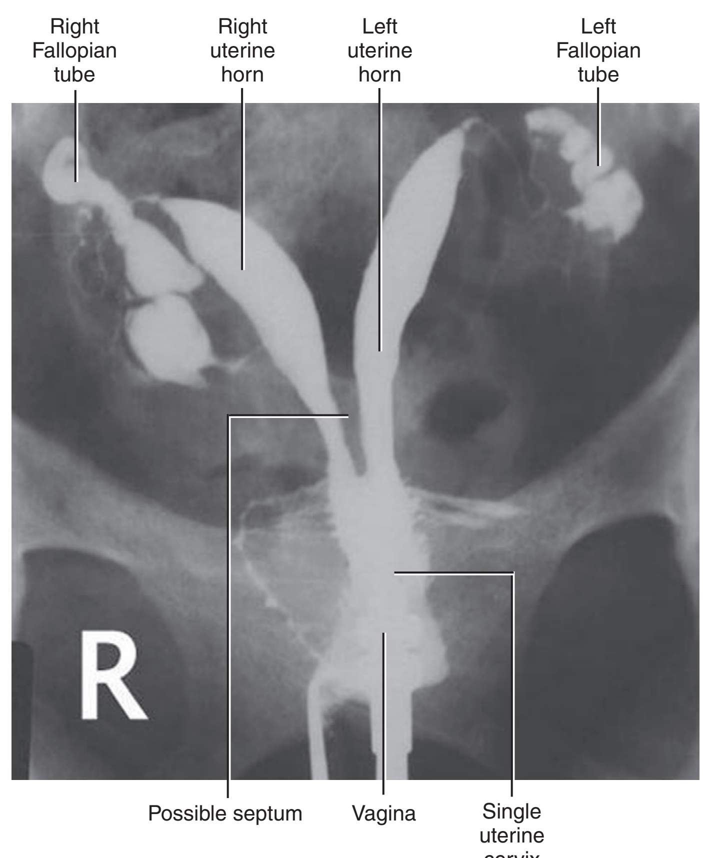


FIGURE 15-4. A number of uterine anomalies may result from failure of proper fusion of the müllerian ducts or from failure of some portion of the system to develop properly. This patient, being investigated for infertility, had a single vagina and a single cervix. Radiologic contrast material injected into the endocervical canal delineates a possible septal structure separating two uterine horns. It was unclear whether the findings represented a subseptate uterus (a partial partition of the endometrial cavity) or a uterus bicornis unicollis (a single cervix and lower uterine cavity with two horns). *(Image courtesy of James Liu, MD.)*

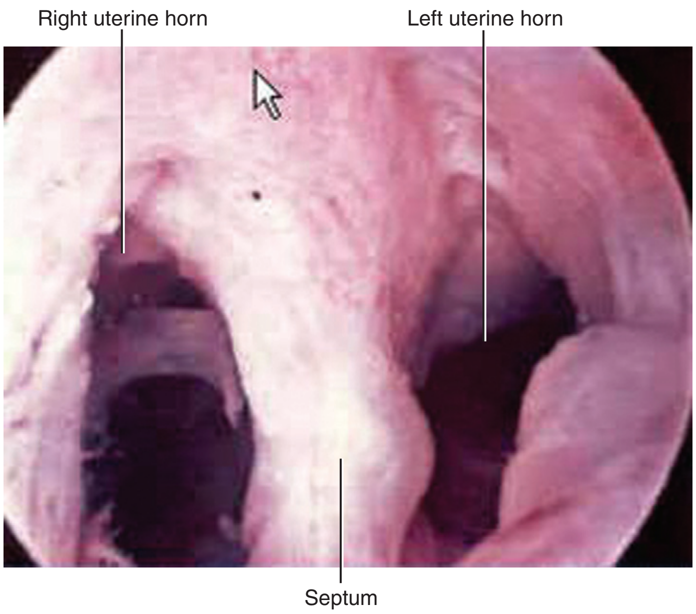


FIGURE 15-5. Hysteroscopy in the patient shown in Figure 15-4 showed findings consistent with a subseptate uterus: a septum partially partitioned the endometrial cavity. The septum was resected endoscopically. *(Image courtesy of James Liu, MD.)*

Should recanalization be incomplete or the epithelium fail to invade the mesenchyme, vaginal atresia is the result. Atresia may also be secondary to failure of that portion of the müllerian duct below the cervix to reach the urogenital sinus, leaving only a shallow depression at the site of the normal vaginal orifice. Hematocolpos will appear with the onset of menstruation. The entire uterus may be absent if the distal ends of the müllerian ducts fail to form.

By the 20th week, the **site of the cervix** may be identified. The junction of the vagina with the urogenital sinus is marked by the **hymen.** The portion of the urogenital sinus below the müllerian tubercle regresses and becomes the **vestibule,** and the müllerian tubercle comes to lie at the level of the hymen. The hymen is usually perforated but may seal off the vagina. The **urethra** and vagina are separated by the **urovaginal septum** to the level of the perineum.

As the müllerian ducts fuse, the broad ligaments are formed coronally from peritoneum, leaving one pouch behind, the uterorectal pouch (Douglas), and one in front, the uterovesical pouch. Within the broad ligament, mesenchyme proliferates to form connective tissue and smooth muscle that becomes the parametrium.

Fate of the Wolffian Duct

At 9 weeks, **mesonephric tubules** persist in conjunction with the **wolffian duct**, which extends to the **urogenital sinus** beside the **uterus** and **vagina** (Fig. 15-7A).

Vestigial structures remain from the wolffian ducts and tubules near the müllerian ducts. The epigenital portion

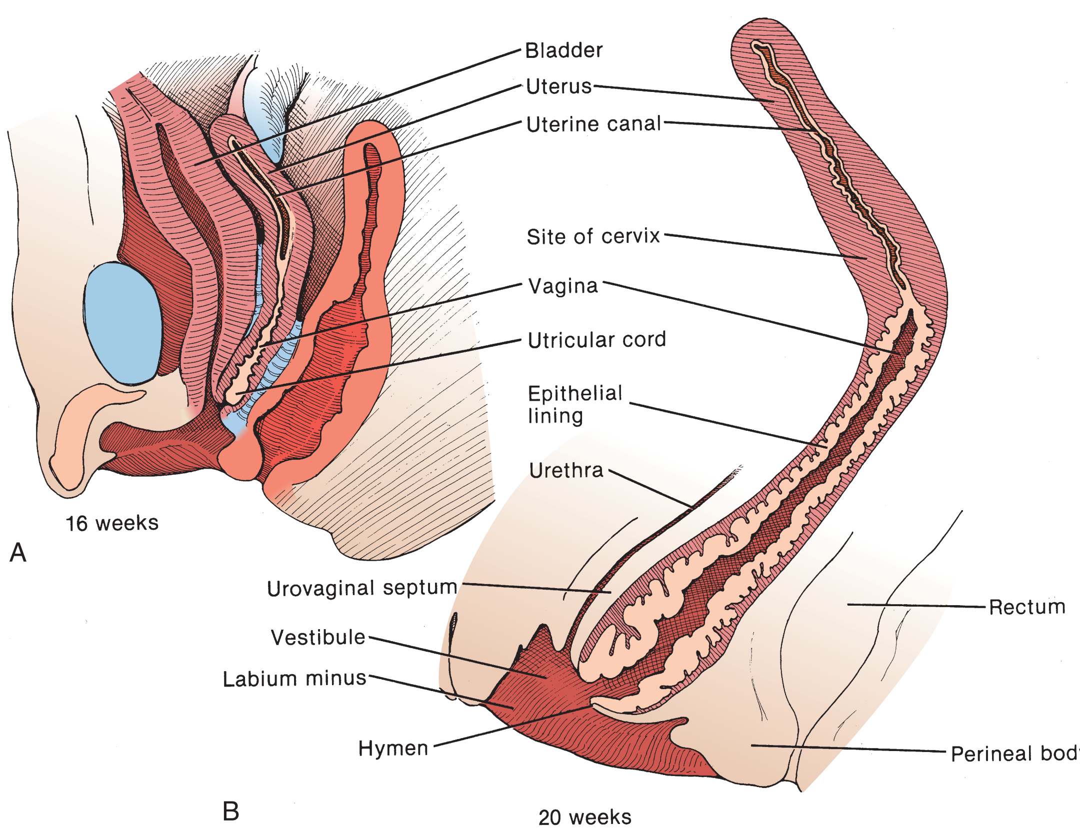


FIGURE 15-6.

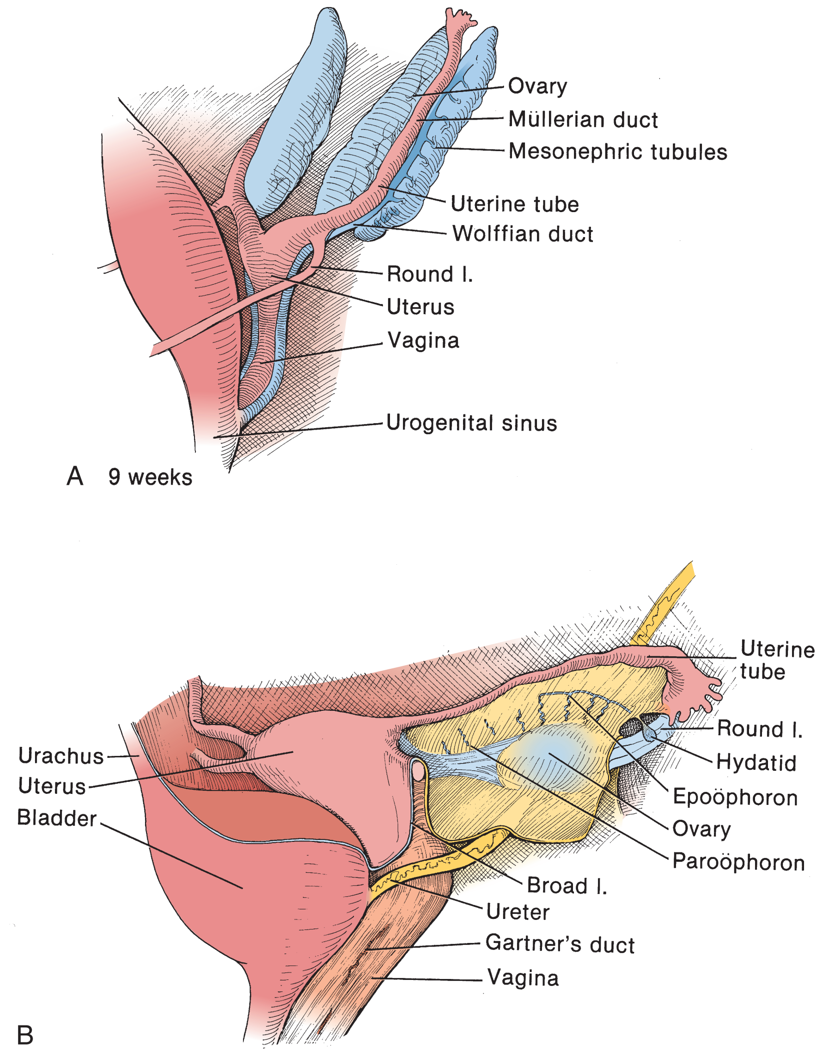


FIGURE 15-7.

becomes the **epoöphoron** and the paragenital part, the **paroöphoron** (Fig. 15-7B). The vesicular ovarian appendix or **hydatid** forms from detached cranial portions of the former wolffian duct.

With regression of the wolffian ducts, remnants persist in the cervical and vaginal walls as **Gartner's ducts** in one-fifth of women. Because the **ureter** is a derivative of the wolffian duct, delayed separation of the ureteric bud would result in an ectopic ureteral opening anywhere along the course of Gartner's duct, including the introitus (see Fig. 13-10).

The homologue of the male gubernaculum is the segment of mesenchyme in the inguinal fold that comes to lie in the ovarian ligament above and in the **round ligament** below, the latter having secondary attachments to the uterus. The ovarian ligament forms the proximal part of the gubernaculum and the round ligament, as the termination of the gubernaculum, will extend it into the inguinal canal. The homologue of the male processus vaginalis is the vaginal sac (or canal of Nuck) that extends into the labium majus, only to be obliterated before birth.

Female Gonadal Development

The ovary arises from the genital ridge during the seventh week as epithelial cells and mesenchyme differentiate. Initially, celomic epithelium forms the medullary cords, as well as the ovarian rete. Epithelial cords (cortical cords) form irregularly and remain attached to the surface of the genital ridge, with those lying deepest forming the rete. The primordial germ cells proliferate in the cortical epithelial cords but remain otherwise unchanged during the development of the ovary, in contrast to the activity of the germ cells in the testis that differentiate from gonocyte to spermatogonia. At about 16 weeks, under the influence of the feminizing genes on the short arms of the two X chromosomes, the cortical cords separate into cell clusters, the primordial follicles, that consist of an oogonium surrounded by a single layer of follicular cells. The oogonia become primary oocytes that, when covered with follicular cells, form a primary follicle.

Perinatally, the follicles grow within a multilayered granulosa that becomes organized into a cellular theca interna and a fibrous theca externa. During the first 3 to 6 months of life, the follicles degenerate but return at puberty.

The germinal epithelium becomes a single layer distinct from the tunical albuginea that forms the fibrous capsule covering the ovarian tissue. Separation from the mesonephros occurs as the ovary develops a mesentery, the mesovarium. The ovary has descended into the pelvis by the end of the third month, and it subsequently rotates laterally.

The derivation of reproductive structures in the male and female is outlined in Table 15-1.

TABLE 15-1

DERIVATION OF REPRODUCTIVE TRACT STRUCTURES FROM WOLFFIAN AND MÜLLERIAN PRIMORDIA*

Male	Female
GENITAL RIDGES	
Testis	Ovary
Seminiferous tubules (medulla)	*Pflüger's tubules*
Rete testis	*Rete ovarii*
Gubernaculum testis	Round ligament of uterus
WOLFFIAN DERIVATIVES	
Mesonephric tubules	
Ductuli efferentes	*Epoöphoron*
Ductuli aberrantes	*Ductuli aberrantes*
Paradidymis	*Paroöphoron*
Mesonephric duct	
Ureter, pelvis, and collecting tubules of kidney	Ureter, pelvis, and collecting tubules of kidney
Trigone of bladder	Trigone of bladder
Ductus epididymidis	*Duct of the epoöphoron*
Ductus deferens	*Gartner's duct*
Ejaculatory duct	
Seminal vesicle	
Appendix epididymidis	*Appendix vesiculosa*
MÜLLERIAN DERIVATIVES	
Appendix testis	*Hydatid of Morgagni*
	Oviduct
	Uterus
Colliculus seminalis	Cervix and upper vagina
UROGENITAL SINUS DERIVATIVES	
Bladder	Bladder
Urethra above colliculus seminalis	Urethra
Prostatic utricle	
Urethra below colliculus	Lower vagina and vestibule
Seminalis	Hymen
Membranous urethra	
Cavernous urethra	
Bulbourethral glands (Cowper's)	Vestibular glands (Bartholin's)
Prostate gland	Paraurethral glands of Skene
EXTERNAL GENITALIS	
Glans penis	Glans clitoridis
Floor of penile urethra	Labia minora
Scrotum	Labia majora

*Vestigial structures in italics.
Adapted from Gray SW, Skandalakis JE: Embryology for Surgeons. Philadelphia, WB Saunders Co, 1972.

Female Urethra

Development of the Female Urethral Musculature

Early in development (around 3 weeks), the components of the musculature of the bladder neck and trigonal system and of the ventral urethral wall are similar in both male and female fetuses.

The *smooth urethral musculature* that lies in midurethra surrounds all but the dorsal part, where it inserts into the extension of the superficial trigone. More caudally, the muscle inserts into a dorsal condensation similar to that developed in the dorsum of the membranous urethra of the male. Although at first some of the smooth muscle surrounds the vaginal primordium, as the vagina grows, it loses this dorsal extension, leaving a small amount of the smooth urethral musculature attached to the lateral urethral wall or to the urethrovaginal septum.

The *striated urethral musculature* is continuous from the base of the bladder to the perineum. It has two parts, one distributed about the urethra and the other about the urogenital sinus. Both are laid down early in development and show little change thereafter. The exception is the extension of the lower border of the urogenital sphincter that lies below the pelvic floor, which becomes attached laterally to the ischiopubic ramus.

Even though mesenchyme originally encircled the urethra, the muscle bundles formed in the cranial part incompletely surround the urethra, being open dorsally where they appear to insert. The bundles of the caudal part cover the vagina on both sides and insert into the uterovaginal septum.

Anomalies

Primary developmental failure of the wolffian duct with consequent failure of the intimately related müllerian duct structures to develop results in the absence of either the entire or the medial part of the uterine tube on the affected side. A unicorn uterus is formed on the opposite side, associated with unilateral renal aplasia (Fig. 15-8).

Persistence of müllerian duct fusion to the wolffian duct may result in an ectopic ureter emptying into the uretero-vaginal canal, the site found in a third of ectopic ureters in females.

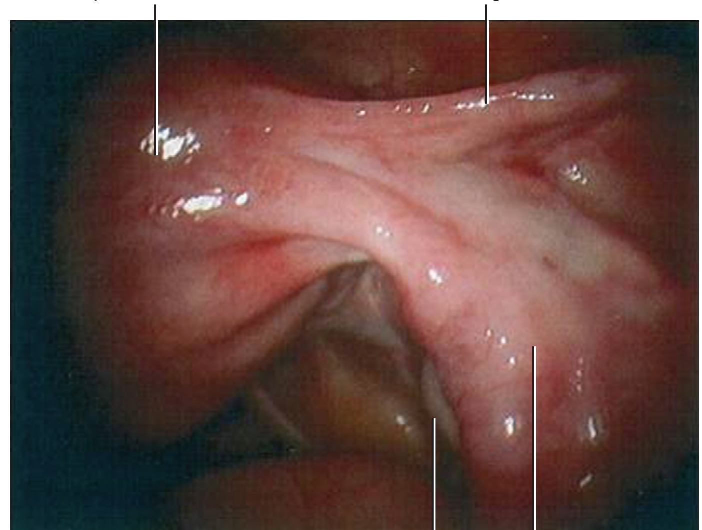


FIGURE 15-8. A combination of imperfect fusion of the müllerian ducts, in conjunction with maldevelopment, produces a double uterus with one normal and one rudimentary horn. The rudimentary horn may or may not communicate with the vagina; the majority do not. This image, taken at laparoscopy, illustrates a developed left uterine horn and a rudimentary right uterine horn. *(Image courtesy of James Liu, MD.)*

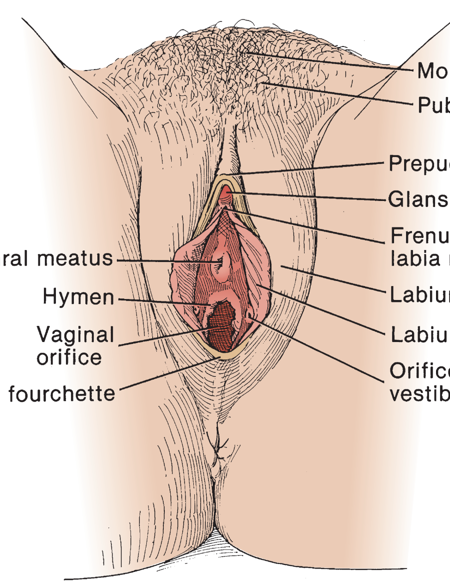


FIGURE 15-9.

FEMALE GENITAL TRACT, URETHRA, AND SPHINCTERS: STRUCTURE AND FUNCTION

Genital Tract

External Genitalia

The pudendum or vulva is the whole of the several parts of the female external genitalia.

The clitoris, homologous with the penis, is bounded anteriorly and posteriorly by the anterior extensions of the **labia minora** that form both a dorsal **prepuce** and a ventral **frenulum of the labia minora** (Fig. 15-9). The corpora cavernosa are contiguous for the terminal 2.5 cm, then diverge as crura covered by the ischiocavernosus to fasten to the pubic and ischial rami. A suspensory ligament holds the clitoris to the pubis. The small **glans clitoridis** is its termination. The clitoris contains only two erectile bodies, the bulbar commissure on the ventral aspect of the clitoris being a distal remnant of the corpus spongiosum. The proximal part consists of narrow tubular masses on either side of the introitus called the bulbs of the vestibule, structures that are covered by the bulbospongiosus.

The **mons pubis** is a fatty structure that covers the symphysis pubis. From it, distinctive **pubic hair** develops at puberty. The **labia majora**, homologue of the male scrotum, are large folds of skin containing appreciable quantities of fat that run from the mons pubis to the perineum. They are the sites of termination of the round ligaments.

The **vestibule** in which the **urethral** and **vaginal orifices** are found between folds of hairless fat-free skin, is the labia minora. Into it empty the lesser vestibular glands. The vestibular fossa is a depression between the vaginal orifice and the frenulum. The **labia minora**, the homologues of the floor of the male urethra, are joined posteriorly as the **labial fourchette**.

The **vaginal orifice** (introitus) opens below the vestibular fossa. The **hymen** consists of folds of mucous membrane and lies at the entrance to the vagina. The bulbourethral glands of the male are represented by the **greater vestibular glands** (Bartholin). These are small round masses situated at the ends of the bulbs of the vestibule; each empties through a 2-cm duct into the vestibule in the groove between the hymen and the labium minus.

The vascular and nerve supply to the female external genitalia are similar to those of the male (see Chapter 16). Most of the lymphatics from the vulva drain to the superointernal group of the superficial inguinal glands; those from the clitoris follow the same pattern as the lymphatics from the male penis. Sensation from the skin of the vulva and the adjacent perineum travels in the perineal branch of the posterior femoral cutaneous nerve.

Ovary, Uterus, and Associated Ligaments

Ovary. The **ovary** lies suspended in the ovarian fossa, a depression in the posterior peritoneum bounded by the obliterated umbilical artery, the ureter, and the internal iliac artery.

Although quite mobile, the ovary is attached anteriorly by the mesovarium to the posterior aspect of the **broad ligament**, is suspended by the infundibulopelvic ligament (suspensory ligament of the ovary), and is attached below to the lateral angle of the uterus by the ovarian ligament (Fig. 15-10).

Uterus. The **uterus** is three times as long as it is thick, and has a width twice as great as its thickness. A constriction at the level of the internal cervical os marks two regions, the larger **uterine body** above and the smaller **cervix** below. At the rounded tip of the cervix, the cervical canal terminates as the external cervical os in the vagina. The uterus is concave at the cervical junction, so that the body is oriented more vertically than the cervix in 80% of cases. As a result of the right angle formed by the junction of cervix with vagina, the external os abuts the posterior vaginal wall.

The mesometrium is that part of the broad ligament that connects the ovary, the ovarian ligament, and the body of the uterus to the pelvis wall. The uterosacral ligament is formed from the rectouterine folds that are attached to the front of the sacrum. The **round ligaments** consist of flat bands within the broad ligaments. Each runs from the lateral angle of the uterus into the **internal inguinal ring** to end as fibers in the fatty tissue of the labium majus.

Uterine tubes. The **uterine** (fallopian) **tubes** emerging from the lateral aspect of the uterus mark the lower margin of the fundus that forms the upper rounded region of the body of the uterus.

The tubes are supported by the mesosalpinx, that portion of the broad ligament investing the uterine tubes and extending to the mesovarium.

The anterior surface of the supravaginal part of the cervix makes contact with the bladder, separated only by the anterior extension of the connective tissue parametrium, a layer that becomes more prominent as it continues laterally between the layers of the broad ligament.

Pouches. The peritoneum-lined **vesicouterine pouch** lies anterior to the body of the uterus. Posterosuperiorly, the uterus is covered by visceral peritoneum. This, with the parietal peritoneum beside the rectum and the visceral peritoneum over it, forms the **rectouterine pouch** (Douglas) that lies dorsal to the

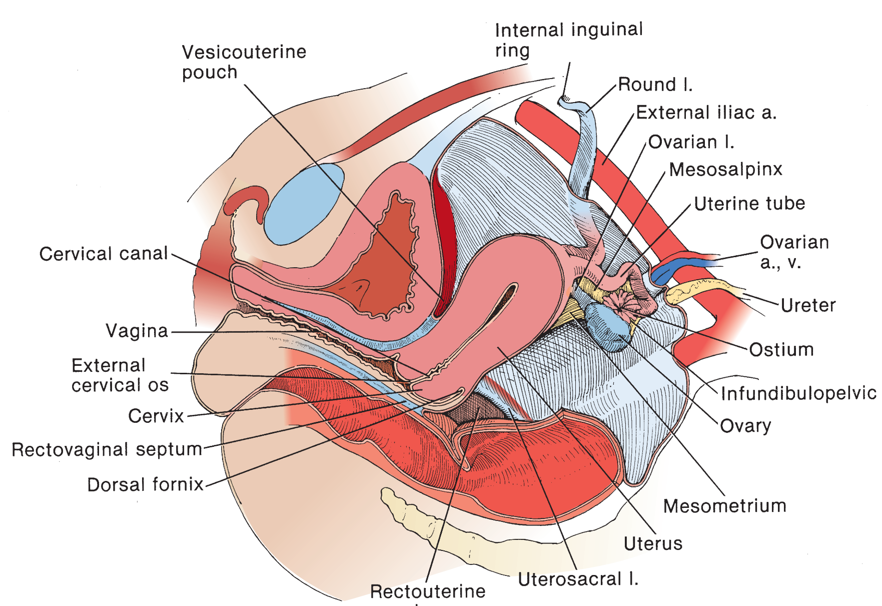


FIGURE 15-10.

uterus. The base of this pouch usually lies near the dorsal fornix of the vagina, thus providing peritoneal covering for only a small area of the dorsal vaginal wall. The two layers of fascia that are derived from the inner stratum of the retroperitoneal connective tissue left behind after fusion of the opposing peritoneal layers (fusion-fascia) continues caudally over the rectal fascia as the rectovaginal septum, similar to the origin and distribution of the anterior lamella of Denonvilliers' fascia in the male (see Figures 14-17 and 14-19).

The vaginal part of the cervix is inserted into the anterior wall of the vagina that is surrounded by the vaginal fornix. The fornix has a shallow anterior (ventral fornix) and a deep posterior recess (dorsal fornix); its depth is due to the greater length of the posterior vaginal wall. Lateral recesses form the lateral fornices.

Uterine Wall. The wall of the uterus is composed principally of smooth muscle fibers, the myometrium, distributed in three layers: (1) an outer longitudinal layer continuous with the fibers in the uterine tube as well as with the round ligament and ligament of the ovary, (2) a middle circular layer, and (3) an inner longitudinal layer. It is lined with mucosa, the endometrium, and is partially covered with peritoneum, the perimetrium, and partially with connective tissue, the parametrium.

Uterine Tubes. The two **uterine** (fallopian) **tubes**, or oviducts, each 10 to 12 cm in length, run in the upper margin of the broad ligament caudal to the **ovaries** to open into the upper angles of the uterus. Each tube has four parts: (1) a short uterine (interstitial) segment; (2) an isthmus in the medial third; (3) an ampulla making up half the length; and (4) an infundibulum that extends to the abdominal ostium, about which fimbriae develop. The tubes pass over the ovaries to end on their medial border. The so-called ovarian fimbria is specialized to support the tube from the upper margin of the ovary.

Vagina. The **vagina** is a canal whose lining shows transverse folds or rugae. The vaginal columns are longitudinal ridges running on the anterior and posterior walls, the anterior column terminating in the urethrovaginal ridge or carina. The vagina has a mucous membrane and lamina propria fixed to the muscular layer. The lamina propria is an areolar layer with a rich plexus of thin-walled veins. The muscle layers are nonstriated, with a strong outer longitudinal layer and an inner circular layer. The muscle is firmly attached to the rectovesical fascia on either side.

The upper quarter of the vagina is opposite the rectouterine pouch. The middle half lies against the fusion-fascia left by resorption of the peritoneal fold of the rectovaginal septum. The distal quarter is in the perineum, associated with the perineal body. The vagina is separable from the bladder but can be dissected from the urethra only with difficulty owing to the lack of planes in the densely fused connective tissue.

Voluntary muscle is distributed about the vagina.

Support of the Pelvic Organs: Fascial Layers, Suspensory Guys, and Potential Spaces

The tissue derived from the retroperitoneal connective tissue that fills the space around the organs responds to stress by thickening in some areas. This results in the formation of supporting ligaments. For the pelvic organs, where the levator sling and the urogenital diaphragm can provide only gross support, they must individually depend on the connective tissue condensations surrounding them. Because it is the intermediate stratum of the retroperitoneal connective tissue that covers them, this layer provides most of the support. The outer stratum that develops into the transversalis fascia and its derivatives, including the endopelvic fascia, assumes importance where the pelvic organs exit from the body, but otherwise it is not closely involved.

The fascial layer covering the vaginal wall (intermediate stratum) is condensed laterally to form the pubovesical and pubocervical fascia and ligaments. The pubovesical ligaments extend from the periosteum of the inferior border of the pubis to fuse with the smooth muscle of the vesicourethral junction. In spite of their relative weakness and width, these ligaments are important structures for maintaining the junction in position. Because these ligaments contain smooth muscle, they retract after surgical division but must be retrieved to receive the distal sutures in suprapubic suspension operations.

Because each organ is enclosed in its own layer of fascia, as is required for independent movement, there are two layers of fascia where the organs make contact. Parts of these fascias condense to form what are called *suspensory guys*. Between the *fascial layers* are *potential spaces*.

FASCIAL LAYERS AND SUSPENSORY GUYS

The vagina, along with the bladder, is supported within the intermediate stratum of the retroperitoneal tissue. Condensations of this stratum form the *vesical and vaginal fascias* and provide the connections between the fascias and supportive areas of the pelvic wall. Similarly, the rectum, as part of the intestinal tract, resides within the inner stratum; condensation of this fascial layer forms the rectal fascia.

The fascial layers not only provide planes of dissection, but the localized condensations of these fascias, particularly on either side of the bladder, vagina, and rectum also provide support for the organs by forming septa of connective tissue between them. Thickenings, here called *suspensory guys*, form along the margins of these septa by reinforcement of the fascia. The suspensory guys remain interconnected by the fascial septa anteroposteriorly and transversely. Two of these thickenings are of greater structural importance than others and so are named as fascias for the organs that they support, as are their subdivisions.

The *pubocervical fascia* lies on the posterior aspect of the bladder and connects the pubis with the cervix. It provides support not only for the bladder, but also for the anterior vaginal wall as well. Surgically, it is viewed in three portions: (1) periurethral, (2) vesicovaginal, and (3) vesicocervical. Periurethrally, the fascias of the urethra and vagina are fused. At the level of the bladder neck, lateral to the vesicovaginal space, the vesical and vaginal fascias fuse to form the pubocervical and vesicouterine ligaments. This closes the vesicovaginal space proximally at the level of the cervix. The vesicocervical space that terminates at the peritoneal fold is an extension of this space.

The *rectovaginal fascia* or septum is the peritoneal fusion-fascia that is the homologue of Denonvilliers' fascia in the male. As a dense layer that is fused to the posterior wall of the vagina and urethra, it extends from the peritoneal fold of the rectouterine pouch to the perineal body.

Potential Spaces

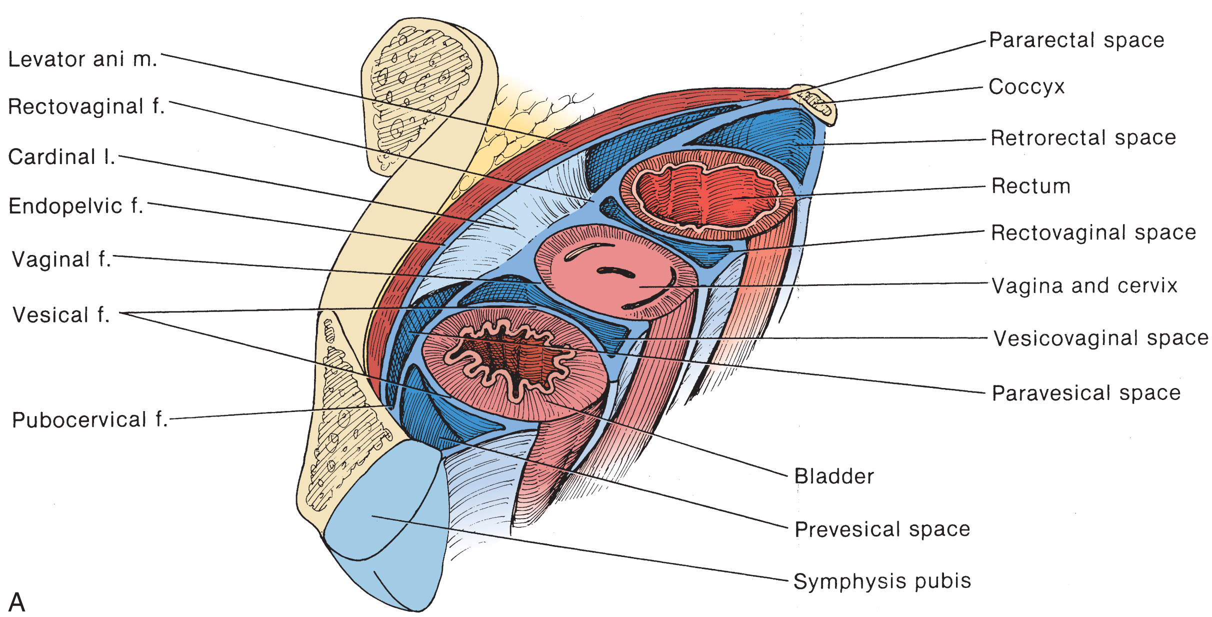
Six potential spaces are distributed among the organs. The most important ones are the midline **vesicovaginal** and **rectovaginal spaces** (Fig. 15-11A). Two other spaces are present in the midline. One is the retropubic or **prevesical space**, lined by the fascia covering the anterior surface of the bladder and the transversalis **(endopelvic) fascia** lying behind the pubis. The other is the **retrorectal space**, which is limited by the rectal fascia (inner stratum) and the transversalis fascia (outer stratum) covering the sacrum.

Two more sets of spaces lie on each side of the pelvic organs. These are the **paravesical space** and the **pararectal space**.

Fascial layers that lie lateral to the vagina on each side join with each other at three potential surgical planes: (1) retropubic, (2) vesicovaginal, and (3) rectovaginal. These planes and spaces are of considerable importance in vaginal dissection.

The potential prevesical space lies between the endopelvic fascia of the outer stratum of the retroperitoneal connective tissue and the vesical fascia from the intermediate stratum. It extends laterally from the umbilicus to the obliterated umbilical artery and anteroposteriorly it passes between the pubis and the bladder.

The potential vesicovaginal space lies between the vesical and vaginal fascias, both derivatives of the intermediate stratum, although the inner stratum may contribute. The



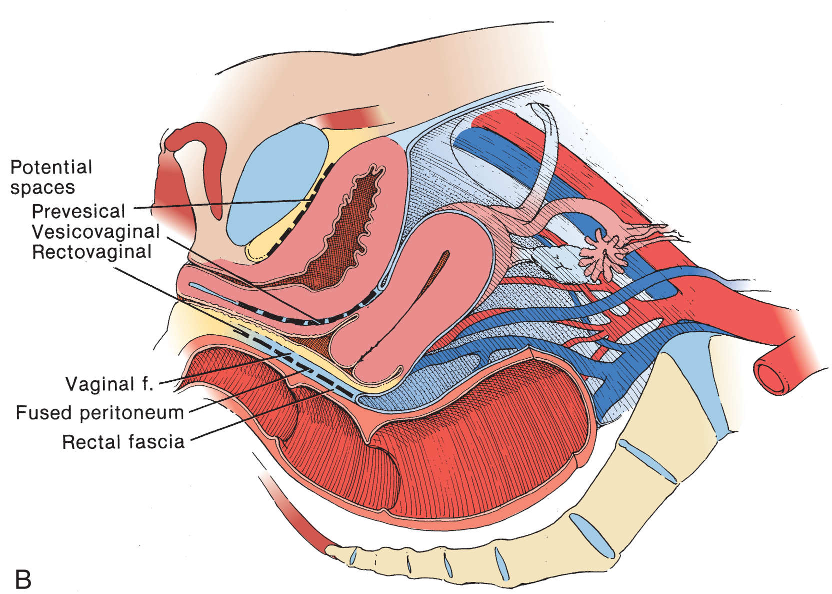


FIGURE 15-11.

space is contained anteriorly by the adventitia of the bladder, laterally by the vesical pillars, and posteriorly by the vaginal adventitia. The space is closed inferiorly by fusion of the vaginal adventitia with that of the distal urethra and ends superiorly with the fusion of the adventitia of the bladder with that of the vagina and cervix, forming the supravaginal septum or vesicocervical ligament. Above this point is another potential space, the *vesicocervical space*, which is a continuation of the vesicovaginal space above the septum; it ends at the peritoneal fold of the vesicouterine pouch.

The potential rectovaginal space lies between the layers of the inner stratum derived from the fused peritoneum of the rectovesical pouch (homologous with Denonvilliers' fascia in the male) and the rectal fascia derived from the inner stratum. Laterally, the rectal septum limits the space, and the peritoneal reflection of the rectouterine pouch forms the upper margin. The junction of the levator ani with the perineal body is the lower margin, similar to the termination of Denonvilliers' fascia in the male.

In addition to the spaces about the vagina, a retrorectal space is found in the midline between the rectal fascia (inner stratum) and the transversalis fascia (outer stratum) over the sacrum.

On either side, between the intermediate stratum and the transversalis fascia is a potential space that is divided transversely by the cardinal ligament into the paravesical space and the pararectal space.

The **prevesical space** lies between the endopelvic fascia derived from the outer stratum and the vesical fascia from the intermediate stratum (Fig. 15-11B). The **vesicovaginal space** has the vesical fascia on one side and the **vaginal fascia** on the other; both fascias are derived from the intermediate stratum. The **rectovaginal space** lies between the vaginal fascia (intermediate stratum) and the fascia from the inner stratum associated with the **fused peritoneum** in the rectovaginal pouch. The retrorectal space forms the dorsal compartment.

Ligaments of the Uterus and Adnexa, Semisagittal Section

The pelvic ligaments are fibrous condensations of the intermediate stratum of retroperitoneal connective tissue and are usually supplemented by fascias from the inner stratum underlying the peritoneum. Support for the female pelvic organs is provided by three levels of fascial condensation with or without muscular invasion. One is the fascia associated with the uterus and adnexa, consisting of the **round, broad, and cardinal ligaments** (Fig. 15-12). A second fascial complex supports the uterocervical region as the **anterior** and **uterosacral ligaments**. The third complex, associated with the bladder neck, is composed of the **pubovesical ligaments**. In addition, condensation of the fascias about the vessels and surrounding the pelvic organs provides support and potential spaces.

The **round ligament** arises anteriorly from the upper margin of the **uterus** and passes ventrolaterally to the internal inguinal ring. In combination with the **ovarian ligament**, it is homologous with the gubernaculum of the male. Posterior to the broad ligament is the infundibulopelvic ligament, which goes from the medial pole of the **ovary** to the lateral surface of the uterus just below the entrance of the **uterine tube**.

The broad ligament runs from the lateral wall of the uterus to the lateral pelvic wall. It is made up of two layers

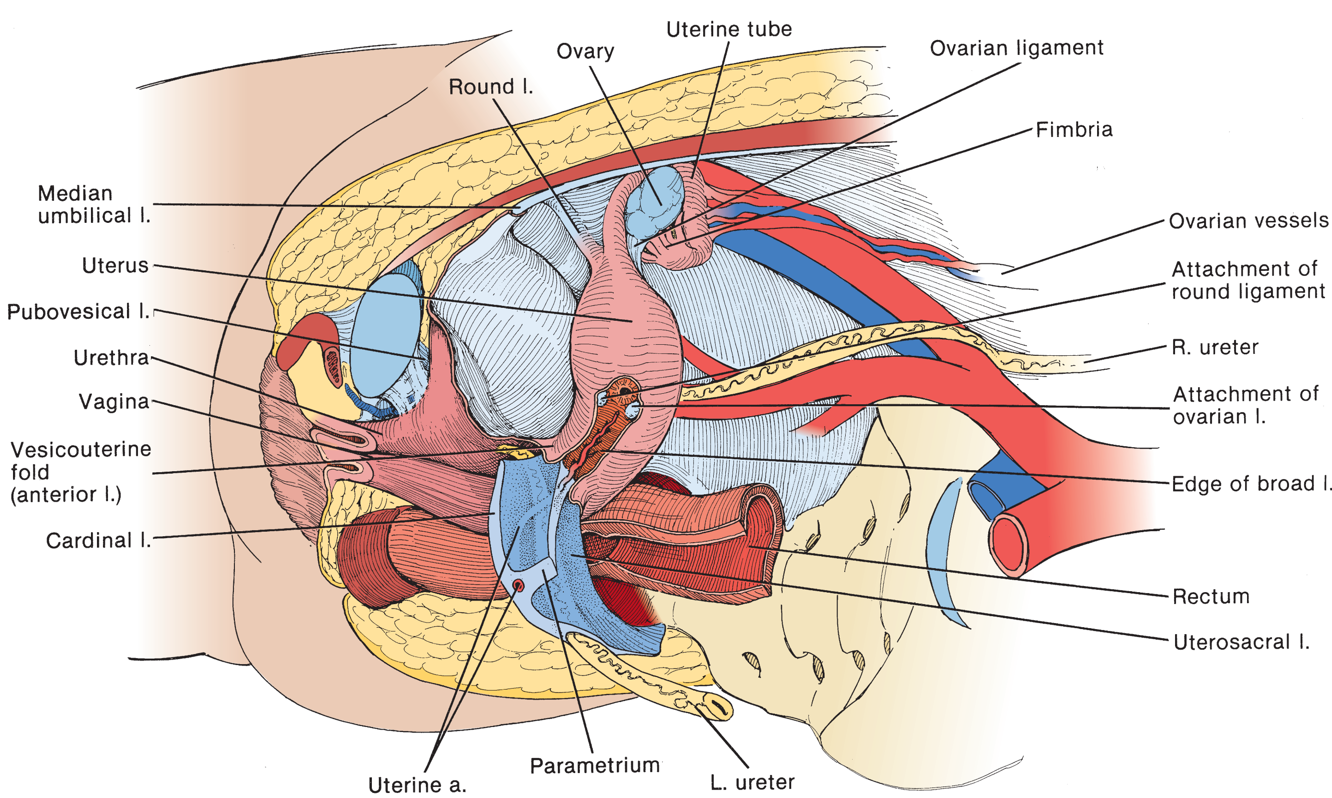


FIGURE 15-12.

of peritoneum and encloses the **parametrium** with the **uterine artery**, veins, and nerves, along with some smooth muscle and fibrous tissue. It also covers the lateral ligament of the ovary.

The infundibulopelvic ligament (suspensory ligament of the ovary) containing the ovarian vessels runs laterally with the broad ligament to the pelvic wall.

The **cardinal ligament** (transverse cervical ligament, Mackenrodt) attaches the cervix and vaginal vault to the fascia about the pelvic blood vessels. Through this ligament pass the major vessels from the internal iliac system, which are vessels that join the cervix and uterus at their lateral margins.

Ligaments of the Uterus and Cervix

The tissue underlying the peritoneal **vesicouterine fold** forms the **anterior ligament** that joins the uterus to the bladder at the junction of the cervix and uterine body. The posterior ligament is from the rectovaginal fold of peritoneum. The rectouterine folds run from the cervix on either side of the rectum to the posterior pelvic wall and form the **uterosacral ligaments**.

Ligaments of the Bladder Neck

The **pubovesical ligaments** (pubourethral ligaments) are homologous with the puboprostatic ligaments in the male. They are fibromuscular bands that extend from the periosteum of the inferior portion of the pubis to fuse with the smooth muscle of the detrusor at the urethrovesical junction.

These ligaments are composed of collagen intermixed with smooth muscle, especially at the vesical end, probably from their relation with the urogenital diaphragm. The smooth muscle is derived from the detrusor and has cholinergic innervation so that with detrusor contraction, the bladder neck may be held in place. The pubovesical ligaments are wider than the puboprostatic ligaments and are more often closely attached to the periurethral muscles and to the vagina, making the triangular space beneath them more shallow than in the male. The space contains the deep dorsal vein of the clitoris and the vesical venous plexus, as well as a small amount of areolar tissue.

Surgical Course of the Ureter

The **ureter** lies against the peritoneum in the intermediate stratum and so can be seen transperitoneally along most of its course. Only after it passes under the medial umbilical ligament (obliterated hypogastric artery) does it disappear from view (see Fig. 12-82) and become liable to injury.

