Urinary System

19

Introduction to the Urinary System 676
Kidneys 676
Ureters, Urinary Bladder, and Urethra 684

CLINICAL CONSIDERATIONS 688

Developmental Exposition: The Urinary System 689

Clinical Case Study Answer 694
Chapter Summary 695
Review Activities 696

Clinical Case Study

A 17-year-old male was involved in a knife fight in which he sustained two stab wounds to the anterior abdomen. He was brought to the emergency room where he complained of mild abdominal pain and an urgent need to urinate. Although neither of the stab wounds was bleeding externally, examination by the surgeon revealed signs of moderate hemorrhagic shock. One wound was 3 cm below the right costal margin at the midclavicular line; the other was just medial to the right anterior superior iliac spine. The surgeon immediately ordered preparations for an emergency exploratory laparotomy. She noted that the patient's urinary bladder was quite full and chided the intern for not having placed a urinary catheter. Placement of the catheter yielded a brisk flow of bright red blood.

How would you explain the phenomenon of hematuria (blood in the urine) in this case? Which of the two stab wounds is most likely associated with the hematuria? Regarding the blood draining into the catheter, trace and explain its course of flow. Begin at a point in the abdominal aorta, and end the course with drainage into the catheter. Assuming that the surgeon would be prompted to remove the kidney in order to quickly control hemorrhage, what possible anatomical variant should she keep in mind?

Hints: Study the positions of the kidneys within the abdominal cavity and note the location of the supportive and protective serous membrane. Carefully examine the specific location of urine production and the route of urine passage through the urinary system.

FIGURE: The placement of a urinary catheter is a common procedure for patients who have abdominal trauma or abdominal surgery. A laboratory assessment (urinalysis) of the collected urine may help reveal the extent of the trauma or a patient's progress in healing.

INTRODUCTION TO THE URINARY SYSTEM

The urinary system maintains the composition and properties of the body fluid that establishes the internal environment of the body cells. The end product of the urinary system is urine, which is voided from the body during micturition.

Objective 1 List the functions of the urinary system.

Objective 2 Identify the arteries that transport blood to the urinary system for filtration.

The urinary system, along with the respiratory, digestive, and integumentary systems, excretes substances from the body. For this reason, these systems are occasionally referred to as excretory systems. In the process of cellular metabolism, nutrients taken in by the digestive system and oxygen from inhaled air are used to synthesize a variety of substances while providing energy needed for body maintenance. Metabolic processes, however, produce cellular wastes that must be eliminated if homeostasis is to be maintained. Just as the essential nutrients are transported to the cells by the blood, the cellular wastes are removed through the circulatory system to the appropriate excretory system. Carbon dioxide is eliminated through the respiratory system; excessive water, salts, nitrogenous wastes, and even excessive metabolic heat are removed through the integumentary system; and various digestive wastes are eliminated through the digestive system.

The urinary system is the principal system responsible for water and electrolyte balance. Electrolytes are compounds that separate into ions when dissolved in water. Electrolyte balance is achieved when the number of electrolytes entering the body equals the number leaving. Hydrogen ions, for example, are maintained in precise concentration so that an acid-base, or pH, balance exists in the body.

A second major function of the urinary system is the excretion of toxic nitrogenous compounds—specifically, urea and creatinine. Other functions of the urinary system include the elimination of toxic wastes that may result from bacterial action and the removal of various drugs that have been taken into the body. All of these functions are accomplished through the formation of *urine* by the kidneys.

The urinary system consists of two *kidneys*, two *ureters*, the *urinary bladder*, and the *urethra* (fig. 19.1). Tubules in the kidneys are intertwined with vascular networks of the circulatory system to enable the production of urine. After the urine is formed, it is moved through the ureters to the urinary bladder for storage. *Micturition*, or voiding of urine from the urinary bladder, occurs through the urethra.

Blood to be processed by a kidney enters through the large *renal artery*. After the filtration process (see chapter 3), it exits through the *renal vein*. The importance of filtration of the blood is demonstrated by the fact that during normal resting conditions the kidneys receive approximately 20% to 25% of the entire cardiac output. Every minute, the kidneys process approximately 1,200 ml of blood.

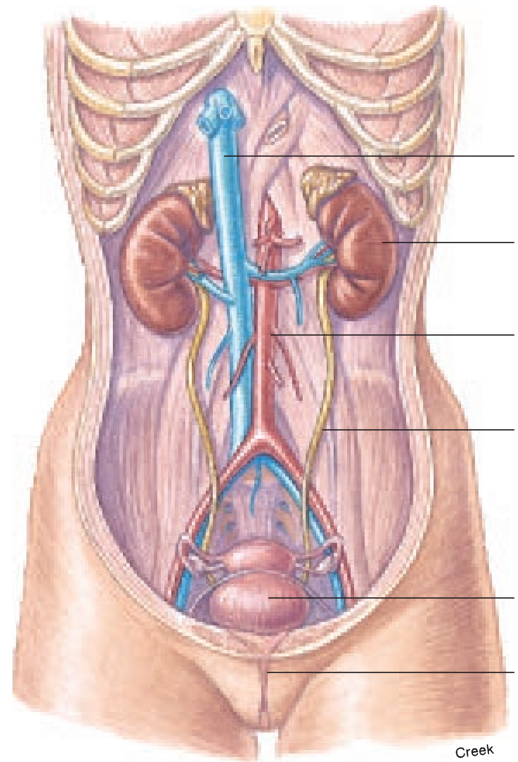


FIGURE 19.1 The organs of the urinary system are the two kidneys, two ureters, urinary bladder, and urethra.

Knowledge Check

1. Drawing on your knowledge of the functions of the urinary system, list the basic substances that compose normal urine.
2. Explain the role of the renal vessels in maintaining homeostasis. Approximately how much blood is processed in the kidneys each minute?

KIDNEYS

The kidney consists of an outer renal cortex and an inner renal medulla that contains the renal pyramids. Urine is formed as a filtrate from the blood at the nephrons and collects in the calyces and renal pelvis before flowing from the kidney via the ureter.

Objective 3 Describe the gross structure of the kidney.

Objective 4 Describe structure of a nephron and explain how its components are oriented within the kidney.

Objective 5 Describe the position of cortical and juxtamedullary nephrons with respect to the gross structure of the kidney.

FIGURE 19.2 A color-enhanced radiograph of the calyces and renal pelvises of the kidneys, the ureters, and the urinary bladder. (Note the position of the kidneys relative to the vertebral column and ribs.)

Position and Appearance of the Kidneys

The reddish brown **kidneys** are positioned against the posterior wall of the abdominal cavity between the levels of the twelfth thoracic and the third lumbar vertebrae (fig. 19.2). The right kidney is usually 1.5 to 2.0 cm lower than the left because of the large area occupied by the liver on the right side.

The kidneys are *retroperitoneal,* which means that they are located behind the parietal peritoneum (fig. 19.3). Each adult kidney is a lima-bean-shaped organ about 11.25 cm (4 in.) long, 5.5 to 7.7 cm (2–3 in.) wide, and 2.5 cm (1 in.) thick. The lateral border of each kidney is convex, whereas the medial border is strongly concave (figs. 19.2 and 19.3). The **hilum** (*hī'lum*) of the kidney is the depression along the medial border through which the **renal artery** enters and the **renal vein** and **ureter** (*yoo're'ter*) exit. The hilum is also the site for drainage of lymph vessels and innervation of the kidney. The superior border of each kidney is capped by the adrenal gland (see figs. 14.21 and 19.4*a*).

Each kidney is embedded in a fatty fibrous pouch consisting of three layers. The **renal capsule** (fibrous capsule), the innermost layer, is a strong, transparent fibrous attachment to the surface of the kidney. The renal capsule protects the kidney from trauma and the spread of infections. Surrounding the renal capsule is a firm protective mass of fatty tissue called the **renal adipose capsule** (fig. 19.3). The outermost layer, the **renal fascia,** is composed of dense irregular connective tissue. It is a supportive layer that anchors the kidney to the peritoneum and the abdominal wall.

Although the kidneys are firmly supported by the renal adipose capsule, renal fascia, and even the renal vessels, under certain conditions these structures may give in to the force of gravity and the kidneys may drop a bit in position. This condition is called *renal ptosis* (*to'sis*) and generally occurs in extremely thin elderly people, who have insufficient amounts of supportive fat in the adipose capsular layer. It also may affect victims of *anorexia nervosa,* who suffer from extreme weight loss. The potential danger of renal ptosis is that the ureter may kink, blocking the flow of urine from the affected kidney.

Gross Structure of the Kidney

A coronal section of the kidney shows two distinct regions and a major cavity (figs. 19.4*b* and 19.5). The outer **renal cortex,** in contact with the renal capsule, is reddish brown and granular in appearance because of its many capillaries. The deeper **renal medulla** is darker, and the presence of microscopic tubules and blood vessels gives it a striped appearance. The renal medulla is composed of 8 to 15 conical **renal pyramids.** Portions of the renal cortex extend between the renal pyramids to form the **renal columns.** The apexes of the renal pyramids are known as the *renal papillae* (*pă-pil'e*). These nipplelike projections are directed toward the inner region of the kidney.

The cavity of the kidney collects and transports urine from the kidney to the ureter. It is divided into several portions. The papilla of a renal pyramid projects into a small depression called the **minor calyx** (*ka'liks*—in the plural, *calyces*). Several minor calyces unite to form a **major calyx.** In turn, the major calyces join to form the funnel-shaped **renal pelvis.** The renal pelvis collects urine from the calyces and transports it to the ureter.

Microscopic Structure of the Kidney

The **nephron** (*nef'ron*) is the functional unit of the kidney that is responsible for the formation of urine. Each kidney contains more than a million nephrons surrounded by associated small blood vessels. Fluid formed by capillary filtration enters the nephron and is subsequently modified by transport processes. The resulting fluid that leaves the nephron is urine.

Renal Blood Vessels

The kidneys have an extensive circulatory network to allow for the continuous cleansing and modification of large volumes of blood (fig. 19.6). Arterial blood enters the kidney at the hilum through the **renal artery,** which divides into **interlobar** (*in''ter-lo'bar*) **arteries** that pass between the renal pyramids through the renal columns. **Arcuate** (*ar'kyoo-ăt*) **arteries** branch from the interlobar arteries at the boundary of the renal cortex and renal medulla. Small **interlobular arteries** radiate from the arcuate arteries and project into the renal cortex. Microscopic **afferent glomerular arterioles** arise from branches of the interlobular

hilum: L. *hilum,* a trifle

ptosis: Gk. *ptosis,* a falling
arcuate: L. *arcuare,* to bend

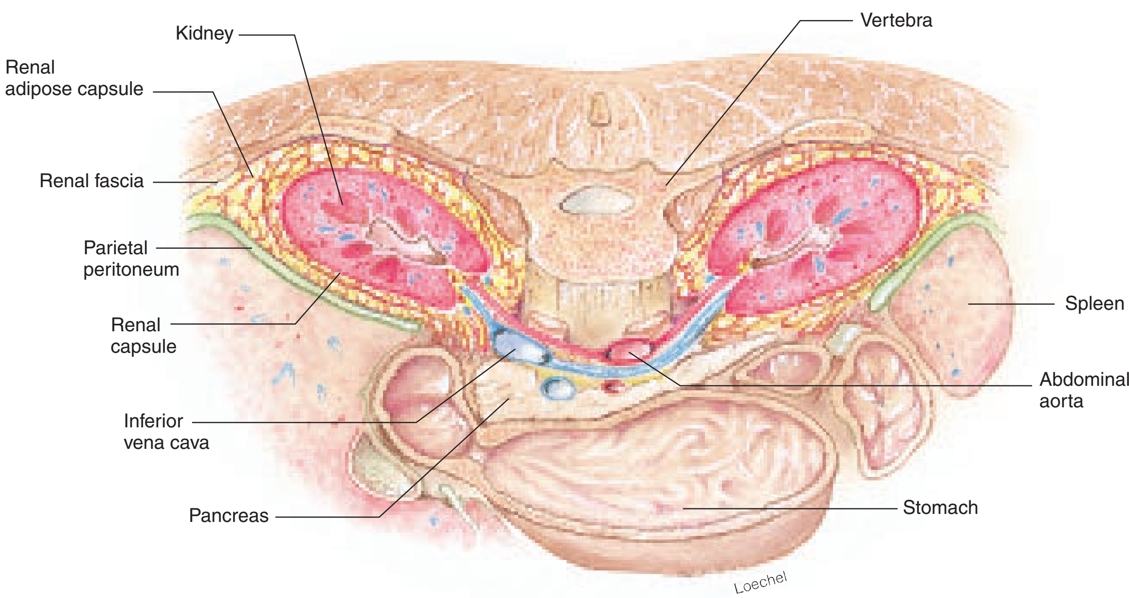


FIGURE 19.3 The position of the kidneys as seen in cross section through the upper abdomen. The kidneys are embedded in adipose tissue behind the parietal peritoneum.

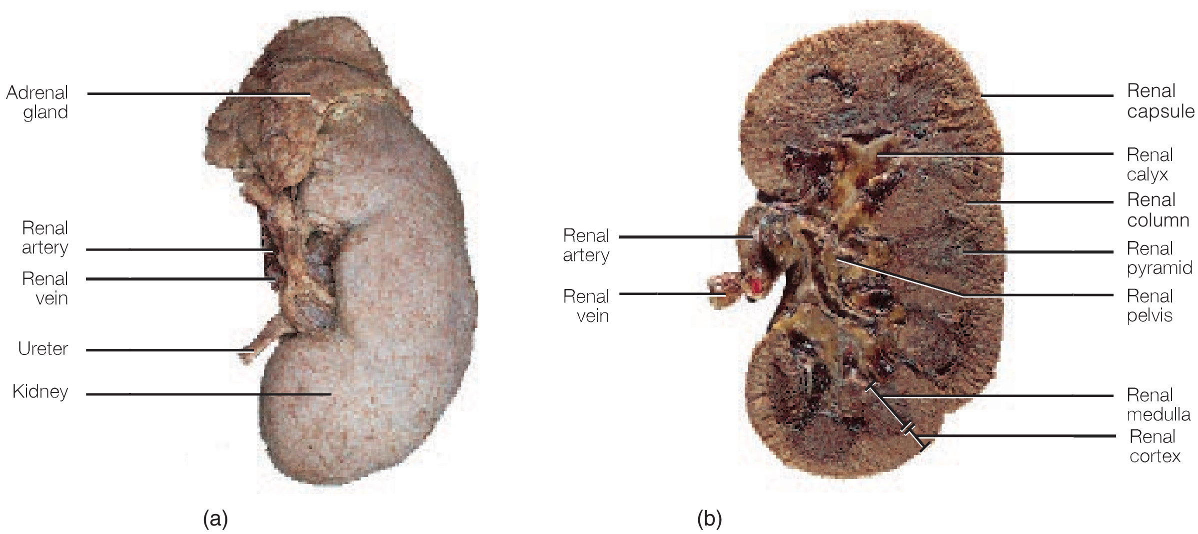


FIGURE 19.4 The kidney. (*a*) The anterior surface and (*b*) a coronal section.

arteries. The afferent glomerular arterioles transport the blood into ball-shaped capillary networks, the **glomeruli** (*glo-mer′yŭ-li*), which produce a blood filtrate that enters the urinary tubules. The blood remaining in the glomerulis leaves through **efferent glomerular arterioles.** This blood vessel arrangement is unique because blood usually flows out of a capillary bed into venules rather than into other arterioles. From the efferent glomerular arterioles, the blood enters either the **peritubular capillaries** surrounding the convoluted tubules or the **vasa recta** surrounding the ascending and descending tubules (fig. 19.7). From these capillary networks, the blood is drained into veins that parallel the course of the arteries in the kidney. These are the **interlobular veins, arcuate veins,** and **interlobar veins.** The interlobar veins descend between the renal pyramids, converge, and then leave the kidney as a single **renal vein** that empties into the inferior vena cava.