The ureter is vulnerable to surgical injury as it crosses the infundibulopelvic ligament under the site of entrance of the **ovarian artery** and as it swings medially within 2.5 cm of the **uterine artery** (Fig. 15-13). It may also be injured as it passes through the **cardinal ligament** enclosed in the uterine venous plexus, where it lies within 1.5 cm of the **cervix** itself (Fig. 15-14 shows another view).

Blood Supply, Lymphatic Drainage, and Innervation

Blood Supply, Posterior View

Arterial Supply

The **ovary** is supplied by the **ovarian artery**, which arises from the aorta below the renal arteries. It passes in the **infundibulopelvic ligament** to the mesovarium to enter the **hilum** of the ovary (Fig. 15-14). The artery continues in the **broad ligament**, first supplying the uterine tube and then joining the **uterine artery**.

Blood to the **uterus** comes from the uterine artery, a branch of the anterior trunk of the internal iliac artery. This is a surgically important vessel because it crosses the ureter 2 cm from the **cervix**. It provides a small **branch** to the ureter. On reaching the uterus, the artery takes a tortuous course in the **broad ligament** to reach the site of entry of the uterine tube and then runs laterally to reach the ovary, where it joins the ovarian artery. It also passes caudally to supply the cervix. Branches go to the **vagina** as the vaginal

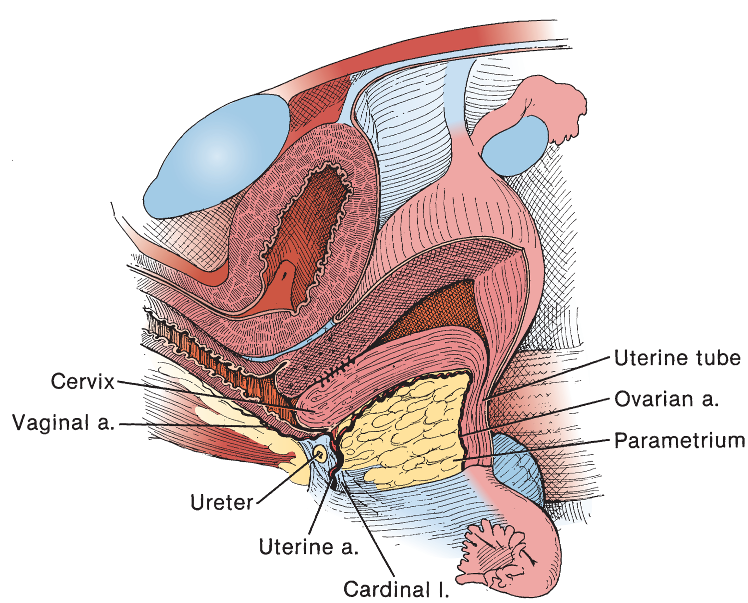


FIGURE 15-13.

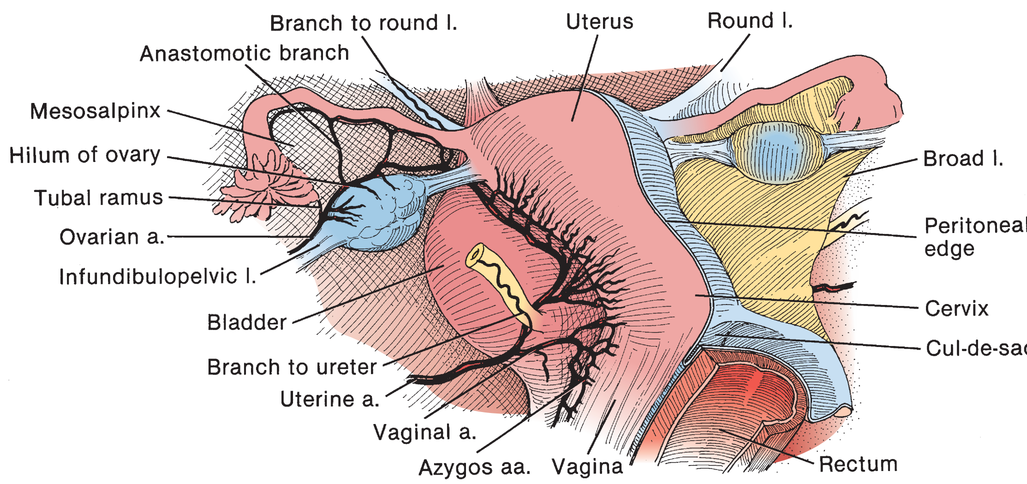


FIGURE 15-14.

artery and terminate as the **azygos arteries of the vagina**. These run longitudinally on the anterior and posterior aspects of the vagina. Within the uterus, very tortuous (helicine) arteries form the arterial termination. Anastomoses are present between the uterine and ovarian arteries and between the right and left uterine arteries above and between the vaginal arteries below.

The **vaginal artery**, which is often represented as multiple branches, takes a course similar to that of the male inferior vesical artery to supply the upper portion of the vagina, the bulb of the vestibule, the fundus of the bladder, and the adjacent rectum. It also may provide a small branch to the terminal ureter. The blood supply to the upper portion of the vagina is from vaginal branches of the uterine artery, and that to the mid-portion is from the vaginal branches of the middle rectal artery. The distal portion is supplied from the internal pudendal artery.

Venous Drainage. Drainage from the *ovary* is by a venous pampiniform plexus formed outside the ovarian hilum. The vessels of the plexus merge to form an ovarian vein. The right ovarian vein empties into the lateral wall of the vena cava below the renal vein; on the left, the vein joins the left renal vein.

Drainage of the *uterus* is by uterine plexuses that run on the lateral side of the uterus in the broad ligament and connect with the vaginal and ovarian plexuses. These lead the venous drainage through the uterine vein into the internal iliac vein.

The vaginal plexuses run on the lateral sides of the *vagina* to join the uterine, vesical, and rectal plexuses and drain into the internal iliac veins.

Lymphatic Drainage

The lymphatic drainage of the *ovary* accompanies that of the **ovarian artery** and, as with that of the testis, goes to the **lateral aortic** and **preaortic nodes** at the level of the kidneys (Fig. 15-15).

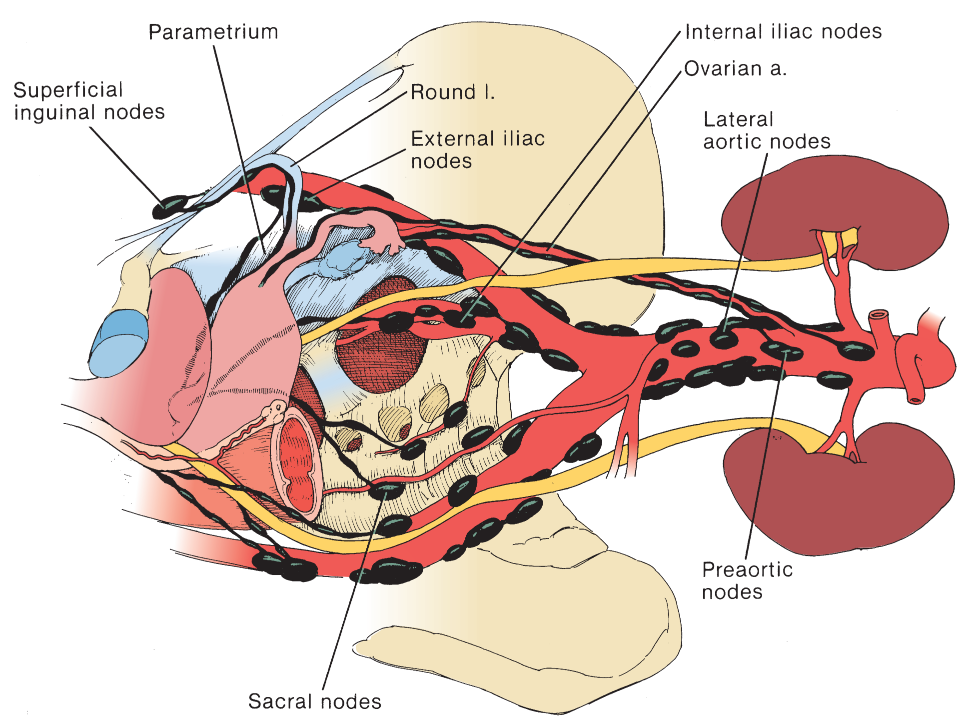


FIGURE 15-15.

The *cervix* drains into the **external iliac nodes** by channels in the **parametrium** and into the **internal iliac nodes**, as does the lower part of the uterine body. The cervix is also served by the **sacral nodes** and the rectal nodes.

Drainage channels from the *uterus* lie in a superficial system under the peritoneum and in a deep system from the uterine substance. From the upper part of the uterus and the uterine tubes, lymph vessels run with those of the ovary to the **lateral aortic** and **preaortic nodes**. From the tissue in the region of the attachment of the round ligament, lymphatic vessels run to the **superficial inguinal nodes**. Lymph from the uterine body drains into the **external iliac nodes**. The fundus is drained, with the ovary and uterine tube, by vessels along the course of the ovarian artery into the para-aortic and lateral aortic nodes.

The upper portion of the *vagina* drains in lymphatics along the uterine artery to the external iliac nodes and the middle part via the vaginal artery to the internal iliac nodes. Lymphatics from the lower part of the vagina go with the vulvar lymphatics to both the superficial and deep inguinal nodes.

Innervation

The relationships among the nerve plexuses supplying the internal genitalia are shown in Table 15-2.

The *ovary* is innervated by the ovarian plexus along with nerve fibers from the inferior mesenteric plexus that follow the ovarian artery.

Innervation of the *uterus* is through the uterovaginal plexus as part of the pelvic (inferior hypogastric) plexus. The pelvic splanchnic nerves transmit sensation to the S2 and S3 levels and efferent fibers come from the T11 and T12 levels.

The *vagina* is innervated by nerves from the uterovaginal plexus, which extends from the lower part of the pelvic plexus. The pudendal nerve provides sensory innervation to the distal part.

Urethral Structure

Urethral Wall

The length of the female urethra is about 4 cm; its internal diameter averages 0.4 cm during micturition and may measure up to 1 cm (30°F) when stretched (Fig. 15-16). When the urethra is empty, the lining is forced into longitudinal folds that effectively obliterate the lumen, with the mucosa acting as a seal against incontinence. A crest rises in the

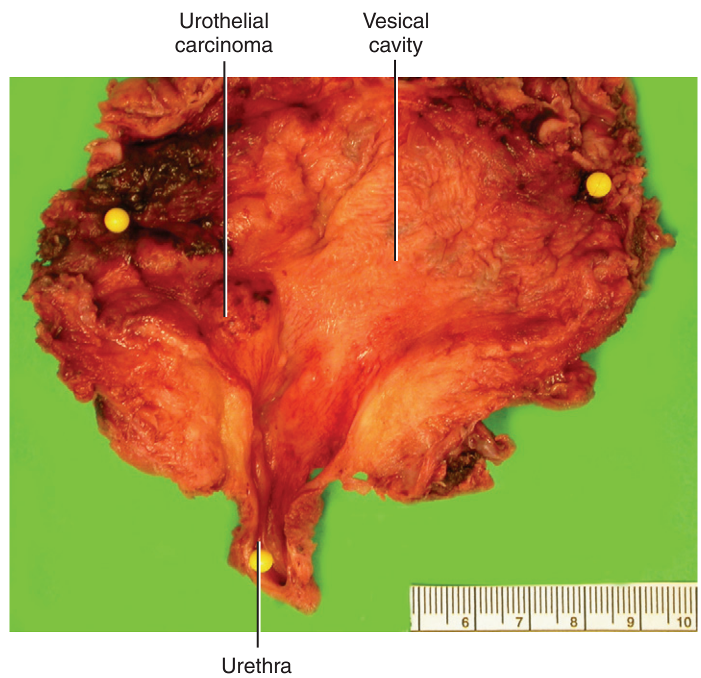
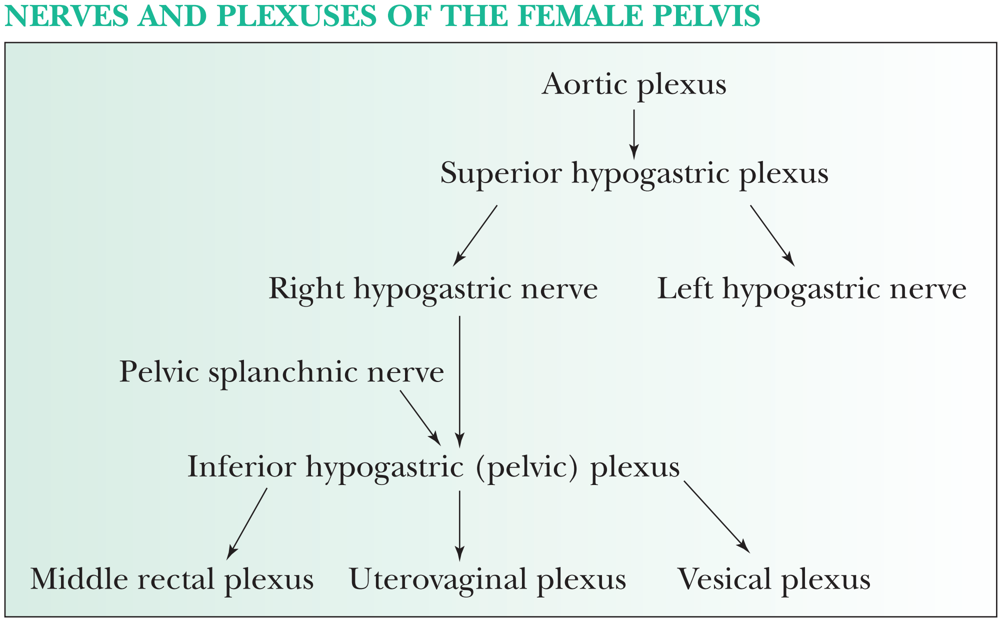


FIGURE 15-16. Photograph of a cystectomy specimen from a female with urothelial cancer, illustrating the typically thin detrusor muscle in females. Urethra is at bottom.

TABLE 15-2 NERVES AND PLEXUSES OF THE FEMALE PELVIS



proximal urethra posteriorly in the midline to shape the lumen like a crescent; with age, it gradually flattens out.

The **internal meatus** lies at the bladder neck, where it merges with the lining of the bladder (Fig. 15-17A). From there, the urethra runs anteroinferiorly to its midportion, where it penetrates the perineal membrane, then runs in a slightly more horizontal course behind the symphysis pubis to the **external meatus**.

When filled during urination, the lumen is narrow at the internal meatus, widens in the area lying above the perineal membrane, narrows slightly as it passes the sphincteric structures of the perineal floor, widens again at the female equivalent of the fossa navicularis, and finally narrows into a more or less vertical slit at the external meatus.

Numerous orifices of urethral glands lie in the dorsolateral portion of the distal third of the urethra. Later in development, pitlike depressions (lacunae) that are sometimes lined with glandular epithelium, appear in the middle and proximal urethra. A more or less distinct pair of paraurethral ducts (Skene's ducts) run submucosally on either side of the urethra and open laterally inside the meatus. Each duct drains a large group of paraurethral (Skene's) glands, which may be considered homologous with the glands in the preprostatic portion of the male urethra. The urethral orifice with its slightly protruding margins lies in the vestibule on the fourchette just above the vaginal introitus and about 2.5 cm below the glans clitoridis.

Thin-walled tortuous veins running longitudinally under the epithelium are interspersed among elastic fibers; they are especially prominent in the proximal third, forming a **proximal venous plexus** and, in the distal few millimeters, the **distal venous plexus**. This arrangement probably plays a role in urethral closure, supplementing the seal produced by intrinsic urethral softness. Numerous small arteriovenous aneurysms appear in the plexuses during the fertile period of life.

The urethral **mucosa** is composed of pseudo-stratified columnar epithelium, with some transitional epithelium near the bladder and stratified squamous epithelium near the external meatus (Figs. 15-17B and 15-18). The hormonal status of the subject plays an important role in epithelial type and distribution. By scanning electron microscopy, the cells of the more proximal region show microplicae; the more distal cells have microvilli like those of the vagina.

The **lamina propria** (submucosa) contains numerous elastic fibers that are partially arranged in circular but principally in longitudinal directions. Small bundles of smooth muscle may be found in the urethral crest, representing an extension of the superficial trigone.

Urethral Sphincters

The muscular, and consequently the functional, anatomy of the female urethra has been extensively studied, with each student tending to contribute an individual interpretation. At the present time it is possible to get only a general consensus from this work.

The urethral sphincters are the *smooth muscle* internal *sphincter* and the *striated urogenital sphincter*.

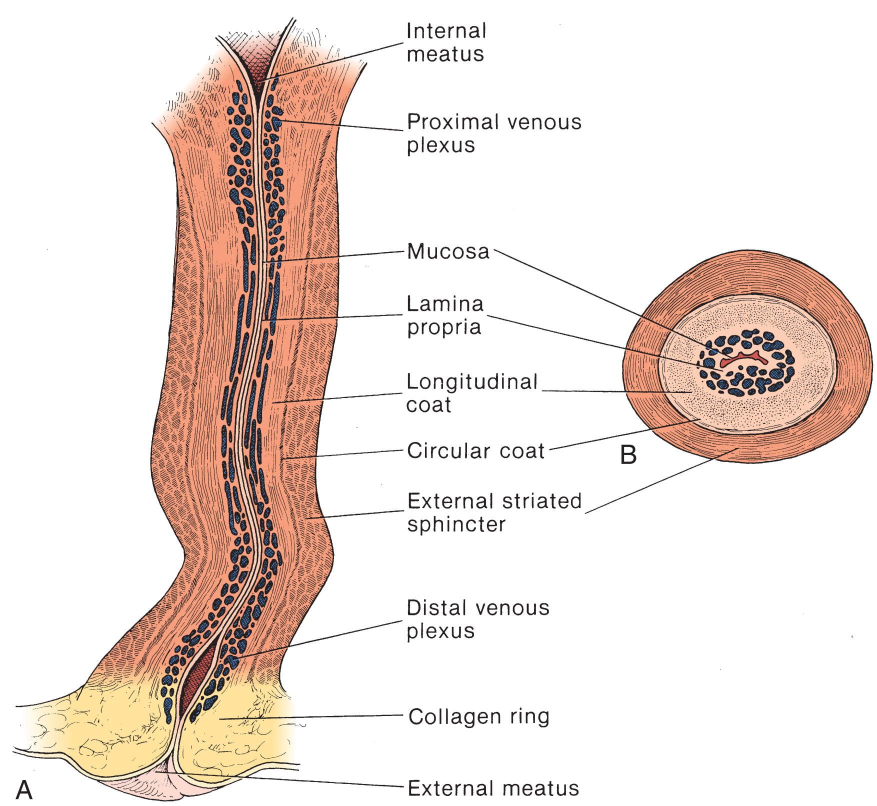


FIGURE 15-17.

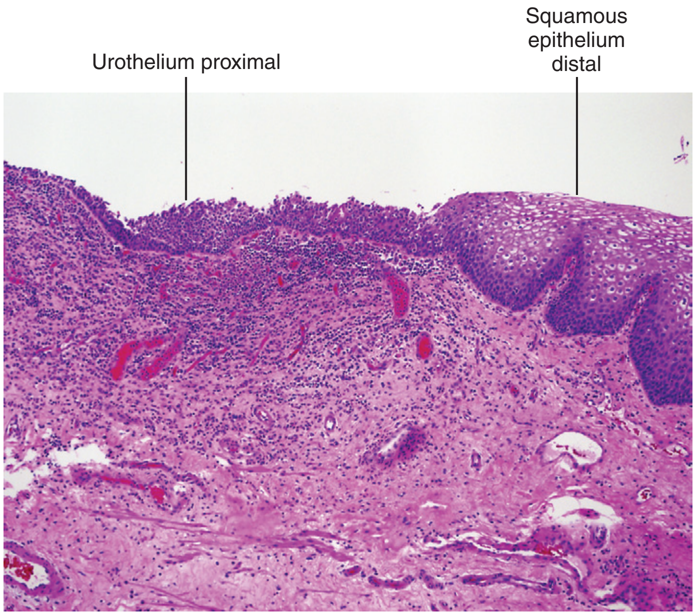


FIGURE 15-18. Photomicrograph of urethral mucosa in a female. Transitional epithelium lines the proximal third and nonkeratinizing stratified squamous epithelium lines the distal two-thirds of the female urethra. The lamina propria is richly vascular and is infiltrated in this case by abundant chronic inflammatory cells.

SMOOTH MUSCLE SPHINCTER

Although structurally there is no true sphincter at the bladder neck or within the urethra, a functional sphincter is present, made up of smooth muscle, collagen, and elastic fibers.

The smooth muscle sphincter has two coats, a dominant inner **longitudinal coat** and a sparse outer **semicircular coat**, that invest it from the neck of the bladder to just within the meatus. The inner longitudinal layer joins the inner longitudinal layer of the detrusor but is made up of much more delicate bundles. The muscle fibers are held together by elastic tissue and a large amount of firm collagen. The middle semicircular layer (probably from the outer longitudinal layer of the detrusor) appears to form loops at the bladder neck and provides fibers organized in a semicircular fashion down the urethra. The circular coat is more prominent in the mid-urethra, where the smooth fibers mix with the striated fibers of the external sphincter. Both coats decrease in thickness as they approach termination distally in the dense **collagen ring** immediately proximal to the meatus. In comparison with those in the male, the circular smooth muscle components are much less well defined, there being no structure in the female resembling the preprostatic sphincter in the male.

Collagen forms a major component of the urethra, occupying more of the tissue mass than does the smooth muscle. It, too, is oriented with the smooth muscle in both the longitudinal and circular layers. The collagen fibers associated with the circular muscle fibers are considered an important component of passive closure of the urethra, especially because they require no energy to maintain tone. Elastic fibers, composing a very small proportion of the total mass, play a minor role but help prevent overdistention with resulting tissue damage.

The smooth muscle sphincter surrounds a layer of spongy tissue, the spongiose erectile tissue (not homologous with the spongiosus in the male), which is composed of veins interspersed with smooth muscle and elastic fibers. Continence is maintained by the combined efforts of the smooth and surrounding striated urethral musculature that maintain the mucosal lining in apposition.

The *function* of the longitudinal fibers appears to be to shorten the urethra and thereby increase its diameter for voiding. The function of the relatively few circular elements may be to allow radial distention during voiding and to resist distention at other times; it is doubtful whether they have sphincteric capability. Of interest is the possibility that the two layers may have a different autonomic innervation.

Innervation is provided by cholinergic terminals, which are very similar to those of the detrusor. In contrast to the male urethra, few sympathetic nerves are present. The larger nerves are associated with muscle bundles and the smaller ones with individual muscle fibers. The adrenergic terminals in the female urethra and bladder neck are sparse, with a density similar to that found in the male bladder neck.

STRIATED UROGENITAL SPHINCTER

Organization of the Striated Urogenital Sphincter

The striated musculature develops in three parts. One is the striated sphincter that surrounds the middle third of the urethra. A second is the urethrovaginal sphincter disposed about the more distal portion of the urethra and the vaginal vestibule. The third is a urethral compressor that passes over the ventral side of the urethra.

External Urethral Sphincter

The striated urethral sphincter, as in the male, is embryologically and anatomically separate from the surrounding striated musculature. The elements are not differentiated in the fetus, but they subsequently differentiate in the female as they do in the male, events that are described in Figure 14-9.

The striated urethral sphincter encircles the smooth muscle sphincter of the urethra from the bladder base to the perineal component without distinction of a urogenital diaphragm. It is attached to a dorsal raphe. The most dense collection of striated muscle fibers is found in the midurethra in the area of the high-pressure zone found on urodynamic study. Some fibers continue proximally to the bladder neck, and some connect with the vaginal wall or to the endopelvic fascia. The fibers are small and are of the slow-twitch variety that promote closure over long periods. The striated musculature is infiltrated with smooth muscle fibers, especially in the midportion, and with collagen and elastic tissue.

Periurethral Striated Musculature

The periurethral striated musculature forms a urethral compressor and a urethrovaginal sphincter (Fig. 15-19).

The **urethral compressor** portion crosses the perineum from an area near one ischial tuberosity to a similar area near the other. As it passes over the urethra, the band of muscle appears to rotate and become thicker, so that some of its fibers reach as far proximally as the distal margin of the striated urethral muscle. Functionally, contraction of this muscle would elongate the urethra by pulling the mid-urethra back and down at the same time that the levators were pulling the proximal part up.

A thin sheet of muscle, the **transverse vaginal muscle**, can be identified as part of the compressor that lies dorsal to it as it fills the space between it and the urethrovaginal sphincter.

The **urethrovaginal sphincter** is a flat muscle that merges ventrally with the urethral compressor and extends along the sides of the urethra and vagina to enclose them.

The **pubococcygeus**, composed of the most medial fibers of the levator system, abuts the urethra as it runs from the pubis past the lateral walls of the vagina to the coccyx. The pubococcygeus does not attach to the urethra but passes on either side. As with its counterpart in the male, it does not constitute a true sphincter, but it does contain both fast-twitch and slow-twitch fibers that function to increase resistance in the urethra.

The *innervation* of the striated urethral sphincter is somatic through the ventral root of the S3 spinal nerves, with some contribution from the S2 nerves. The nerve fibers run in branches of the pelvic (splanchnic) nerve that pass to the pelvic (inferior hypogastric) plexus. This is in contrast to the nerve supply to the urethrovaginal sphincter and urethral compressor, which, with the nerves to the pubococcygeus, is transmitted over the pudendal nerves, principally from the ventral roots of spinal nerve S2.

Urethral Vascular Supply

Arterial Supply

The blood supply to the upper third of the urethra is shared with the adjacent bladder. The supply to the remainder of the urethra and to the adjacent vagina is from the inferior vesical artery through the vaginal artery that runs along the superior lateral aspect of the vagina (see Fig. 15-14).

Venous Drainage

Blood from the urethra is carried through the inferior, middle, and superior vesical veins as well as through the clitoral plexus.

Lymphatic Drainage

Lymph from the distal urethra and adjacent vagina is carried via the vestibular plexus into the superficial and deep inguinal nodes. Because much of the urethra is closely associated with the vagina, lymphatic vessels from the middle third of the urethra and vagina accompany the vaginal artery. From the proximal urethra, lymphatics drain onto the anterior bladder wall to the external iliac chain; *onto* the lateral bladder wall to internal nodes of the external iliac chain, the internal iliac chain, and the obturator nodes; and *onto* the posterior surface of the bladder and into uterine channels.

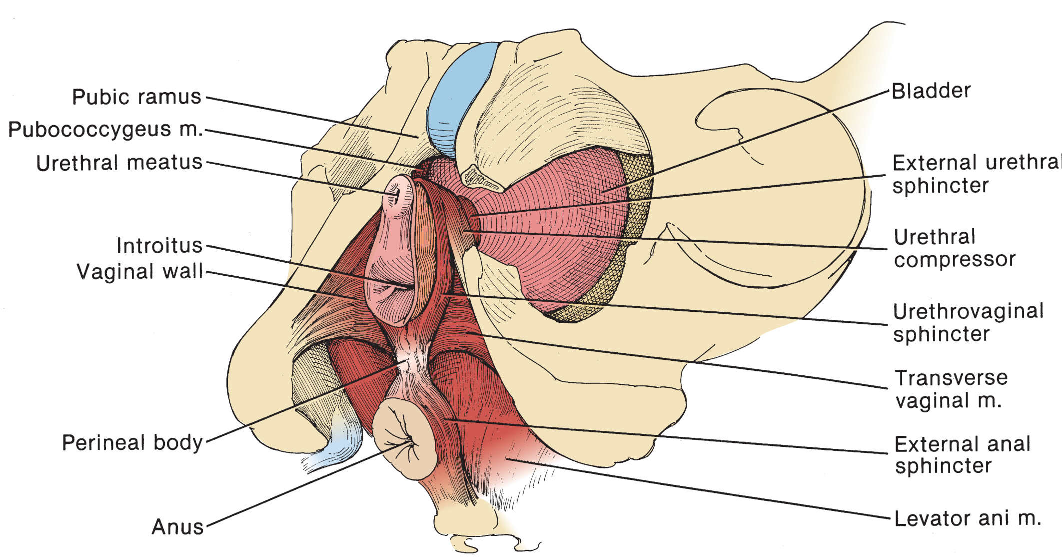


FIGURE 15-19.

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Chapter 16

Penis and Male Urethra

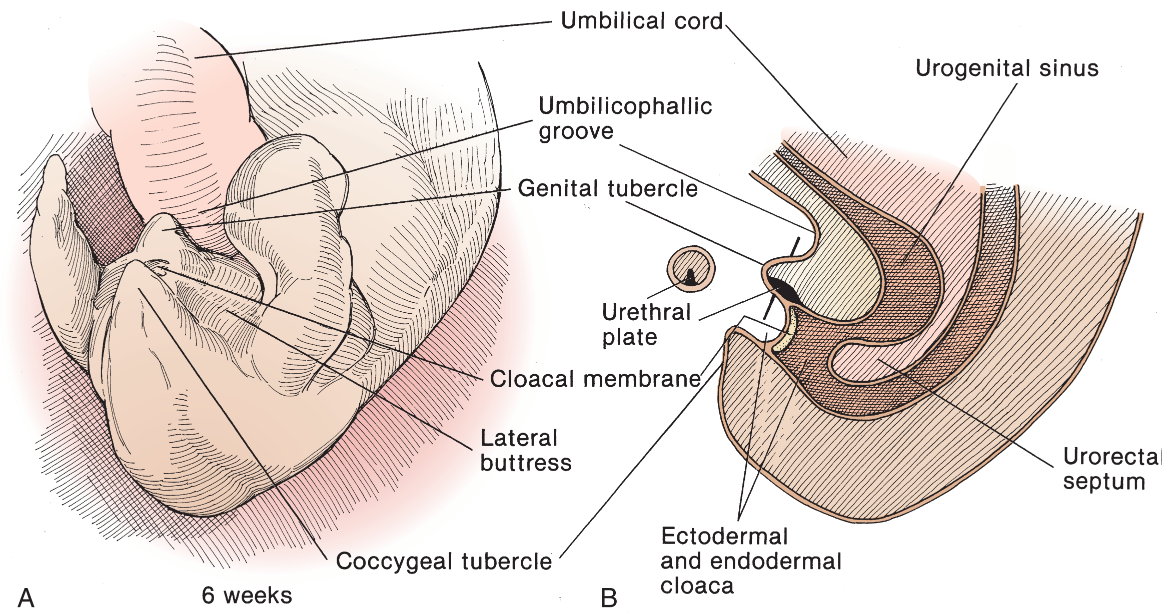


FIGURE 16-1.

Penis, the Yard, made up of two nervous Bodies, the Channel, Nut, Skin, and Fore-skin, etc.

BPD (ed.2) 1693.

DEVELOPMENT OF THE PENIS AND URETHRA

Early Stages of Genital Development

Cloacal Membrane and Genital Tubercle

The **cloacal membrane** is the inducer of developmental processes in the perineal region in early embryonic life. It is a patch of thickened endoderm and closely applied ectoderm without the usual intervening mesoderm that is positioned strategically at the caudal end of the embryo between the umbilical cord and the base of the tail. The outer, depressed region comprises the **ectodermal cloaca,** and the **endodermal cloaca** is the portion within the cloaca proper.

At 6 weeks, the **genital tubercle** appears as a wide cone. It has a gradual slope caudally where it is further amplified by **lateral buttresses,** structures destined to become the corporal bodies (Fig. 16-1A). The genital tubercle arises between the **coccygeal tubercle** at the end of the embryo and the **umbilical cord** at the umbilicus, from which it is separated by the **umbilicophallic groove** (Fig. 16-1B).

The descending **urorectal septum** will divide the cloaca into a **urogenital sinus** and an **anal canal** and, on contact with the cloacal membrane, stimulate it to divide into a urogenital membrane extending onto the undersurface of the genital tubercle and an anal membrane caudally (see Fig. 16-3). The anterior extent of development of the urogenital membrane is limited by the proximity of the genital tubercle to the umbilicus.

Genital Swellings, Tubercles, and Grooves

Paired **genital** (labioscrotal) **swellings** soon arise by the encroachment of the most caudal rim of mesoderm on either side of the **urogenital membrane,** forming thickened areas beside the genital tubercle that are separated from it by the **lateral phallic grooves** (Fig. 16-2).

The shallow **primitive urethral groove** forms on the caudal slope of the **genital tubercle,** flanked by the slightly

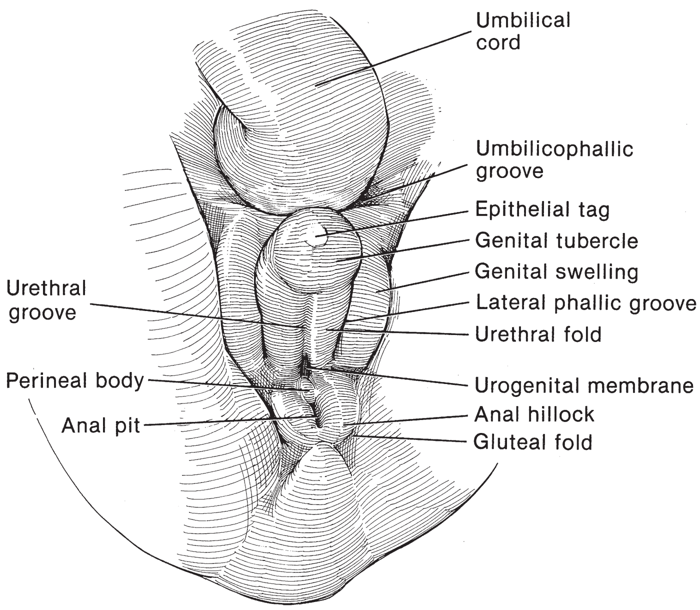


FIGURE 16-2.

elevated **urethral** (genital) **folds.** The tubercle is pushed into a vertical position by the widening **umbilicophallic groove** and is enlarged by incorporation of the lateral buttresses. Caudal to the urogenital membrane are two swellings, the **anal hillocks** (tubercles). These lie medial to the **gluteal folds** and are oriented about the **anal pit.** They are continuous with the urethral folds except for the intervening **perineal body.**

The lower abdominal wall is formed by further growth of mesodermal cells between the endoderm and ectoderm and will later acquire muscle cells from ingrowth of the mesodermal somites. This ventrally directed growth has the effect of rotating the plane of the urogenital membrane more into the long axis of the body.

In the interior during this time, the urogenital sinus, derived from the ventral part of the endodermal cloaca, becomes separated by the descent and coaptation of the urorectal septum (see Figure 13-7). The vesicourethral canal has been formed from the anterior portion of the urogenital sinus. The urogenital sinus develops into a short tubular *pelvic part* and a flattened *phallic part*. The pelvic part is the future site of the prostate; the phallic portion makes up the distal portion of the urethra. The overlying urogenital membrane becomes perforated in the urethral groove to form the urogenital orifice so that as the urethral groove deepens, it is in communication with the phallic portion of the urogenital sinus.

Up to this point, the male and female genitalia are essentially indistinguishable. One of the first signs of masculinization is an increase in the distance between the anus and the genital structures.

Male Differentiation

Genetic information from the short arm of the Y chromosome (the testis-determining factor gene) operating through the H-Y antigen influences the indifferent gonad in the second month to develop into a testis. In the absence of the Y chromosome, the gonad becomes an ovary. The testis, in turn, produces testosterone and müllerian-inhibiting substance, agents that influence development of the sexual ducts in the male direction. The testosterone produced by the interstitial (Leydig) cells causes the nearby wolffian (mesonephric) duct to form the epididymis, vas deferens, and seminal vesicles. The müllerian-inhibiting substance, coming from the Sertoli cells at the end of the second month, blocks the development of the müllerian ducts, which were destined to form the fallopian tubes, uterus, and the upper portion of the vagina.

Second, testosterone, produced by the interstitial cells in response to a surge of luteinizing hormone from the pituitary from the 6th to the 14th weeks, is converted to 5-dihydrotestosterone by the enzyme 5-alpha reductase, which is present in the cells of the external genitalia and urogenital sinus. This hormone, transported to the nucleus after binding to cytosol receptors, causes translation and transcription of the genetic material to promote male development of the genital swellings and folds and the genital tubercle. Later, testosterone itself, its production stimulated by maternal chorionic gonadotropin, enlarges the penis.

After significant elongation of the phallus, the first steps toward masculinization are the formation of the penile urethra from the urethral groove and the development of the prepuce.

Growth of the Genital Tubercle and Formation of the Urethral Plate

The **genital tubercle** grows over the ventral part of the **urogenital membrane** during the eighth week by the insertion of rapidly proliferating mesoderm in paired masses between its endodermal and ectodermal layers (Fig. 16-3A). The phallus is a simple tubular structure up to 9 weeks of gestation, at which time a circumferential **depression** appears that marks the site of demarcation of the glans. The depression deepens into the coronal sulcus, to be followed in 4 days by formation of the scrotal swellings from the genital swellings at the base of the phallus. As the phallus enlarges, its floor is formed by the urogenital membrane, beneath which is the **phallic part of the urogenital sinus.**

The **urethral plate** forms at the same time by the forward invasion of a strip of sagittally stacked endodermal cells into the solid mesodermal core of the genital tubercle. These come to lie just beneath the ectodermal surface epithelium.

A cut through **x–x′** shows the sagittally oriented endodermal **urethral plate** extending into the mesodermal body of the genital tubercle under the ectoderm over the phallic part of the urogenital sinus that is still closed by the urogenital membrane (Fig. 16-3B).

Enlargement of the Urethral Folds

Proliferation of mesenchyme on either side of the urethral plate raises the primitive **urethral folds.** The **urethral groove** develops between them as they become more prominent (Fig. 16-4). The folds also extend caudally alongside the cloacal membrane that lies in the depression of the external, ectodermal cloaca. By this time, the internal, endodermal

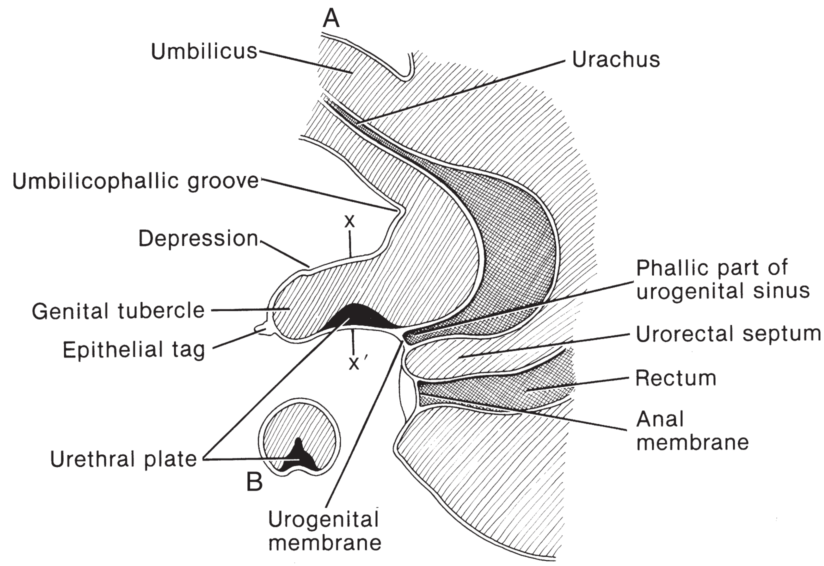


FIGURE 16-3.

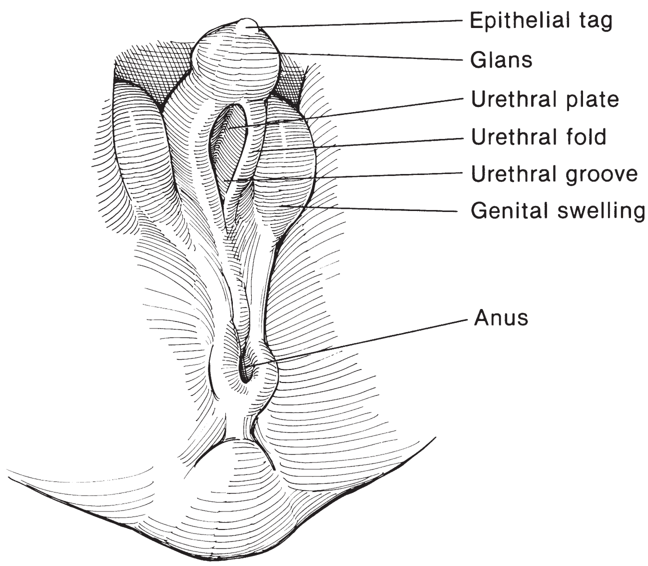


FIGURE 16-4.

cloaca is divided by the formation of the urorectal septum (see Figure 13-7).

The **genital swellings,** destined to form the scrotum, enlarge and appear to move caudally.

Formation of the Primary Urethral Groove, Transverse Sections

The **endodermal urethral plate** invades the **mesodermal core** of the primitive phallus that is covered by the **ectodermal surface epithelium** (Fig. 16-5A).

The primary urethral groove indents the urethral plate (Fig. 16-5B).

The overlying ectoderm in the groove regresses to expose the endoderm of the urethral plate (Fig. 16-5C).

The edges of the urethral plate become attached to the ectodermal margin of the groove. The breakdown of the central endoderm of the plate increases the depth of the groove, forming the secondary (definitive) urethral groove, which is lined by endoderm and flanked by the ectodermal urethral folds (Fig. 16-5D).

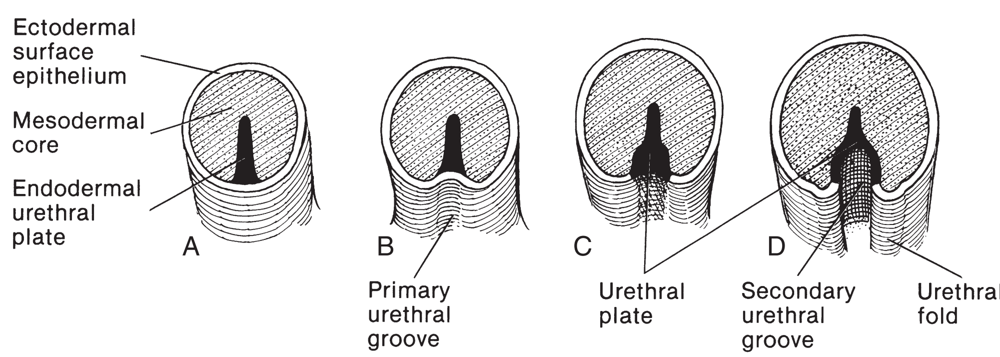


FIGURE 16-5.

Developing Urethral Groove

The **urethral plate** extends within the mesenchyme of the phallus. Its partial degeneration forms the **secondary urethral groove** (Fig. 16-6).

Enclosure of the Urethra

The ectoderm lying over the **urethral plate** regresses, exposing the **secondary urethral groove** lined by the endodermal **urethral plate** (Fig. 16-7A). Beginning near the anus, the adjacent ectodermal **urethral folds** fuse over the urethral plate to form the penile urethra, with the distal urethra (at the coronal sulcus) being the last to close.

In a section through **x–x′** in Figure 16-7A, the endodermal urethral plate is seen enclosed as the lining of the **penile urethra** (Fig. 16-7B). The site of fusion of the urethral folds forms the **perineal raphe,** an ectodermal formation (Figs. 16-8 and 16-9). The endodermal urethra now lies within the mesoderm, which, in turn, is enclosed in ectoderm.

The mesenchyme within the urethral folds forms the corpus spongiosum after their fusion. It develops separately from the erectile tissue of the glans.

Formation of the Glanular Urethra

The glanular segment of the urethra that will be part of the fossa navicularis is formed later than the urethra in the shaft and by a different mechanism.

A groove does form on the undersurface of the glans, but only the proximal part of it is reached by the endodermal **urethral plate** as it progresses down the shaft (Fig. 16-10A). Thus, because the plate does not extend all the way to the tip of the glans, it will form only the proximal portion of the glanular urethra, leaving the terminal portion to be formed differently.

A plug of ectoderm from the tip of the glans invades the mesenchyme as an **ectodermal intrusion.**

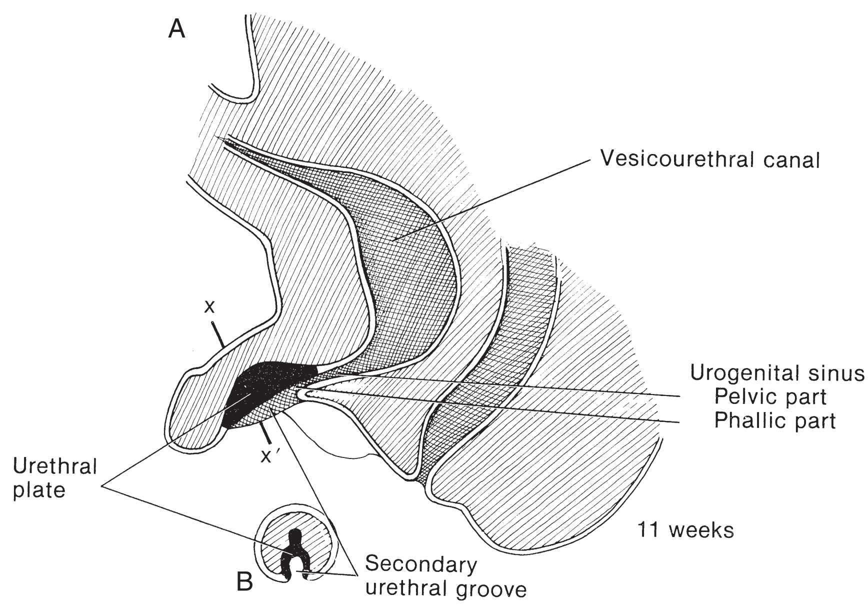


FIGURE 16-6. A, Sagittal section. **B,** Transverse section through line x-x′ at 11 weeks.

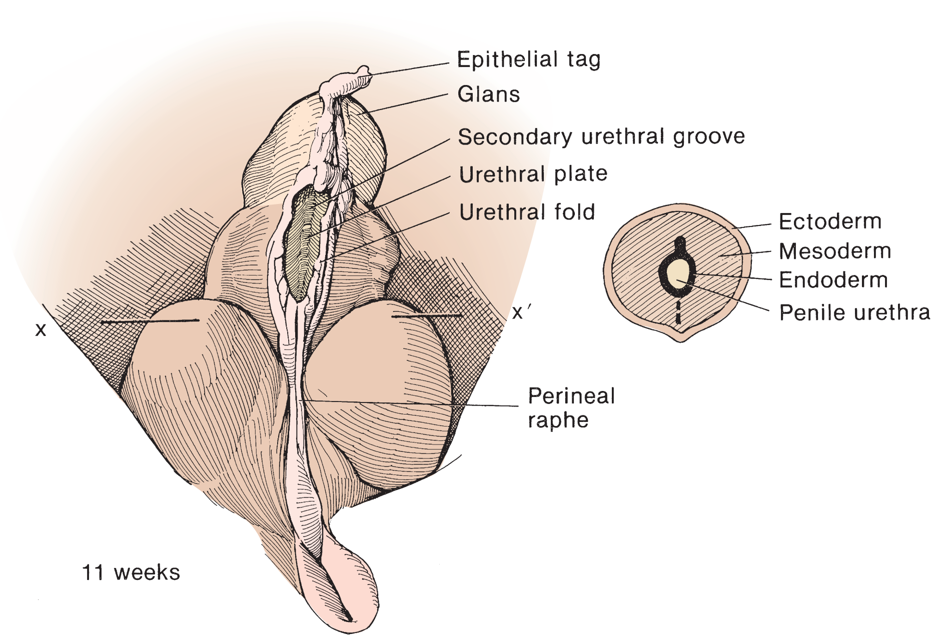


FIGURE 16-7.

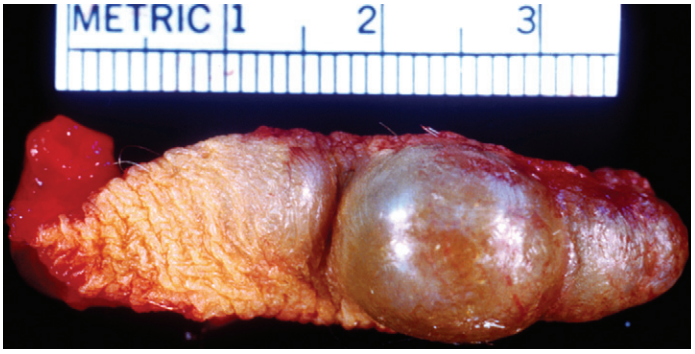


FIGURE 16-8. Median raphe cyst. This is a midline developmental cystic lesion that may be unilocular or multilocular. It presents as a solitary nodule on the ventral surface of the penis, or in the midline median raphe of the scrotal skin, as in the case shown here. *(From MacLennan GT, Resnick MI, and Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

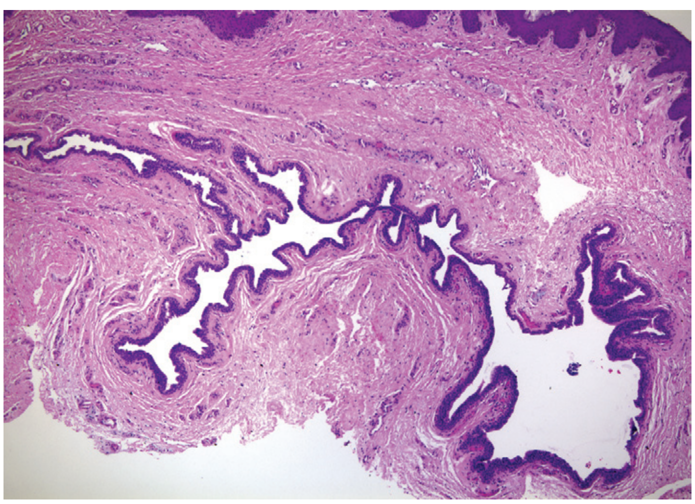


FIGURE 16-9. Median raphe cyst. The cyst is lined by pseudostratified columnar epithelium. Such cysts often contain mucinous material. *(From MacLennan GT, Resnick MI, and Bostwick D: Pathology for Urologists. Philadelphia, Saunders, 2003.)*

As the ectoderm invades more deeply into the glans, it develops a **lumen** at the same time that the **urethral folds** enclose more of the **urethral plate** (Fig. 16-10B). The ventral segment (marked **VS**) of the proximal end of the invading ectodermal intrusion comes to lie dorsal to the distal extremity of the advancing urethral plate.

The primary urethral folds proliferate and close over the groove (Fig. 16-10C). The floor of the ectodermal intrusion makes contact with the end of the urethral plate that forms the roof of the advancing urethra and the intervening double wall breaks down. This places the new ectodermal lumen in continuity with the proximal, endodermal portion of the urethra.

In this way, the dorsal wall of the fossa navicularis is composed of ectoderm and the ventral wall, endoderm, an explanation of why stratified squamous epithelium (from ectoderm) is found in this most distal portion, even though transitional epithelium (of endodermal origin) lines most of the urethra. The abortive urethral depression seen at the normal meatal site in hypospadias and the fish-mouth meatus may be explained by abnormalities of ectodermal intrusion.

Should the tissue lying between the ectodermal ingrowth and the outgrowth of the urethral plate be incompletely resorbed, a diverticulum is left on the anterior wall. This will form the lacuna magna or sinus of Guérin. The sinus lies under a flap, the valve of Guérin, that is covered on both sides by squamous epithelium.

Frenulum

The urethral folds are continuous with the glandar lamella that initiates development of the prepuce. As the folds join at the base of the glans, the margins of the lamella are fused to the preputial folds, forming the **frenulum.**

Corporal Bodies

During the third month, the primitive mesenchyme that produced phallic growth begins differentiation into the corporal bodies. The corpora cavernosa of the penis develop from densely packed cells of the initially paired genital tubercles, and the corpus spongiosum and glans are formed from the caudal end of the urogenital sinus and the paired urethral folds. These bodies later become perforated by vascular passages that form erectile tissue.

Until the 14th week, no difference is noted between the phallus of the male and female fetus, even though appreciable sexual differentiation has already occurred. After that time, the penile growth rate in males becomes linear, so that at birth the stretched length of the penis is 3.5 cm, with a diameter of 1.1 cm.

Origin of the Prepuce

Formation of the Preputial Folds

At about 8 weeks of gestation, low **preputial folds** appear on both sides of the penile shaft, which join dorsally to form a flat ridge at the proximal edge of the corona. The ridge does not entirely encircle the glans because it is blocked on the ventrum by the incomplete development of the glandar urethra (Fig. 16-11A). Simultaneously with the formation of the ridge, epithelium proliferates into the base of the fold. This is the so-called **glandar lamella**, which is an actively proliferating layer many cells thick at its proximal margin (Fig. 16-11B).

Within a week, proliferation of the lamella rolls the preputial folds progressively over the base of the glans to form a **preputial groove** between the corona and the nascent prepuce.

Proliferation of the Glandar Lamella

In the proximal part of the preputial groove, epithelial cells of the **glandar lamella** (stippled) grow to form a shelf between the **preputial fold** and the **glans** (Fig. 16-12A).

As the preputial folds are pushed distally, the **epithelial tissue** of the lamella remains most active at the proximal end, the base of the groove (Fig. 16-12B). That the process is not one of fusion is shown by the fact that the more

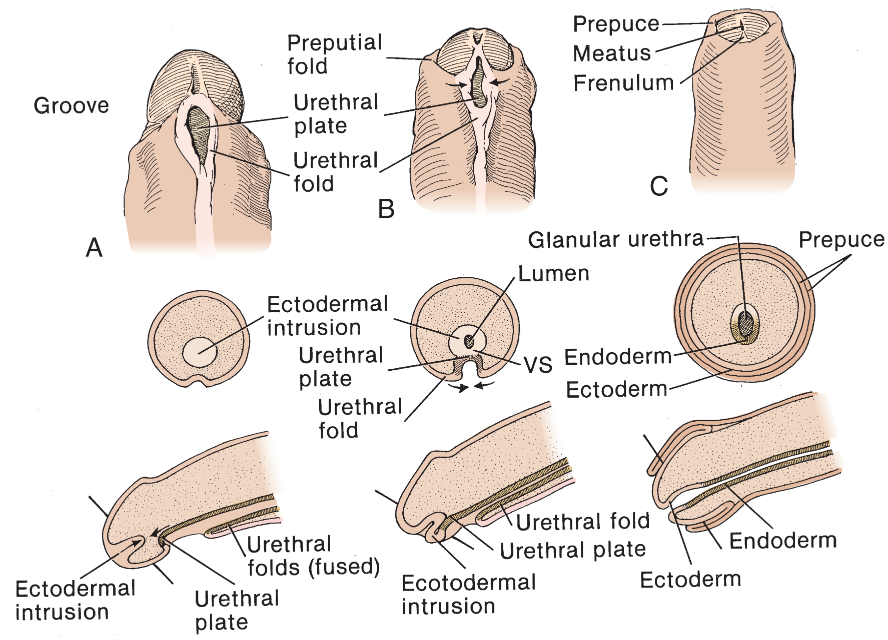


FIGURE 16-10.

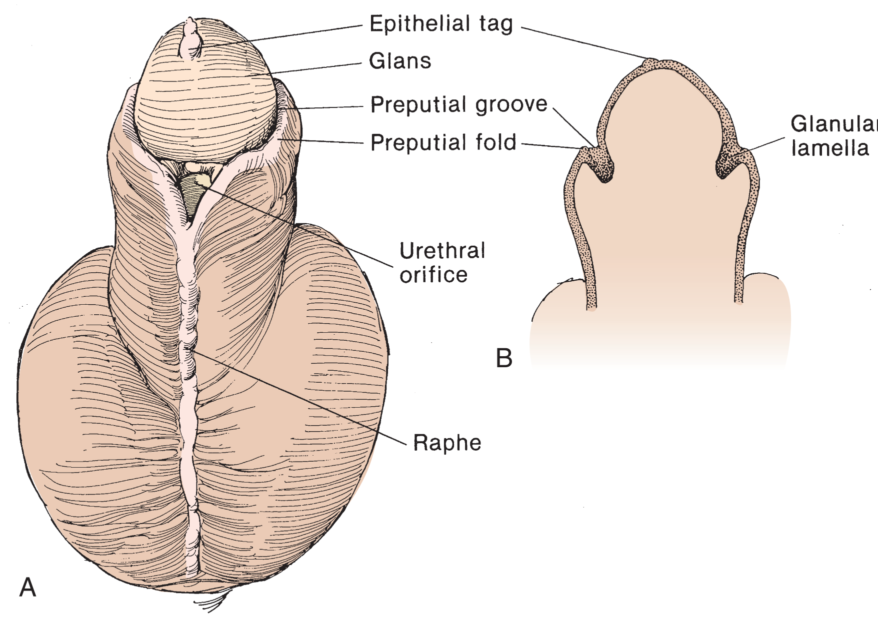


FIGURE 16-11.

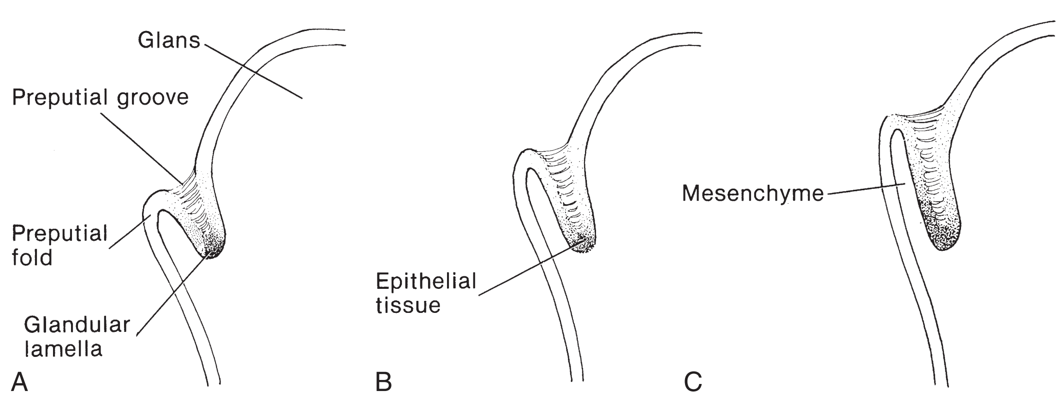


FIGURE 16-12.

proximal part of the glandar lamella is always less differentiated than the more distal parts.

The **mesenchyme** lying between the epithelium of the preputial fold and the glandar lamella becomes active in conjunction with the lamellar epithelium and is incorporated between the margins of the glandar lamella as the preputial fold and the ventral margin of the glandar lamella are carried onto the glans with it (Fig. 16-12C). Thus, the preputial fold is transported distally by active growth of the mesenchyme between the folds as well as by the rapid proliferation of the ectoderm of the glandar lamella. The process continues until the preputial fold covers all of the glans except for the ventral portion, which is blocked by the late closure of the urethral groove.

Covering of the Glans

By the time the fetus reaches 12 weeks of age, the distal urethra has formed and the flattened **preputial fold** not only covers the entire glans but, because of continued mesenchymal proliferation, extends beyond it (Fig. 16-13).

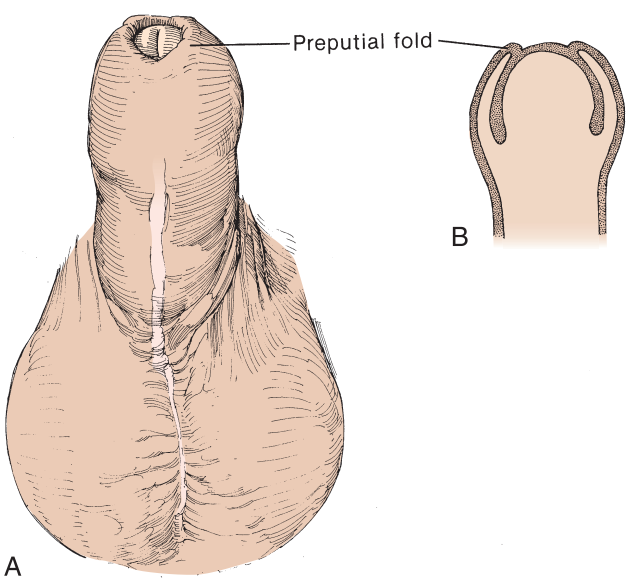


FIGURE 16-13.

Separation of Prepuce and Glans

The single **epithelial layer** between the **prepuce** and the **glans** forms epithelial pearls that start its degeneration into two layers (Fig. 16-14A).

The separation starts distally, forming the **glandopreputial space** and it continues to the time of birth (Fig. 16-14B).

Development of the Corpora

The *corpus spongiosum* is formed from the mesenchyme carried ventrally with the urethral folds and remaining after their fusion.

The unorganized mesenchyme of the paired bodies of the *corpora cavernosa* at first is supplied by capillaries. Dorsal vessels develop from the capillaries to become recognized as the dorsal arteries and deep dorsal vein by the 13th week. Two weeks later, the peripheral cells differentiate into the tunica albuginea, and those centrally distributed become organized into trabeculae. The erectile tissue of the glans itself is formed separately. The adult structure of the penis is formed in the newborn period, with the aggregation of smooth muscle and elastic tissue around the cavernous spaces.

Female Genital Differentiation

Differentiation of Female External Genitalia

Other than an increase in the distance between the anus and the genital structures, the most certain sign of male differentiation in the genitalia is the appearance of a longer urethral groove on the caudal slope of the male genital tubercle. The end of the indifferent stage at about 9 weeks also may be indicated by the formation of the perineal raphe through fusion of the urethral folds at the junction of the penis and scrotum and by the caudal migration of the genital swellings to form the scrotum. The formation of the posterior commissure is the comparable event in the female. Female sex may be even more definitely determined at about 10 weeks when the caudal curvature of the clitoris is apparent and no perineal raphe has developed. Compared with those in the male, the homologous genital structures in the female undergo relatively little change after the indifferent stage.

In the indifferent stage, the noncurved *phallus* has a **recess** at the site of the future coronal sulcus (Fig. 16-15A). The

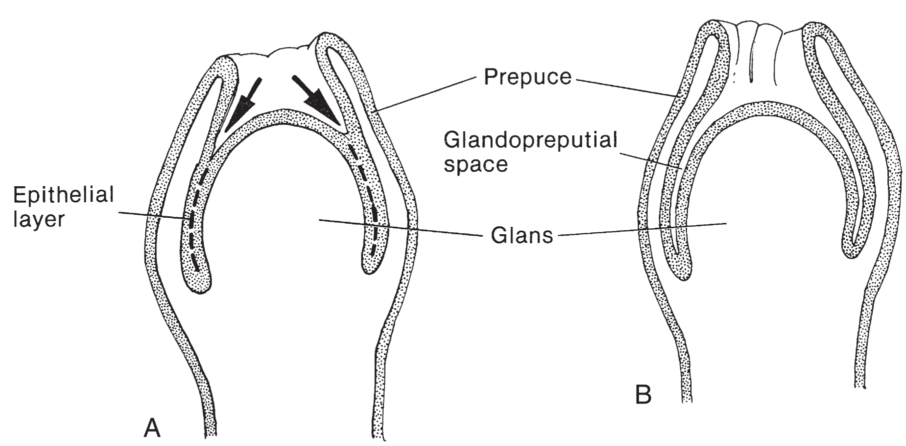


FIGURE 16-14.

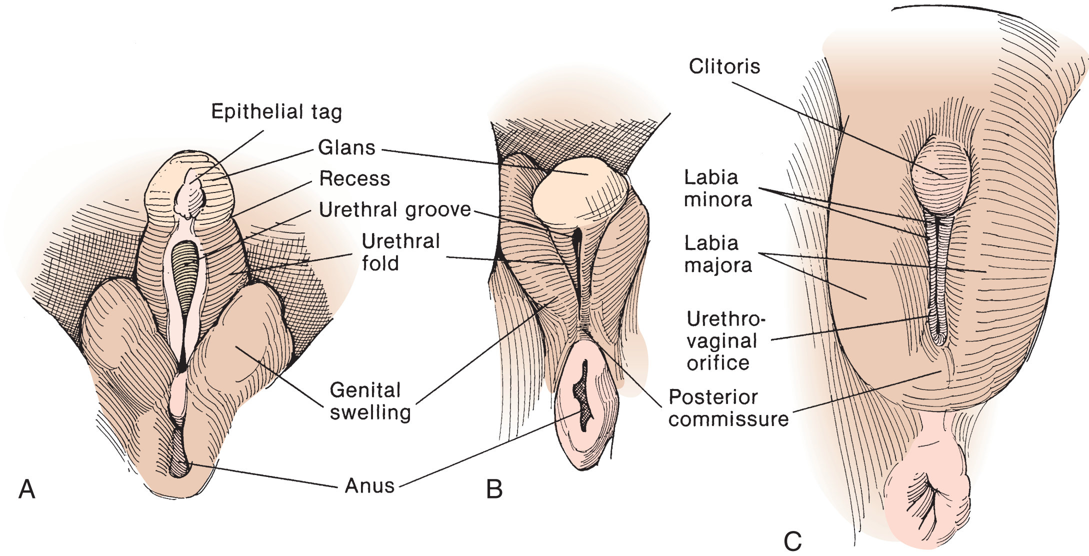


FIGURE 16-15.

urethral folds are present on either side of the **urethral groove.** The glanular portion has an **epithelial tag.** The **genital swellings** lie midway between the phallus and the perineum.

By 8 weeks, the *phallus* appears to recede as the **genital** (labioscrotal) **swellings** surround it and as greater growth of cavernous tissue compared with that of urethral tissue produces downward curvature (Fig. 16-15B). The **urethral groove** ends at the posterior commissure.

The caudal ends of the **genital swellings** that are to become the **labia majora** fuse to form the **posterior commissure,** and the **urethral folds** elongate to become the **labia minora** (Fig. 16-15C). The persisting primary urogenital opening remains as the **urethrovaginal orifice.** Differentiation is virtually complete by 20 weeks.

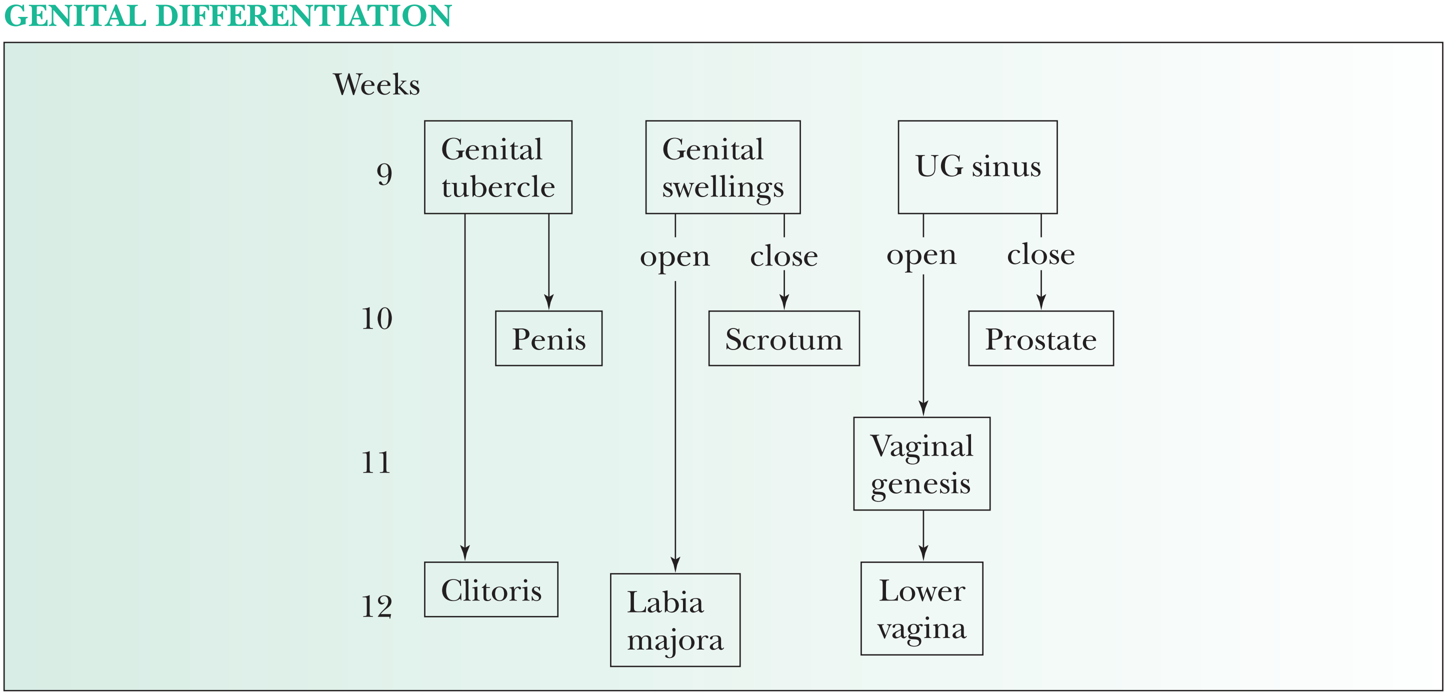
Female Prepuce

The development of the female prepuce is similar to that in the male, although it is formed more slowly and in more complicated steps. One difference is that, although three glandar lamellae are formed, only the middle one evolves like the male counterpart, and then it does not extend over more than half the circumference. For that reason, the frenulum is very wide. The urethral groove prevents fusion of the urethral folds with the glandar lamella, leaving the prepuce covering only the dorsum of the clitoris.

Table 16-1 presents a comparison of male and female genital differentiation.

TABLE 16-1

GENITAL DIFFERENTIATION



Adapted from Gray SW, Skandalakis JE: Embryology for Surgeons. The Embryological Basis for the Treatment of Congenital Defects. Philadelphia, WB Saunders Co, 1972.

Female and Male Genital Homologies

At 9 *weeks*, the **urethral** and **genital swellings** and the **phallic tubercle** in the female have evolved to a degree similar to that of the male (Fig. 16-16A).

The **phallic tubercle** develops at a slower rate in the female than in the male and develops into a **clitoris** *at term* (Fig. 16-16B). The clitoris bends downward, in contrast to the perpendicular stance of the male phallus. It contains corpora cavernosa, but the corpus spongiosum remains vestigial except for the divided posterior portion, which remains as erectile tissue on either side of the vagina. The posterior ends of the **urethral folds** fuse, and the remaining portion develops into the **labia minora.** Incomplete fusion of the labia minora is occasionally seen. The labioscrotal folds from the **genital swellings** do not grow and fuse as in the male, but remain smaller and separated to form the **labia majora** joined only at the **posterior commissure.**

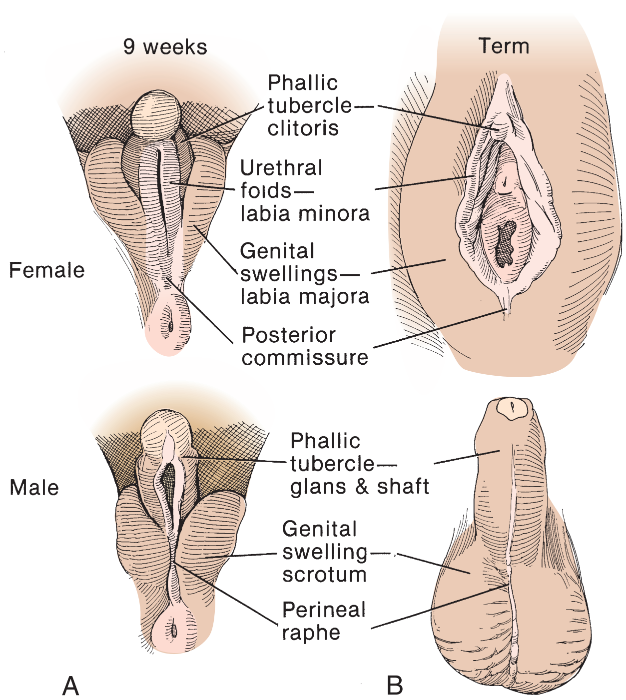


FIGURE 16-16.

Genital Anomalies

Epispadias

Epispadias results from failure of the mesodermal swellings to fuse in the midline in time, leaving a portion of the cloacal membrane exposed ventral to the genital tubercle. The defect in the urethra may be restricted to the dorsum of the penis (Fig. 16-17A). Rarely, the penile urethra and even the posterior urethra may be absent so that the opening lies at the neck of the bladder (Fig. 16-17B; Table 16-2).

Superior duplication of the urethra may be due to late fusion of the margins of an epispadiac urethral groove.

Exstrophy of the bladder and cloacal exstrophy are described in the chapter on the bladder in Figures 13-37 to 13-41, and bladder exstrophy is also illustrated in Fig. 10-5). Briefly, compared with epispadias, vesical exstrophy is the result of greater displacement and persistence of an abnormally large cloacal membrane that prevents ingrowth of mesenchyme.

Duplication of the clitoris is the rule in the female with vesical exstrophy, and failure of fusion of the müllerian ducts is commonly seen with more severe forms of cloacal exstrophy. In the male, the effects are more extreme. The penis is markedly bifid in cloacal exstrophy, although in milder cases of the anomaly, the findings are a short penis resulting from separation of the pubic rami and dorsal chordee secondary to a short urethra or urethral plate.

Hypospadias

Meatus. Hypospadias is a form of incomplete male differentiation that leaves the **meatus** lying proximal to its normal terminal position secondary to failure of the urethral groove to form or from its failure to close completely. The result is the exposure of the urethral plate that is covered with endodermal transitional epithelium. The short terminal portion that is lined by stratified squamous epithelium forms the blind pit that is found on the glans at the site of the normal meatus, a remnant of the intrusion of epithelium that normally occurs to form the distal part of the fossa navicularis (Fig. 16-18) (see also Fig. 16-10). In hypospadias, the urethra derived from the urethral plate has not been closed by the urethral folds far enough distally to reach this ingrowth.

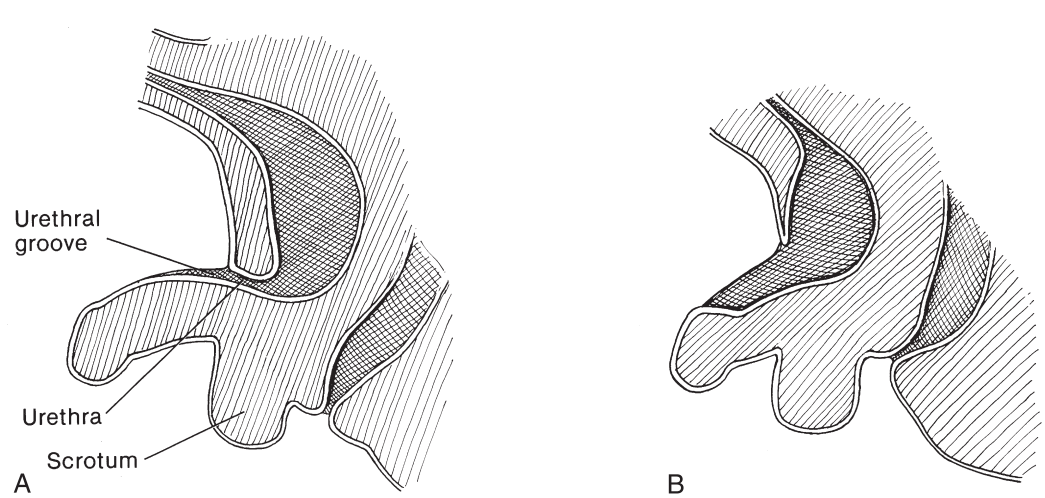


FIGURE 16-17.

TABLE 16-2

TIMING OF ANOMALIES OF THE EXTERNAL GENITALIA

Anomaly	Gestational Age (Weeks)
Agenesis of the penis	4
Agenesis of the glans penis	16
Defects of the corpus spongiosum and corpora cavernosa	12
Duplication of the penis	Various
Transposition of the penis and scrotum	9
Duplications of the penile urethra	10–14
Atresia and stenosis of the urethra	Various
Hypospadias	8 or later

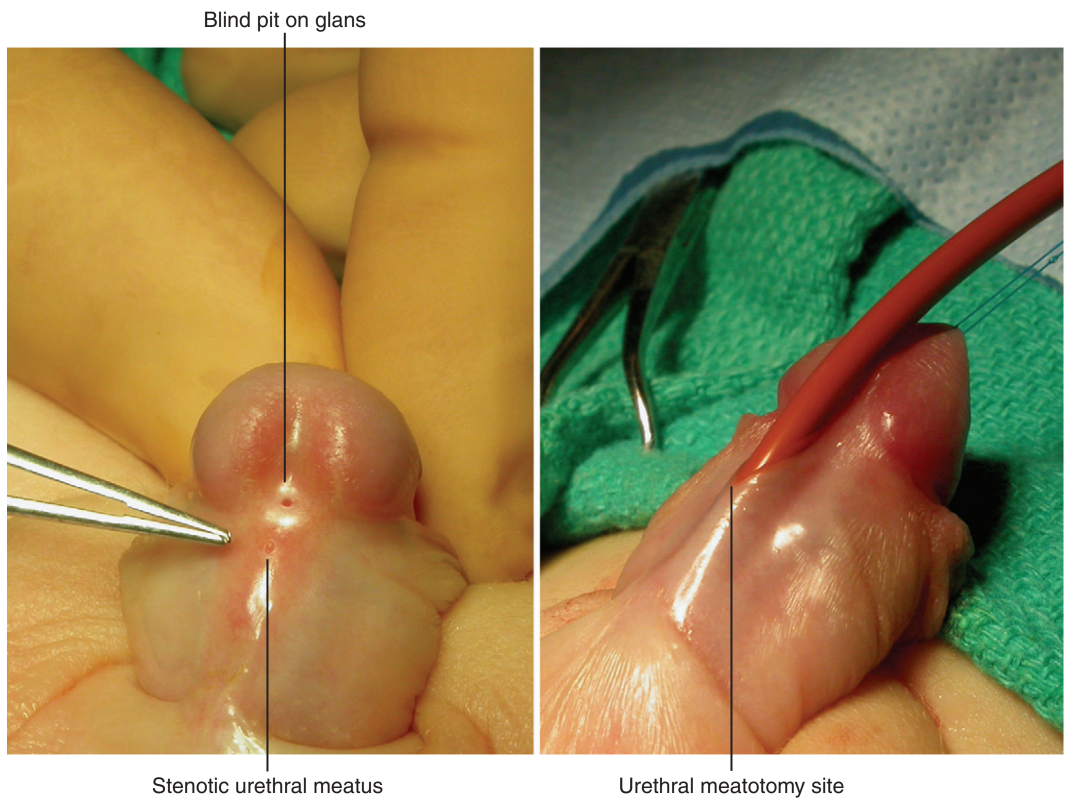


FIGURE 16-18. Hypospadis with chordee. At left, the tip of the forcep is near the urethral meatus, which lies proximal to its normal position, indicated by the blind pit in the glans. The surgeon's fingers have retracted the hooded prepuce. At right, urethral meatotomy has been performed, a catheter has been inserted into the urethra, and the repair is about to begin. *(Images courtesy of Jonathan Ross, MD.)*

Prepuce. Failure of fusion of the urethral folds in the formation of the glandar urethra and the associated development of the preputial fold and glandopreputial lamella inhibit preputial development on the ventrum, leaving a hooded **prepuce** (Fig. 16-19A). The perineal raphe, although it normally starts in the central point of the perineum where urethral closure begins, extends only to the proximal margin of the urethral orifice.

Chordee. The ventrally curved shaft producing **chordee** may simply result from an arrest at an early stage in normal development, in which case fibrosis is not involved (Fig. 16-19B). It may result from abnormal evolution of the mesenchyme destined to form the corpus spongiosum and Buck's and dartos fascias, or it may represent residual tissue from an incompletely developed urethral plate resulting in differential growth between the corpora and the plate. At operation, chordee usually appears as a sheet of disorganized fibrous tissue extending from the meatus distally along the shaft but may be represented only as ventral mucous membrane adherent to the incomplete urethral groove.

The more severe the degree of hypospadias, the greater the enlargement of the prostatic utricle. This is evidence for the intersexual nature of the anomaly. Development of

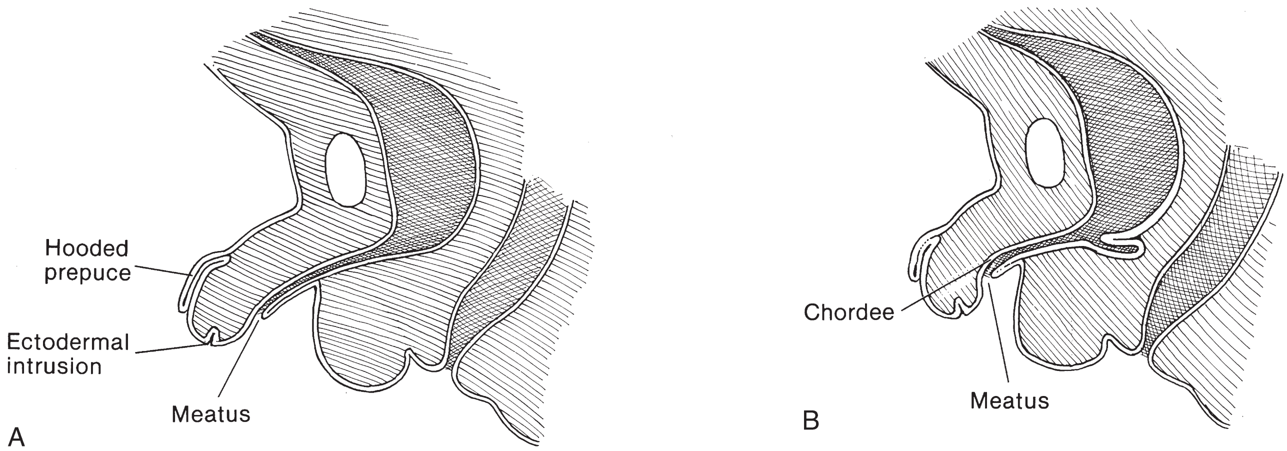


FIGURE 16-19.

other müllerian duct remnants is commonly associated with hypospadias.

Possible causes of hypospadias include a lapse in testosterone production during fetal life, inadequate conversion of testosterone to dihydrotestosterone by 5-alpha reductase in the local tissues or deficient local androgen receptors. A familial incidence has been reported by Bauer and associates who found that the risk of a second son being born with hypospadias is 26%.

Other congenital anomalies are often found in boys with hypospadias: abnormalities associated with the upper urinary tract that are found on intravenous urography, undescended testes, and, rarely, orthopedic and cardiac defects.

Chordee without Hypospadias. The condition is not common and has several possible causes. It may come from mesenchyme laying dysgenetic fibrous tissue beneath the urethra, which, in turn, is related to abnormal differentiation of Buck's and the dartos fascias. Alternatively, even though the corpus spongiosum forms normally, the ventral aspect of the corpora cavernosa may fail to develop at the same rate as the dorsal side. Finally, the urethra itself may not develop to its normal length.

Phimosis. Phimosis is probably the result of continued distal growth of the preputial lamella and delay in breakdown of the glandar lamella.

Urethrophallic Anomalies. These anomalies include urethral duplication, a condition that may arise when canalization of the urethral plate is defective or when the laterally invading mesenchyme in effect pinches off part of the urethra to form two. The **Y**-urethra may be secondary to abnormal downgrowth of the urorectal septum. Accessory urethral openings are found, usually exiting on the ventrum, although they can open on the dorsum (Fig. 16-20). Failure of the urethral plate to become canalized may result in absence of the entire penile urethra or, more rarely, in the absence of the glandar portion (urethral atresia), a condition incompatible with life.

Duplication of the Penis. This anomaly takes many forms: bilateral, sagittal, total, or partial, with or without an accompanying urethra. Duplication is often associated with imperforate anus and other regional anomalies. The penis and scrotum may be transposed because the scrotal swellings fail to shift below the genital tubercle. Defects in the corpus spongiosum may result in a diverticulum on the ventrum of the penis or in megalourethra, in which the entire spongy urethra is enlarged.

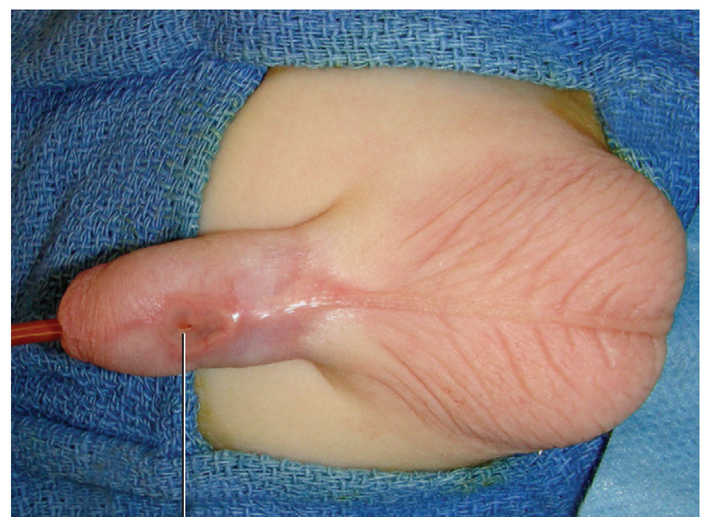


FIGURE 16-20. Accessory urethral opening. A catheter has been inserted via the normal urethral opening. The catheter can be seen through the defect in the urethral wall. *(Image courtesy of Jonathan Ross, MD.)*

Penile Agenesis. Should the genital tubercle not be formed during the sixth week, or should it fail to differentiate, the penis will not form. A third of cases reported at autopsy have associated anomalies that are incompatible with life, and half of the cases have other anomalies of the genitourinary tract, but in a quarter of newborns with penile agenesis, it is an isolated phenomenon. The presence of a normal scrotum with absent penis shows that development of the tubercle is unrelated to that of the labioscrotal folds. In these cases, the urethra opens into the anterior part of the perineum or into the rectum, although it may not be formed at all or may end blindly.

Microphallus. Inadequate androgen priming may retard development of the penis, resulting in microphallus. A second form of microphallus occurs from anomalous development within a normal hormonal environment. It occurs without a specific pattern and is often associated with other anomalies of the penis (accessory penis, buried penis), cryptorchidism, and anomalies of other organs.

STRUCTURE AND FUNCTION OF THE PENIS AND MALE URETHRA

Gross Structure of the Penis

The penis is composed of paired **corpora cavernosa**, each with a proximal prolongation, the **crus**, attached to the **pubic arch**, the **corpus spongiosum**, and its proximal part, the **bulb** of the penis, and the **glans** (balanus), an expansion of the corpus spongiosum (Fig. 16-21). The dorsum of the penis is defined as the superior surface as found during erection; the urethral surface is called the ventrum.

The *corpora cavernosa* (penis) are closely apposed for three-quarters of their length, separated only by a common septum. Proximally, they diverge and form the blunt-ended crura. Distally, their ends are rounded where they meet the upper two-thirds of the glans.

The *corpus spongiosum* (corpus cavernosum urethrae), arising at the perineal membrane and terminating where it joins the glans penis, has its own tunica albuginea and its own fascial sheath, an extension of Buck's fascia, that surrounds it. Buck's fascia separates it from the corpora cavernosa, but the three structures are essentially encased together. Few communicating vessels cross this sheath from the corpora cavernosa, so the body of the corpus spongiosum may be detached from its position in the cavernosal groove if that becomes necessary during surgical procedures, such as repair of a urethral stricture, ventral access to the corpora for tucking the tunica albuginea in correction of dorsal penile curvature in Peyronie's disease or closure of a cavernous-glanular fistula after glanular shunt for priapism. It must be appreciated that the dorsal arteries and nerves curve ventrally as they approach the coronal sulcus before entering the glans (see Fig. 16-32) and prevent surgical separation of the glans from the ends of the corpora.

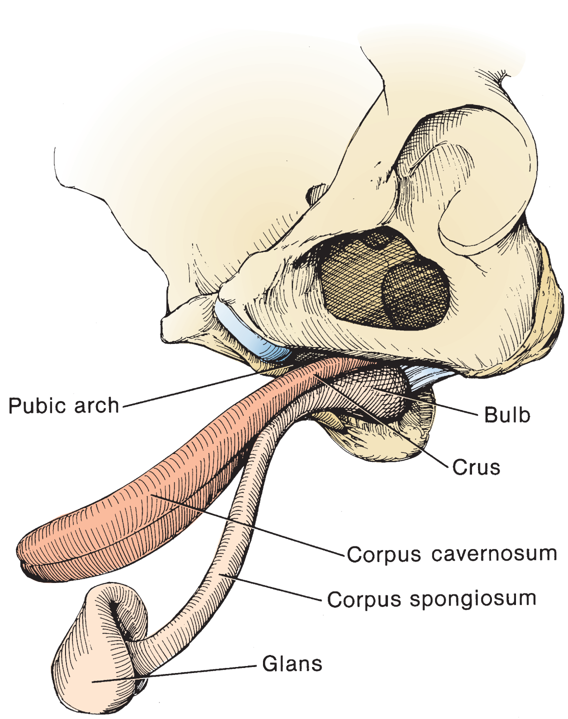


FIGURE 16-21.