glomerulus: L. diminutive of *glomus*, ball

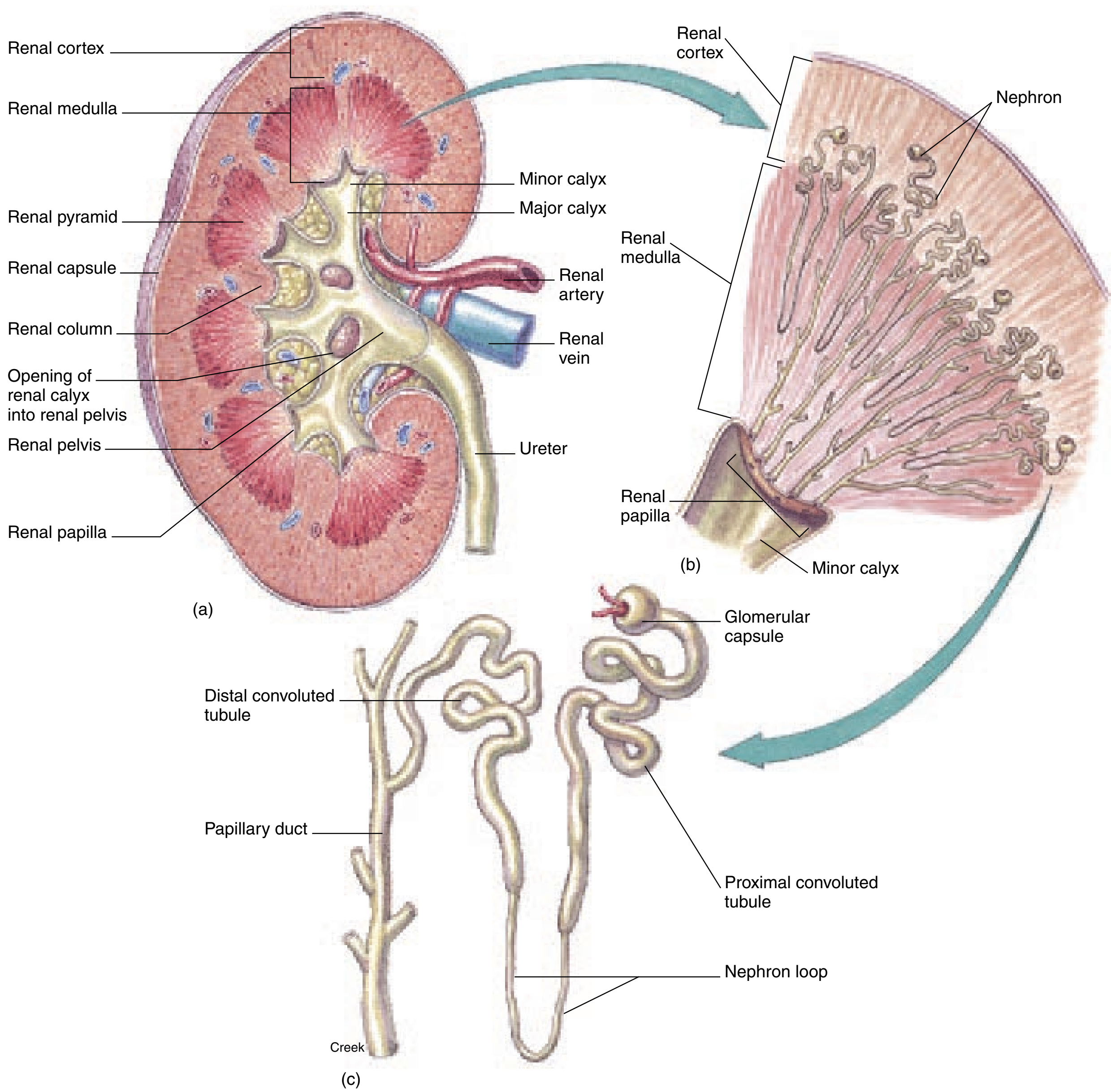


FIGURE 19.5 The internal structures of a kidney. (*a*) A coronal section showing the structure of the renal cortex, renal medulla, and renal pelvis. (*b*) A diagrammatic magnification of a renal pyramid to depict the renal tubules. (*c*) A diagram of a single nephron and a papillary duct.

In summary, vessels are at a capillary level between the arterioles in each glomerulus of the kidney. The blood pressure at the glomerulus is strong enough to force water and dissolved wastes from the blood into the urinary tubular portion of the nephron. Thus, this capillary network produces the filtrate. A secondary capillary network of peritubular capillaries and vasa recta surrounds various tubular portions of the nephron. This capillary bed, however, is adapted for absorption rather than filtrate formation. It reabsorbs water and other substances that should not be excreted with the urine, reclaiming most of the filtrate produced in the glomerulus.

Although the kidneys are generally well protected in that they are encapsulated retroperitoneally, they may be injured by a hard blow to the lumbar region. Such an injury can produce blood in the urine, because the highly vascular kidneys are particularly susceptible to hemorrhage.

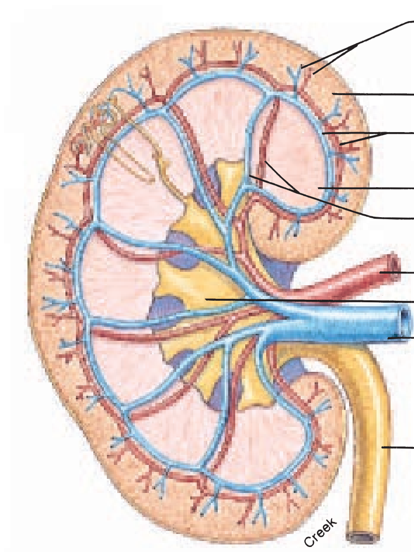


FIGURE 19.6 The principal arteries and veins of a kidney.

Nephron

The tubular nephron consists of a *glomerular capsule, proximal convoluted tubule, descending limb of the nephron loop (loop of Henle), ascending limb of the nephron loop,* and *distal convoluted tubule* (fig. 19.7).

The **glomerular** (Bowman's) **capsule** surrounds the glomerulus. The glomerular capsule and its associated glomerulus are located in the renal cortex of the kidney and together constitute the **renal corpuscle** (fig. 19.8). The glomerular capsule contains an inner visceral layer of epithelium, in contact with the glomerular capillaries and an outer parietal layer. The space between these two layers, called the **capsular space,** is where the glomerular filtrate collects.

The glomerular epithelium contains tiny pores called **fenestrae** (*fĕ-nes'tre*) that permit the filtrate to pass from the blood into the glomerular capsular space (fig. 19.8). Although the fenestrae are large, they are still small enough to prevent the passage of blood cells, platelets, and most plasma proteins into the