During erection, the pressure in the corpus spongiosum is lower than in the corpora cavernosa. This vascular independence during erection allows semen to pass through the corpus spongiosum, which would be difficult if the pressure were as high as that in the corpora cavernosa. At the same time, sufficient turgidity is maintained to reduce the caliber of the urethra from a large size that would be suitable for urinary flow to one small enough that pooling of the relatively small amount of semen passing through during ejaculation does not occur. Moreover, the engorged spongy tissue acts as an intermediator during ejaculation to allow transmission to the urethra of the pressure created by the contracting bulbospongiosus muscle in order to eject the semen.

The *prepuce*, attached distally at the coronal sulcus, normally covers the glans. The opening of the prepuce, the preputial ring, may be smaller than the glans, resulting in phimosis. The preputial glands of Tyson are present in the coronal sulcus and on the inner surface of the prepuce; they secrete a sebaceous material that constitutes smegma when mixed with desquamated epithelial cells.

Superficial and Deep Fascias about the Penis

The fascial layers of the penis and scrotum are continuous with those of the perineum and the lower abdomen (Fig. 16-22).

Camper's fascia is not a true fascia but a subcutaneous fibroareolar layer that covers the ilioinguinal area and lower abdomen, and overlies **Scarpa's fascia** (see Fig. 9-4). It appears to fuse with **Colles' fascia** below the symphysis.

The **superficial penile fascia**, or penile dartos, is a subregion of the superficial layer of the superficial fascia of the groin and perineum. It is continuous with adjacent layers of superficial fascia, that is, with the **dartos muscle of the scrotum** and Scarpa's fascia of the lower abdomen. Posteriorly, it becomes recognizable as Colles' fascia, which covers the ischiocavernosus and bulbospongiosus muscles. Although called a dartos layer or tunic, strictly speaking, there is no dartos fascia on the penis.

Buck's fascia (fascia penis), the deep layer of the superficial fascia, covers the tunica albuginea of the penile bodies, including the crura, individually and together, and extends to the **perineal membrane**. Distally, it attaches to the coronal sulcus. Buck's fascia separates the **superficial** from the **deep dorsal vein**.

Posteriorly, Buck's fascia approaches the perineal membrane behind the bulb but does not fuse with it. It encloses the corpora cavernosa in one compartment and the corpus spongiosum in an individual compartment. These compartments are separated proximally from the superficial layer of the superficial fascia of the groin (Colles' fascia) by both a deep septum and a crural septum (see Fig. 17-28). A break in the pendulous or bulbous urethra is followed by extravasation of

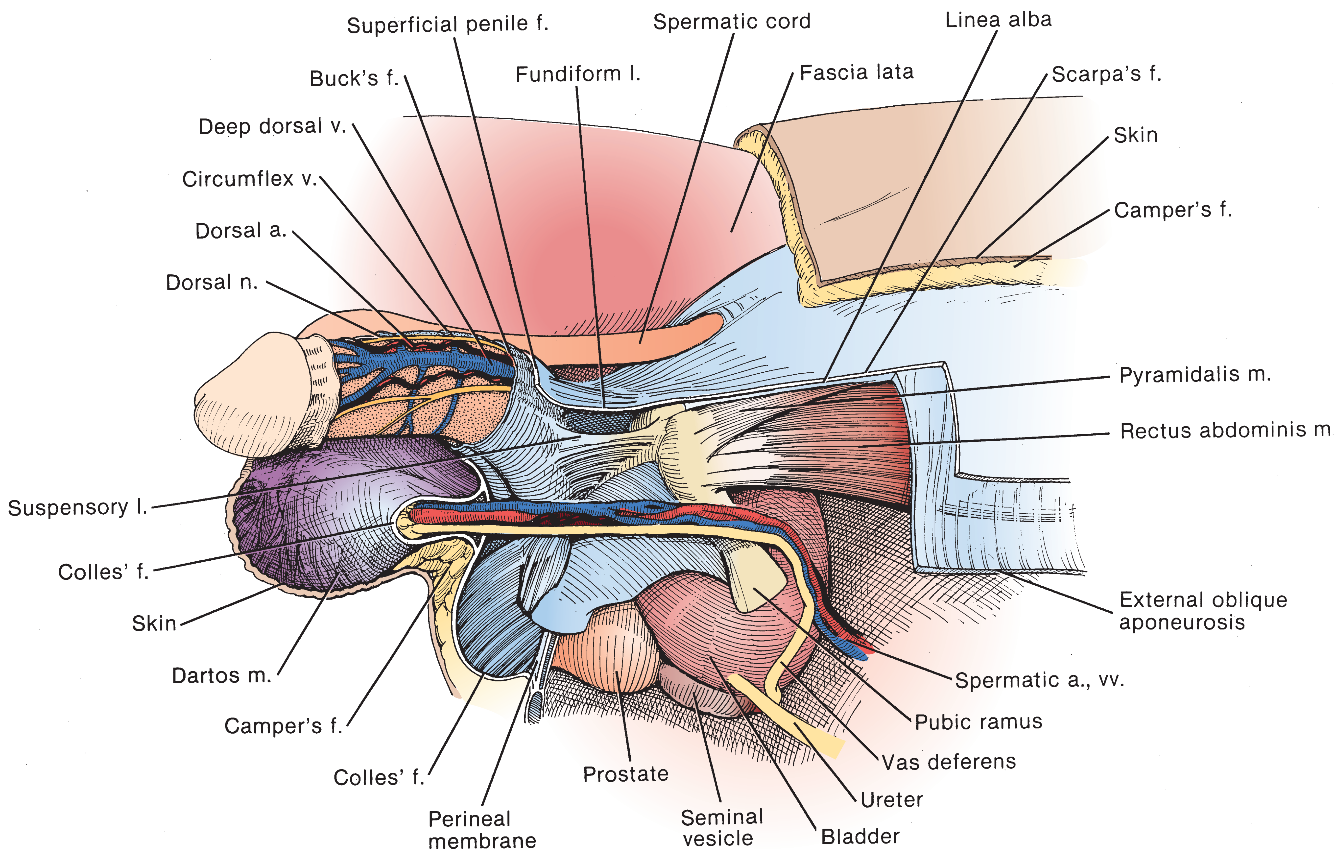


FIGURE 16-22.

blood or urine limited proximally by these attachments. At the distal end, Buck's fascia is firmly attached to the base of the glans at the coronal sulcus, where it fuses with the ends of the corpora. The ischiocavernosus and bulbospongiosus muscles lie beneath the superficial penile and Colles' fascias but superficial to Buck's fascia, to which their intrinsic fascia is loosely attached.

Of importance in directing urinary extravasation from the bulbomembranous urethra is the firm attachment of the Buck's fascia to the pubic rami and the ischial spines and tuberosities, directing spread onto the abdomen under Scarpa's fascia and, by its continuity with the dartos layer, into the scrotum.

Suspensory Ligaments

The root of the penis is suspended by two ligaments. The more superficial **fundiform ligament** is merely a diffuse midline thickening of the superficial fascia, Scarpa's fascia. The ligament originates at the linea alba and, after splitting to pass around the base of the penis, joins Colles' fascia. It is not important to preserve or restore it at surgery. Beneath it, attached to the symphysis pubis, is the **suspensory ligament** proper, in continuity with Buck's fascia. This is an important structure for the maintenance of penile position during coitus; surgical severance may cause the penis to assume a lower, less effective angle during erection. Thus, reapposition of the ligament with sutures is advisable. However, after partial resection for stricture, division may be needed to allow retraction of the shaft for anastomosis of the shortened urethra.

Structural Layers of the Penis

Covering Layers

Five layers of tissue surround the shaft of the penis: (1) penile skin, (2) superficial layer of the penile fascia, (3) tela subfascialis, (4) deep layer of the penile fascia, and (5) tunica albuginea (Figs. 16-23 and 16-24).

The **skin** over the penis is particularly moveable and expandable to accommodate erection. Such flexibility and lack of adherence makes it susceptible to edema. Along with its thinness, the absence of fat beneath it accounts for its darker color. The penile skin adapts readily to prolonged contact with urine, making it suitable material for urethral replacement. Other advantages of this skin for urethral construction are its distensibility and good vascularity, as well as its ready availability.

The skin over the symphysis (and over the female mons pubis) not only covers fatty-areolar tissue but also develops specialized pubic hair at puberty, distinct from that on the lower abdomen.

The **superficial fascia of the penis**, or dartos fascia, is a part of the membranous layer of the superficial fascia of the groin and perineum or Colles' fascia. Imbedded in it are the **superficial penile arteries** and the **superficial dorsal vein**, vessels that supply the skin. This layer is only loosely applied to the one beneath it and, hence, is mobile. It separates the superficial veins from the deep dorsal veins.

Beneath the dartos fascia and Colles' fascia lies a very thin connective tissue layer, the **tela subfascialis** (Eberth), more

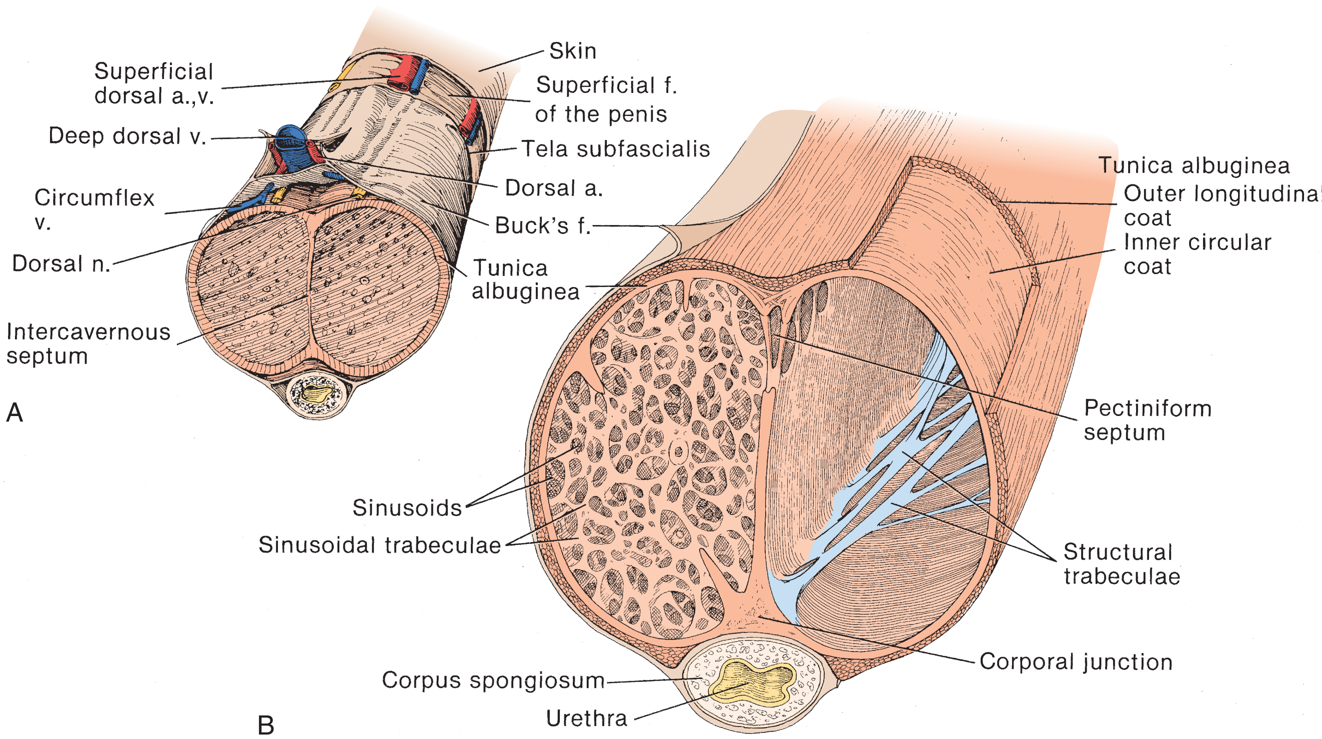


FIGURE 16-23.

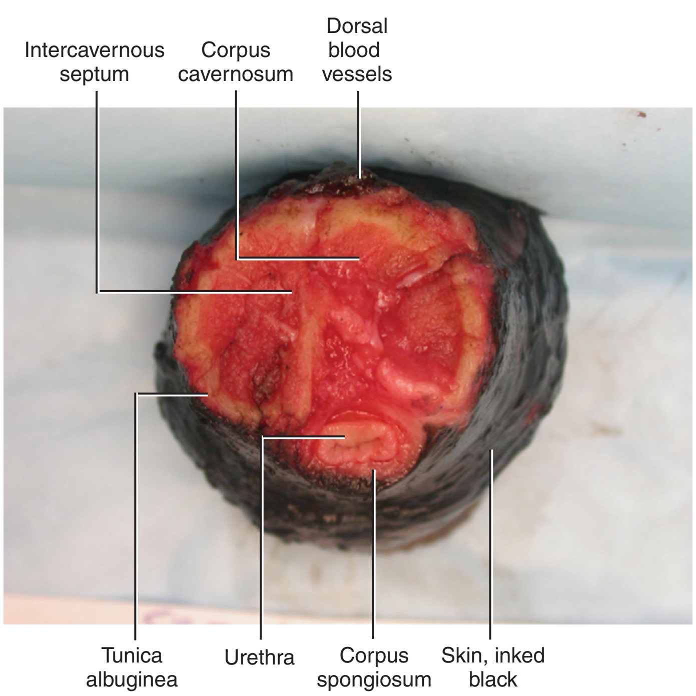


FIGURE 16-24. Cross-section of surgical margin in a distal penectomy specimen, from a patient with squamous cell carcinoma of the penis. The skin has been inked as part of routine pathology practice. Normal anatomic structures are readily identified.

prominent at the base of the penis, where it covers the extracorporal segments of the cavernous arteries, veins, and nerves.

A deep layer of fascia is the penile, or **Buck's fascia**. It is a heavy elastic layer that encloses not only the two corpora cavernosa but, in a somewhat separate compartment, the corpus spongiosum as well. It also encloses the **deep dorsal vein** and the **dorsal arteries** and **dorsal nerves**. It is not continuous with either the dartos layer, which lies superficial to it, or Colles' fascia, and it lies under the ejaculatory musculature.

Buck's fascia has a dense structure, in contrast to the loose superficial fascia of the penis. It is composed of longitudinally running fibers and is firmly attached to the underlying tunica albuginea.

Tunica Albuginea

The deepest layer is the **tunica albuginea**, forming a thick white coat set in a fibroareolar matrix (Fig. 16-25). This layer encloses the corpora cavernosa and the corpus spongiosum. It is covered closely by Buck's fascia. Two layers may be identified: (1) an **outer longitudinal coat** and (2) an **inner circular coat**. The tunica albuginea becomes thicker ventrally as it forms a groove for the corpus spongiosum. Ventromedially, it is thinned as the outer coat becomes attenuated, leaving only the inner coat. This difference in the thickness of the tunic explains the greater susceptibility of the urethra to inadvertent entry during insertion of a penile prosthesis. Similarly, at the crura, it is only the inner coat that provides the cover.

Internal Structure

The two corpora cavernosa are separated in the sagittal plane by a dense tunica albugineal layer that passes between them as the **intercavernous septum**. The septum is incomplete distally, being perforated on its dorsal margin by vertically oriented openings in the **pectiniform septum** that provide free vascular communication between the corpora. Continuous with the inner surface of the tunica albuginea within the corporal bodies are numerous flattened columns or **sinusoidal**

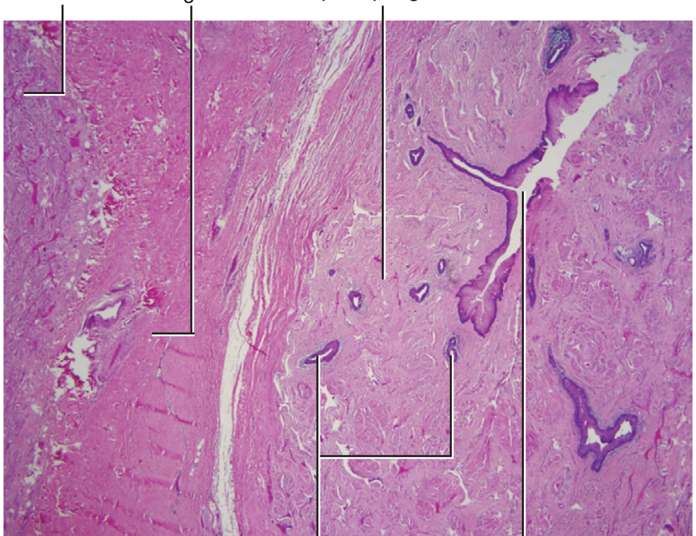


FIGURE 16-25. Low-power view of normal penile histology. A thick fibrous structure (tunica albuginea) separates the corpus cavernosum, at left, from the corpus spongiosum, at right, which surrounds the urethra. Numerous periurethral glands are arrayed in proximity to the urethral lumen.

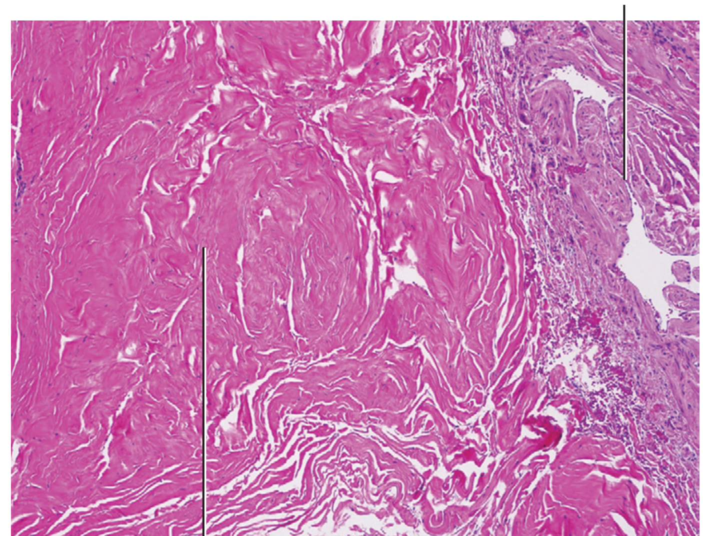


FIGURE 16-26. Peyronie's disease. This is a condition of unknown etiology, which affects men older than age 40, causing penile deformity and pain with erection, and evident clinically as palpable dorsal penile plaques, localized in the tunica albuginea. Mature plaques consist of hypocellular and extensively hyalinized fibrous tissue, sometimes with associated calcification or bone formation, and their appearance is similar to that of fibromatosis in other sites, such as Dupuytren's contracture.

trabeculae, composed of fibrous tissue, elastin fibers, and smooth muscle surrounding the endothelial-lined **sinusoids** or cavernous spaces. In addition, a row of **structural trabeculae** arises near the junction of the three corporal bodies, the **corporal junction**, and inserts on the wall of the corpora about the midplane of the circumference.

The tunica albuginea covering the **corpus spongiosum** is about half as thick as that over the corpora cavernosa and contains smooth muscle fibers that may contract during ejaculation to aid in the expulsion of semen. The caliber of the corpus spongiosum is uniform throughout its penile segment, but it, along with the contained urethra, widens proximally where it is covered by the bulbospongiosus muscle to form the urethral bulb.

During erection, when the tunica albuginea becomes distended with blood, its composition (two layers of fibers running at right angles, like those in an automobile tire) limits expansion and provides the necessary longitudinal rigidity at full erection. Because the tunic is then under tension, it is subject to flexion injury, either a fracture or a lesser injury that, if repeated, may result in a deforming scar in susceptible men (Peyronie's disease) (Fig. 16-26).

Ejaculatory Musculature, Perineal View

The crus of the corpus cavernosum is encased in an **ischiocavernosus** muscle (Fig. 16-27). The paired muscles arise from the inner surfaces of the **ischial tuberosities** beside each crus and insert into their medial and inferior surface. They do not completely envelop the crura, being deficient on the side against the bone. Known as the erector penis, these muscles act as a pump to increase penile turgor during erection beyond that attainable by arterial

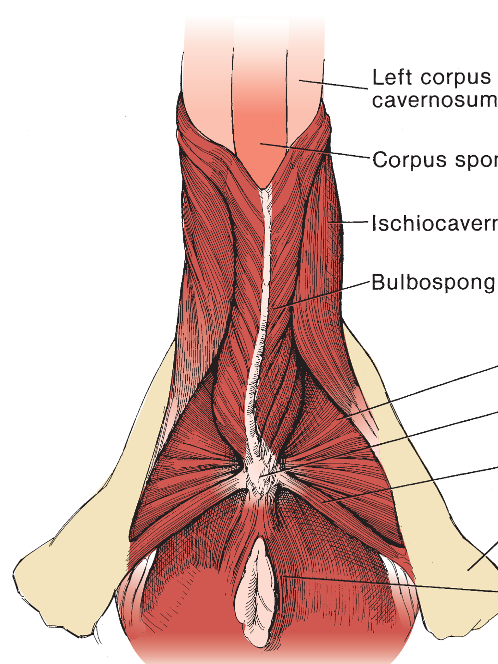


FIGURE 16-27.

pressure alone. The nerve supply is through the perineal branch of the pudendal nerve, derived from sacral nerves S3 and S4.

The corpus spongiosum is covered by the **bulbospongiosus** muscle, which invests the bulb of the corpus spongiosum including the bulbar urethra. The fibers of the bulbospongiosus arise from the **perineal body** (central tendon of the perineum), an important landmark in perineal surgery because approaching the prostate anterior to it leads into the bulb.

The bulbospongiosus forms a thin muscular coat that runs obliquely on each side of the corpus to surround the bulb and insert in the midline inferiorly. The ischiocavernosus and bulbospongiosus muscles are attached to the underlying layer of Buck's fascia by their investing fascia. The bulbospongiosus, like the ischiocavernosus, receives innervation through a deep branch of the perineal nerve. The muscle serves to propel the last few drops of urine from the bulbous urethra and to aid in the ejaculation of semen. In the female, the bulbospongiosus constricts the vagina and is useful surgically as a covering layer after completion of urethral repair. An additional small muscle, the **superficial transverse perineal muscle**, also innervated by the perineal branch of the pudendal nerve, runs from the inferior ramus of the ischium to the perineal body beneath the bulb and from there to the opposite ramus. This area is described in detail in Chapter 11.

Ejaculatory Musculature, Coronal Section

In a cutaway coronal view from the dorsal side, the **ischiocavernosus** covers the caudal and medial aspects of the **corpus cavernosum** at the **crus** and the **bulbospongiosus** encloses the **bulb** of the **corpus spongiosum**. On the left, their relation to the **bulbourethral** (Cowper's) **glands** is shown (Fig. 16-28). The **perineal membrane**, or superficial fascia of the urogenital diaphragm, lies deep to the ischiocavernosus adjacent to the **pudendal vessels** and **nerve**. On the right, these structures are seen in semi-sagittal section related to the **perineal body** and the two sets of **transverse perineal muscles**.

Arterial Blood Supply

The penis is supplied by two systems of arteries: (1) a superficial system that takes origin from the external pudendal arteries and (2) a deep arterial system, arising on each side from the internal pudendal artery, as shown in Fig. 16-32.

Superficial Arterial System

The superficial arterial supply to the penile skin and prepuce lies in the superficial layer of the **superficial fascia of the penis** overlying Buck's fascia. The penile skin is well-vascularized with a very flexible cutaneous blood supply of coiled vessels running along the shaft. Two more or less symmetrically arranged, longitudinally oriented vessels, the **superficial penile arteries**, arise from each inferior **external pudendal artery**, a branch of the **femoral artery** (Fig. 16-29).

The superficial penile arteries divide on each side, usually into a **dorsolateral** and a **ventrolateral branch**. However, there are equally common arrangements that make the skin partially dependent on one or the other principal superficial artery. When the blood supply is symmetric, each artery enters the lateral aspect of the penis near the base, then branches as it runs out the shaft to form a dorsolateral and a ventrolateral vessel. When the total supply comes from one artery, that vessel divides soon after entering the penis, so that one branch crosses over the dorsum to the opposite side. In either case, subsequent branches course dorsolaterally and ventrolaterally on each side. At intervals, these vessels give off fine branches to the skin. The only point of connection between the deep and superficial systems is an anastomosis at the coronal sulcus, where the superficial vessels circle back dorsally to join the dorsal artery of the penis.

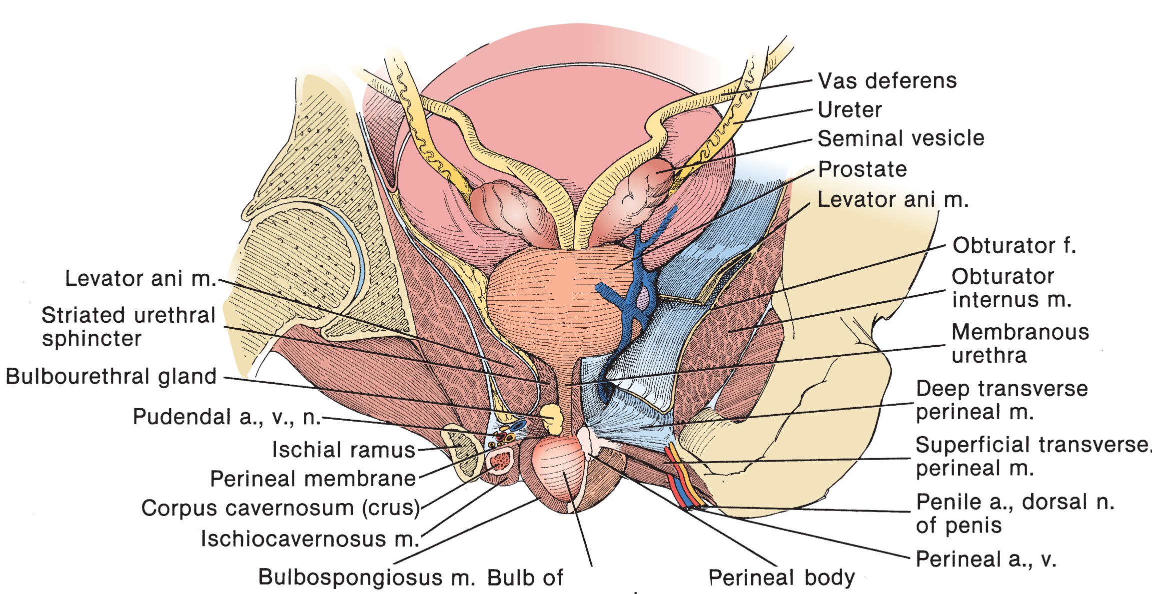


FIGURE 16-28.

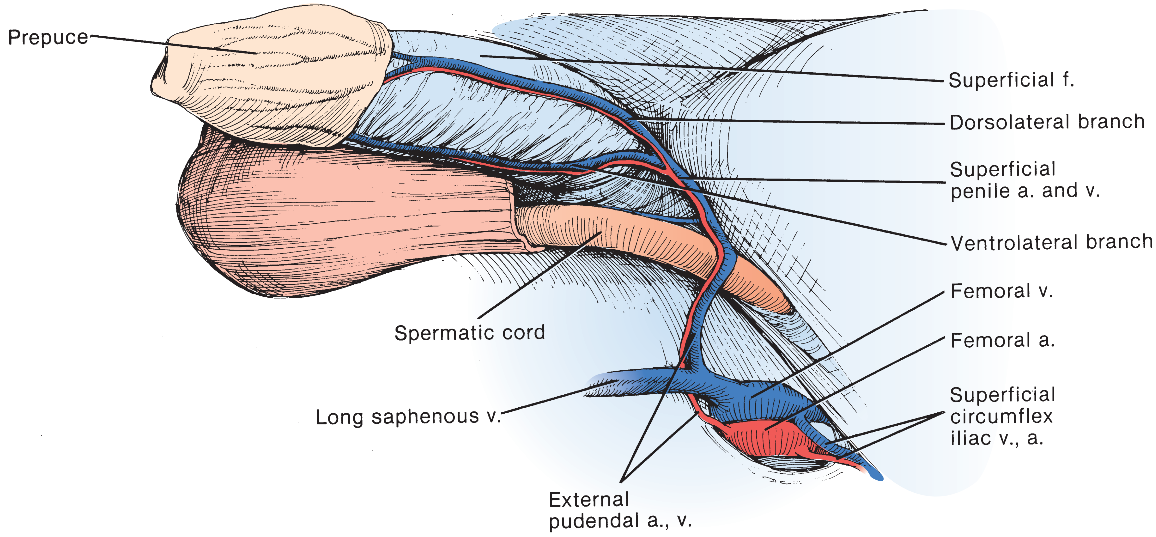


FIGURE 16-29.

Deep Arterial Supply to the Penis

The **anterior branch** of the **internal iliac artery** divides to form the **inferior gluteal artery** and the **internal pudendal artery** (Table 16-3). Viewed from within the pelvis, the internal pudendal artery passes beneath the **sacrospinous ligament** and over the **sacrotuberous ligament** and bifurcates into the perineal artery and continues as the penile artery, which runs under the **superficial transverse perineal muscle** and the **symphysis** (Fig. 16-30).

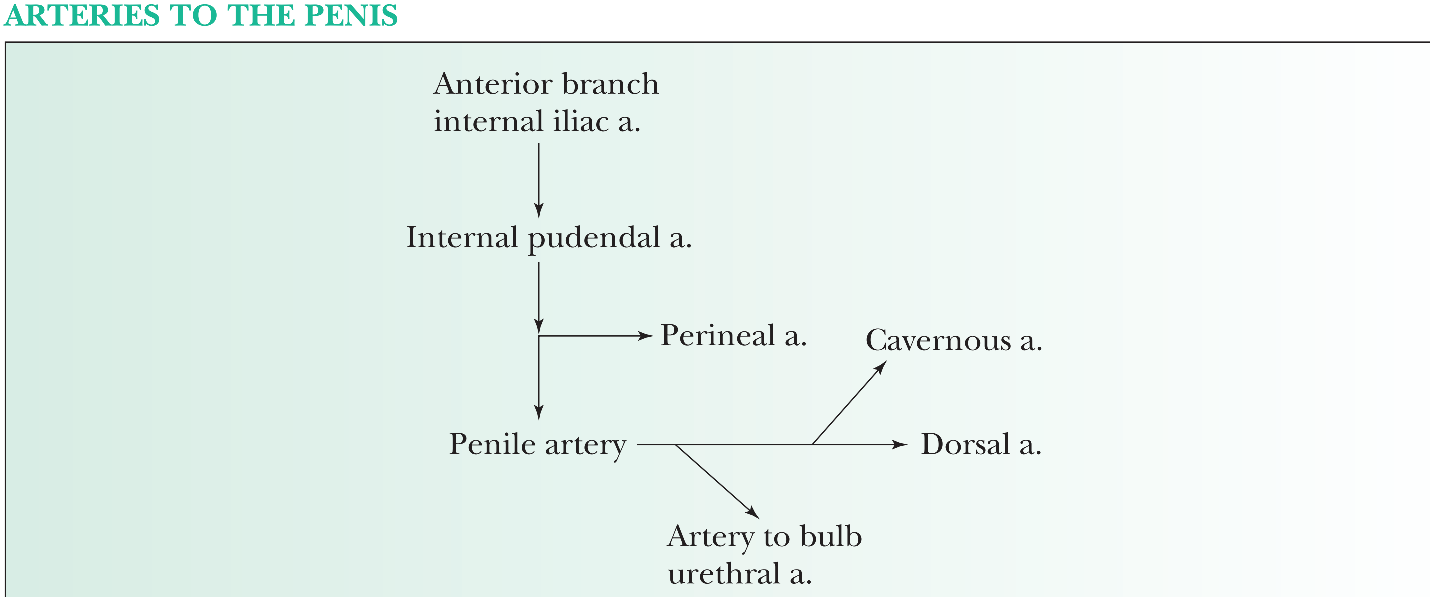
The **penile artery** pierces the urogenital diaphragm along the medial margin of the inferior ramus of the ischium behind the superficial transverse perineal muscle near the bulb of the urethra, and divides into three branches: (1) the **bulbourethral artery** (artery to the bulb of the penis), (2) the urethral artery, and (3) the **cavernous artery** or the deep artery of the penis. It then terminates as the **dorsal artery of the penis**.

Considerable variation can be found: an accessory internal pudendal artery is common, arising from the obturator artery, the inferior vesical artery, or the contralateral superior vesical artery. It is this alternate but essential blood supply to the corpora that may be inadvertently divided in total prostatectomy and cystectomy, resulting in vasculogenic impotency.

The **bulbourethral artery** (subject to several variations in origin, occasionally arising from the cavernous, dorsal, or accessory pudendal arteries) supplies the **bulb of the urethra**, the **corpus spongiosum**, and the glans. These structures are anatomically independent from the body of the penis. This, the first branch of the penile artery, is a short, relatively large-caliber artery that passes medially to traverse the inferior layer of the urogenital diaphragm before entering the bulb (see Fig. 11-4). It supplies the bulb through a posterior group of branches and also supplies the proximal

TABLE 16-3

ARTERIES TO THE PENIS



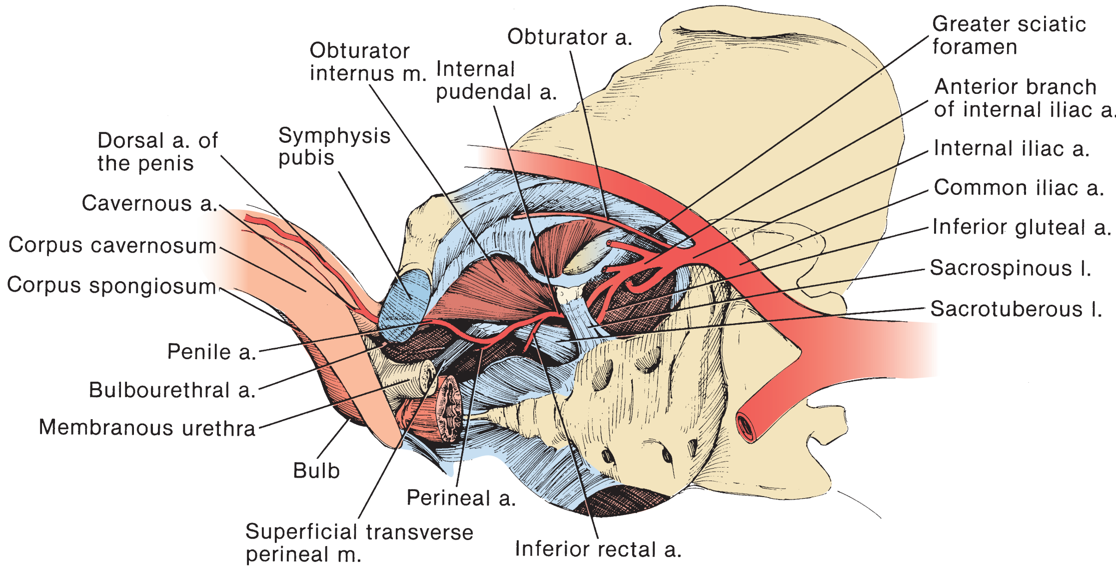


FIGURE 16-30.

quarter of the cavernous tissue of the corpus spongiosum through an anterior group.

The urethral artery, the second branch, is not always present. It may arise from the artery to the bulb, but if present, it more commonly takes origin directly from the penile artery or from the cavernous artery or dorsal artery. It runs on the ventral surface of the corpus spongiosum beneath the tunica albuginea.

Distal Arterial Distribution to the Penis

The **cavernous artery** (deep artery of the penis) usually arises before the penile artery terminates as the **dorsal artery of the penis**, but it may originate from an accessory pudendal artery or it may be double, appearing as two vessels running in parallel. It runs lateral to the cavernous vein along the dorsomedial surface of the crus of the corpus cavernosum to enter the erectile tissue where the two corpora fuse and then continues in the center of the corpus almost to its tip (Fig. 16-31). This distribution is not constant because many times the cavernous artery gives off branches before entering the corpus.

The **dorsal artery**, as the termination of the penile artery, runs over the respective **crus** and then along the dorsolateral surface of the penis as far as the glans between the deep dorsal vein medially and the dorsal nerve of the penis laterally. Two-thirds of the time, the two dorsal arteries are asymmetric; they may even arise from the same internal pudendal artery. These arteries have a tortuous configuration to accommodate for elongation during erection. As they near the glans, they run lateroventrally before entering it.

The penile artery may originate from an accessory internal pudendal artery within the pelvis, making it vulnerable to ligation with the dorsal vein complex or with the prostatic pedicle.

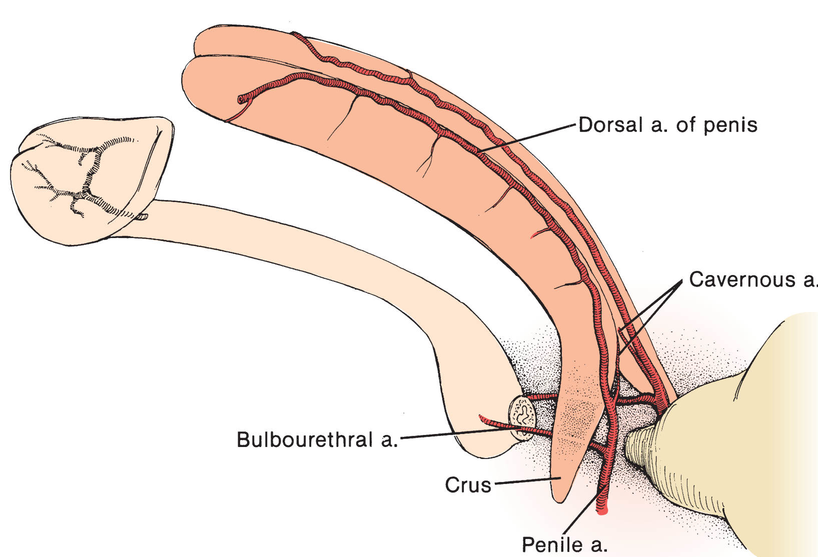


FIGURE 16-31.

Blood Supply to the Glans and Frenulum

Although the **dorsal artery** provides a few cortical branches that penetrate the tunica albuginea and some **circumflex arteries** that run with corresponding **circumflex veins** to supply the corpus spongiosum and contained urethra, its principal destination is the **glans,** where it turns to a ventrolateral position near the coronal sulcus prior to its entrance (Fig. 16-32).

The **frenulum,** a pyramidal structure that extends from the meatal groove to the coronal sulcus, is not embryologically part of the prepuce (see Fig. 16-10C). It has a separate blood supply from the **frenular branches** of the dorsal artery that curve around each side of the distal shaft to enter the frenulum and glans ventrally.

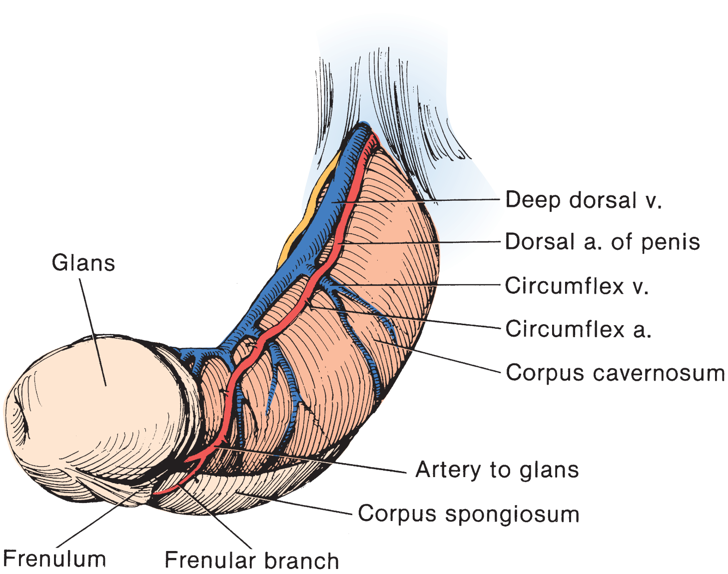


FIGURE 16-32.

Preputial Blood Supply

The penile skin has been freed by a circumcising incision, split ventrally, and suspended dorsally at the base of the penis.

Arterial Supply

The prepuce is supplied by two branches from the inferior external pudendal arteries, the superficial penile arteries (see Fig. 16-29). These arteries divide into anterolateral and posterolateral branches (Fig. 16-33A). On reaching the preputial ring, the branches become tortuous and minute and the terminal arteries turn circumferentially before ending at the coronal sulcus.

The superficial penile arteries do not communicate with the circulation to the rest of the penis.

Venous Drainage

The multiple small veins in the prepuce are distributed without particular orientation. In the skin of the shaft, they join one or two **superficial penile veins** that drain through the **inferior external pudendal vein** into the **saphenous vein** (Fig. 16-33B).

Vascularization of the Prepuce and Glans, in Sagittal Section

Branches of the **superficial penile arteries** extend to the **preputial ring,** where, in addition to spreading circumferentially, they turn back to terminate near the **coronal sulcus** (Fig. 16-34).

Surgical Implications

For operations such as hypospadias repair that make use of the prepuce, some important aspects of its vascularization must be considered. First, it is necessary to keep intact at least one, and preferably two, of the four branches of the

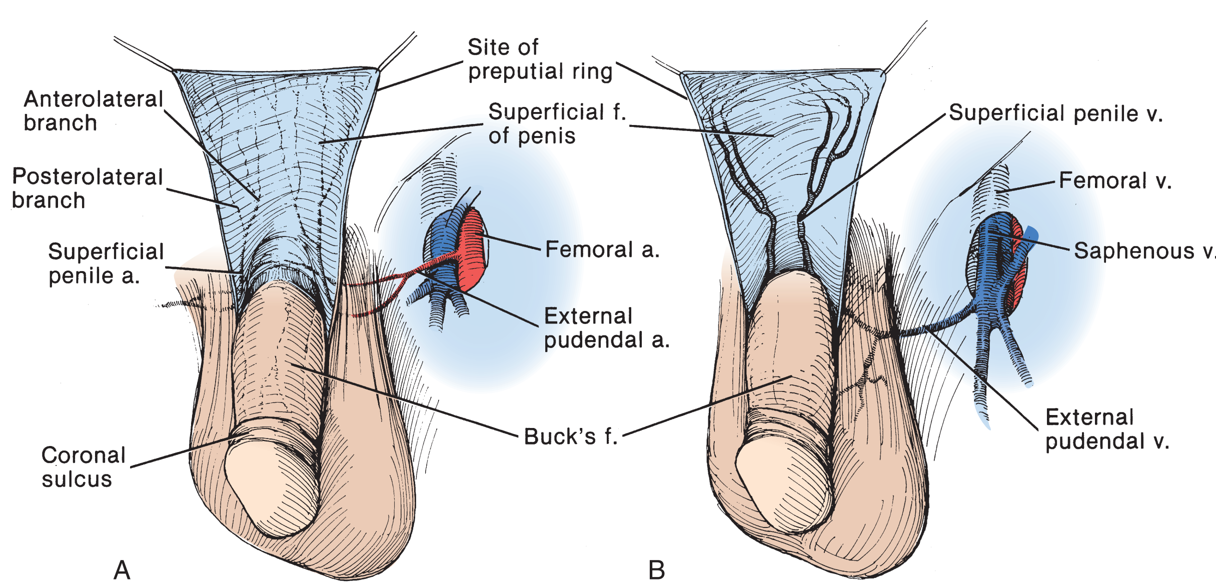


FIGURE 16-33.

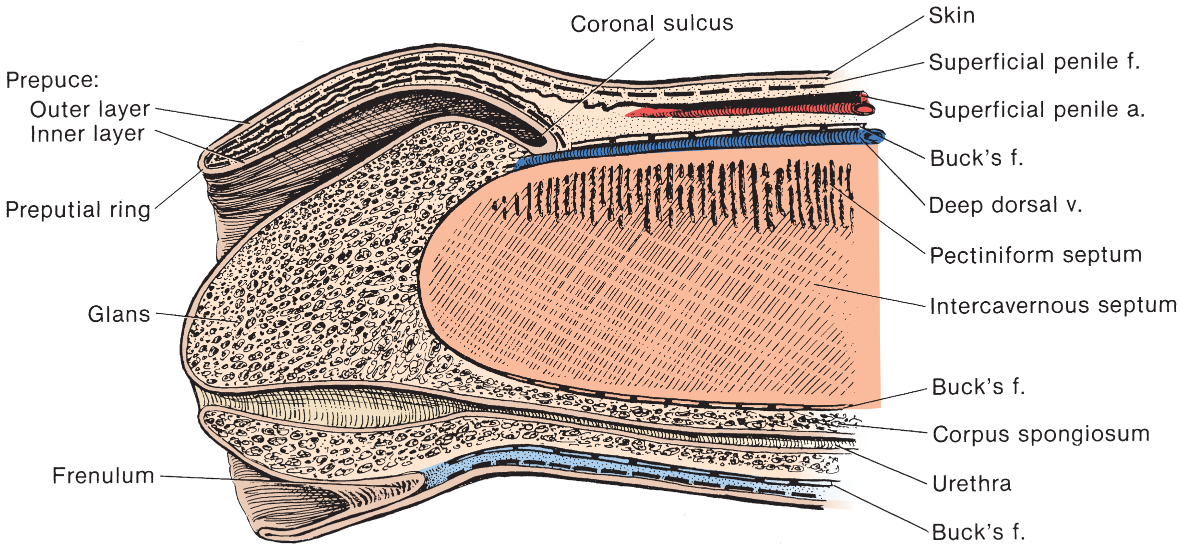


FIGURE 16-34.

external pudendal artery supplying the penile skin. The dorsolateral pair are the ones usually used for a pedicle. Second, because the vessels are arranged axially, only longitudinal pedicles can be raised. Third, the superficial fascia is indivisible, because it contains the blood supply. It can support only one flap, although two flaps could be formed side by side. Fourth, because there are usually four arteries to the prepuce, a second flap, if necessary, could be raised from one of the two ventrolateral vessel systems, provided that the area about the frenulum is avoided. Fifth, the closer to the corona that the preputial skin is obtained, the more tenuous will be its vascularization; a flap from the shaft will have a better blood supply than one from the prepuce, which, in turn, will be more vascular than one taken from the inner preputial surface. This can be an important factor when a flap is to be placed at a scarred site, such as those found at secondary hypospadias operations and in stricture repair in adults. Sixth and most obvious, because the prepuce is not supplied by vessels distally from the corona, all flaps must be based on the superficial fascial system of blood vessels that enter the prepuce proximally.

Blood Vessels and Nerves to the Penile Shaft, in Cross Section

The superficial penile arteries and veins and superficial penile nerves lie within the superficial penile fascia (see Fig. 16-29). Beneath Buck's fascia are the deep dorsal vein, the dorsal arteries, and the dorsal nerves (Fig. 16-35). The circumflex arteries and veins run circumferentially to

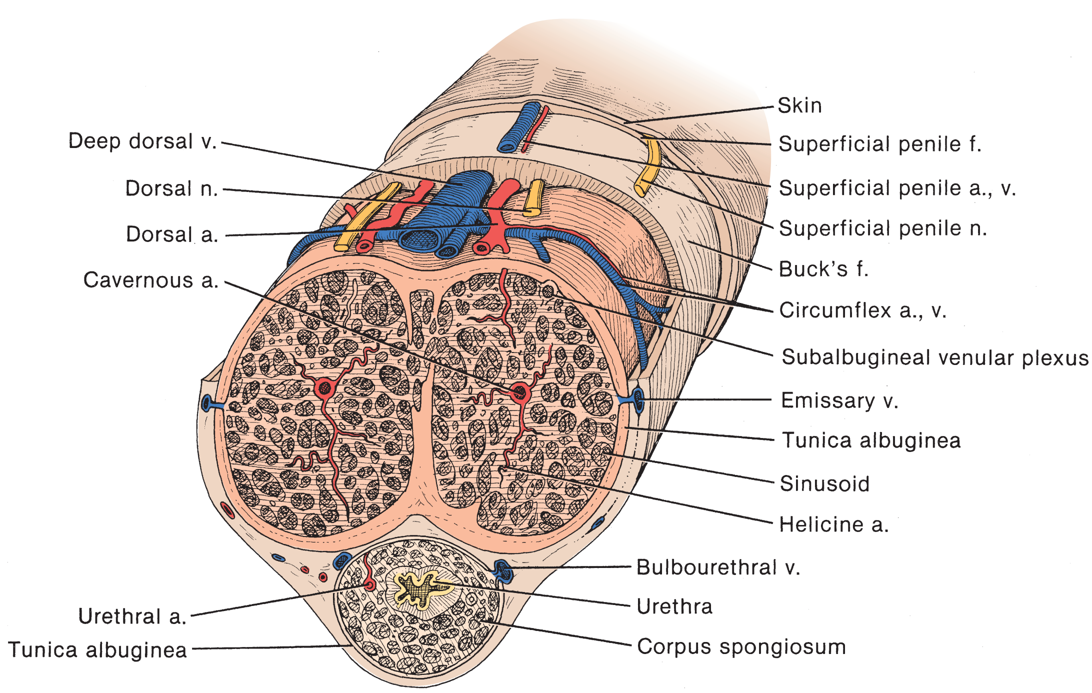


FIGURE 16-35.

connect with emissary veins that connect with the subalbugineal venular plexuses and the sinusoids.

Circulation within the Corpus Cavernosum

Arterial blood is conveyed to the erectile tissue through the deep system consisting of the **dorsal,** the **cavernous,** and the bulbourethral arteries (see Figs. 16-31, 16-32, and 16-33).

The **cavernous** (central) **artery** gives off multiple short terminal branches, the **helicine arteries,** among the cavernous spaces within the center of the erectile tissue (Fig. 16-36). Most of these open directly into the **sinusoids,** those cavernous spaces bounded by **trabeculae.** (In the corpus spongiosum, the trabeculae are finer and the sinusoids are smaller than those in the corpora cavernosa.) A few of the helicine arteries end in capillaries that provide a second system of circulation that nourishes the trabeculae. The **pectiniform septum** provides an opening distally in the **intercavernous septum** that allows free flow of blood from one corpus to the other.

Emissary veins at the periphery collect the blood that is returning from the sinusoids through the **subalbugineal venular plexuses** and empty it into the **circumflex veins**. These veins drain into the **deep dorsal vein** (see Fig. 16-38).

The sequence of the interior circulation is cavernous artery > helicine artery > cavernous sinuses > postcavernous venules > subalbugineal venular plexus > emissary vein. The alternate route is: cavernous artery > capillaries > postcavernous venules > subalbugineal venular plexus > emissary vein.

With erection, the arteriolar and sinusoidal walls relax secondary to neurotransmitters and the cavernous spaces dilate, enlarging the corpora cavernosa and stretching the tunica albuginea. The small venules are trapped between the trabeculae. The principal venous obstruction that maintains an erection is the compression of the subalbugineal venular plexus against the tunica albuginea that blocks the outflow of blood, supplemented by compression of the emissary veins by the matrix of the tunica albuginea.

Relation of Arteries to Sinusoids

The **circumflex arteries** from the **dorsal artery** send **penetrating branches** through the **tunica albuginea**. These divide into **helicine arteries** and spread among the **trabeculae** to enter the **sinusoids** (Fig. 16-37).

Penile Venous Drainage Systems

Three systems drain the penis: (1) superficial, (2) intermediate, and (3) deep (Fig. 16-38).

The *superficial drainage system* for the prepuce, skin, and subcutaneous tissue is carried in multiple superficial veins that run somewhat randomly on the dorsolateral surface of the penis under the superficial penile fascia (see Fig. 16-33B). These join a single or double **superficial dorsal vein** that drains into either saphenous vein, usually that on the left. It may also pick up some blood from the scrotum and spermatic cord before making the connection.

An *intermediate drainage system,* composed of the deep dorsal vein and the circumflex veins, drains the glans penis, the corpus spongiosum, and the distal two-thirds of the corpora cavernosa. Many small veins leave the glans penis via the **retrocoronal plexus** to enter the **deep dorsal vein** that runs in a groove at the junction of the two corpora. Emissary veins from the corpora join the **circumflex veins.** These communicate with each other and with corresponding veins on the opposite side and are joined by **lateral veins,** ultimately becoming multiple trunks running under Buck's fascia before emptying obliquely into the deep dorsal vein.

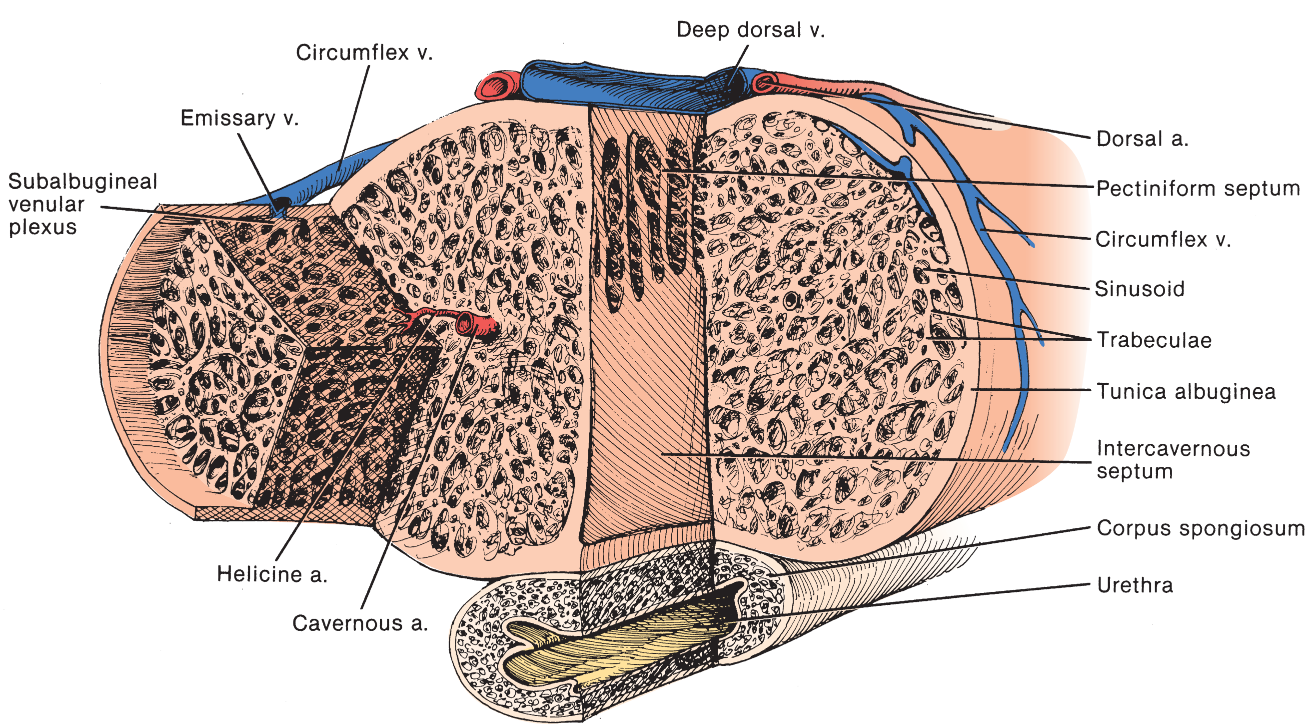


FIGURE 16-36.

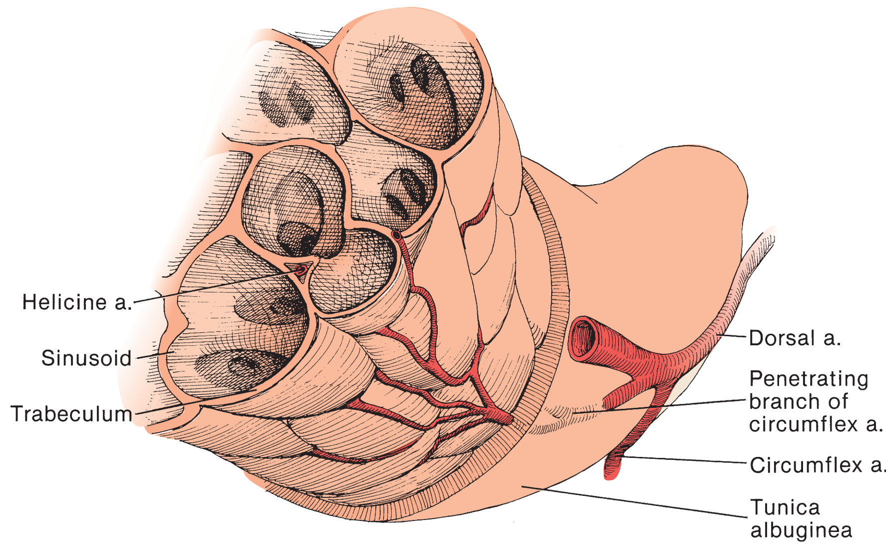


FIGURE 16-37

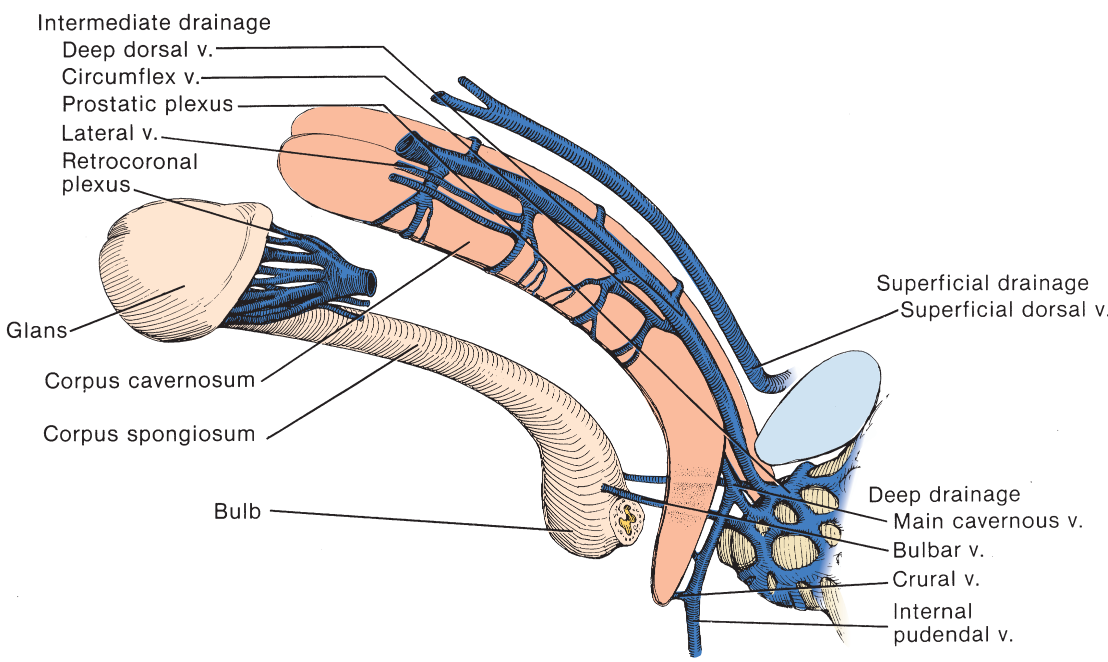


FIGURE 16-38.

The deep dorsal vein then passes through a space in the suspensory ligament and between the puboprostatic ligaments to drain into the **prostatic plexus,** where multiple bicuspid valves are present near the entry of the vein. The deep dorsal vein may be multiple and may, in turn, connect with the superficial system before joining the plexus. The prostatic plexus drains into the vesical plexus and thence into the internal iliac veins.

The *deep drainage system* is composed of the cavernous veins, the bulbar veins, and the crural veins. Blood collected from the sinusoids of the proximal third of the penis by the emissary veins drains directly into cavernous veins at the periphery of the corpora cavernosa, forming the principal drainage system for the corpora. In addition, the capillaries that form a second circulatory system drain into the subalbugineal venular plexus and thence into the emissary veins (see Fig. 16-36). The cavernous veins unite between the crura into one or two large thin-walled **main cavernous veins** that lie under the cavernous arteries and nerves, making them less readily accessible for surgical ligation. The cavernous veins, in turn, run between the bulb and the crus to drain into the **internal pudendal vein,** then to the internal iliac vein. Bicuspid valves are uniformly present, although they may not be competent in older men. Connections exist between cavernous veins and the prostatic plexus. **Crural veins,** which are few in number, arise from the dorsolateral surface of each crus and unite to drain into the internal pudendal vein, with some contribution to the prostatic plexus. The bulb itself is drained by the **bulbar veins,** which empty into the prostatic plexus.

The routes of blood circulation during erection and detumescence are outlined in Table 16-4.

BLOOD CIRCULATION DURING ERECTION AND DETUMESCENCE

TABLE 16-4

ARTERIAL SUPPLY Tumescence	VENOUS DRAINAGE Detumescence
CORPORA CAVERNOSA Principal cavernous arteries (accessory cavernous arteries) *to* dorsal arteries *to* helicine arteries *to* sinusoids	1. Emissary veins *to* circumflex veins *to* deep dorsal vein *to* periprostatic plexus 2. Cavernous vein *to* internal pudendal vein 3. Crural vein *to* internal pudendal vein
CORPUS SPONGIOSUM Bulbourethral arteries *to* urethral arteries *to* circumflex branches of dorsal arteries	Vein of the bulb *to* periprostatic plexus *to* internal pudendal vein
GLANS Dorsal artery *to* urethral artery	Retrocoronal venous plexus *to* deep dorsal vein *to* periprostatic plexus

Lymphatic Drainage of the Penis and Urethra

The surface of the **glans penis** has three superposed networks, one in the papillae, another in the superficial mucosal layer, and a third beneath the other two. The collecting trunks converge on the frenulum, where they pick up collectors from the urethral mucosa. One to three trunks then pass around to the dorsum in the coronal sulcus to join those from the opposite side (Fig. 16-39A). One or more **major collecting trunks** running with the **deep dorsal vein** carry the lymph to the region of the suspensory ligament where they join the **presymphyseal plexus**. Two or three trunks run from this plexus to the **superficial inguinal nodes** along either a femoral or an inguinal path.

Delicate preputial lymphatics arise both from the inner and, more abundantly, from the outer surfaces of the prepuce. As they run proximally, they anastomose and curve to become confluent on the dorsum (Fig. 16-39B). From 5 to 10 channels course to the base of the penis, uniting as they go. The penile skin proper is drained by lymphatics that run from the median raphe obliquely around the penis to join the dorsal lymphatic channels already draining the prepuce.

At the base of the penis, branches from the skin and prepuce connect with a presymphyseal plexus before passing right and left to join trunks draining the perineal and scrotal skin. The joint trunks run with the superficial external pudendal vessels to drain into the superficial inguinal lymph nodes, especially the superomedial ones. Anastomoses loosely connect the right and left sides.

Some drainage occurs through the *femoral route,* passing into the femoral canal to enter a deep node there, to enter the node of Cloquet, and also to enter a medial retrofemoral node. For the *inguinal route,* a single trunk approaches the inguinal canal below the spermatic cord to reach the lateral retrofemoral node. Thus, the lymphatics of the penile skin empty through the superficial lymphatic drainage system into the superficial inguinal nodes, particularly the superomedial group, whereas the glans and penile urethra drain into the deep inguinal nodes and the presymphyseal nodes and, occasionally, into the **external iliac nodes.** The lymphatic drainage of the inguinal area is shown in Figures 9-21 and 9-22.

Somatic Innervation of the Penis

The somatic nerve supply comes principally from spinal nerves **S2, S3,** and **S4** by way of the pudendal nerve. The **pudendal nerve** passes under the **sacrospinous ligament,** close to its attachment to the **ischial spine** (a landmark for perineal nerve block) and over the **sacrotuberous ligament** through the **pudendal** (Alcock's) **canal** (Fig. 16-40). There, it gives off the **perineal nerve** with branches to the posterior part of the scrotum or to the labia majora in the female and the **rectal nerve** to the inferior rectal area. It continues as the **dorsal nerve of the penis** as it runs over the surface of the **obturator internus** and under the levator ani on the medial side of the internal pudendal vessels that lie within the obturator fascia. The dorsal nerve runs on the deep layer of the so-called urogenital diaphragm, where it gives off a branch to the crus. It then passes through the **deep transverse perineal muscle** to course on the dorsum of the penis (see Fig. 16-41). It is accompanied along the dorsolateral surface of the penis by the dorsal artery of the penis and terminates in multiple branches in the glans.

In epispadias and exstrophy, the dorsal nerves are displaced laterally in the middle and distal portions of the shaft; they become anterolateral only proximally.

The main *cutaneous nerve supply* to the penis and scrotum comes through the dorsal and posterior branches of the pudendal nerve, but the anterior portion of the scrotum and the proximal part of the penis are supplied by the ilioinguinal nerve after it leaves the superficial inguinal ring (see Fig. 9-23).

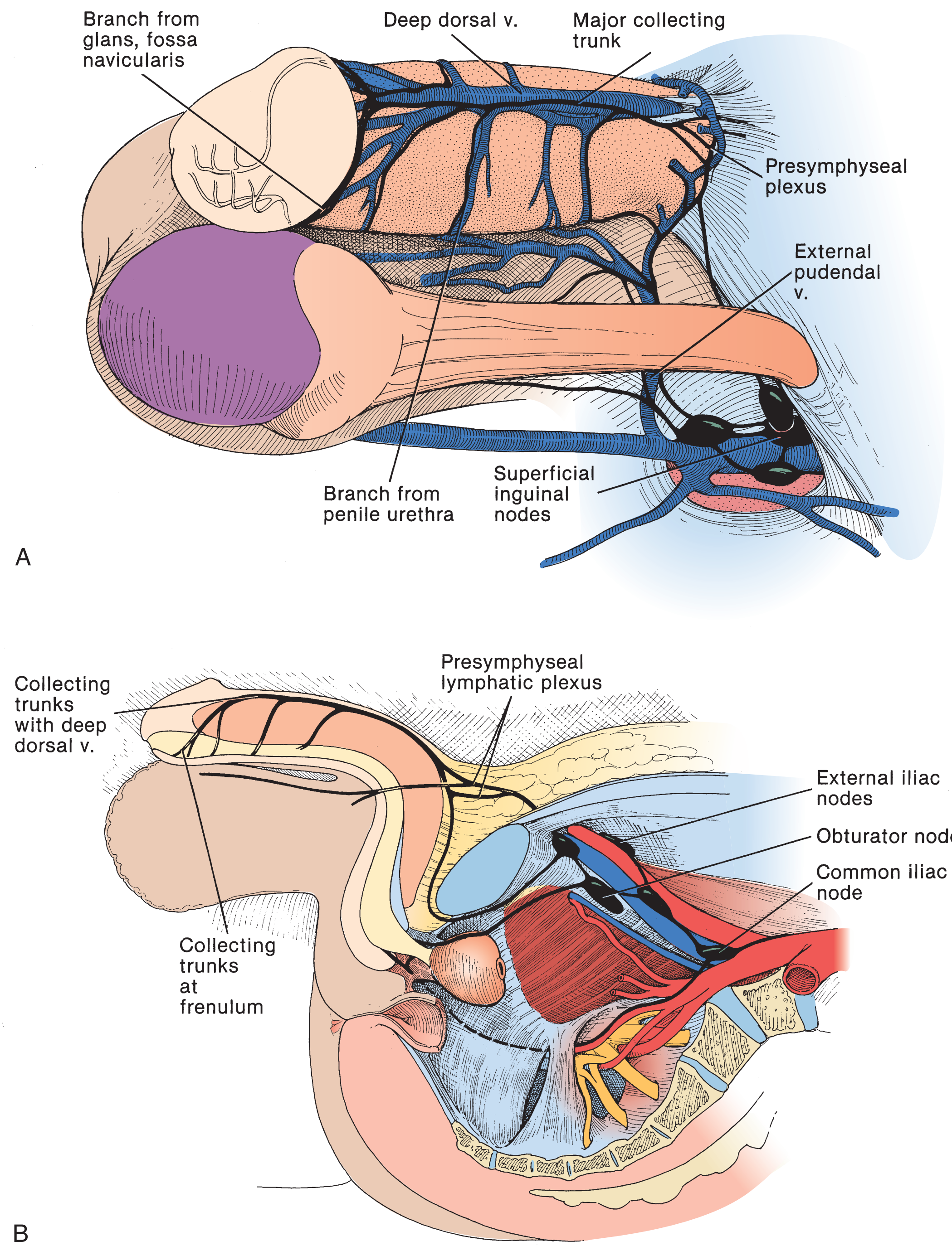


FIGURE 16-39. A, Dorsolateral view. **B,** Sagittal section.

Autonomic Innervation of the Penis

The sympathetic nerves arise from the lumbar nerves L1 and L2 and the parasympathetic nerves from **sacral nerves S2, S3,** and **S4**.

White rami communicantes from L1 and L2 pass to ganglia in the lumbar sympathetic chain. From the ganglia, the third and fourth lumbar splanchnic nerves join the **superior hypogastric plexus** that lies over the aortic bifurcation, the left common iliac vein, and the promontory of the sacrum. From each side of this plexus, the right and **left hypogastric nerves** descend medial to the internal iliac artery to the right and left pelvic (inferior hypogastric) plexuses. The hypogastric nerves also provide branches to the ureteric and testicular plexuses. The pelvic plexus, adjacent to the bladder base, prostate, and seminal vesicles, contains not only sympathetic fibers but also parasympathetic fibers derived from the **sacral pelvic splanchnic nerves.** The anterior part of each pelvic plexus constitutes the **vesical plexus,** with the nerves running along with the arteries to the bladder at its base. The lower part makes up the **prostatic plexus,** the nerves from which supply the prostate and ejaculatory ducts, seminal vesicles, membranous and penile urethra, and the bulbourethral glands.

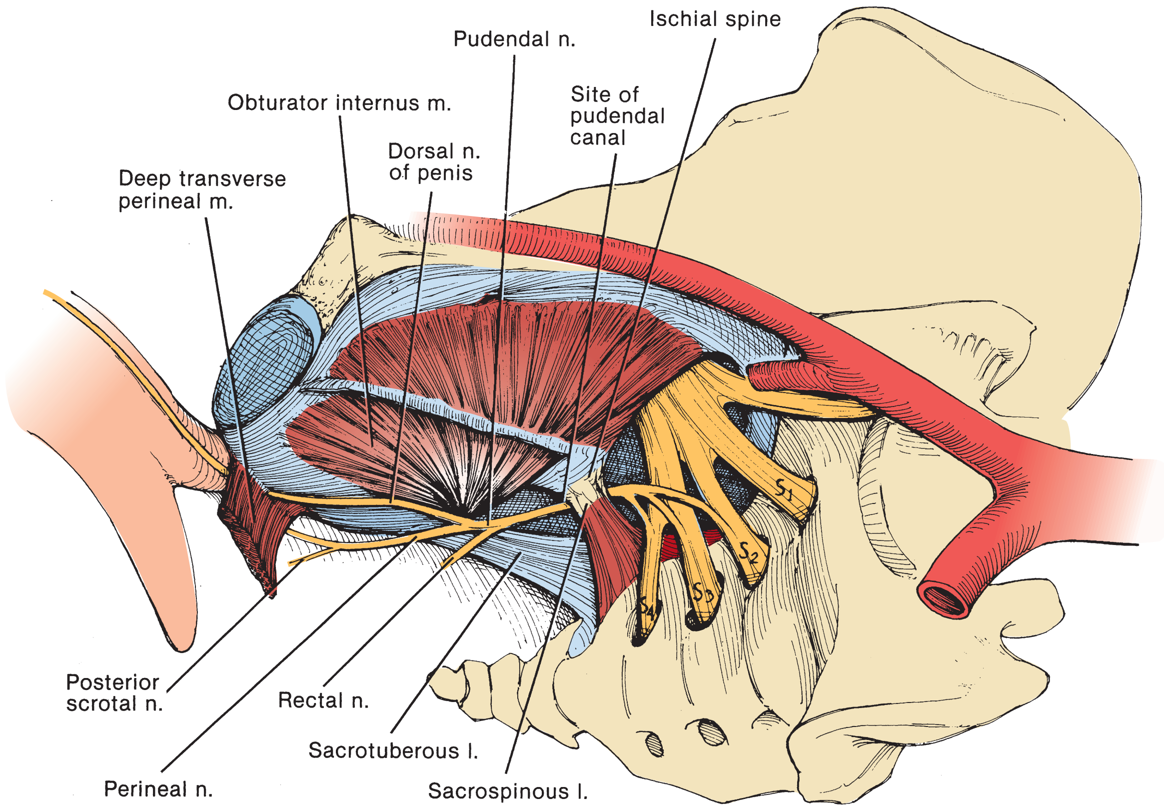


FIGURE 16-40.

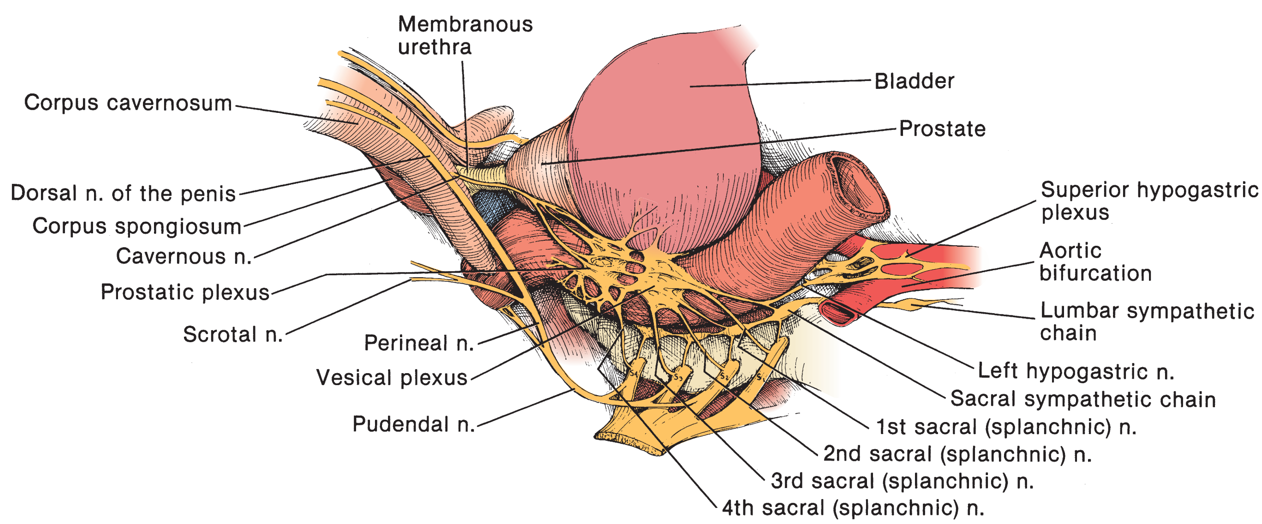


FIGURE 16-41.

Cavernous Nerve

The **cavernous nerve** leaves the pelvis between the transverse perineal muscles and the membranous urethra before passing beneath the arch of the pubis to supply each **corpus cavernosum** (Fig. 16-41). Two branches may be found. One is the lesser cavernous nerve that supplies the erectile tissue of the **corpus spongiosum** as well as the penile urethra. The other branch, the greater cavernous nerve, stays beneath the prostatic venous plexus to be distributed to the erectile tissue of the corpora cavernosa before ending as a delicate network of fibers about the cavernous vessels in the hilum of the penis.

The cavernous nerve arises as many fine fibers from the pelvic plexus. These are mixed nerves, with the sympathetic fibers producing vasodilatation and the parasympathetic ones, producing vasoconstriction. (Further details of the nerve supply to the pelvis will be found in Chapter 10.)

Neurovascular Bundle

As one or several large bundles, the cavernous nerve runs with branches of the prostatovesicular artery and veins as the so-called **neurovascular bundle.** It passes anterior to Denonvilliers' fascia between the posterolateral surface of the prostate and the rectum to lie above the endopelvic fascia and under the prostatic venous plexus (see Figure 14-24, 14-46, and 14-47). As it passes posterolaterally to the prostate, the bundle gives off fine branches to the vessels supplying the prostatic capsule.

Also shown is the somatic **pudendal nerve.** It branches into the **inferior rectal nerve** and **scrotal nerve,** and continues as the **dorsal nerve of the penis** (see Fig. 16-40).

Relation of the Cavernous and Dorsal Nerves to the Arterial and Venous Systems in the Penis

A **dorsal nerve** lies on the dorsum of each corpus cavernosum within Buck's fascia and in the same plane as the **dorsal arteries** (Fig. 16-42A). It also runs superficial to the **circumflex arteries** and **veins,** the **lateral veins,** and the **retrocoronal plexus.**

The **cavernous nerve** enters the perineum deep to the **prostatic venous plexus** and enters the base of the corresponding corpus lateral to the **cavernous artery** (Fig. 16-42B). The **crural veins** join the **internal pudendal vein** medial to the **internal pudendal artery.**

Gross Structure of the Urethra

It is customary for anatomists to divide the male urethra into three parts: (1) prostatic, (2) membranous, and (3) penile. However, from a surgical viewpoint, it is more practical to consider the combined membranous-penile urethra as composed of three segments instead of two: (1) the **bulbomembranous urethra,** (2) the **bulbospongy urethra,** and (3) the pendulous or **penile urethra.** The prostatic urethra is considered separately as part of the prostate.

The **bulbomembranous urethra,** labeled **A** in Figure 16-43, comprises the approximately 2 cm of urethra lying in the so-called urogenital diaphragm and within the **striated urethral sphincter** in addition to the proximal few centimeters of the bulbous urethra. The neuromuscular makeup of this region is detailed in Chapter 14, where the continence mechanisms are described.

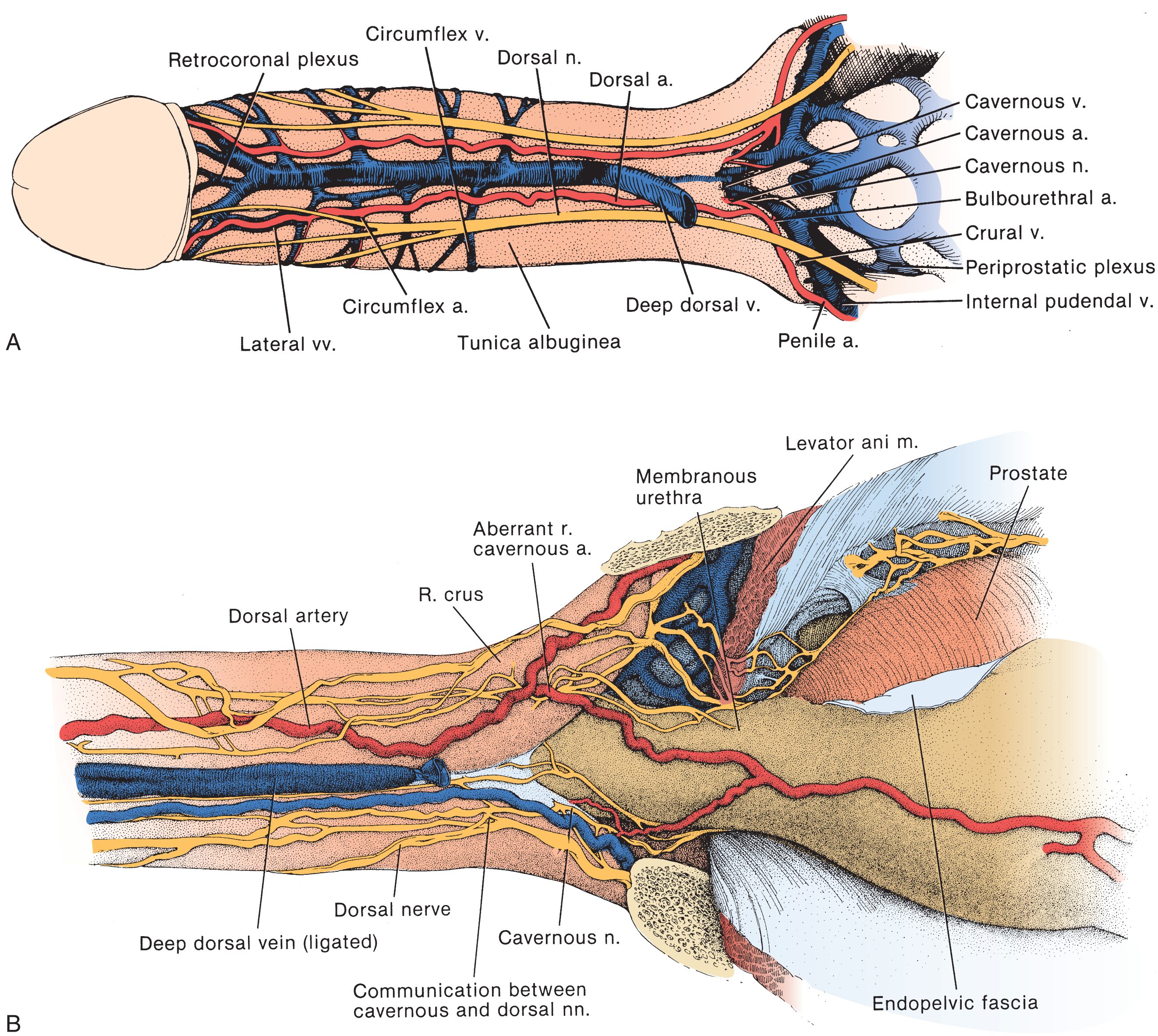


FIGURE 16-42.

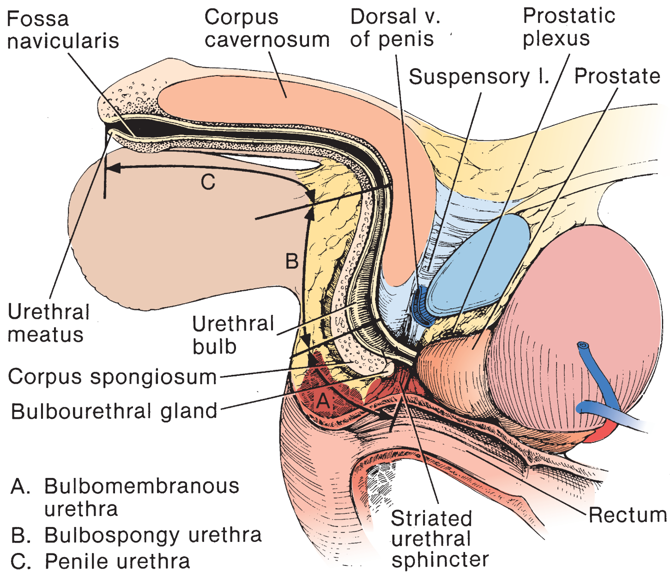


FIGURE 16-43.

The **bulbospongy urethra,** labeled **B,** extends from within a few centimeters of the anatomic membranous urethra distally to the level of the **suspensory ligament.** Its lumen widens to form the urethral bulb (intrabulbar fossa), where the semen collects before expulsion through contraction of the surrounding bulbospongiosus muscle. The ducts of the **bulbourethral** (Cowper's) **glands** empty into this segment at 3 and 9 o'clock positions, although the glands themselves lie more proximally on either side of the membranous urethra. The cavernous tissue of the corpus spongiosum surrounding the bulbar urethra is somewhat thicker here than it is more distally; this thickness serves to compensate for its greater circumference and to provide greater efficiency of ejaculation. The larger amount of spongy tissue available to react to inflammation by contraction perhaps accounts for the greater density of strictures occurring in this segment. The fixity and curvature of this portion of the urethra and its proximity to the undersurface of the symphysis pubis also make it more vulnerable to injury than the distal segment.

The penile (or cavernous) urethra, labeled **C,** is about 15 cm long, running from the suspensory ligament to the meatus (Fig. 16-44). It lies within the corpus spongiosum throughout its length in a position somewhat nearer the dorsum than the ventrum. The lumen of the urethra, although dilated as it passes through the bulb, is otherwise of uniform caliber except at the **fossa navicularis,** where it widens out before narrowing into the vertical slit of the **urethral meatus**.

The function of the fossa navicularis may be to convert the energy of the narrow but faster stream in the distal urethra into a slower stream but with higher pressure. The result is increased velocity as the stream passes through the narrow meatus that provides a jet for directing the stream to prevent self-contamination.

The membranous urethra is involved in urinary continence and control of ejaculation of semen. The remainder of the urethra serves two different functions: one is to allow

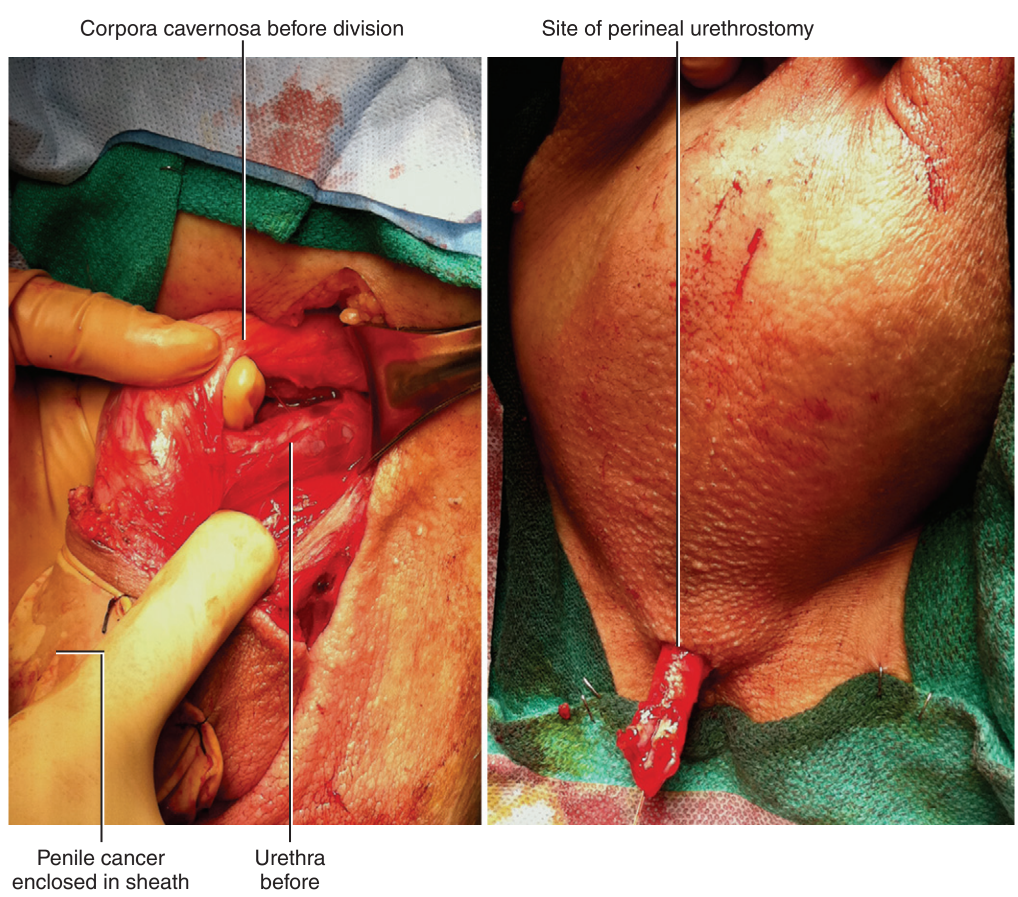


FIGURE 16-44. Penectomy for penile squamous cell carcinoma. At left, the surgeon has separated the corporal bodies from the urethra and is about to excise them along with the cancer, which is encased in a sheath. The urethra was also divided and the portion of unresected urethra was anastomosed to perineal skin to create a perineal urethrostomy. *(Images courtesy of Rabii Madi, MD.)*

the free passage of urine during urination; the other is to assist the expulsion of semen during ejaculation. To this end, it is surrounded by specialized tissue, the corpus spongiosum, that is normally relaxed for the free passage of urine. However, during sexual activity, the corpus spongiosum limits the diameter of the lumen, although because of its relatively low pressure not severely, to prevent pooling of the small amount of seminal fluid. When it is engorged, it also provides bulk against which the compressive action of the bulbospongiosus can act to evacuate the semen.

Sensation from the urethra enters through axons in the submucosal connective tissue and is passed centrally through the dorsal nerve of the penis.

Mucosa and Glands of the Penile Urethra

The penile urethra is lined with **pseudostratified columnar** epithelium (Fig. 16-45). However, islands of stratified squamous epithelium are found near the meatus, reflecting the ectodermal source of this portion of the urethra. The urethra in the distal portion of the glans is lined with more differentiated squamous cells lying over connective tissue papillae. These cells even become keratinized at the meatus, which is further evidence of their separate origin. The surface epithelium has no muscularis mucosae because it is separated from the smooth muscle of the spongy tissue by loose connective tissue.

The lateral and especially the dorsal surfaces of the fossa navicularis contain numerous pockets. One large pocket, the lacuna magna (Morgagni), opens on the roof of the fossa navicularis. On the anterior wall of the distal urethral segment are small recesses, the urethral lacunae. In addition, on the posterior wall of the penile and bulbar urethra are orifices of the ducts draining minute clusters of mucus-secreting cells, the **glands of Littré**, that lubricate the urethra prior to ejaculation (Fig. 16-46). These ducts run obliquely beneath the submucosal connective tissue to open toward the meatus and so may be entered inadvertently during urethral instrumentation. These glands, rich in **goblet cells**, penetrate the spongy tissue among the trabeculae and vascular spaces. This tissue reacts by dense fibrous proliferation to infection arising in these glands or from urinary extravasation. Subsequent contraction of the inflamed spongy tissue creates the spongiofibrosis of urethral strictures.