Bowman's capsule: from Sir William Bowman, English anatomist, 1816–92

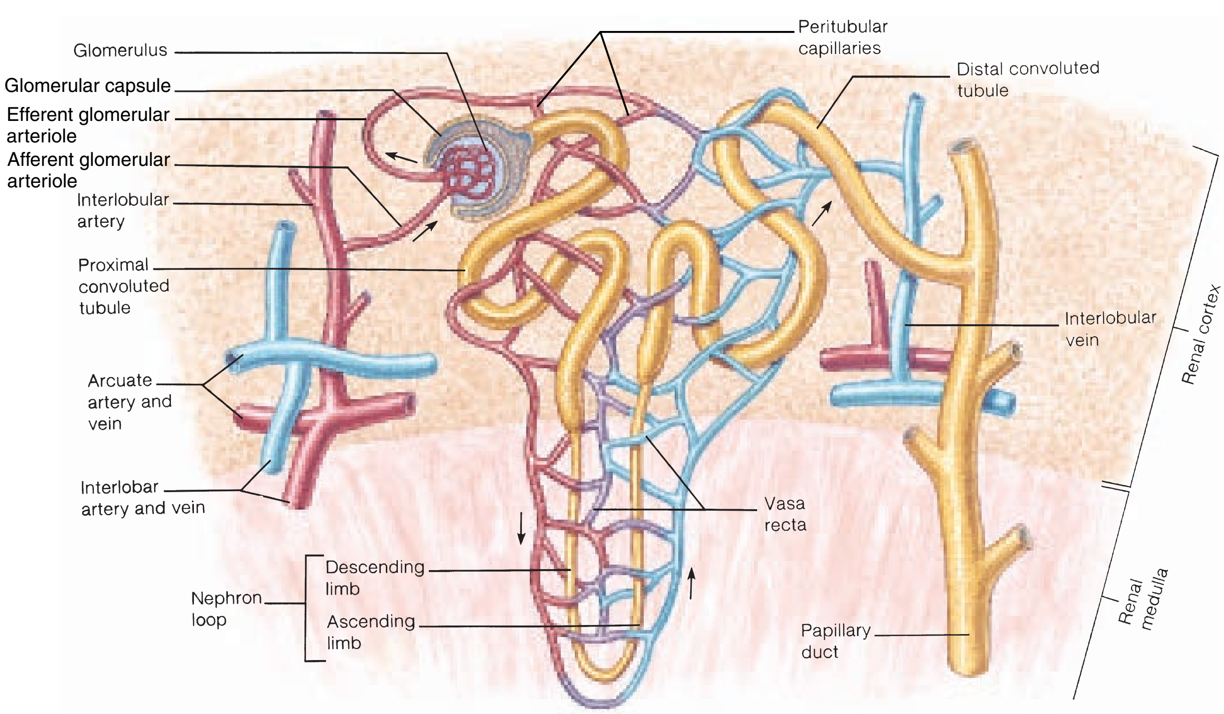


FIGURE 19.7 A simplified illustration of blood flow from a glomerulus to an efferent glomerular arteriole, to the peritubular capillaries, and to the venous drainage of the kidney.

CHAPTER 19

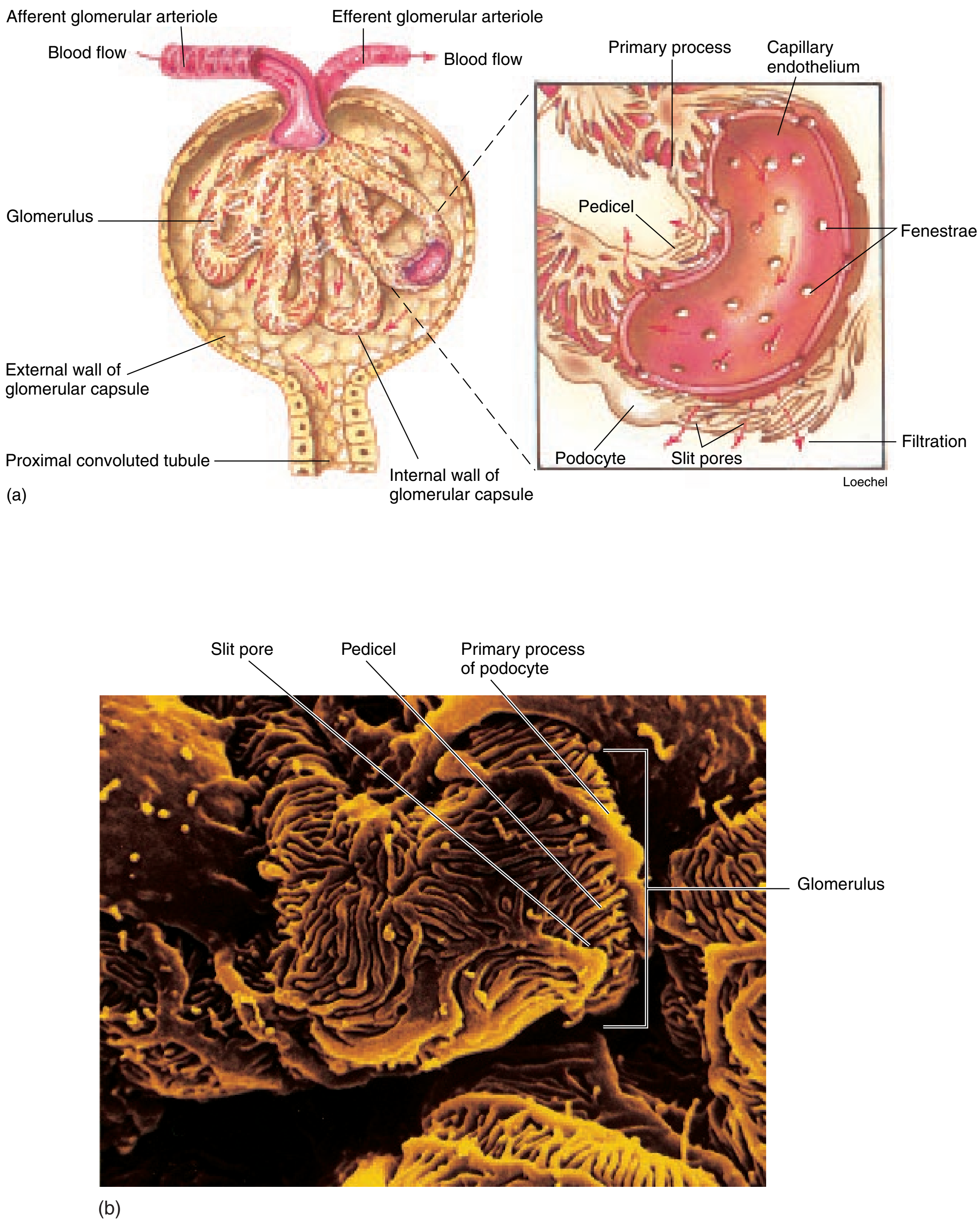
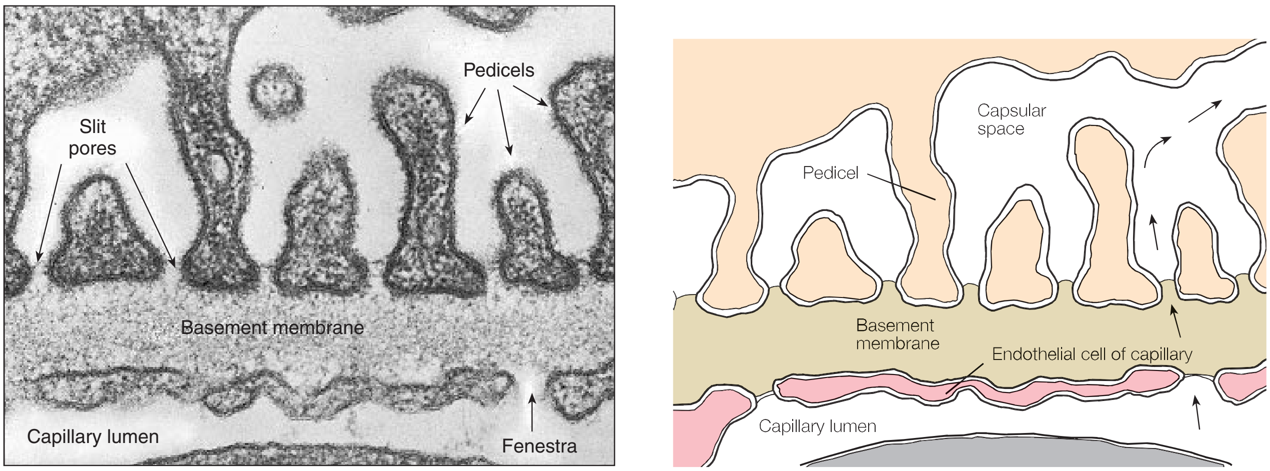


FIGURE 19.8 The structure of a glomerulus. (*a*) A renal corpuscle is composed of a glomerulus and a glomerular (Bowman's) capsule. Note that the diameter of the efferent glomerular arteriole carrying blood away from the glomerulus is smaller than that of the afferent glomerular arteriole transporting blood into the glomerulus. This is one of the contributing factors in the maintenance of high blood pressure within the glomerulus. The first step of urine formation is the filtration through the glomerular membrane (arrows) into the glomerular space of the glomerular capsule. (*b*) A scanning electron micrograph of a glomerulus (8,000×).