Urethral Lymphatics

The lymphatics from the urethra arise in a network associated with the mucous membrane, a network that extends throughout its length. It is especially well developed in the region of the fossa navicularis. The vessels in the network are more or less longitudinally oriented but anastomose obliquely and transversely. They drain proximally to unite

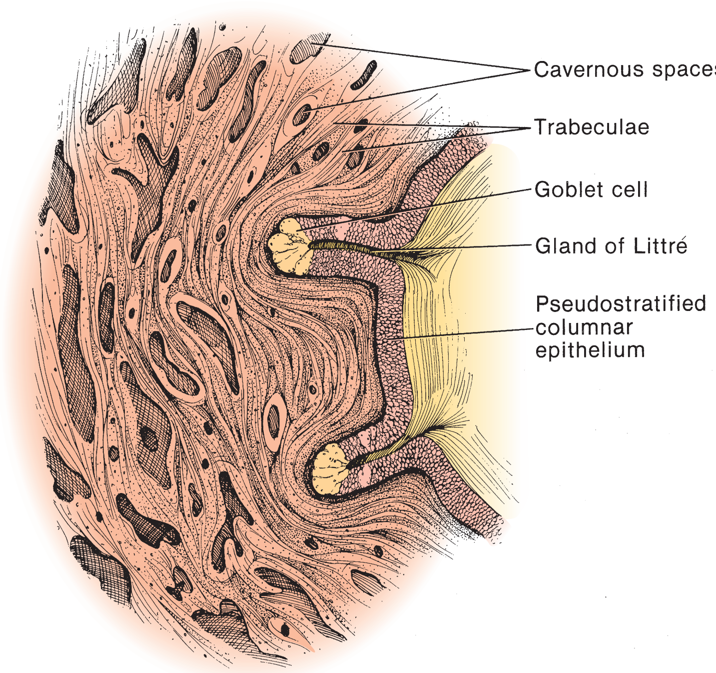


FIGURE 16-45.

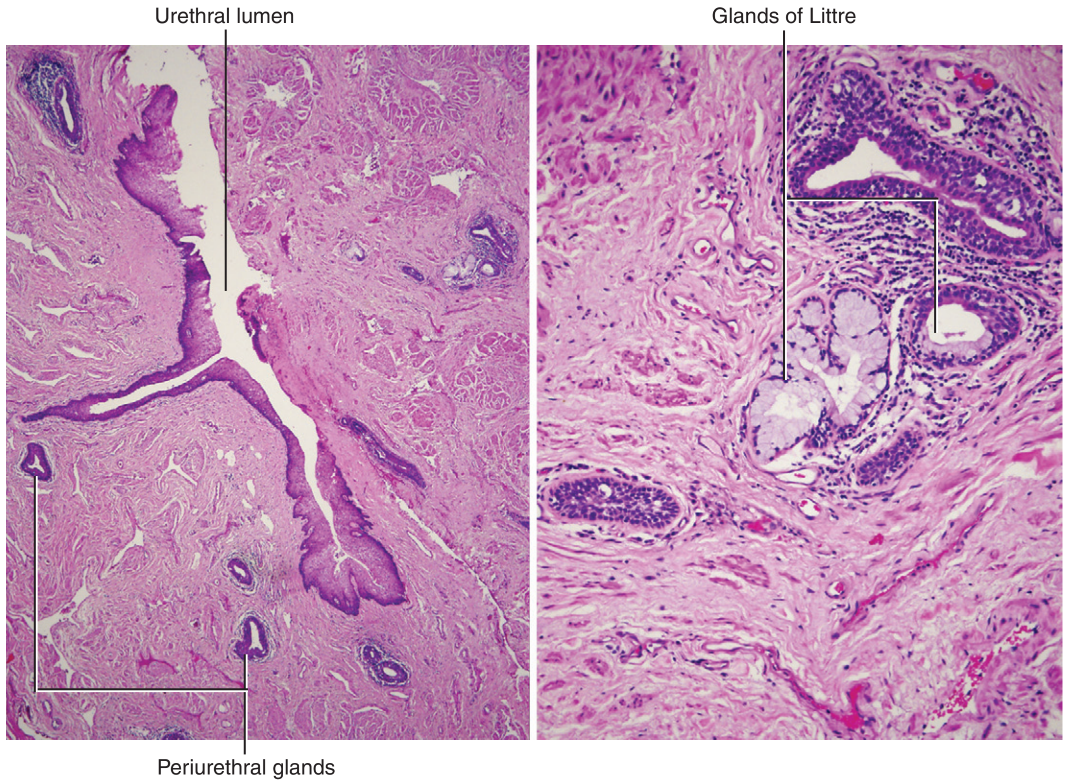


FIGURE 16-46. Histology of penile urethra. Penile urethra and surrounding glands are shown at left. The image on the right shows mucus-secreting cells that line the tubular and acinar mucous glands of Littre, which are found along the full length of the corpus spongiosum.

into collecting trunks that include those from the penile and bulbomembranous portions of the urethra.

The collectors from the fossa navicularis pass through the urethral wall on either side of the frenulum and join the vessels from the glans. Those from the penile urethra emerge on the ventral surface of the penis and curve around the corpora to also join the collectors from the glans. The bulbomembranous urethra has a more complicated and inconstant system. A vessel emerges from the bulb at its junction with the corpora cavernosa to accompany the urethral artery or the artery to the bulb. Another passes behind the symphysis pubis to end in a medial retrofemoral node. A third that drains the membranous portion ascends in front of the prostate to join those vessels from the anteroinferior portion of the bladder and ends in the anterior or medial retrofemoral nodes and the middle node of the medial group of the external iliac group.

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Chapter 17

Testis

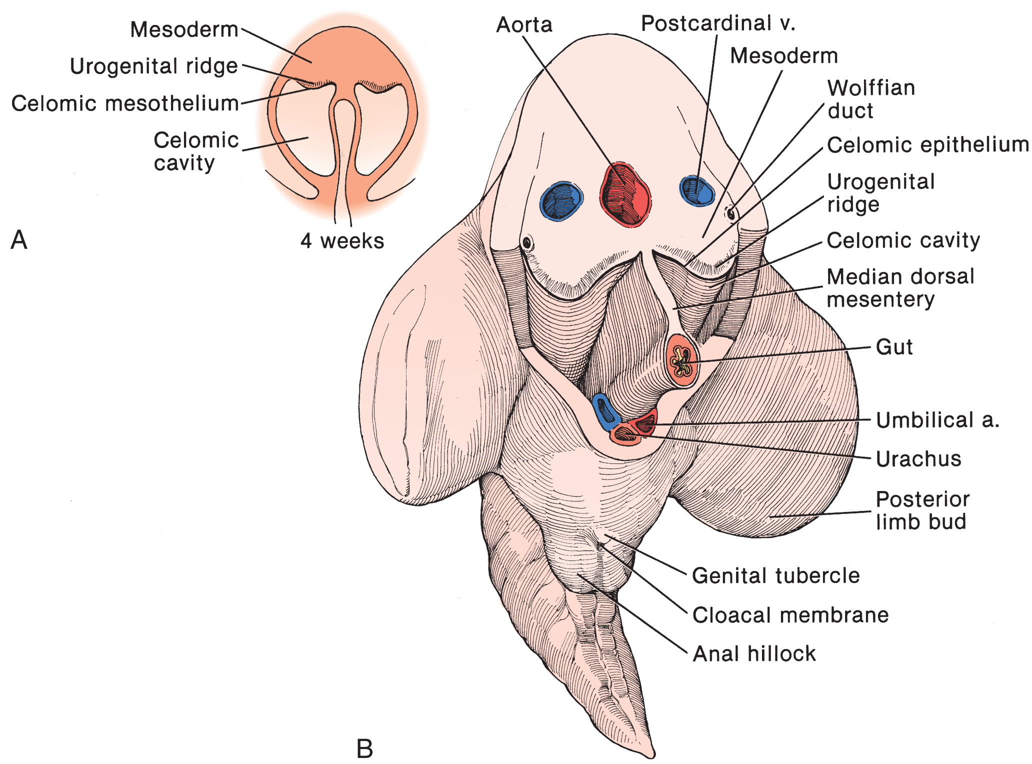

FIGURE 17-1. A, Cross section. **B,** Oblique view. *(Adapted from Jírasek JE: Atlas of Human Prenatal Morphogenesis. Boston, Martinus Nijhoff Publishers, 1983.)*

Next to the yard, the testes, or stones properly take place.
GIBSON
Farrier's Guide I.ii (1738) 16, 1720.

DEVELOPMENT OF THE TESTIS

Formation of the Mesonephric and Genital Ridges

Urogenital Fold and Genital Ridge

The intraembryonic **celomic cavity** is formed by about the fourth week of gestation by the separation of the primitive **mesoderm** into a core that is covered with **celomic mesothelium**, some of which will become the germinal epithelium on the **urogenital ridge** (Fig. 17-1A).

As the mesonephros grows, the **mesoderm** from the posterior body wall becomes extruded into the **celomic cavity**, principally by proliferation of the **celomic epithelium** covering its medial surfaces (Fig. 17-1B). This forms the **urogenital ridge**, which will later contain the mesonephros, müllerian (para mesonephric) and **wolffian** (mesonephric) **ducts**, and the reproductive gland. The testes develop from celomic mesothelium and underlying mesenchyme.

The **postcardinal vein** lies dorsally and the wolffian duct, posterolaterally.

Mesonephric and Genital Ridges

The urogenital ridge is divided longitudinally into a medial **genital ridge** and a lateral **mesonephric ridge**. It becomes partially separated from the body wall by the formation of a **urogenital mesentery** (Fig. 17-2). The genital portion will subsequently acquire its own mesentery, the mesorchium or mesovarium.

Primordial Germ Cells

The germinal cells in the gonad arise from **primordial germ cells** (primary gonocytes) early in ontogenesis. These first appear in the caudal part of the yolk sac adjacent to the

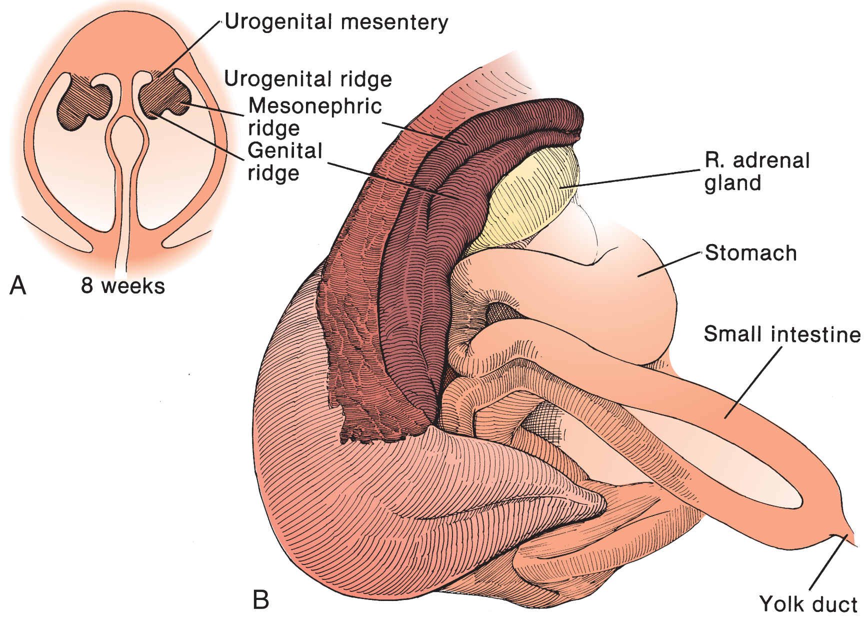

FIGURE 17-2. A, Cross section. **B,** Oblique view.

allantoic duct and migrate by ameboid movement dorsally to the angle between the **median dorsal mesentery** and the genital ridge (Fig. 17-3A). **Proliferating celomic epithelium** lies over the portion of the urogenital ridge destined to become the genital ridge.

Cords of epithelial cells grow onto the mesenchyme of the ridge (the **gonadal blastema**), forming the **primary sex (gonadal) cords** into which the germ cells become incorporated (Fig. 17-3B).

Male Gonadal Development

Formation of the Seminiferous Elements

Between 7 and 8 weeks, in the presence of H-Y antigen, the gonad rapidly differentiates into a testis while the müllerian (paramesonephric) duct degenerates.

The sex cords by epithelial proliferation form a cortex that surrounds the mesenchymal medulla derived from the gonadal blastema. Extensions from the mesenchyme will separate the cords from the celom and become the tunica albuginea, which extends into the gonad as trabeculae (Fig. 17-4A).

As the sex cords lengthen and extend into the medulla to form **seminiferous tubules**, they join to form the **rete testis** (Fig. 17-4B). The rete connects the seminiferous tubules to the **efferent ductules** derived from the few mesonephric tubules lying nearby, some of which may remain as appendages to the testis and epididymis. The efferent ductules are extensions of the **epididymal duct** (derived from the wolffian duct) that provide egress from the sex cords.

The attachment of the sex cords (seminiferous cords) to the germinal epithelium is lost by the interposition of the thick mesenchymal **tunica albuginea** that forms **trabeculae**.

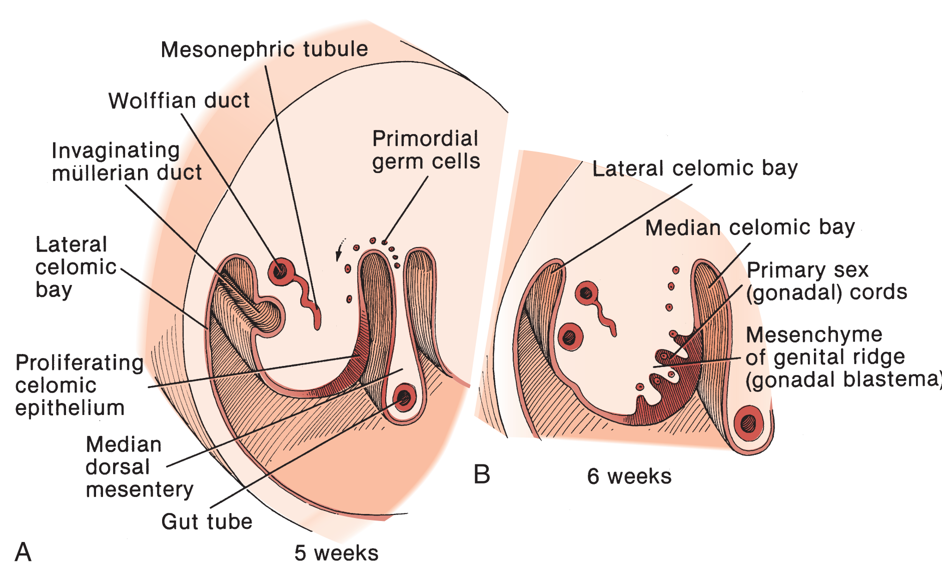

FIGURE 17-3.

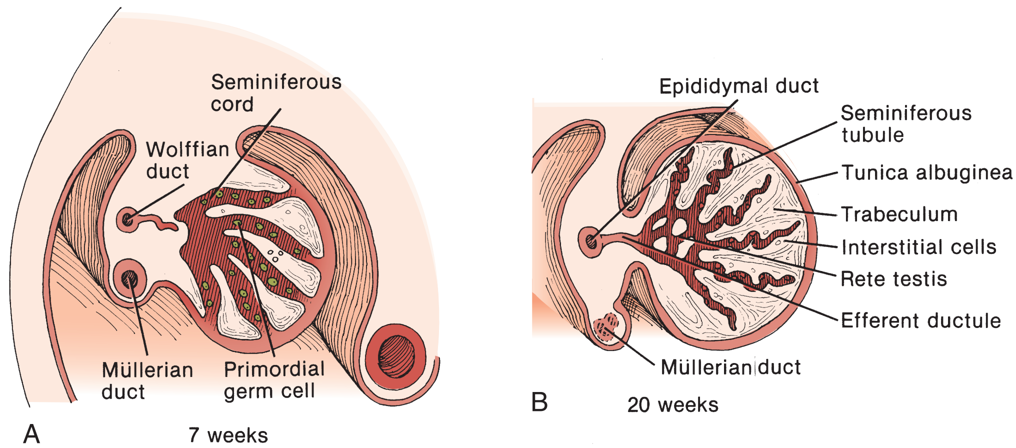

FIGURE 17-4.

Sustentacular (Sertoli) cells arise from germinal epithelium of the surface of the gland. The **interstitial** (Leydig) **cells** form from fibroblast-like cells in the local mesenchyme around the seminiferous cords and possibly from loose epithelial cells not taken up in formation of the tubules. Thus, not only does testicular differentiation occur early, but so does the secretion of hormones from these two types of cells that are essential for the differentiation of the genital ducts and external genitalia.

It is not until the 14th to 18th week that the sex cords acquire lumens and differentiate into seminiferous tubules, tubuli recti, and a more organized rete testis. The rete connects 15 to 20 residual mesonephric tubules, which are the efferent ductules, with the mesonephric duct to form the epididymis. The gonocytes from the primitive germ cells move to the periphery of the testis and become spermatogonia in increasing numbers up to the 17th week, with the multiplication ceasing around the 20th week. The germinal epithelium flattens to form the mesothelium surrounding the testis.

By the second postnatal year, the spermatogonia start differentiating into spermatocytes, maturation that is delayed in cryptorchidism. In the 11th and 12th years, the testis shows significant growth and subsequently matures with puberty.

Urogenital union occurs after 12 weeks, when the paragenital portion of the mesonephric tubules sends out collecting tubules into the indifferent reproductive gland. There, they become surrounded by the inner epithelial cords that will form the rete testis. The tubules of the rete then join the collecting tubules, now termed efferent ductules, completing the union. Those paragenital tubules not taken up in the union remain as vestigial structures.

The *blood supply* to the primitive testis is derived from the 30 pairs of mesonephric arteries that arise from the aorta (see Fig. 12-7), about one-third of which contribute to the urogenital arterial rete that supplies the kidneys and the developing testes. The lowest of the pairs does not become obliterated and forms the testicular artery. That this vessel branches from the urogenital arterial rete accounts for the variability of its origin. The testicular artery runs through the mesonephric fold above the testis, then passes caudally as an unbranched medial descending limb to enter the tunica albuginea at the lower pole. From there, it circles the lower pole to run cranially as the branched lateral ascending limb on the ventral and dorsal surfaces of the testis. Further branching is shown in Figure 17-38. In the female, the artery meets the ovary at hilus, from which it distributes branches.

Mesorchium and Gubernaculum

The epithelium on the medial surface of the urogenital ridge thickens to form two longitudinal projections into the celom: (1) the **gonadal** (genital) **ridge** medially and (2) the **mesonephric ridge** laterally (Fig. 17-5).

The gonadal ridge may be divided longitudinally into a lateral tubal portion, containing the wolffian and müllerian ducts, and a medial gonadal portion. At the upper end, the portions fuse to form the thin **diaphragmatic ligament** (urogenital mesentery) and, below, they join to form the **testicular ligament**, the two ligaments together constituting the mesorchium. The testicular ligament will become the gubernaculum, a structure that is continuous with the mesenchyme of the future inguinal canal (see Fig. 17-6).

Gubernacular growth is an end effect of the hormonal chain: hypothalamic gonadotropic-releasing hormone, pituitary-luteinizing hormone, Leydig cell testosterone, and enzymatically reduced dihydrotestosterone formed locally, to the cells of the gubernaculum by a steroid receptor complex.

The gubernaculum is present before the development of the abdominal musculature, a sequence that promotes formation of the inguinal canal. The gubernaculum appears to hold the testis near the canal during the rapid growth of the lumbar vertebral column that has the effect of carrying the kidney cephalad. Without the gubernaculum, the testis would lie high in the retroperitoneal space. Thus, the pelvic position of the testis comes not so much from retroperitoneal descent of the testis as from its distal fixation as the kidney rises.

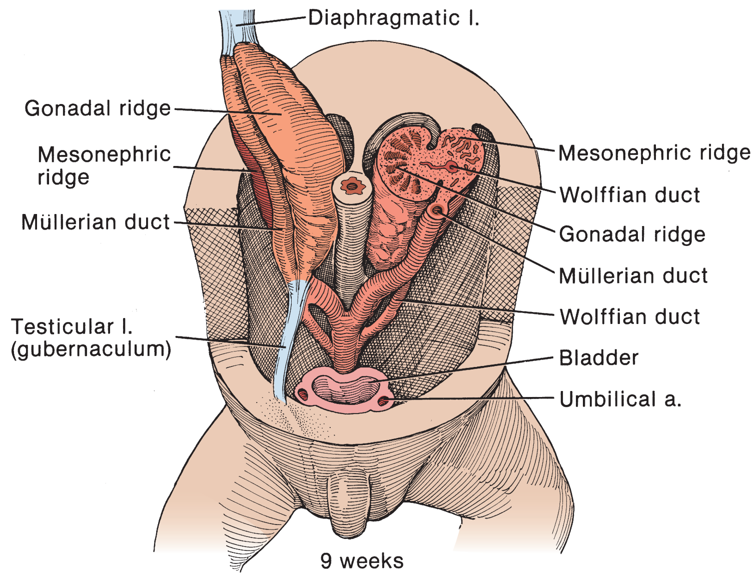

FIGURE 17-5.

Development of the Duct System in the Male

The **gubernaculum** attached to the lower pole of the **testis** will extend to the inguinal canal. The **müllerian duct** has fused, and a remnant remains near the testis.

Under the influence of testosterone, the wolffian (mesonephric) duct gains a thick layer of muscle from which the canal of the epididymis, the vas deferens, and the ejaculatory duct are formed. The upper part of the epididymal canal becomes coiled, and the lower portion expands to form the ampulla. There, the mesonephric duct gives off the primordia of the **seminal vesicle**, with the ejaculatory duct lying distally (Fig. 17-6A).

Through the action of 5-alpha reductase, dihydrotestosterone that is produced locally from testosterone induces the mesenchyme of the endodermal urethral epithelium of the urogenital sinus to differentiate into the **prostate** and bulbourethral glands (Fig. 17-6B) (also see **Figure 14-4**). The müllerian elements disappear as a result of the action of müllerian-inhibiting substance, except for a remnant on the end of each testis as the **appendix testis** and in the posterior urethra in the verumontanum as the prostatic utricle or vagina masculina.

Homologies with female urogenital structures are shown in Table 17-1.

Appendages of the Testis and Epididymis

Appendages derived from vestigial portions of the wolffian (mesonephric) and müllerian (paramesonephric) systems are organized in Table 17-2 (Fig. 17-7).

The **cranial aberrant ductules (appendix epididymis)** represent the persistence of the one or two most cranial mesonephric tubules (Figs. 17-8 and 17-9). It is almost

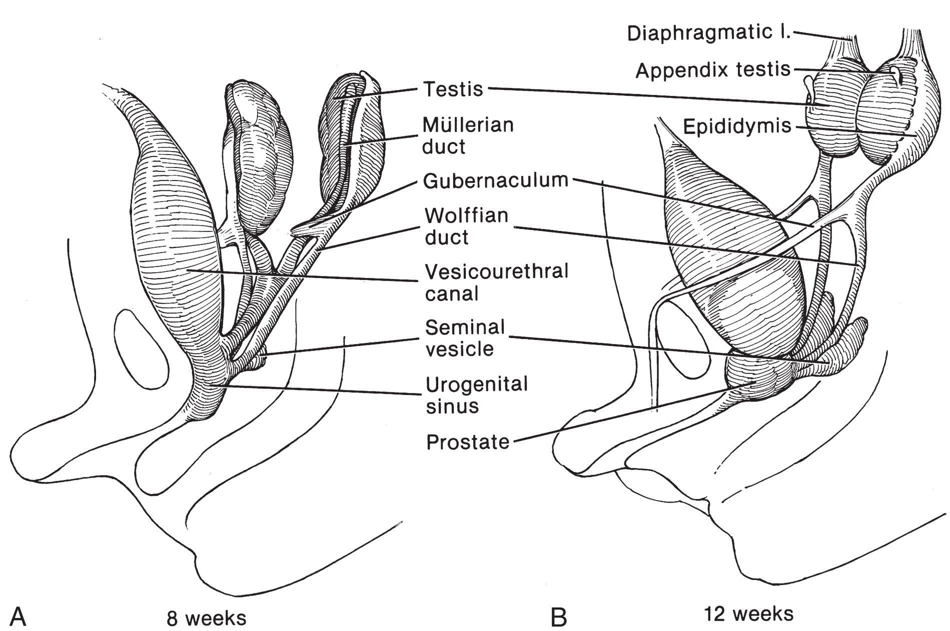

FIGURE 17-6.

TABLE 17-1

UROGENITAL HOMOLOGIES

Precursor	Male Organ	Female Organ
Indifferent gonad	Testis	Ovary
Primordial germ cells	Spermatozoa	Ova
Sex cords	Seminiferous tubules	Follicular cells
Mesonephric tubules	Efferent ductules, paradidymis, appendix epididymis	Epoöphoron
Wolffian (mesonephric) duct	Ductus deferens, seminal vesicles, epididymis	Gartner's canal
Müllerian (paramesonephric) duct	Appendix testis (hydatid), prostatic utricle	Fallopian tube, vagina (part)
Upper urogenital sinus	Bladder, prostatic urethra	Bladder, urethra
Lower urogenital sinus	Urethra	Vestibule
Genital tubercle	Penis	Clitoris
Genital folds	Penile urethra (floor)	Labia minora
Genital swellings	Scrotum	Labia majora

TABLE 17-2

INTRASCROTAL APPENDAGES

Structure	Alternate Name	Origin
Cranial aberrant ductules	Appendix epididymis; diverticulum of epididymal head	Cranial mesonephric tubules
Caudal aberrant ductules	Vas aberrans (Haller); diverticulum of epididymal tail	Caudal mesonephric tubules
Paradidymis	Organ of Giraldés	Caudal mesonephric tubules
Appendix testis	Hydatid of Morgagni	Vestige of paramesonephric (müllerian) duct

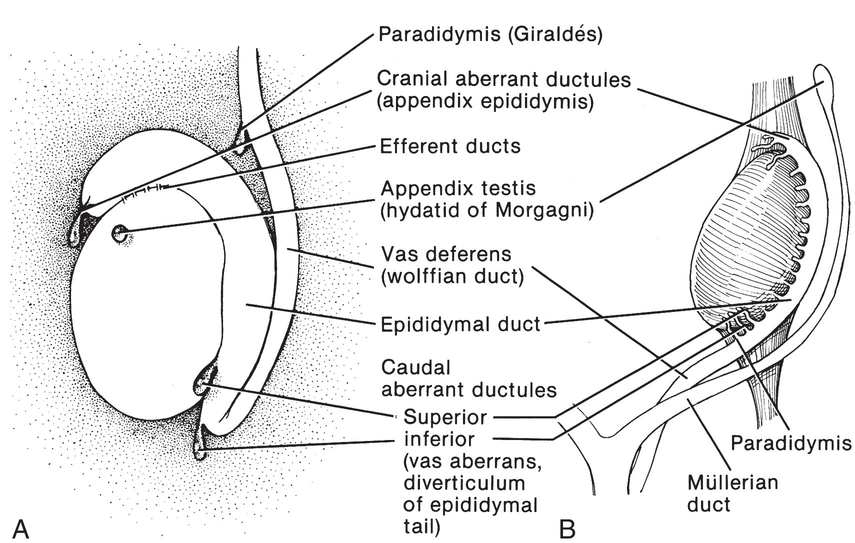

FIGURE 17-7.

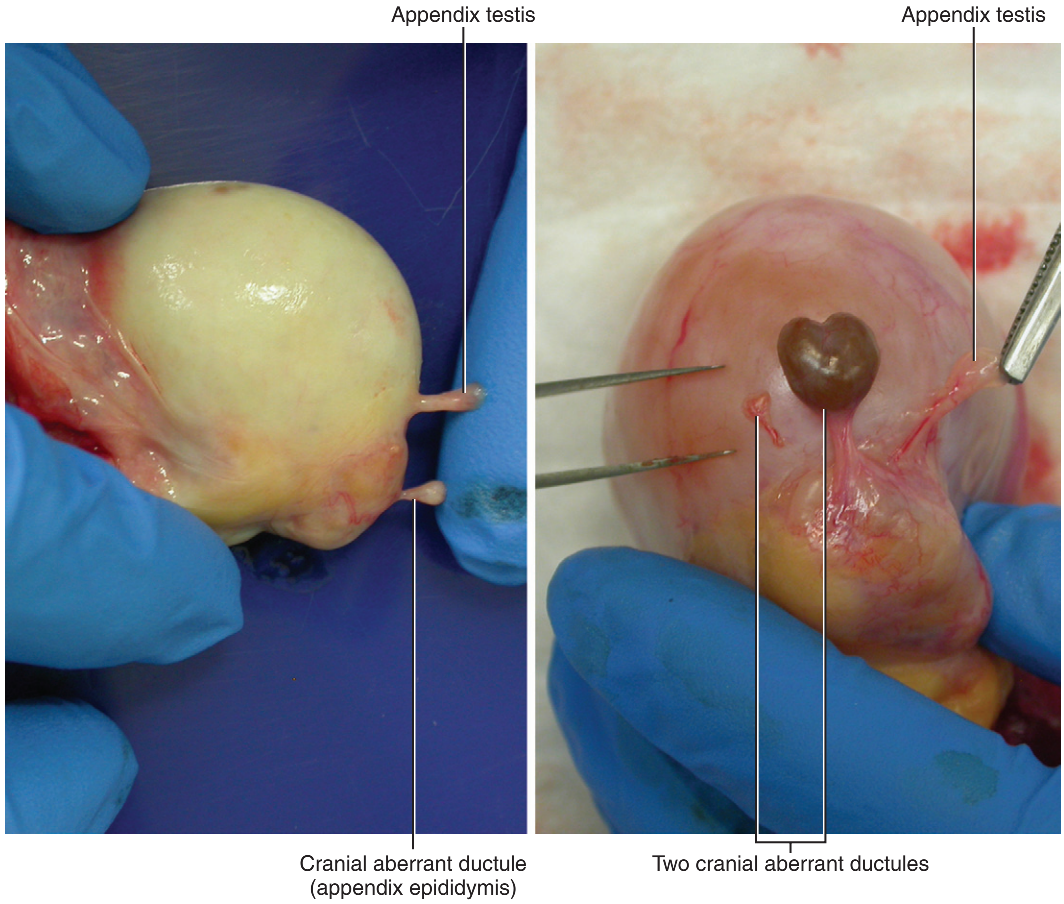

FIGURE 17-8. Appendages of testis and epididymis. In the image at left, an appendix testis and a single appendix epididymis are present. In the image at right, the dark-colored pedunculated structure and the small pedunculated structure indicated by the fine forceps are both epididymal appendices; the structure held by the large forceps is an appendix testis.

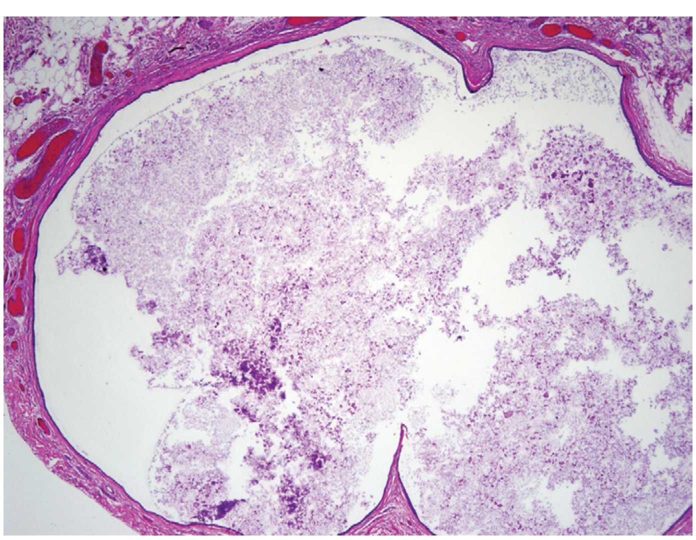

FIGURE 17-9. Appendix epididymis. This wolffian remnant is found in about one-third of testes. It is a pedunculated cystic epithelial-lined spherical or ovoid structure that arises from the anterosuperior pole of the head of the epididymis. The wall of the cyst is loose connective tissue; its outer surface is at least partially lined by cells of the tunica vaginalis.

always pedunculated. The next five or six mesonephric tubules form the definitive **efferent ductules** of the testis and the lobules of the head of the epididymis. In the female, they form the tubules of the epoöphoron. The superior and inferior **caudal aberrant ductules** that form the **vas aberrans** (Haller), the **diverticulum of the epididymal tail**, and the **paradidymis** (the organ of Giraldés) come from the most caudal mesonephric tubules. The paradidymis is homologous with the paroöphoron in the female.

A vestige of the müllerian duct remains as the **appendix testis** (hydatid of Morgagni) (Figs. 17-8 and 17-10) on the anterior superior pole of the testis. It may be on a stalk and even may be fimbriated like a small fallopian tube. In one autopsy study, it was found to be pedunculated in 82% of cases, at least on one side. It differs from the other appendages in its greater vascularity and in having ducts that communicate with the tunic. Painful torsion of the appendix testis is not uncommon and is probably fostered by a particularly long pedicle. The less-developed but pedunculated appendix epididymis and the other appendages only infrequently become symptomatic (Figs. 17-11 and 17-12).

The derivations of the vestigial structures are shown in Table 17-3.

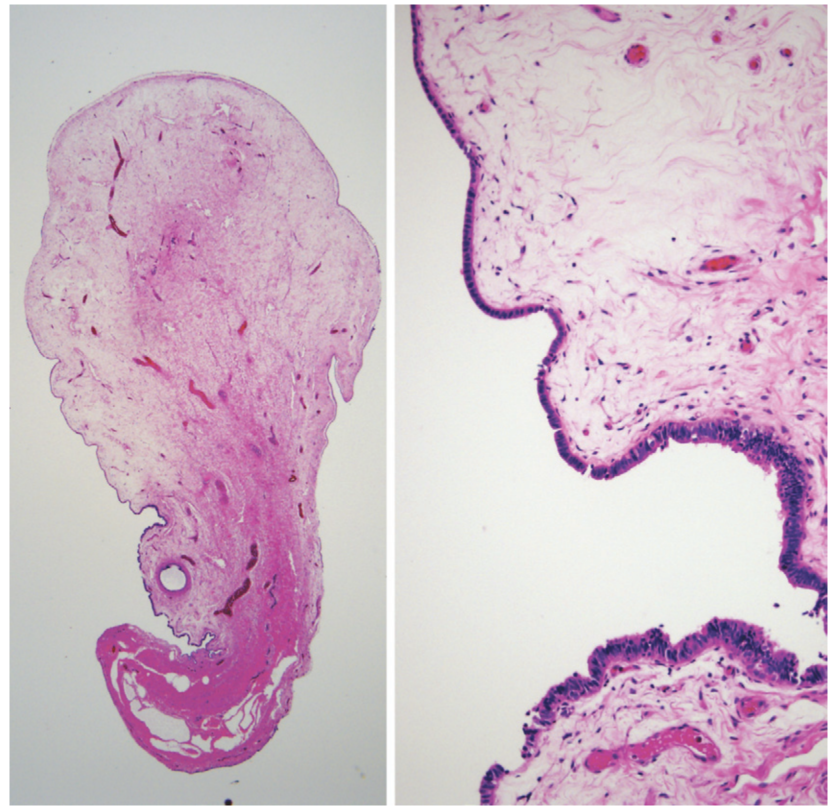

FIGURE 17-10. Appendix testis. This müllerian remnant is present in more than 90% of testes, as a sessile or polypoid mass, 2 to 4 mm in size, located at the superior pole of the testis near the epididymis. It consists of an epithelial-lined fibrovascular core composed of loose connective tissue, and is covered by simple cuboidal or low columnar müllerian-type epithelium that merges with the adjacent tunica vaginalis.

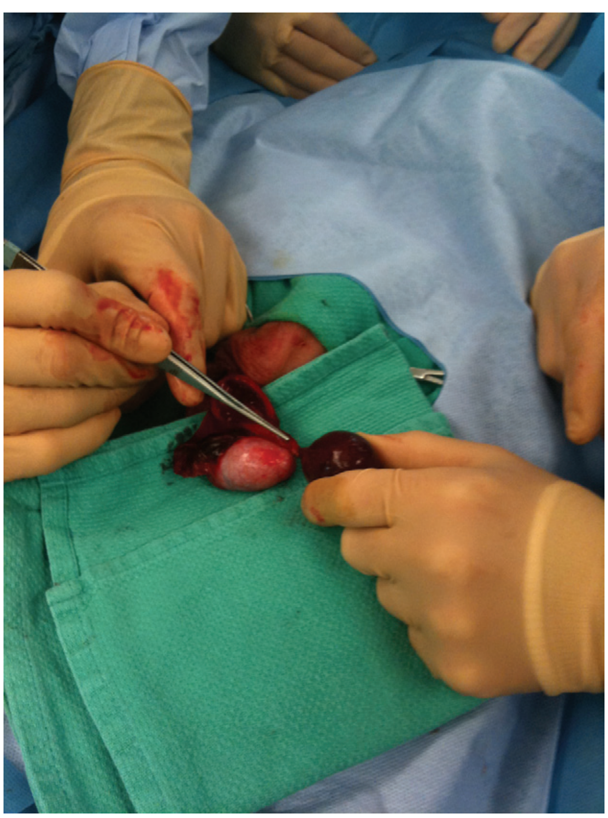

FIGURE 17-11. Torsion of appendix epididymis. This 12-year-old boy was found at surgery to have a large edematous and hemorrhagic appendix epididymis, indicated by the tip of the forcep. *(Image courtesy of Edward Cherullo, MD.)*

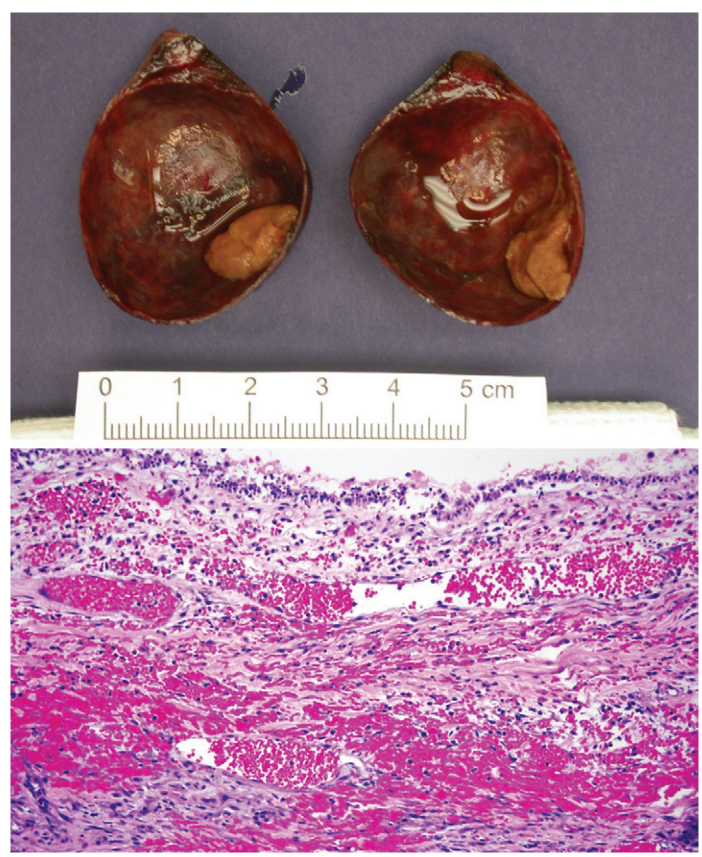

FIGURE 17-12. Torsion of appendix epididymis. A cross-section of the lesion shown in Figure 17-11 is at top. Lesion is centrally cystic, with a thin fibrous wall; the yellow-tan material is fibrinous exudate. At bottom, a section from the wall shows residual epithelium overlying edematous and markedly hemorrhagic stroma.

TABLE 17-3

DERIVATION OF REPRODUCTIVE TRACT STRUCTURES FROM WOLFFIAN AND MÜLLERIAN PRIMORDIA

Male	Female
GENITAL RIDGES	
Testis	Ovary
Seminiferous tubules (medulla)	*Pflüger's tubules*
Rete testis	*Rete ovarii*
Gubernaculum testis	Round ligament of uterus
WOLFFIAN DERIVATIVES	
Mesonephric tubules	
Ductuli efferentes	Epoöphoron
Ductuli aberrantes	*Ductuli aberrantes*
Paradidymis	*Paroöphoron*
Mesonephric duct	
Ureter, pelvis, and collecting tubules of kidney	Ureter, pelvis, and collecting tubules of kidney
Trigone of bladder	Trigone of bladder
Ductus epididymis	*Duct of the epoöphoron*
Ductus deferens	*Gartner's duct*
Ejaculatory duct	
Seminal vesicle	
Appendix epididymis	*Appendix vesiculosa*
MÜLLERIAN DERIVATIVES	
Appendix testis	Oviduct
	Uterus
Colliculus seminalis	Cervix and upper vagina
UROGENITAL SINUS DERIVATIVES	
Bladder	Bladder
Urethra above colliculus seminalis	Urethra
Prostatic utricle	
Urethra below colliculus seminalis	Lower vagina and vestibule
Membranous urethra	Hymen
Cavernous urethra	
Cavernous urethra	
Bulbourethral (Cowper's) glands	Vestibular glands (Bartholin's)
Prostate gland	Paraurethral glands of Skene
EXTERNAL GENITALIA	
Glans penis	Glans clitoridis
Floor of penile urethra	Labia minora
Scrotum	Labia majora

Vestigial structures in italics.
Adapted from Gray SW, Skandalakis JE: *Embryology for Surgeons. The Embryological Basis for the Treatment of Congenital Defects.* Philadelphia, WB Saunders Co., 1972.

Testicular Descent

Descent of the testis is the last phase of a genetic and hormonal sequence that has involved the differentiation of gonads, duct structures, and genitalia. Interference with this complex chain can produce a wide but usually predictable series of abnormalities, with a spectrum ranging from the retractile testis to intersexuality.

Testis and Inguinal Canal

The first movement by the **testis** as it lies suspended by the mesorchium from the dorsal abdominal wall occurs when the cranial end of the mesorchium, the **diaphragmatic ligament**, degenerates and leaves the testis in a lower position. The testis becomes attached to the lower ventral abdominal wall by an inguinal fold of peritoneum containing its blood and nerve supply. The caudal end of the mesorchium, a cord of mesenchyme destined to become the **gubernaculum**, lies inside a peritoneal fold that will extrude to join the skin of the lower part of the anterior abdominal wall at the genital swellings, the future site of the scrotum. Up to this time, the gubernaculum has been an intraperitoneal organ, but as the scrotum develops, it becomes surrounded by the muscles of the anterior abdominal wall that make up the developing **inguinal canal**.

By the 12th week, the anterior abdominal wall elongates to accommodate the intestines and the body bends into an upright position at the same time that the lumbar segments grow. The umbilical artery, which is anchored between the aorta and the umbilicus, becomes elevated and lifts a fold of overlying peritoneum medial to the testis. This forms a partition separating the primitive true pelvis from lateral inguinal fossa. It is from this fossa that the peritoneum evaginates into the scrotum as the processus vaginalis, ventral to the gubernaculum. The defect in the transversus abdominis constituting the **internal inguinal ring** moves laterally, with the result that the gubernaculum must take an oblique course to reach the relatively fixed external inguinal ring.

As the **peritoneum** evaginates to form the **processus vaginalis**, it carries with it the elements of the anterior body wall so that the testis, with the tunica vaginalis, becomes covered with a succession of layers during its passage through the inguinal canal (Fig. 17-13). The inner layer, the internal spermatic fascia, is continuous with, but not part of, the outer stratum of retroperitoneal tissue of the pelvis from which the **transversalis fascia** arises, thus accounting for the belief by some anatomists that it is derived from the transversalis fascia. Strictly speaking, the internal spermatic fascia is not a true fascial layer, but is the connective tissue from the intermediate stratum that embeds the cord structures. It lies within the cremasteric layer, to which it is densely adherent. The second covering, the cremasteric fascia and cremasteric muscle, is a continuation of the **internal oblique** and **transversus abdominis**. The outer coat, the external spermatic fascia, is an extension from the innominate fascia associated with the **external oblique** (see Fig. 9-6).