(a) (b)

FIGURE 19.9 Glomerular filtration. (*a*) A transmission electron micrograph of a glomerular capillary and the glomerular membranes, and (*b*) accompanying diagram. Substances in the blood are filtered through capillary fenestrae. The filtrate then passes across the basement membrane and through slit pores between the pedicels and enters the capsular space. From here, the filtrate is transported to the lumen of the proximal convoluted tubule (see fig. 19.8).

filtrate. The inner layer of the glomerular capsule is composed of unique cells called **podocytes** (*pod′ŏ-sīts)* with numerous cytoplasmic extensions known as **pedicels** (*ped′ĭ-selz*). Pedicels interdigitate, like the fingers of clasped hands, as they wrap around the glomerular capillaries (figs. 19.8 and 19.9). The narrow **slit pores** between adjacent pedicels provide the passageways through which filtered molecules must pass to enter the interior of the glomerular capsule.

Filtrate in the glomerular capsule passes into the lumen of the **proximal convoluted tubule.** The wall of the proximal convoluted tubule consists of a single layer of cuboidal cells containing millions of microvilli; these serve to increase the surface area for reabsorption. In the process of reabsorption, salt, water, and other molecules needed by the body are transported from the lumen through the tubular cells and into the surrounding peritubular capillaries.

The glomerulus, glomerular capsule, and proximal convoluted tubule are located in the renal cortex. Fluid passes from the proximal convoluted tubule to the **nephron loop** (loop of Henle). This fluid is carried into the renal medulla in the **descending limb** of the nephron loop and returns to the renal cortex in the **ascending limb** of the loop. Back in the renal cortex, the tubule becomes coiled again, and is called the **distal convoluted tubule.** The distal convoluted tubule is shorter than the proximal convoluted tubule and has fewer microvilli. It is the last segment of the nephron, and terminates as it empties into a **papillary duct** (collecting duct). Passing through the **renal papilla,** the papillary ducts empty fluid into the **minor calyx,** which in turn passes into the **major calyx.** Once within the calyces, this fluid is known as *urine*. From the major calyces, urine collects in the **renal pelvis** before it passes from the kidney into the ureter.

Two principal types of nephrons are classified according to their positions in the kidney and the lengths of their nephron loops. Nephrons that have their glomulari in the inner one-third of the cortex—called **juxtamedullary** (*juk′′stă-med′yŭ-ler-e*) **nephrons**—have longer loops than the **cortical nephrons** that have their glomeruli in the outer two-thirds of the renal cortex (fig. 19.10).

The kidneys have an autonomic nerve supply derived from the renal plexus of the tenth, eleventh, and twelfth thoracic nerves. Sympathetic stimulation of the renal plexus produces a vasomotor vascular network response in the kidney. This response determines the circulation of the blood by regulating the diameters of arterioles.

The functions of the nephron are summarized in table 19.1.

Urine from a healthy individual is virtually bacteria-free but easily becomes contaminated after voiding because its organic components serve as a nutrient source for contaminating microbes. The breakdown of urine by bacterial action produces ammonia.

A urinalysis is a common procedure in any routine physical examination. The appearance and pH of the urine are noted, as well as the presence of such abnormal constituents as albumin, blood, glucose, and acetone. Abnormal urine is symptomatic of a variety of diseases or problems in the urinary system.

loop of Henle: from Friedrich Gustav Jacob Henle, German physician, anatomist, and pathologist, 1809–85

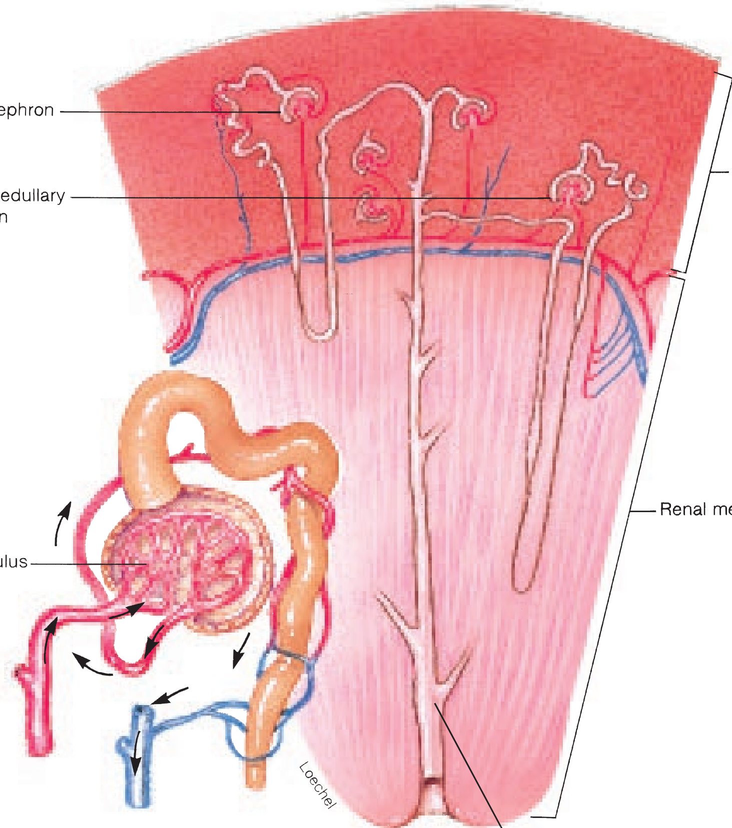


FIGURE 19.10 Cortical nephrons are located almost exclusively within the renal cortex. Juxtamedullary nephrons are located, for the most part, within the outer portion of the renal medulla. (Note the flow of blood through the glomerulus indicated with arrows.)

TABLE 19.1 Functions of the Nephron in Urine Formation

Structure	Function
Renal corpuscle	
Glomerulus	Filtration of water and dissolved substances from blood plasma
Glomerular capsule	Receives glomerular filtrate
Nephron	
Proximal convoluted tubule	Reabsorption of water by osmosis Reabsorption of glucose, amino acids, creatine, lactic acid, citric acid, uric acid, ascorbic acid, phosphate ions, sulfate ions, calcium ions, potassium ions, and sodium ions by active transport Reabsorption of proteins by pinocytosis Reabsorption of chloride ions and other negatively charged ions by electrochemical attraction Active secretion of such substances as penicillin, histamine, and hydrogen ions
Descending limb of the nephron loop	Reabsorption of water by osmosis
Ascending limb of the nephron loop	Reabsorption of chloride ions by active transport and passive reabsorption of sodium ions
Distal convoluted tubule	Reabsorption of water by osmosis Reabsorption of sodium ions by active transport Active secretion of hydrogen ions Passive secretion of potassium ions by electrochemical attraction
Papillary duct	Passive reabsorption of water by osmosis; drains urine from several nephrons

Knowledge Check

3. Describe the general appearance of the renal cortex and renal medulla.
4. Trace the course of blood through the kidney from the renal artery to the renal vein.
5. Trace the course of tubular fluid from the glomerular capsules to the ureter.
6. Draw a diagram of a nephron and label the renal cortex and renal medulla. Also label the structures within each region.