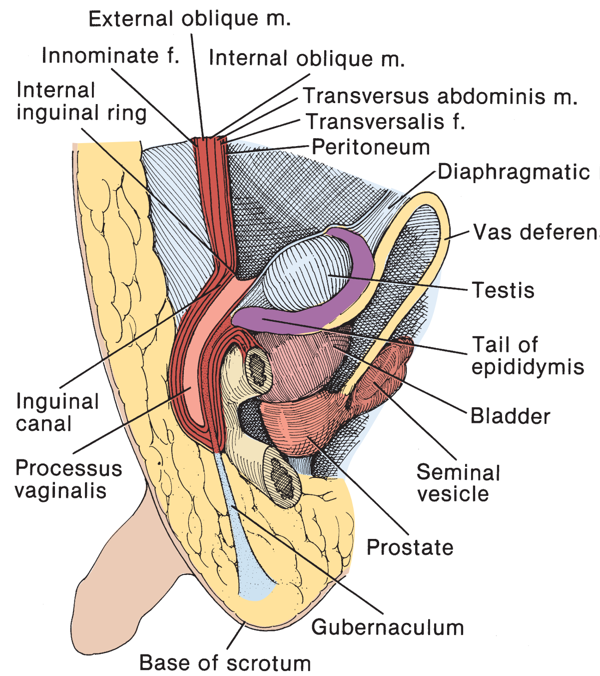

FIGURE 17-13.

The gubernaculum with its content of mucoid material is in the dorsal aspect of the inguinal canal and the cremaster is on the ventral aspect with the processus vaginalis between. The gubernaculum is attached to the **base of the scrotum**. The **tail of the epididymis** is attached to the gubernaculum, which now fills the site of the future canal. As the mesenchyme of the gubernaculum regresses, the epididymis descends and provides a space for the testis to move into the scrotum.

Steps in the Descent of the Testis

The **epididymis** and **testis** are held by the **gubernaculum** at the **internal inguinal ring** until 2 months before birth. Under hormonal stimulation, the gubernaculum swells. By this time, both the gubernaculum and the **processus vaginalis** extend to the **base of the scrotum** (Fig. 17-14A).

As the **gubernaculum** shrinks, the **epididymis** is led into the scrotum, followed by the **testis** (Fig. 17-14B).

A defective attachment to the epididymis is one explanation for nondescent. It is significant that epididymal abnormalities are common with cryptorchidism, having an incidence of 36% in one series. Whether gubernacular traction, abdominal pressure, or other factors are dominant in effecting descent has yet to be determined. Relations among the factors responsible for descent are still unclear and will not be debated here.

After descent, the testis increases in size.

The **processus vaginalis** becomes obliterated prior to birth, leaving a potential space around the testis between the **parietal layer** of the **tunica vaginalis** and the **visceral layer** of the **tunica vaginalis** that covers the tunica albuginea of the testis (Fig. 17-14C). The **gubernacular ligament** at the lower pole of the testis remains as a remnant.

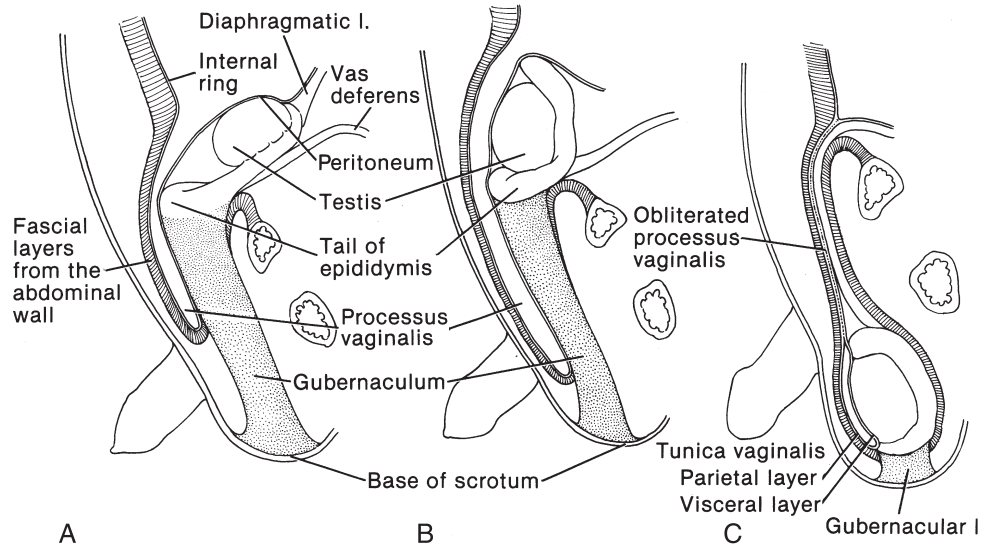

FIGURE 17-14.

ANOMALIES OF THE TESTIS AND EPIDIDYMIS

Cryptorchidism

Approximately 0.8% of boys one year old have at least one testis outside the scrotum (Figs. 17-15, 17-16, and 17-17). Fertility is impaired and the risk of malignancy is increased. The testis must not only be placed in the scrotum to avoid thermal injury, but it must also receive hormonal support.

In general, the higher the position of the testis, the less well developed it will be. Abdominally situated testes are the smallest in size and show the greatest retardation of differentiation of the seminiferous elements. A retractile

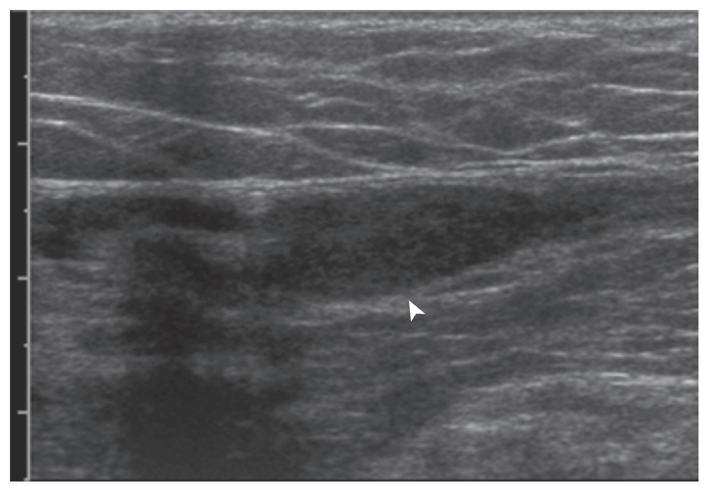

FIGURE 17-16. Undescended testis. Ultrasound demonstrates a testis, indicated by the arrowhead, in the inguinal canal. *(Image courtesy of Vikram Dogra, MD.)*

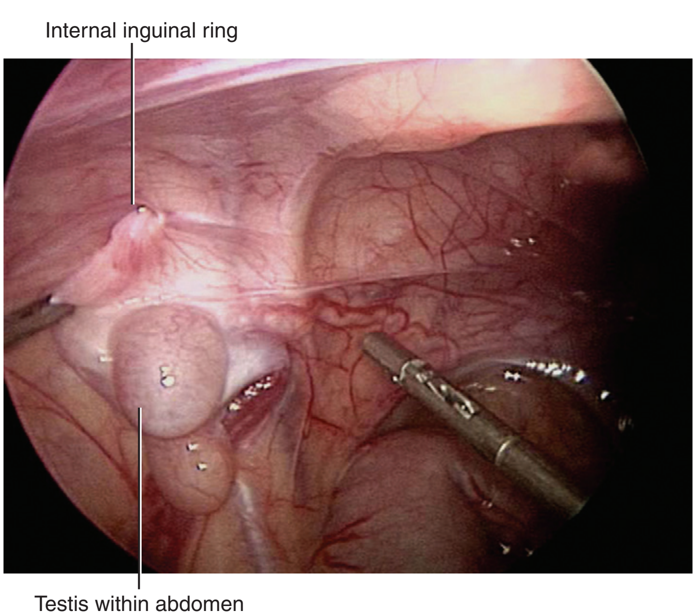

FIGURE 17-15. Undescended testis. Laparoscopic view of a testis retained within the abdomen. The internal ring is visible. *(Image courtesy of Jonathan Ross, MD.)*

FIGURE 17-17. Undescended testis. Operative image of a testis retained in the inguinal canal, just before ligation of hernia sac and orchiopexy. *(Image courtesy of Jonathan Ross, MD.)*

testis, in contrast, is usually normal both structurally and functionally.

Cryptorchidism is associated with a high incidence of local abnormalities, apart from defects of the testis itself caused by hormonal and positional factors. One of three cryptorchid testes is associated with an abnormality of the vas deferens or the epididymis, especially if the testis is found in a high position. The epididymis may be elongated and even detached from the testis; the vas and the tail of the epididymis may take a looping course. In addition, there may be areas of ductal malformation or atresia. Rarely, the vas may be ectopic.

Ectopic Testis

If the gubernaculum has more than one embryonic "tail" connecting it to the scrotum, a second, more dominant tail might lead the testis to an abnormal position in the superficial inguinal, perineal, pubic, penile, or femoral area.

Abnormalities of Number

Polyorchidism is rare, and the supernumerary testis is usually worth preserving for endocrine function if any surgery is performed. With transverse testicular ectopia, two testes are found in one side of the scrotum, usually associated with a contralateral hernia and a palpable inguinal mass. Fusion of splenic tissue with the testis (splenogonadal fusion) is secondary to adhesions between the splenic and genital primordia. Tiny adrenal rests may occur in the proximal cord within the cremaster and may precipitate torsion or may become hyperplastic or neoplastic.

The testis is unilaterally absent in 4% of boys with cryptorchidism, and it is missing on the left side in four-fifths of these cases. Absence might be due to agenesis, which would be associated with persistent müllerian duct remnants, but this is a rare finding. Because wolffian duct remnants or a blind-ending testicular artery are usually found at exploration, torsion with in utero obliteration of the venous drainage is the common cause of absent testis. The episode of ischemia occurs after 16 weeks' gestation, because in these cases, the induction of vas and epididymis is found to be complete.

Associated Anomalies

The presence of a normal ureter and kidney demonstrates that a wolffian duct has been formed. If the wolffian duct then regresses, beginning cranially as it does in females, the result will be partial ureteral agenesis. The distal, epididymal end of the duct will be absent, whereas the more proximal part forming the seminal vesicle may persist. In severe cases, the entire vas and even the seminal vesicle may be missing. If no part of a wolffian duct forms, not only will the epididymis, vas, and seminal vesicle be absent, but the kidney and ureter will be missing as well. The testis will have formed, but because it lacks a mesonephric fold and hence a gubernaculum, it will remain abdominal.

Extravaginal Torsion of the Spermatic Cord, Left Testis

Extravaginal torsion occurs in infants in whom the testicular coverings are not firmly attached to the scrotal wall (Fig. 17-18A).

Rotation is outside the **tunica vaginalis** with consequent obstruction to venous drainage (Fig. 17-18B).

Intravaginal Torsion

Intravaginal torsion is the common type in adolescents and young men.

The testis and, usually, the epididymis are not adequately attached to the posterior wall of the **tunica vaginalis** (bell-clapper configuration). A potential space surrounds the **tunica albuginea** of the testis and leaves the testis and epididymis hanging free (Fig. 17-19A).

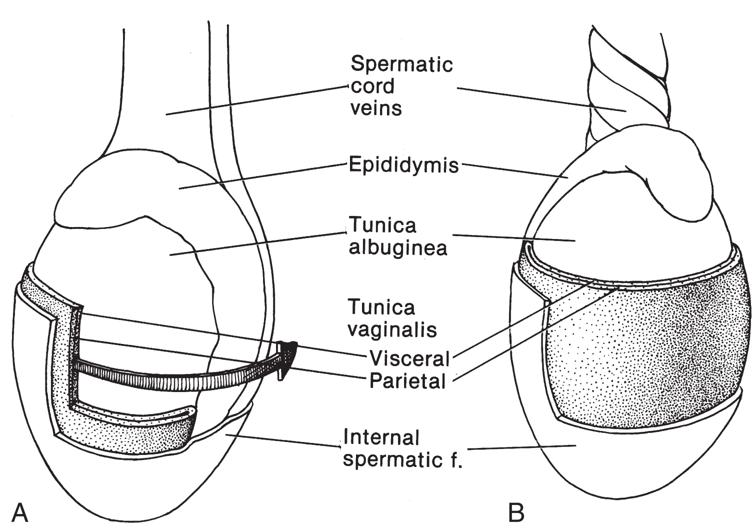

FIGURE 17-18.

Rotation of the **testis** and **epididymis** within the **tunica vaginalis** produces venous occlusion above the epididymis (Figs. 17-19B, 17-20, 17-21, 17-22, and 17-23).

Hydrocele, Hernia, And Hydrocele of the Cord

Normally, the processus vaginalis becomes obliterated throughout its entire length from the peritoneal cavity to the **tunica vaginalis,** leaving only a potential space between

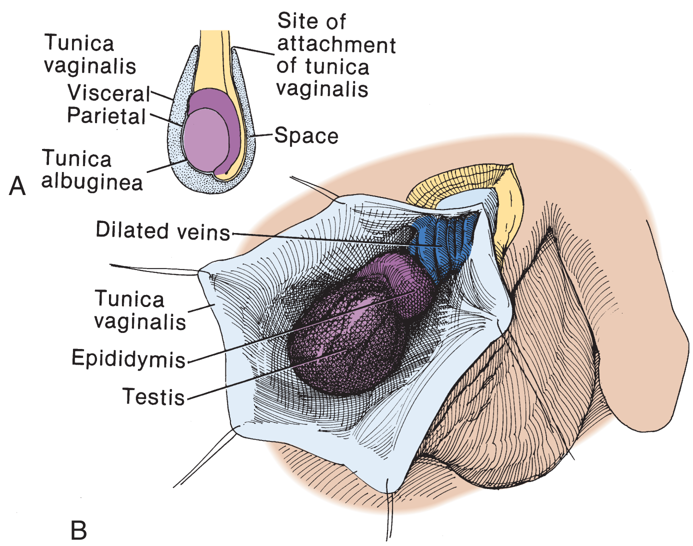

FIGURE 17-19.

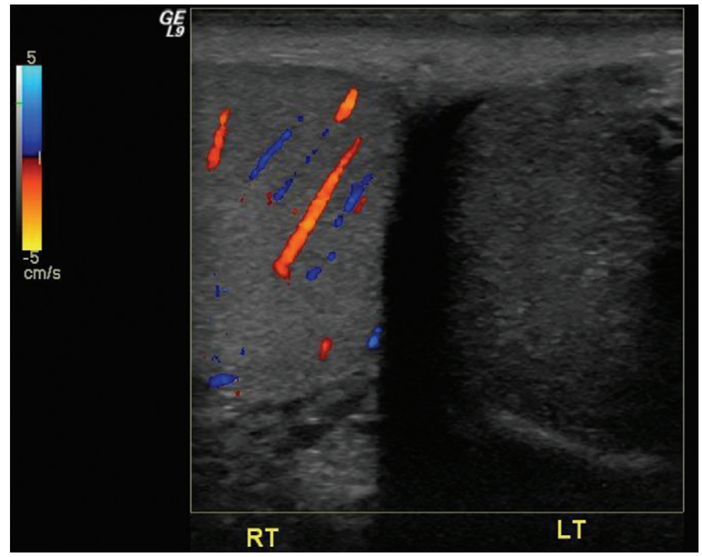

FIGURE 17-20. Testicular torsion. Doppler ultrasound confirms blood flow to the right testis. No blood flow to the left testis is evident; in this case, absence of blood flow was due to torsion of testis and spermatic cord. *(Image courtesy of Vikram Dogra, MD.)*

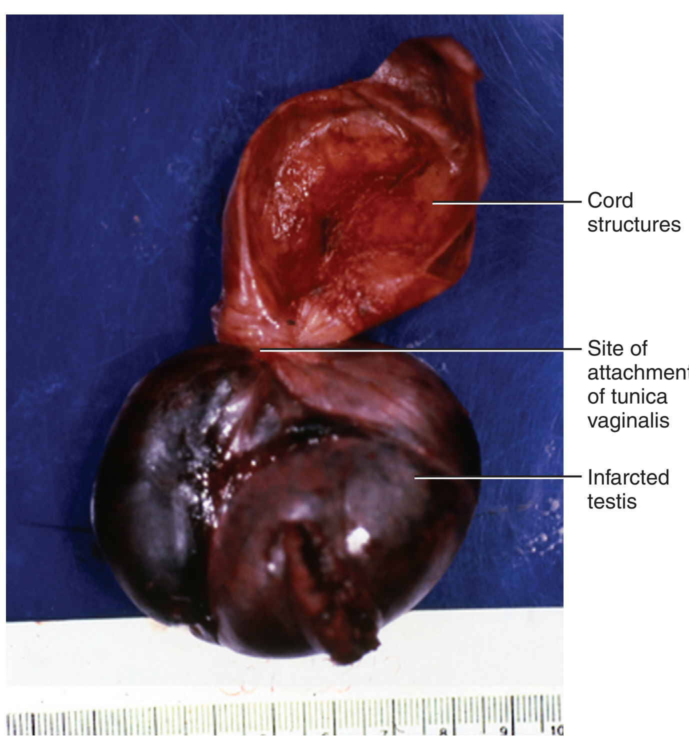

FIGURE 17-21. Testicular torsion. This testis demonstrates the "bell-clapper deformity," in which the tunica vaginalis completely encircles the distal spermatic cord, the epididymis and testis, rather than reflecting off the posterolateral aspect of the testis, resulting in an anomaly reminiscent of a clapper inside a bell. The testis has undergone at least one complete rotation within the tunica sac, compromising its blood supply. The testis has been incised, and the parenchyma appears nonviable.

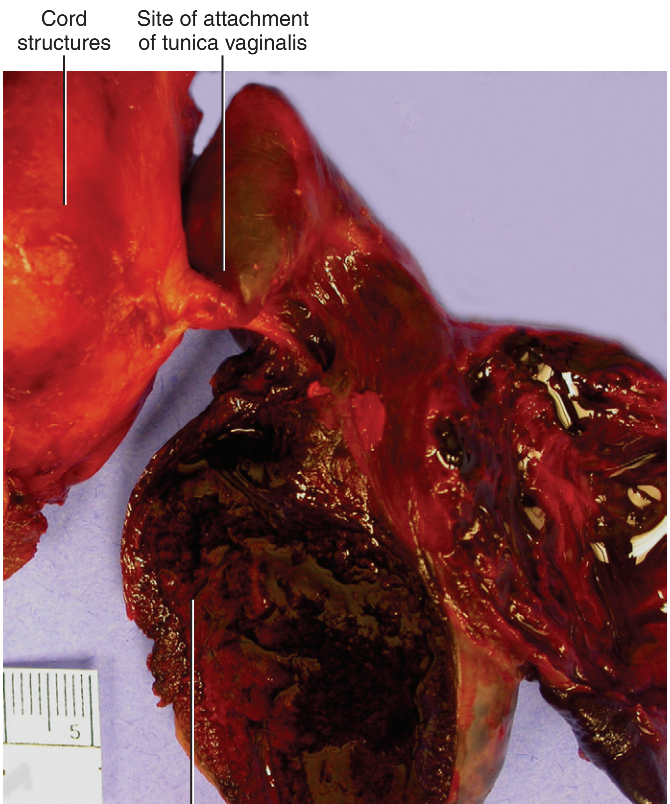

FIGURE 17-22. Testicular torsion. Another example of torsion and testicular infarction, also showing the "bell-clapper deformity" associated with high insertion of the tunica sac on the spermatic cord. The testis and epididymis have been sectioned from top to bottom; they appear hemorrhagic and nonviable.

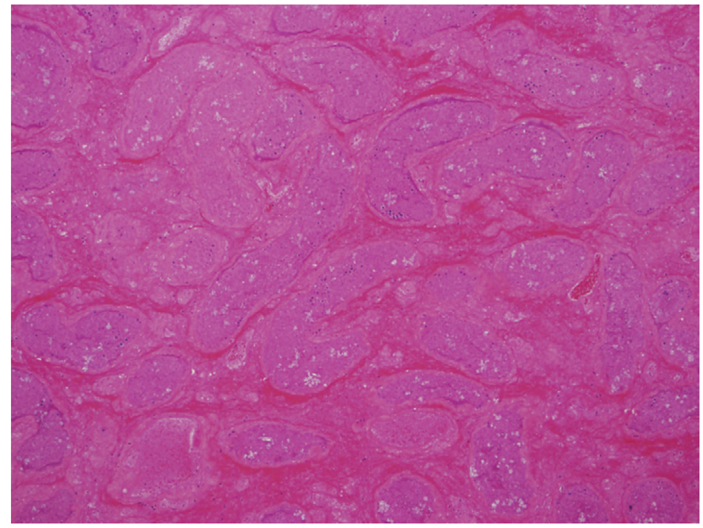

FIGURE 17-23. Testicular torsion. Only the ghostly outlines of the seminiferous tubules are evident; tissue is nonviable.

the **parietal and visceral tunics**. A hydrocele results from excess formation or decreased absorption of peritoneal fluid within the tunica vaginalis (Figs. 17-24 and 17-25). The relationships of the testis and epididymis to the **potential space** are shown in cross section at **x–x′** (Fig. 17-26A).

A congenital hernia occurs when the proximal portion of the processus fails to close (Fig. 17-26B).

If only the central portion of the processus vaginalis remains unfused, fluid secreted by the enclosed peritoneum accumulates and forms a hydrocele of the cord (Fig. 17-26C).

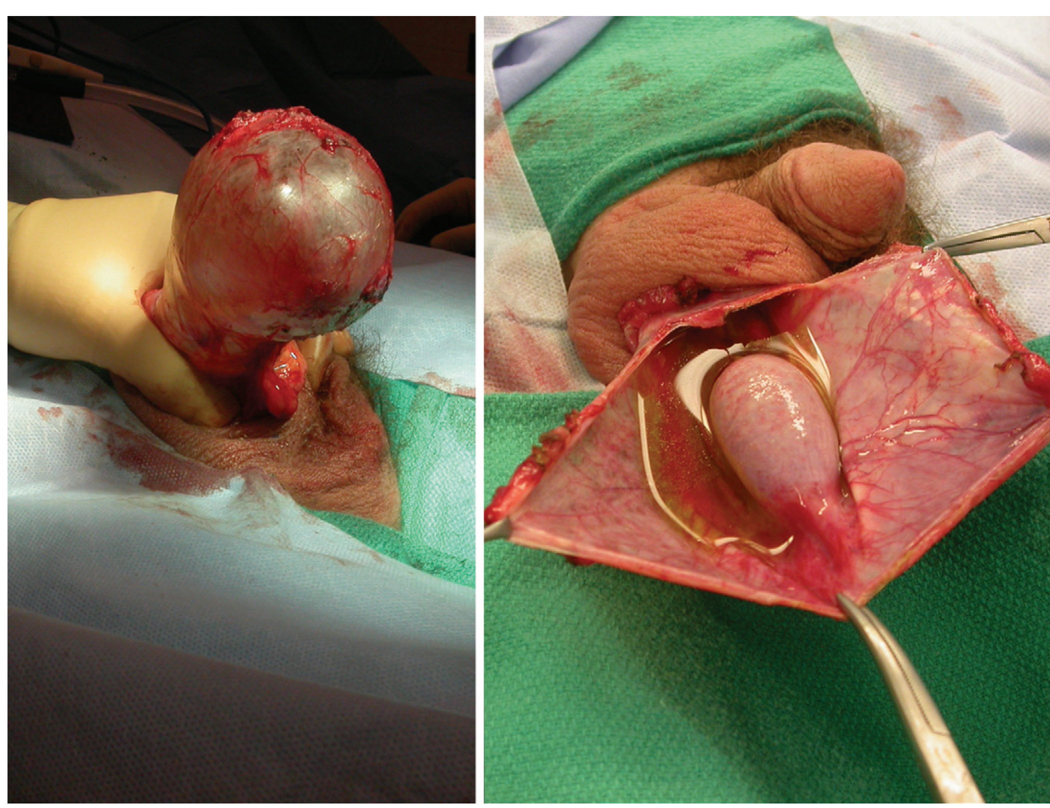

FIGURE 17-24. Hydrocele. This is a noncommunicating hydrocele in an adult man. The tunica sac is massively distended by clear serous fluid. *(Images courtesy of Robert Abouassaly, MD.)*

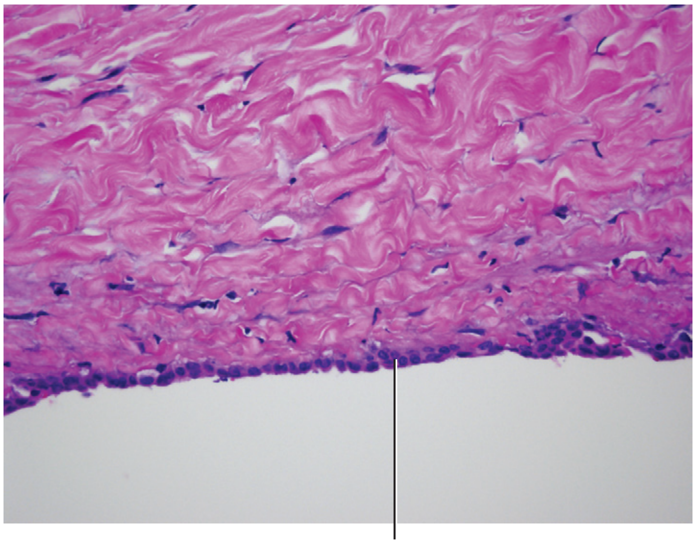

FIGURE 17-25. Hydrocele. The fibrous wall of a hydrocele sac is typically lined by a single layer of flat or cuboidal mesothelial cells that lack significant cytologic atypia. In this case, no inflammation is seen.

Intermittent Hydrocele

The **processus vaginalis** may close only partially, leaving a fine channel for the flow of peritoneal fluid into the **space** between the **tunica vaginalis** and tunica albuginea, causing an intermittent hydrocele (Fig. 17-27). Typically the size of the sac varies, depending on the posture and physical activity of the child.

Scrotal Abnormalities

The labioscrotal swellings develop on either side of the genital tubercle. The caudal portions merge beneath the penis and form the scrotal raphe that continues as the penile raphe where the urethral folds meet. One segment of a scrotal swelling may migrate to produce an accessory scrotum; persistence of the raphe is evidence for migration. Or one of the swellings may fail to develop caudally, resulting in penoscrotal transposition; absence of the raphe is evidence for nonformation. A cryptorchid testis is usually found adjacent to the abnormally placed scrotum, presumably due to the presence of the gubernaculum prior to the descent of the scrotal swelling.

THE TESTES AND ADNEXAE: STRUCTURE AND FUNCTION

The normal adult testes are symmetric in size but not in position; the left testis, with a longer spermatic cord, lies lower than the right. Each testis is approximately 4 cm long, 3.5 cm wide, and 3 cm thick, resulting in a volume of about 30 ml.

Fascia of Scrotum and Testis

Scrotum

The scrotum has two layers, and the testicular coat has three (Fig. 17-28A). The outer layer of the scrotum is composed of richly vascularized rugous **skin** that contains well-developed sweat glands that assist in testicular temperature regulation and sebaceous glands with an odoriferous,

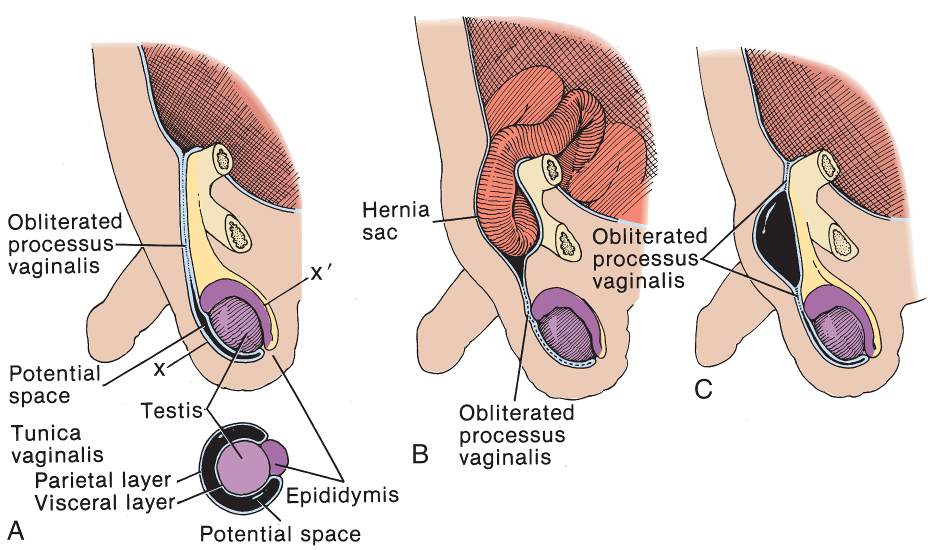

FIGURE 17-26.

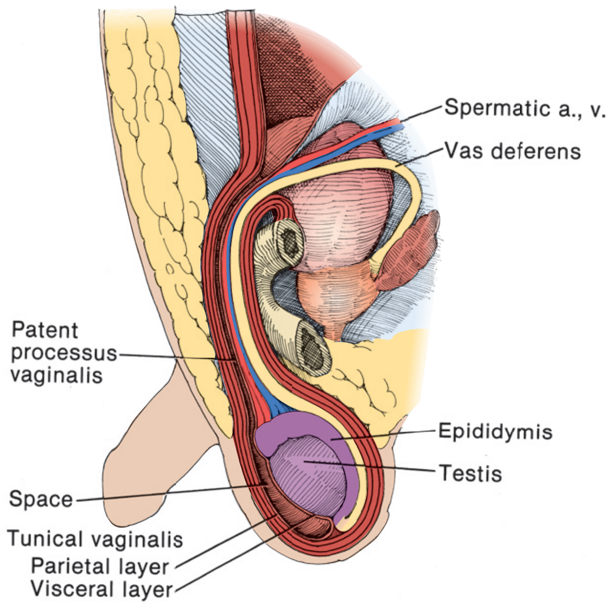

FIGURE 17-27.

presumably pheromonal secretion. The second layer is a thin nonstriated **dartos muscle** (tunic). It can contract the scrotal skin into rugae to conserve heat. It is continuous with the dartos layer of the penis.

The two compartments of the scrotum are indicated on the skin by the **scrotal raphe** and in the deeper tissue by a loosely organized **scrotal septum** derived from the dartos muscle and Colles' fascia. It separates the testes with their intimate coverings. This anatomic arrangement reflects the origin of the scrotum from the paired genital swellings.

Testis

Three layers of fascia, all derived from the layers of the anterior abdominal wall, form the testicular coats and the covering of the cord. The first layer is the **external spermatic fascia** that is continuous with the innominate fascia covering the aponeurosis of the external oblique. The second layer, an extension of the internal oblique and transversus abdominis, is the **cremasteric fascia** and **muscle** (Cooper's fascia), which by relaxation can reduce scrotal temperature and by contraction can protect the testis from trauma. The deepest fascial layer, the **internal spermatic fascia,** arises from the retroperitoneal connective tissue related to the transversalis fascia or to the intermediate stratum of the retroperitoneal connective tissue; anatomists are not in agreement. It overlies the parietal and visceral layers of the tunica vaginalis that are derived from the peritoneum.

The **testis** rests within the **tunica vaginalis,** which is the distal extension of the processus vaginalis. Within the evagination of peritoneum that originally covered the testis when it was intra-abdominal, most of the testis and the medial part of the epididymis are covered by the thin **visceral layer** of the **tunica vaginalis** that covers the tunica albuginea of the testis. The combined coats over the testis are often called the tunica albuginea because they appear surgically as a single layer. These structures are surrounded by the remainder of the processus, forming the **parietal layer** of the tunica vaginalis. The testis and epididymis are attached to the scrotum posterolaterally where they are

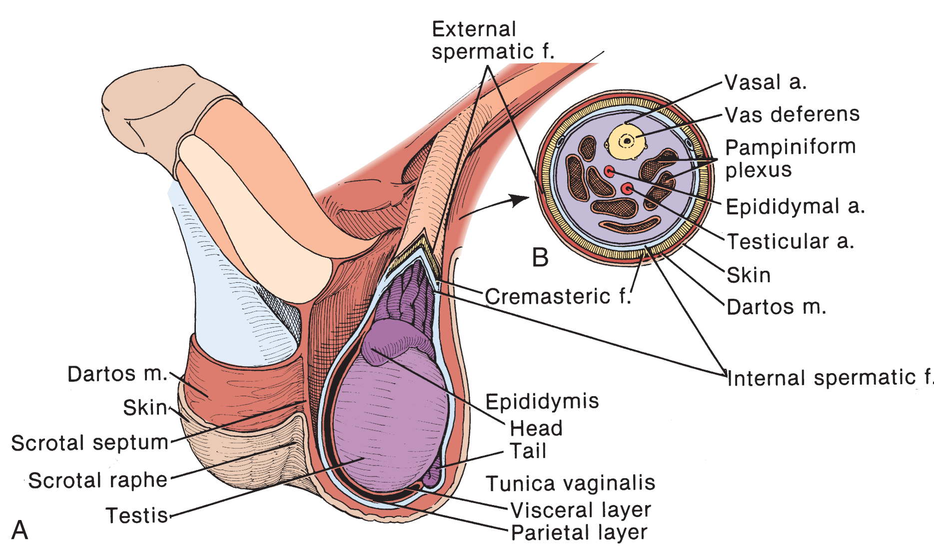

FIGURE 17-28. **A,** Cut-away view. **B,** Cross-sectional view.

not covered by the visceral layer. The visceral tunic forms a recess, the sinus of the epididymis, between the epididymis and the testis.

Spermatic Cord

The cord starts at the internal inguinal ring and ends at the testis and epididymis.

The **external spermatic fascia,** a continuation of the innominate fascia covering the external oblique aponeurosis, surrounds the testis and epididymis, with the ilioinguinal nerve lying exteriorly (Fig. 17-28B). The **cremasteric fascia** posteriorly and the cremasteric muscle anteriorly lie beneath and are derived from the internal oblique aponeurosis. This fascia is accompanied by the cremasteric nerves and vessels. The **internal spermatic fascia** from the outer or intermediate fascial stratum blends with the loose tissue of the parietal layer of the tunica vaginalis. It is composed of connective tissue and fat but may contain muscle fibers. Within the internal spermatic fascia, embedded in the fatty-areolar intermediate stratum of the retroperitoneal connective tissue, are the **vas deferens** surrounded by its vessels and lymphatics, the **testicular** and **epididymal arteries**, the **pampiniform plexus**, and the autonomic nerves to the testis. A portion of the processus vaginalis may persist as a fine cord lying anteriorly in this layer of the spermatic cord. It may remain proximally open (congenital hernia) or entirely open (communicating hydrocele), or it may close at both ends (hydrocele of the cord).

STRUCTURE OF THE TESTIS AND EPIDIDYMIS

Testis

The testis is covered in all aspects except posterolaterally by the **visceral layer** of the **tunica vaginalis** (Figs. 17-29 and 17-30). This very thin layer of flattened cells of peritoneal origin is not separable from the **tunica albuginea** proper so that, surgically, it is considered as a single coat. The tunica albuginea is a thick, tough fibrous layer that tightly encloses the testicular substance, giving it a firm, somewhat rubbery feel on palpation. It has contractile capability that, owing to activity of nonstriated muscle under stimulation from autonomic nerve cells, serves to compress the tubules and move the spermatozoa into the efferent ducts. Trabeculae (septa) project into the testicular substance from

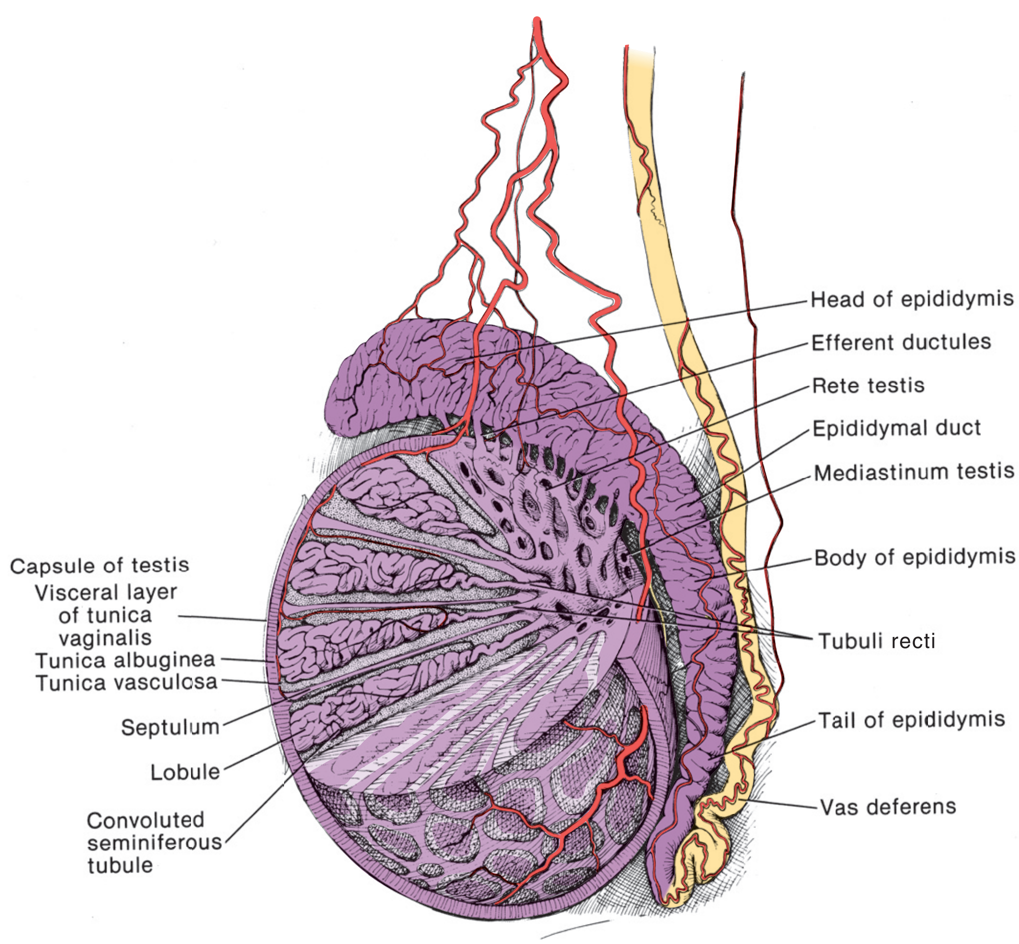

FIGURE 17-29.

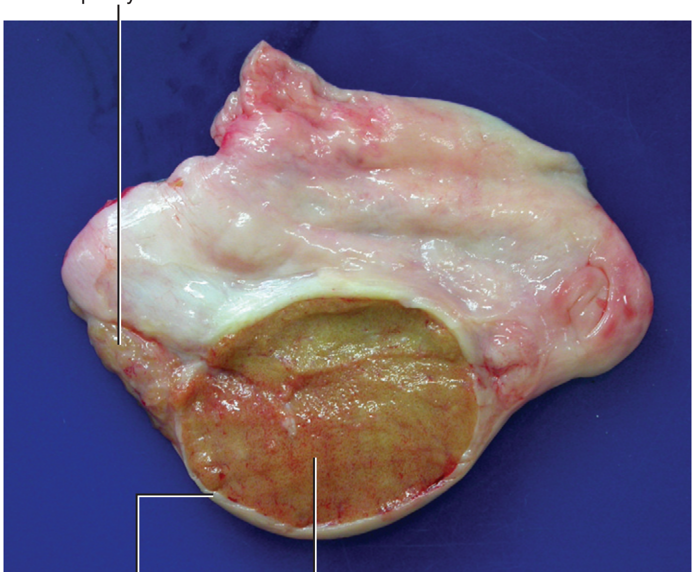

FIGURE 17-30. Normal testis. The testicular parenchyma is enclosed by a fibrous capsule, composed collectively of tunica vaginalis, tunica albuginea, and tunica vasculosa.

the tunica albuginea, dividing the seminiferous tubules into lobules. The **tunica vasculosa** lies beneath the tunica albuginea to which it is closely applied. All three layers are known collectively as the capsule of the testis.

The **mediastinum of the testis** is a continuation of the tunica albuginea that runs vertically for a short distance along the posterior border of the testis. It resembles a hilum as it conducts the vessels and nerves supplying the gland. It contains no interstitial cells, a fact of importance in subcapsular orchiectomy. **Septula** radiate from the mediastinum to divide the testis, not always completely, into 200 to 300 conical **lobules**, each containing one or more convoluted **seminiferous tubules** (Fig. 17-31). These tubules may end blindly, may form loops, and may anastomose with their neighbors before emptying into 20 or 30 straight seminiferous tubules or **tubuli rectae**, which in turn enter the mediastinum to form the **rete testis**, a collecting network of anastomosing ducts (Fig. 17-32). At the upper end of the mediastinum, **efferent ductules** that have a thin coat of circularly oriented muscle cells emerge from the rete testis.

Epididymis

After leaving the rete testis, the efferent ductules run directly through the tunica albuginea into the **head of the epididymis**, where they enlarge and become convoluted, each forming an epididymal lobule. Together, the lobules form the **head of the epididymis** (caput, globus major) (Fig. 17-33).

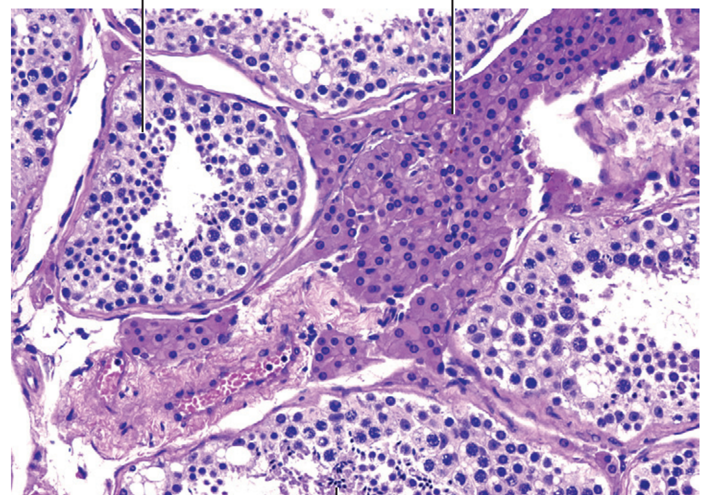

FIGURE 17-31. Normal testis. After puberty, seminiferous tubules are encircled by a 6 μm thick structure composed of basement membrane, myofibroblasts, fibroblasts, collagen, elastic fibers, and extracellular matrix, and are populated by Sertoli cells and germ cells in various phases of maturation. Leydig cells occupy the interstitium of the testis, singly and in clusters. They have abundant eosinophilic cytoplasm and round eccentric nuclei with one or two nucleoli.

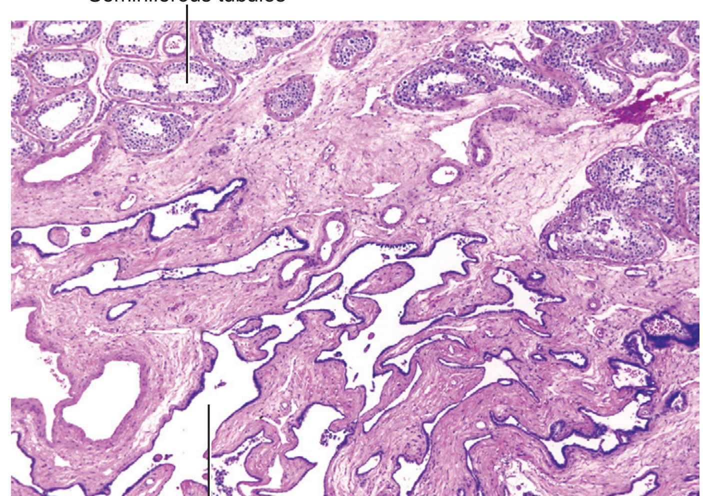

FIGURE 17-32. Normal testis. About 1500 seminiferous tubules converge at the hilum of the testis and drain into the rete testis, a network of interconnecting irregular cavernous channels that begin within the testis, traverse the tunica albuginea and eventually converge outside the testis to form 12 to 15 efferent ductules, which form a substantial portion of the head of the epididymis.