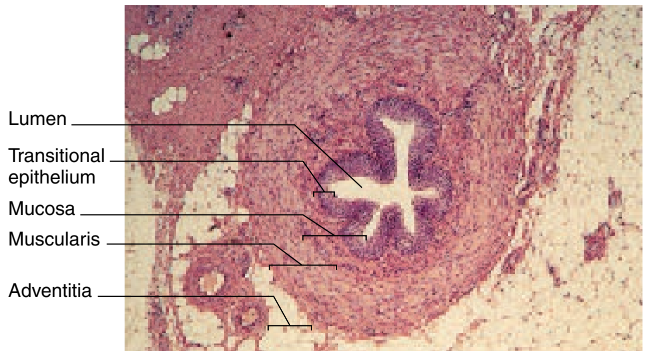


FIGURE 19.11 A photomicrograph of a ureter in cross section. (Note the transitional epithelium lining the lumen.)

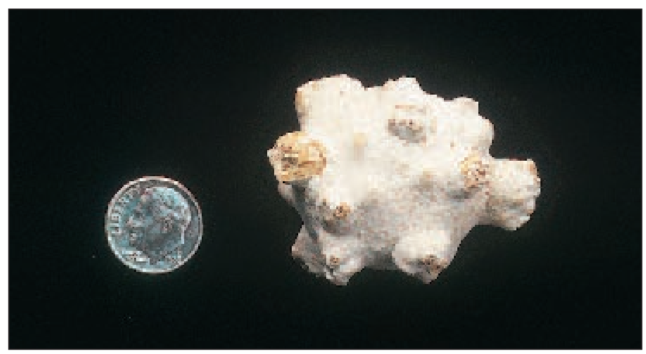


FIGURE 19.12 A renal stone (kidney stone) placed next to a dime for size comparison. Factors contributing to renal stone formation may include the ingestion of excessive mineral salts, a decrease in water intake, and overactivity of the parathyroid glands. A renal stone generally consists of calcium oxalate, calcium phosphate, and uric acid crystals.

URETERS, URINARY BLADDER, AND URETHRA

Urine is channeled from the kidneys to the urinary bladder by the ureters and expelled from the body through the urethra. The mucosa of the urinary bladder permits distension, and the muscles of the urinary bladder and urethra function in the control of micturition.

Objective 6 Describe the location, structure, and function of the ureters.

Objective 7 Describe the gross and histological structure and the innervation of the urinary bladder.

Objective 8 Describe the micturition reflex.

Objective 9 Compare and contrast the structure of the male urethra with that of the female.

Ureters

The **ureters** (*yoo-re'terz*), like the kidneys, are retroperitoneal. These tubular organs, each about 25 cm (10 in.) long, begin at the renal pelvis and course inferiorly to enter the urinary bladder at the posterolateral angles of its base. The thickest portion of a ureter, near where it enters the urinary bladder, is approximately 1.0 cm (0.4 in.) in diameter.

The wall of the ureter consists of three layers, or tunics. The inner **mucosa** is continuous with the linings of the renal tubules and the urinary bladder. The mucosa consists of transitional epithelium (fig. 19.11). The cells of this layer secrete a mucus that coats the walls of the ureter with a protective film.

The middle layer of the ureter is called the **muscularis.** It consists of inner longitudinal and outer circular layers of smooth muscle fibers. In addition, the proximal one-third of the ureter contains another longitudinal layer to the outside of the circular layer. Muscular peristaltic waves move the urine through the ureter. The peristaltic waves are initiated by the presence of urine in the renal pelvis, and their frequency is determined by the volume of urine. The waves, which occur from once every few seconds to once every few minutes, force urine through the ureter and cause it to spurt into the urinary bladder.

The outer layer of the ureter is called the **adventitia** (*ad''ven-tish'ă*) The adventitia is composed of loose connective tissue that covers and protects the underlying layers. In addition, extensions of the connective tissue anchor the ureter in place.

The arterial supply of the ureter comes from several sources. Branches from the renal artery serve the superior portion. The testicular (or ovarian) artery (also called gonadal artery) supplies the middle portion, and the superior vesicular artery serves the pelvic region. The venous return is through corresponding veins.

A *urinary stone* (calculus) may develop in any organ of the urinary system. A *renal stone* ("kidney stone") is one that forms in a kidney (fig. 19.12). A renal stone may obstruct the ureter and greatly increase the frequency of peristaltic waves in an attempt to pass through. The pain from a lodged urinary stone is extreme and extends throughout the pelvic area. A lodged urinary stone also causes a sympathetic ureterorenal reflex that results in constriction of renal arterioles, thus reducing the production of urine in the kidney on the affected side.

calculus: L. *calculus*, small stone

CHAPTER 19

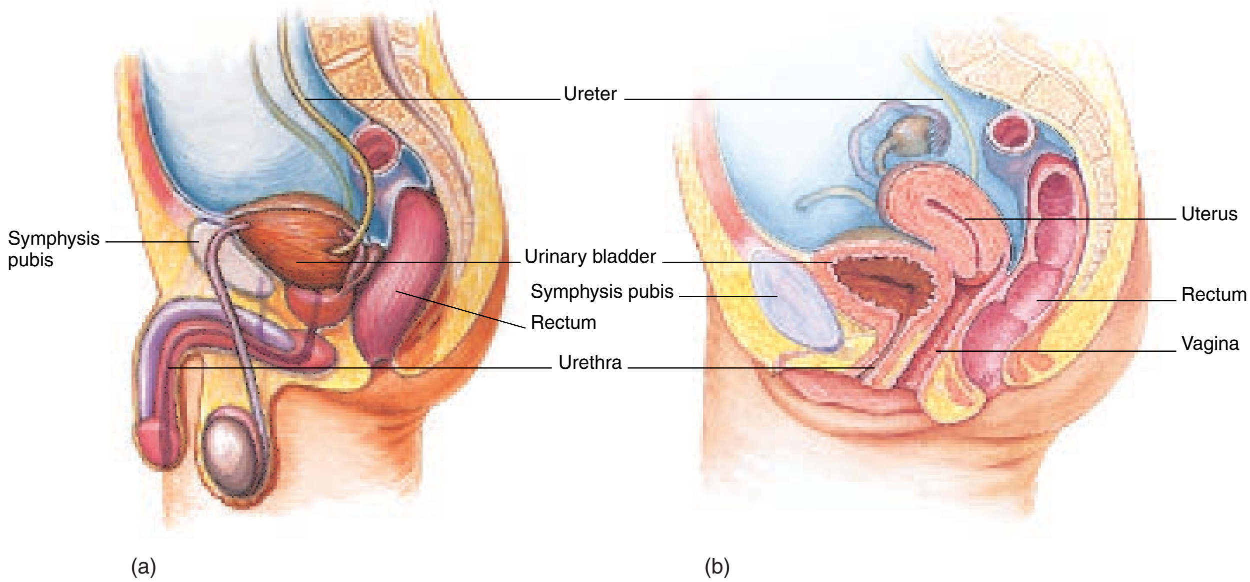


FIGURE 19.13 A sagittal section of the male and female pelves. In the male (*a*), the urinary bladder is located between the symphysis pubis and the rectum. In the female (*b*), the urinary bladder is located between the symphysis pubis and the uterus and upper portion of the vagina. In a female, the volume capacity of the urinary bladder is diminished during the last trimester of pregnancy, when the greatly enlarged uterus exerts constant pressure on the urinary bladder.

Urinary Bladder

The **urinary bladder** is a saccular organ for storage of urine. It is located just posterior to the symphysis pubis, anterior to the rectum (fig. 19.13). In females, the urinary bladder is in contact with the uterus and vagina. In males, the prostate is positioned below the urinary bladder.

The shape of the urinary bladder is determined by the volume of urine it contains. An empty urinary bladder is pyramidal; as it fills, it becomes ovoid and bulges upward into the abdominal cavity. The **median umbilical ligament,** a fibrous remnant of the embryonic urachus (see Developmental Exposition, pp. 689–690), extends from the anterior and superior border of the urinary bladder toward the umbilicus. The base of the urinary bladder receives the ureters, and the urethra exits at the inferior angle, or apex. The region surrounding the urethral opening is known as the **neck** of the urinary bladder.