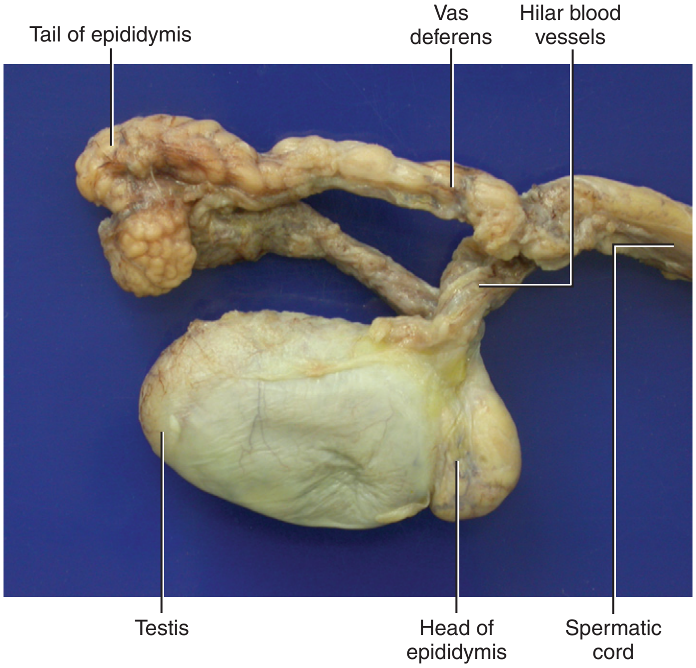

FIGURE 17-33. Normal testis, epididymis, and vas deferens. The structures have been partially dissected to show their relationships.

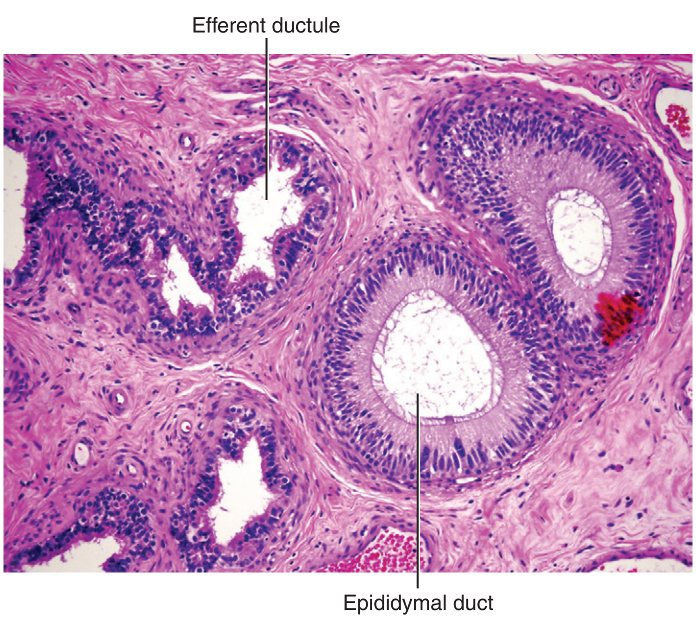

FIGURE 17-34. Normal epididymis. Basal cells admixed with ciliated and nonciliated columnar cells line the efferent ductules, imparting a pseudostratified appearance. The single highly convoluted epididymal duct, which is formed by the convergence of the efferent ductules is surrounded by a prominent basement membrane and a distinct muscular coat and is lined by tall columnar or pseudostratified cells with long straight microvilli resembling cilia.

The ducts from the lobules then join to form a single, highly convoluted **epididymal duct** that measures approximately 5 to 6 meters in total length (Figs. 17-33 and 17-34). It follows a convoluted path down the **body** (corpus) of the epididymis to the **tail of the epididymis** (cauda, globus minor), where it becomes larger. After some terminal convolutions, it emerges as the **vas deferens** (Figs. 17-35 and 17-36). Here, the wall is thicker, highly muscular, and capable of propelling the vasal contents toward the ampulla of the vas on ejaculation. The vas deferens passes through the inguinal rings within the spermatic cord, crosses in front of the ureter and behind the medial umbilical ligament to run behind the bladder, where it becomes dilated to form the ampulla of the vas. A narrow segment, the ejaculatory duct, enters the prostate accompanied by vessels, lymphatics, and nerves after receiving the seminal vesicle on its lateral border (see Figure 14-56).

Microscopically, the first portion of the epididymal duct is lined by tall stratified or pseudostratified cells with long straight microvilli resembling cilia (stereocilia) that appear to obliterate the lumen. In the middle portion, the duct becomes wider and the cilia are bent. In the terminal portion, the lumen is very large and filled with spermatozoa.

Principal cells are tall columnar cells that show evidence of metabolic activity and absorption of fragments of spermatozoa by the formation of phagocytic vesicles. The smooth muscle of the epididymal head and of the vas deferens has a rich nerve supply suitable for active contraction with ejaculation. The innervation of the epididymal duct is sparse, consistent with slow, spontaneous, and local contractions adapted for sperm maturation.

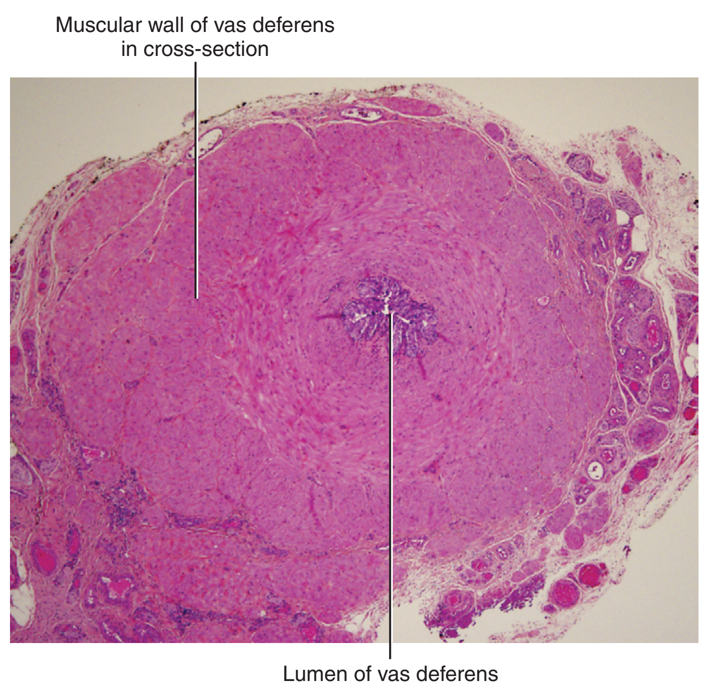

FIGURE 17-35. Normal vas deferens. The vas deferens is 30 to 40 cm long and enlarges in its distal 4 to 7 cm to form the ampulla of the vas, which joins the excretory duct of the seminal vesicle to form the ejaculatory duct. The vas deferens comprises three layers of smooth muscle—inner longitudinal, middle circular, and outer longitudinal— surrounding a small lumen lined by somewhat folded columnar epithelium. The thick muscular wall surrounding the lumen is evident in this cross-section.

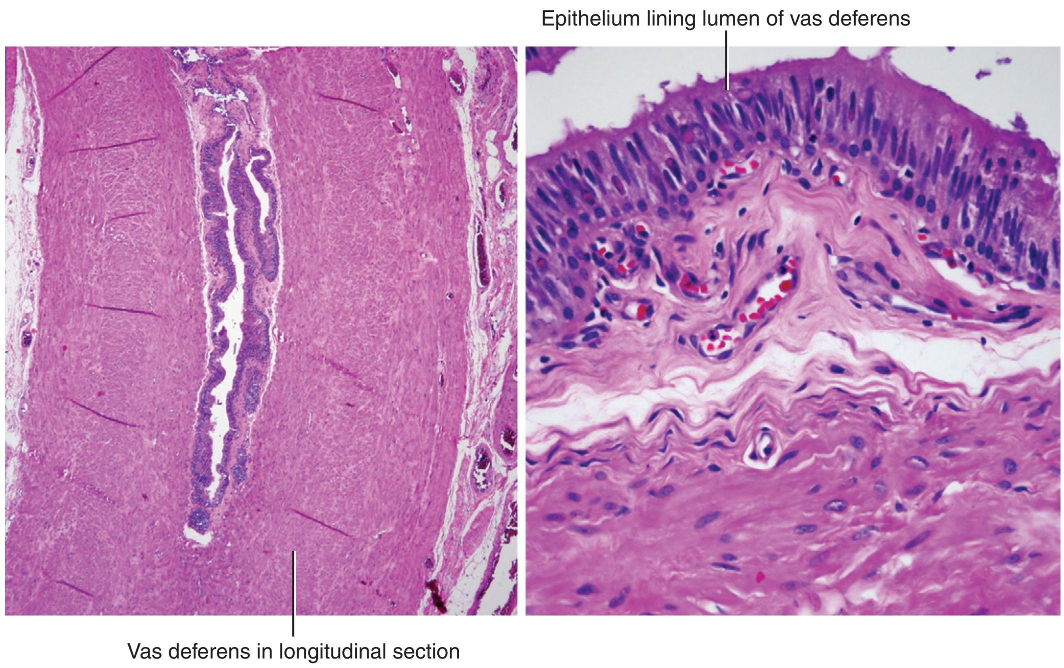

FIGURE 17-36. Normal vas deferens. The vas deferens is lined by pseudostratified epithelium composed of a mixture of columnar cells and basal cells. The columnar cells bear stereocilia, which become shorter and more sparse near the ampulla.

External Testicular Arterial Supply

The arterial vessel to each testis most often arises from the anterolateral surface of the **aorta** just below the renal artery, although one of the vessels may originate from the renal artery or one of its branches. The **right testicular** (spermatic) **artery** runs over the psoas muscle and inferior vena cava, anterior to the genitofemoral nerve, the ureter, and the pelvic part of the external iliac artery to meet the spermatic cord at the internal inguinal ring (Fig. 17-37). The **left testicular artery** passes behind the **inferior mesenteric artery** and left colic artery but otherwise takes a course similar to that of the right artery. In 6% to 8% of cases, each artery may divide high on the cord into an **inferior testicular artery** and an **internal testicular artery**. This division may occur retroperitoneally, requiring careful dissection of the cord during orchiopexy and making microvascular transplantation for cryptorchidism difficult.

Internal Arterial Distribution

As the **testicular artery** leaves the inguinal canal and approaches the upper end of the testis, if it has not done so at a higher level, it divides into two tortuous main branches,

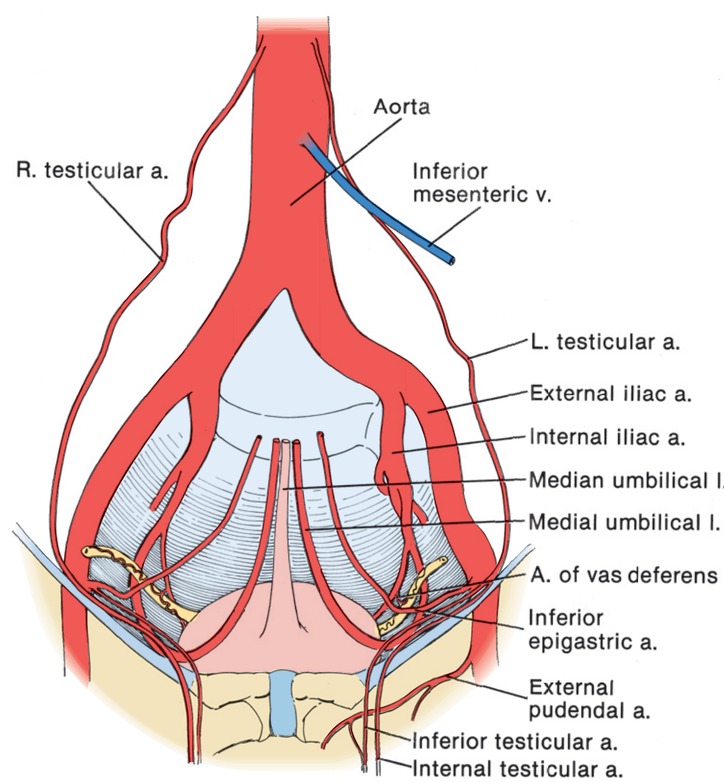

FIGURE 17-37.

an **outer branch**, the **internal testicular artery** and an **inner branch**, the **inferior testicular artery** (Fig. 17-38).

Surrounded by the pampiniform plexus, the tortuosity of the testicular arteries increases as they approach the testis. This arrangement may be considered a heat-exchange system to cool the arterial blood.

The inner, larger branches from the inferior testicular artery run between the testis and the epididymal body. They enter the posterior border of the testis, medial to the epididymis, at several points. The outer branches, arising from the internal testicular artery, pass obliquely through the **tunica albuginea** to enter the **tunica vasculosa**. These vessels form an aggregation, appearing as a vascular hilum, that requires ligation during intracapsular orchiectomy after the testicular substance has been separated from the interior of the tunica albuginea. The distribution of these vessels under the tunica albuginea is not uniform; the superior medial and superior lateral portion of the tunic have the fewest major branches, whereas the superior anterior and all inferior aspects have the most.

Considerable variation is found in the branching and distribution of the vessels, but typically, the outer and inner arterial branches ramify in the tunica vasculosa over the lateral and the medial curvatures of the testis as the coiled **centripetal arteries**. These run toward the rete and, in turn, put out branches that reverse the course and return as **centrifugal arteries**. Both sets of arteries divide further in the testicular parenchyma and end as **intertubular arterioles**. The capillaries that arise from the arterioles enter the **interstitial tissue** and are separated from the germinal and supporting cells by a basement membrane that constitutes the "blood-testis barrier."

An understanding of the centripetal distribution of the arteries is important during testicular biopsy, when they will be most liable to section by an incision on the anterolateral aspect of the testis; a major superficial artery will most likely be encountered on the anterior, lateral, and medial aspect of the lower pole and is least likely on the medial and lateral aspect of the upper pole. An anchoring suture in the lower pole may similarly jeopardize the blood supply.

The **rete testis** is meagerly supplied by small vessels from the mediastinum of the testis and from small centripetal branches of the testicular artery. The tunica albuginea has its own system of capillary networks at several levels that are not related to the vasculature of the testis proper but arise independently from branches of the testicular artery, from vessels supplying the rete and from branches of the epididymal artery.

The **epididymal artery**, a single branch of the **testicular artery**, arises at variable distances proximal to the epididymis. It supplies the head and body of the epididymis through one or more **capital arteries**. The tail is vascularized by a complex arrangement of vessels involving the epididymal, vasal, and testicular arteries, with supplementation from the **cremasteric artery**. This system provides

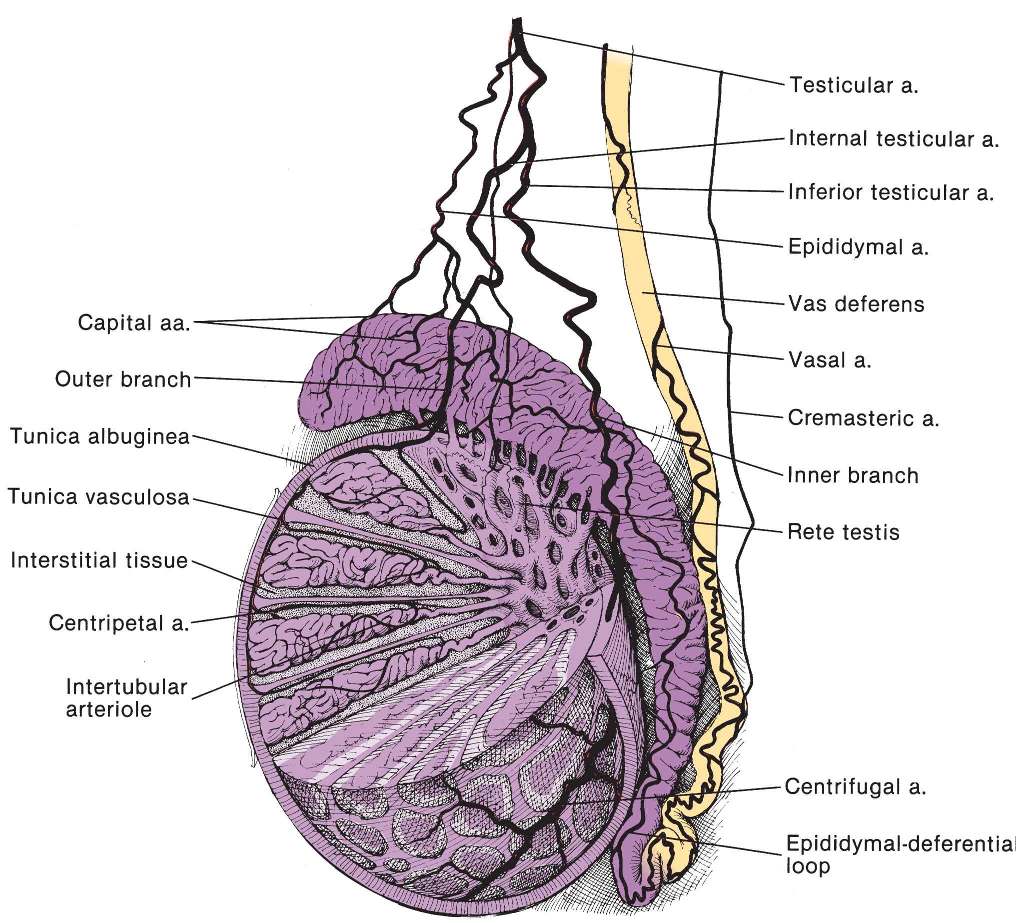

FIGURE 17-38.

an extensive anastomotic loop among these vessels that is important when the testicular artery must be divided to achieve scrotal placement of the testis. It has been determined that the sum of the diameters of the cremasteric and vasal arteries is equal to the diameter of the testicular artery in a third of cases, but in another third the cremasteric artery is not anastomotic.

The **vasal artery** along its course on the vas provides small branches, some of which may join the testicular artery in the cord just above the epididymis. The artery branches to join the posterior epididymal arteries to form an **epididymal-deferential loop**.

After ligation of the testicular artery during orchiopexy, the testis becomes dependent on the anastomosis of this loop with the terminal part or distal branches of the testicular artery, a connection that may or may not be adequate to support the testis. Anastomoses between the testicular and vasal arteries do not follow a regular pattern, which may account for the variable results of long-loop orchiopexy.

The **cremasteric artery** runs outside of the internal spermatic fascia and so supplies an extremely limited amount of blood to the structures within. However, some terminal branches may reach the lower pole of the testis and anastomose with the epididymal-deferential loop, with a terminal branch of the testicular artery or with branches of the epididymal artery. In cryptorchidism, the artery is usually too short to be mobilized and must be sacrificed.

Extratesticular Venous Pathways

The very variable number and distribution of veins draining the testis, epididymis, and vas deferens connect with a deep and a superficial venous network (Fig. 17-39).

Deep Venous Network

The most common pathway has three components: (1) an anterior set composed of the pampiniform plexus and the testicular vein; (2) a middle set composed of the deferential vein; and (3) a posterior set composed of the cremasteric veins.

Anterior Set, Labeled A

The veins emerging from the testis and from the superficial plexus overlying the anterior part of the epididymis form the anterior portion of the deep venous network. These vessels typically provide as many as 10 branches, which anastomose to form a meshlike complex of large veins, the **pampiniform plexus**. This plexus courses about the testicular artery and in front of the vas deferens in the spermatic cord. As noted, the pampiniform plexus is closely associated with the tortuous branches of the testicular artery below the **external inguinal ring**, a relationship that may act as a heat-exchange mechanism.

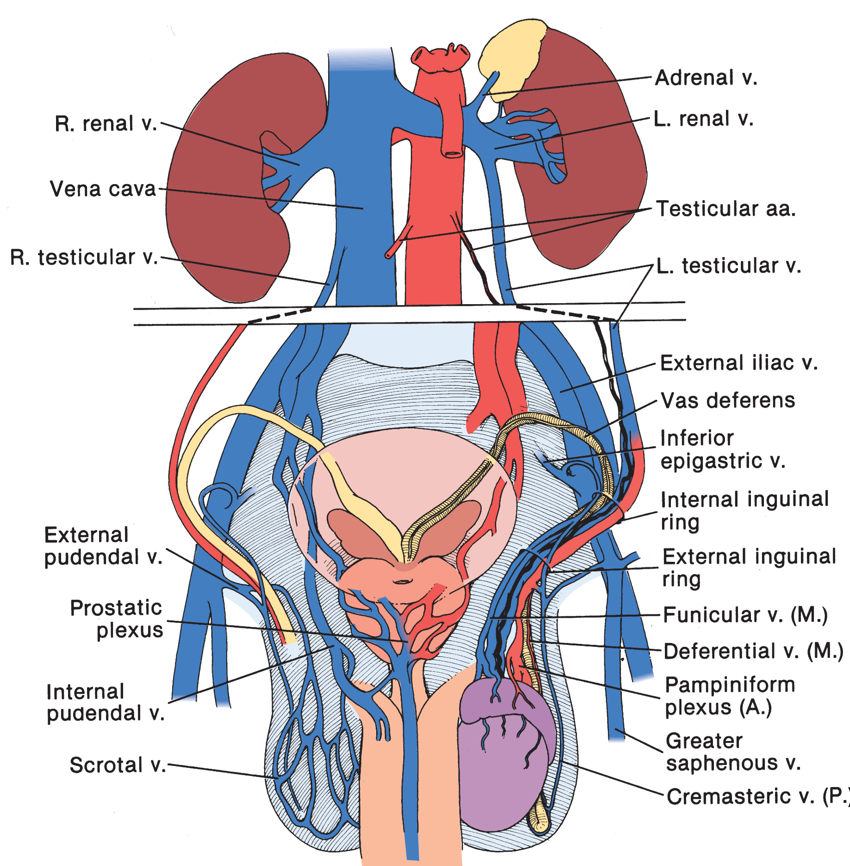

FIGURE 17-39.

The vessels of the pampiniform plexus become reduced to three or four veins, then to two as they pass through the **external inguinal ring**. The two veins combine into a single vein that ascends in the pelvis as the testicular vein lateral to the artery and anterior to the ureter. The **left testicular vein** deviates medially from the accompanying artery below the lower pole of the kidney and ascends vertically to uniformly enter the **left renal vein** usually lateral to the **adrenal vein**, joining it most often at a right angle. The **right testicular vein** enters the anterolateral surface of the **vena cava** obliquely at a site below the **renal vein**, at the level of the second lumbar vertebra, and below the exit of the testicular artery from the aorta. In 10% of cases, it drains into the renal vein.

Middle Set, Labeled M. This set is made up of the funicular and deferential veins. The **funicular veins** drain the posterior part of the epididymis into the inferior epigastric and **external iliac veins**. The **deferential veins** accompanying the vas deferens drain into the venous plexus of the testicular cord as well as the **prostatic plexus** and vesical plexus.

Posterior Set, Labeled P. This set, collecting from the **cremasteric veins**, becomes separated from the cord near the external ring. It drains into the internal saphenous or the **inferior epigastric vein**.

Superficial Venous Network

The **scrotal veins** drain through the **external pudendal veins** into the internal saphenous vein or through the superficial perineal veins into the **internal pudendal vein**. Within this system, the **cremasteric vein** joins the venous plexus of the spermatic cord and the inferior epigastric vein. Small anastomotic channels occur frequently between the superficial and deep systems and between the elements of each.

Varicoceles

Varicose dilatation of the pampiniform plexus begins at puberty in about 10% of men (Fig. 17-40). In 90% of these cases, the left side is involved, in 8% it is bilateral, and in 2% it is on the right side. Varicoceles may be associated with impairment of testicular function, possibly an effect of venous back pressure on the testis, although endocrine and vasoactive factors have been considered.

Because it appears that two types of varicoceles develop, circulation may be impaired either by obstruction to venous return or by reflux during periods of increased intra-abdominal pressure. One is occlusive because of abnormal venous formations, such as a circumaortic renal ring; the other is from reflux because of incompetent valves (Fig. 17-41). Whether from obstruction or reflux, varicoceles are corrected by ligation of the testicular vein in the inguinal canal in 80% of cases (Fig. 17-42).

There may be several reasons for the predilection for the left side. The left testicular vein is longer than the right and enters the left renal vein at a right angle. This relationship may produce obstruction, because the venous pressure in the renal vein is slightly higher than that in the vena cava. In addition, because the left renal vein passes behind the lower part of the ascending colon, it may be indented by colonic contents or compressed against the aorta by the superior mesenteric artery. Finally, lack of valves in the testicular vein promotes reflux. Valves were found present in the left testicular vein in approximately half of cadavers. In another study, valves were absent in the left vein in 40% of men compared with absence on the right in 23%. They were absent bilaterally in one-third of cases. When present,

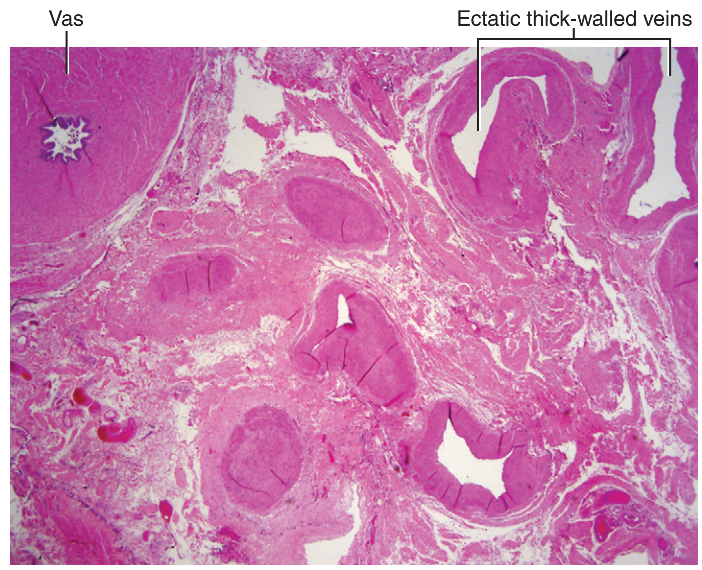

FIGURE 17-40. Varicocele. Section through the spermatic cord of a patient with a varicocele who underwent radical orchiectomy for a germ cell neoplasm. Numerous markedly dilated veins with eccentric mural fibrosis are present.

FIGURE 17-41. Varicocele. Venography demonstrates retrograde flow of contrast into the dilated veins of the pampiniform plexus. *(Image courtesy of Joel Marmar, MD.)*

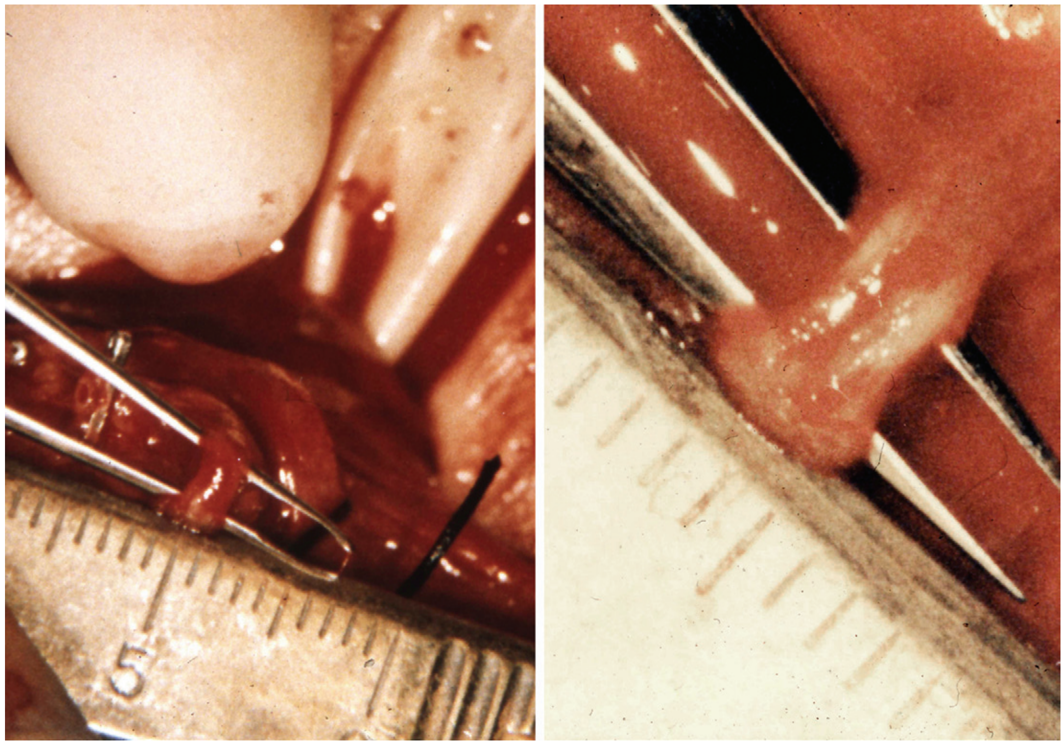

FIGURE 17-42. Varicocele. At left, the testicular artery has been identified in the spermatic cord. Note its small size. On the right, a varicose vein larger than 2 mm is identified, and is about to be divided. *(Image courtesy of Joel Marmar, MD.)*

valves are usually found within 1 cm of the renal vein. Even with competent valves, retrograde flow with varicocele can occur from bypass of blood through communicating veins that enter the spermatic vein distal to the valves.

The testis lies outside the abdominal cavity in the scrotum which functions as a cooling mechanism, where it is at atmospheric pressure (Fig. 17-43). The pampiniform plexus may function as a shock absorber to protect the testis from the sudden back flow of blood under high pressure during increases in intra-abdominal pressure. If valves were absent or rendered incompetent, the rise in intra-abdominal pressure during coughing or during athletic activities, especially in adolescent boys would be transmitted freely, to the venous plexus, distending it and conceivably producing a varicocele.

The schema of venous drainage as described is typical but is subject to many variations. The reason for this lies in the embryologic development of the inferior vena cava, passing through regression, anastomoses, and replacement of the dorsally situated postcardinal and supracardinal veins and the ventrally situated subcardinal veins (see Fig. 2-5). Because the left testicular vein is the caudal remains of the left subcardinal vein, it classically enters the renal vein at a right angle. However, in more than half the cases, it actually enters at an acute or obtuse angle. The testicular vein may be multiple and may even open into the renal vein in two places. Reflux may occur even in the presence of competent valves because of venous communications below the valves, which is one reason for ligating the vein in the inguinal canal rather than at a higher level. Ligation of one or more testicular veins in the inguinal canal—the standard

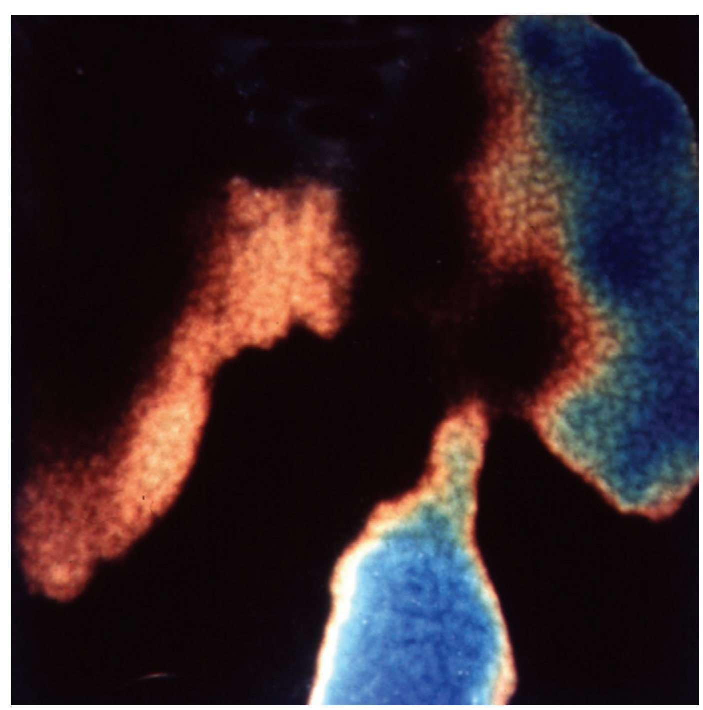

FIGURE 17-43. Thermogram in a case of a left-sided varicocele, produced by a color-sensitive heat strip placed against the scrotum. The blue color on the left indicates increased warmth related to the presence of the varicocele. The central area of blue color at bottom represents the penis. The area at right, lacking blue color, represents the relative coolness of the right scrotal contents. *(Image courtesy of Joel Marmar, MD.)*

treatment for symptomatic varicocele—will correct 80% of cases. However, more than one-third of cases have two or more spermatic vein trunks at the level of the internal ring, which may be missed during an inguinal approach. Phlebography is reserved for failures to determine what particular venous anomaly is present.

That the testicular vein can be ligated without apparent harm to the testis is an indication of the rich collateral circulation through the vasal and cremasteric vessels.

Venous Drainage

The veins arise diffusely from a dense microvascular bed about the tubules. They join **collecting venules**, which pass either peripherally or centrally, in contrast to the arteries, which are organized peripherally in the testis. The peripherally directed veins reach the **tunica vasculosa** and continue on the anterolateral aspect of the testis, where they form large channels on the surface (Fig. 17-44). The centrally directed veins, providing the principal drainage of the testis, run to the **rete testis**, pass through the posterior surface of the **tunica albuginea** at the **mediastinum**, and are joined by veins from the anterior portion of the epididymis before they reach the **pampiniform plexus** (see Fig. 17-39).

Lymphatic Drainage of the Testis and Epididymis

Testicular Lymphatics

The lymph in the network of intertubular tissue of the testis passes into channels in the interlobular septula. Some of these channels reach the mediastinum, where they form several larger trunks, but the majority pass more or less directly through the tunica albuginea. All of these channels course along the upper posterior border of the testis to form a series of four to eight collector vessels that accompany the **spermatic cord**. At the crossing of the **ureter**, they separate from the blood vessels and deviate medially to terminate in the precaval nodes and the nodes about the aorta at the site of origin of the testis.

The collectors from the *right testis* join the aortic nodes lying between the take-off of the **renal vein** and the **aortic bifurcation** (Fig. 17-45). Usually, several vessels join one of the **precaval nodes**, whereas none may join an adjacent node. The lowest node, lying at the bifurcation, always receives a collector. In half the cases, the **preaortic nodes** receive one or two trunks, and in 10% of cases, the node at the angle of the renal vein with the inferior vena cava receives one.

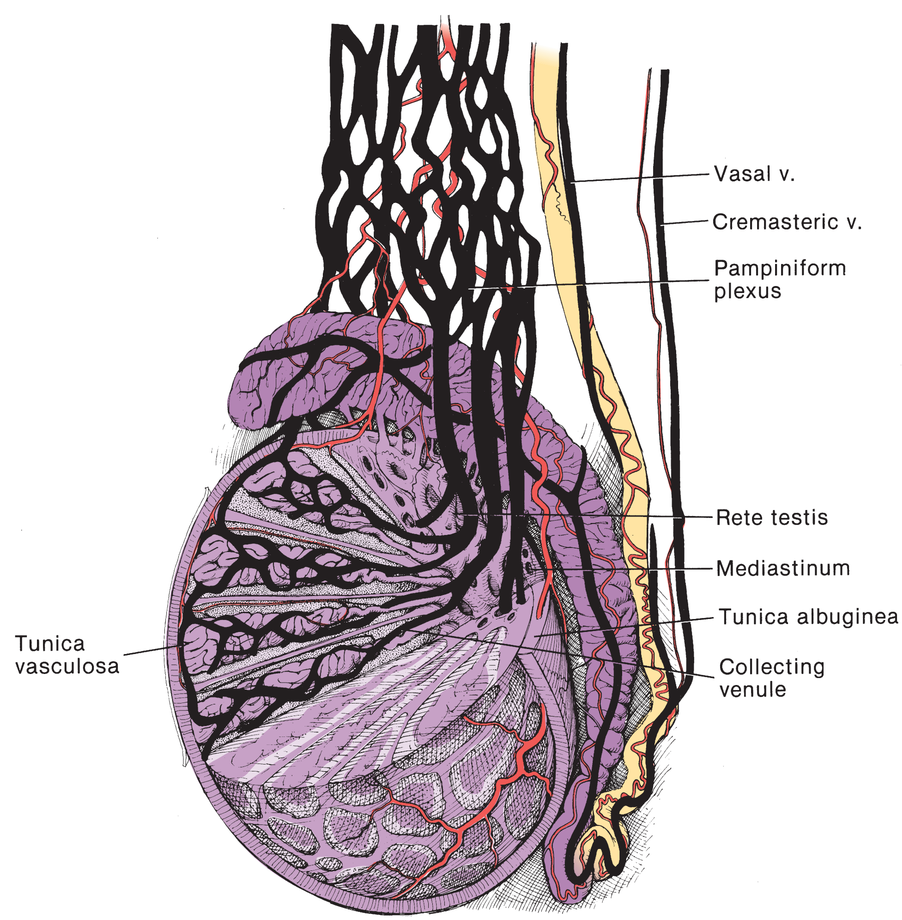

FIGURE 17-44.

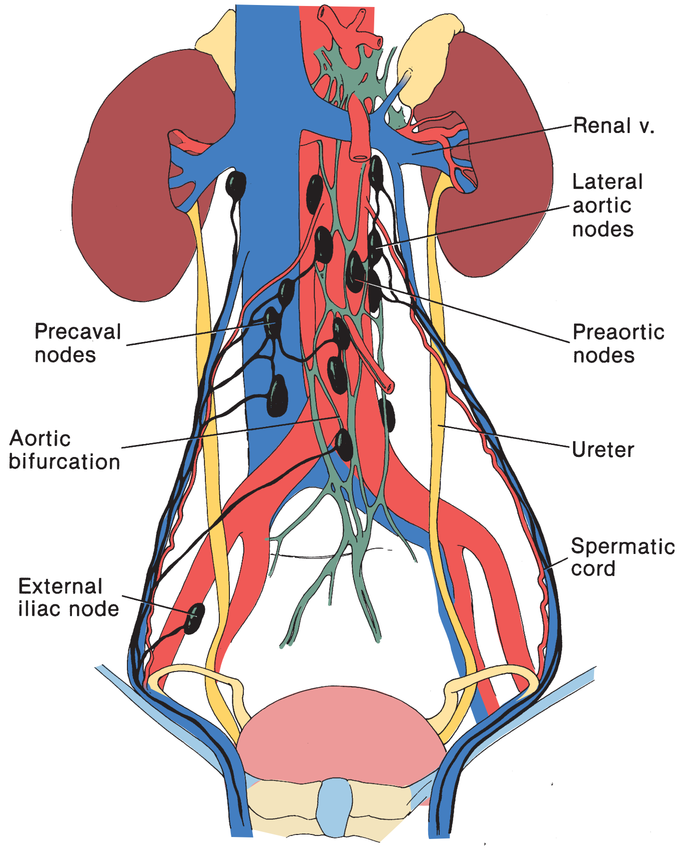

FIGURE 17-45.

From the *left testis*, two-thirds of the collectors run to the **lateral aortic nodes**, especially those lying most cephalad, and some terminate as low as the bifurcation; the other third end in the preaortic nodes. Rarely, a lymph vessel may run directly to the **external iliac nodes** after ascending with the vessels of the vas deferens. Because the testis originally arises at the level of the kidney and adrenal, connections between the trunks from the testis and the trunks of those organs are commonly found.

Although the lumbar sympathetic trunk lies posterior to the outer stratum of the retroperitoneal fascia, it could be resected with the lymph nodes with resulting anejaculation.

Epididymal Lymphatics

The lymph vessels run to the surface of the epididymis to join those in the epididymal tunic. Collectors from the head and body run with the branch of the epididymal artery that supplies that area; similarly, those from the tail join the appropriate branch. Some drainage from the tail occurs along the deferential and testicular arteries. The collectors accompanying the epididymal artery ascend with the testicular vessels, whereas those accompanying the deferential artery run with that vessel to an **external iliac node**. In addition, small vessels connect the anterior portion of the testis with the head of the epididymis.

Scrotal Lymphatics

The network of **lymphatics** that covers all parts of the scrotum is especially dense about the raphe, the site where the lymph vessels join the two sets of collecting trunks. The **superior trunks** arise at the base of the penis, pass around to the dorsum, and run with the penile trunks to the superomedial group of the superficial inguinal nodes (Fig. 17-46). Seven or eight **inferior trunks** arise more posteriorly along the raphe, run in the genitofemoral fold to the lateral part of the scrotum, and end in the inferior, lateral, and medial superficial inguinal nodes. Anastomoses commonly occur between the lymphatics of the penile skin and those of the skin of the adjacent thigh. Vessels from the perineal skin join the inferior collecting trunks of the scrotum, which drain into the inferomedial group of superficial inguinal nodes.

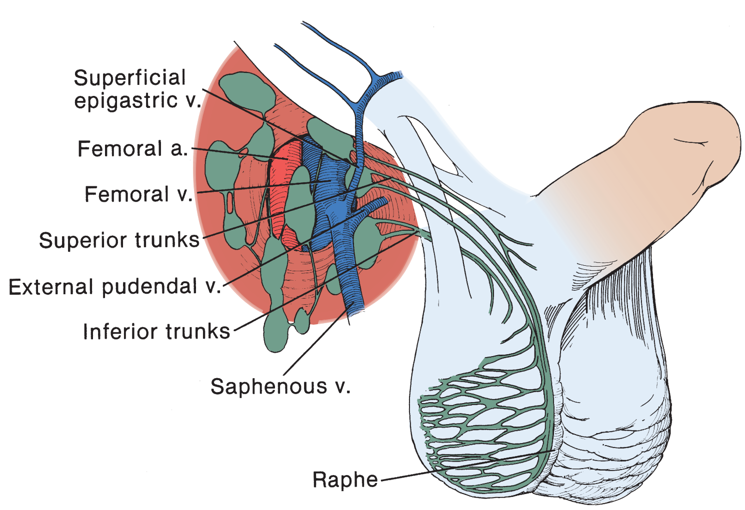

FIGURE 17-46.

Nerve Supply to the Testis and Scrotum

The **testicular nerves** arise from spinal nerves T10 and T11 and pass through the **aortorenal ganglion** to descend and become included in the spermatic cord (Fig. 17-47). In the testis, terminal plexuses occur perivascularly and in the interstitial tissue.

The nerve supply to the epididymis is concerned with sperm transport. That to the scrotum regulates testicular temperature. Reflex contraction of the dartos muscle in response to cold throws the well-vascularized scrotum into heat-conserving folds. In addition, a rich network of superficial nerve endings in the scrotal skin reflexively transmits signals of warmth and cooling for contraction or relaxation of the cremaster muscle.

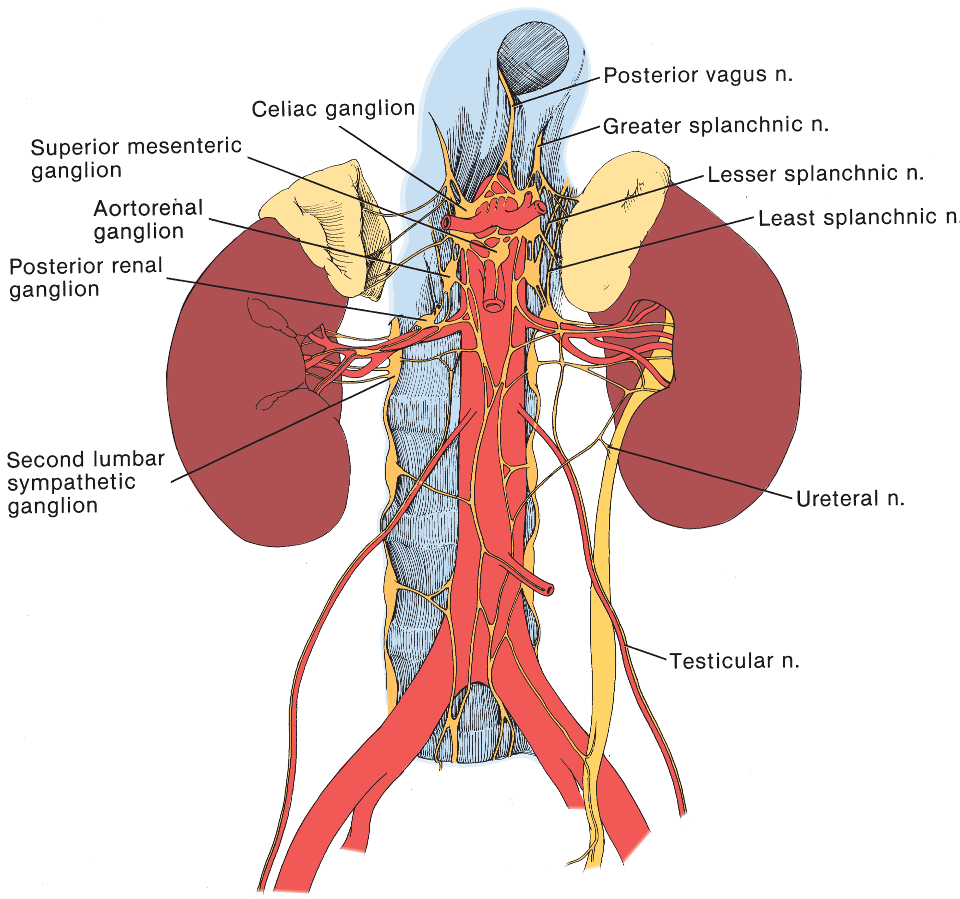

FIGURE 17-47.

Index

Q

R

S

V

W

Y