The wall of the urinary bladder consists of four layers. The **mucosa** (fig. 19.14), the innermost layer, is composed of transitional epithelium that becomes thinner as the urinary bladder distends and the cells are stretched. Further distension is permitted by folds of the mucosa, called **rugae** (*roo'je*), which can be seen when the urinary bladder is empty. Fleshy flaps of mucosa, located where the ureters pierce the urinary bladder, act as valves to prevent a reverse flow of urine toward the kidneys as the urinary bladder fills. A triangular area known as the **trigone** (*tri'gōn*) is formed on the mucosa between the two uretal openings and the single urethral opening (fig. 19.15). The internal trigone lacks rugae; it is therefore smooth in appearance and remains relatively fixed in position as the urinary bladder changes shape during distension and contraction.

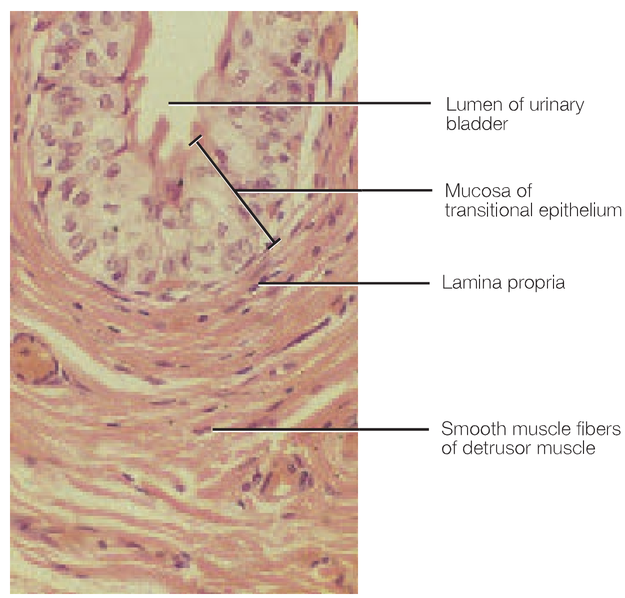


FIGURE 19.14 The histology of the urinary bladder (50×).

trigone: L. *trigonum*, triangle

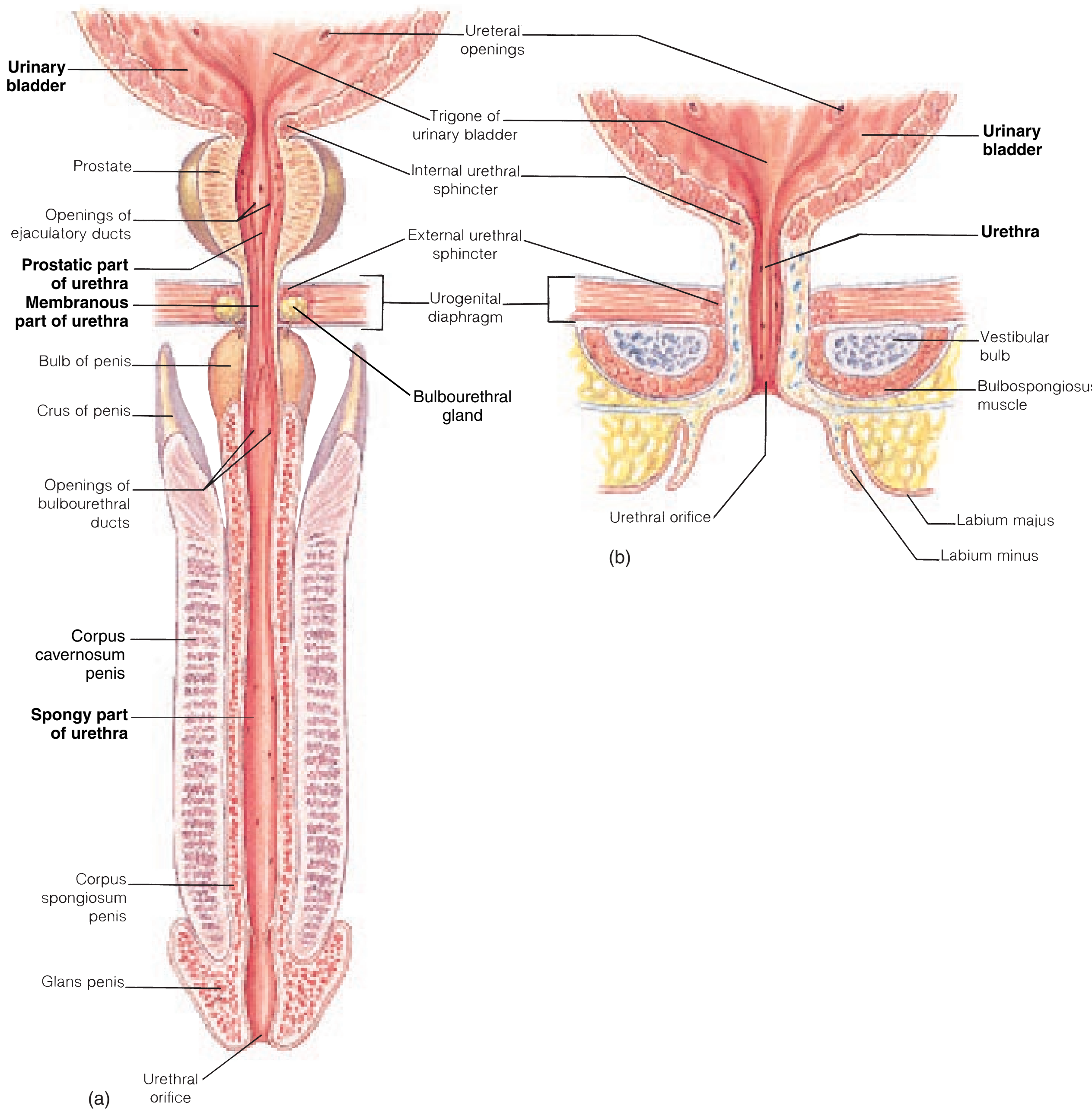


FIGURE 19.15 A frontal section of the male and female urinary bladder and urethra. (*a*) The urethra of a male transports both urine and seminal fluid. It consists of a prostatic part that passes through the prostate, a membranous part that passes through the urogenital diaphragm, and a spongy part that passes through the penis. (*b*) The considerably shorter urethra of a female transports only urine.

The second layer of the urinary bladder, the **submucosa,** functions to support the mucosa. The **muscularis** consists of three interlaced smooth muscle layers collectively called the **detrusor** (*de-troo′sor*) **muscle.** At the neck of the urinary bladder, the detrusor muscle is modified to form the superior (called the internal urethral sphincter) of two muscular sphincters surrounding the urethra. The outer covering of the urinary bladder is the **adventitia.** It appears only on the superior surface of the urinary bladder and is actually a continuation of the parietal peritoneum.

The arterial supply to the urinary bladder comes from the superior and inferior vesicular arteries, which arise from the internal iliac arteries. Blood draining the urinary bladder enters a vesicular venous plexus and then empties into the internal iliac veins.

The autonomic nerves serving the urinary bladder are derived from pelvic plexuses. Sympathetic innervation arises from the last thoracic and first and second lumbar spinal nerves to serve the trigone, urethral openings, and blood vessels of the urinary bladder. Parasympathetic innervation arises from the second, third, and fourth sacral nerves to serve the detrusor muscle. The sensory receptors of the urinary bladder respond to distension and relay impulses to the central nervous system via the pelvic spinal nerves.

The urinary bladder becomes infected easily, and because a woman's urethra is so much shorter than a man's, women are particularly susceptible to urinary bladder infections. A urinary bladder infection, called *cystitis,* may easily ascend from the urinary bladder to the ureters, because the mucous linings are continuous. An infection that involves the renal pelvis is called *pyelitis;* if it continues into the nephrons, it is known as *pyelonephritis.* To reduce the risk of these infections, a young girl should be taught to wipe her anal region in a posterior direction, away from the urethral orifice, after a bowel movement.

Urethra

The tubular **urethra** (*yoo-re′thră*) (fig. 19.15) conveys urine from the urinary bladder to the outside of the body. The urethral wall has an inside lining of mucous membrane surrounded by a relatively thick layer of smooth muscle, the fibers of which are directed longitudinally. Specialized **urethral glands,** embedded in the urethral wall, secrete protective mucus into the urethral canal.

Two muscular sphincters surround the urethra. The involuntary smooth muscle sphincter, the superior of the two, is the **internal urethral sphincter,** which is formed from the detrusor muscle of the urinary bladder. The lower sphincter, composed of voluntary skeletal muscle fibers, is called the **external urethral sphincter** (fig. 19.15).

The urethra of the female is a straight tubular organ, about 4 cm (1.5 in.) long, that empties urine through the **urethral orifice** into the vestibule between the labia minora. The urethral orifice is positioned between the clitoris and vaginal orifice (see fig. 21.15). The female urethra has a single function: to transport urine to the exterior.

The urethra of the male serves both the urinary and reproductive systems. It is about 20 cm (8 in.) long, and is S-shaped because of the shape of the penis (see fig. 19.13). Three portions can be identified in the male urethra: the prostatic part, the membranous part, and the spongy part (fig. 19.15).

The **prostatic part of the urethra** is the proximal portion, about 2.5 cm long, that passes through the **prostate** located near the neck of the urinary bladder. The portion of the urethra receives drainage from small ducts of the prostate and two **ejaculatory ducts** of the reproductive system.

The **membranous part of the urethra** is the short portion (0.5 cm) that passes through the urogenital diaphragm and proximal portion of the penis. The external urethral sphincter muscle is located in this portion.

The **spongy part of the urethra** is the longest portion (15 cm), extending from the outer edge of the urogenital diaphragm to the external urethral orifice on the glans penis. This portion is surrounded by erectile tissue as it passes through the corpus spongiosum of the penis. The ducts of the *bulbourethral glands* (Cowper's glands) of the reproductive system attach to the spongy part of the urethra near the urogenital diaphragm.

Micturition

Micturition (*mik″tŭ-rish′un*) commonly called urination, is a reflex action that expels urine from the urinary bladder. It is a complex function that requires a stimulus from the urinary bladder and a combination of involuntary and voluntary nerve impulses to the appropriate muscular structures of the urinary bladder and urethra.

In young children, micturition is a simple reflex action that occurs when the urinary bladder becomes sufficiently distended. Voluntary control of micturition is normally developed by the time a child is 2 or 3 years old. Voluntary control requires the development of an inhibitory ability by the cerebral cortex and maturation of various portions of the spinal cord.

The volume of urine produced by an adult averages about 1,200 ml a day, but it can range between 600 and 2,500 ml. The average capacity of the urinary bladder is 700 to 800 ml. A volume of 200 to 300 ml will distend the urinary bladder enough to stimulate stretch receptors and trigger the micturition reflex, creating a desire to urinate.

The micturition reflex center is located in the second, third, and fourth sacral segments of the spinal cord. Following stimulation of this center by impulses arising from stretch receptors in the urinary bladder, parasympathetic nerves that stimulate the detrusor muscle and the internal urethral sphincter are activated. Stimulation of these muscles causes a rhythmic contraction of the urinary bladder wall and a relaxation of the internal urethral sphincter. At this point, a sensation of urgency is perceived in the brain, but there is still voluntary control over the external urethral sphincter. At the appropriate time, the

detrusor: L. *detrudere*, thrust or forced down

Cowper's glands: from William Cowper, English surgeon, 1666–1709

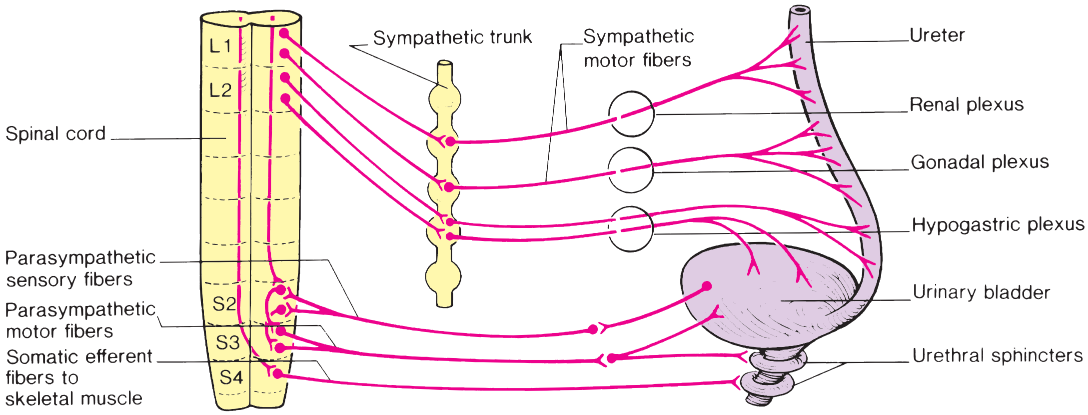


FIGURE 19.16 Innervation of the ureter, urinary bladder, and urethra.

TABLE 19.2 Events of Micturition

1. The urinary bladder becomes distended as it fills with urine.
2. Stretch receptors in the urinary bladder wall are stimulated, and impulses are sent to the micturition center in the spinal cord.
3. Parasympathetic nerve impulses travel to the detrusor muscle and the internal urethral sphincter.
4. The detrusor muscle contracts rhythmically, and the internal urethral sphincter relaxes.
5. The need to urinate is sensed as urgent.
6. Urination is prevented by voluntary contraction of the external urethral sphincter and by inhibition of the micturition reflex by impulses from the midbrain and cerebral cortex.
7. Following the decision to urinate, the external urethral sphincter is relaxed, and the micturition reflex is facilitated by impulses from the pons and the hypothalamus.
8. The detrusor muscle contracts, and urine is expelled through the urethra.
9. Neurons of the micturition reflex center are inactivated, the detrusor muscle relaxes, and the urinary bladder begins to fill with urine.

conscious activity of the brain activates the motor nerve fibers (S4) to the external urethral sphincter via the pudendal nerve (S2, S3, and S4), causing the sphincter to relax and urination to occur.

The innervation of the ureter, urinary bladder, and urethra is shown in figure 19.16, and the events of micturition are summarized in table 19.2.

Urinary retention, or the inability to void, may occur postoperatively, especially following surgery of the rectum, colon, or internal reproductive organs. The difficulty may be due to nervous tension, the effects of anesthetics, or pain and edema at the site of the operation. If urine is retained beyond 6 to 8 hours, *catheterization* may become necessary. In this procedure, a catheter (tube) is passed through the urethra into the urinary bladder so that urine can flow freely.

Knowledge Check

7. Describe the location and the structure of the ureters and indicate the function of the muscularis layer.
8. Describe the structure of the urinary bladder. What structural modifications permit the organ to be distended?
9. Compare the male urinary system with that of the female.
10. Explain the mechanisms by which micturition is controlled, with reference to the structures involved.

CLINICAL CONSIDERATIONS

Urology (*yoo-rol'ă-je*) is the medical specialty concerned with dysfunctions of the urinary system. Urinary dysfunctions can be congenital or acquired; they may result from physical trauma or from conditions that secondarily involve the urinary organs.

Developmental Problems of the Urinary Organs

Abnormalities of the organs of the urinary system occur in about 12% of newborn babies. These deviations range from insignificant anomalies to those that are incompatible with life.

Developmental Exposition

The Urinary System

EXPLANATION

The urinary and reproductive systems originate from a specialized elevation of mesodermal tissue called the **urogenital ridge.** The two systems share common structures for part of the developmental period, but by the time of birth two separate systems have formed. The separation in the male is not totally complete, however, because the urethra serves to transport both urine and semen. The development of both systems is initiated during the embryonic stage, but the development of the urinary system starts and ends sooner than that of the reproductive system.

Three successive types of kidneys develop in the human embryo: the *pronephros*, *mesonephros*, and *metanephros* (exhibit I). The third type, or metanephric kidney, persists as the permanent kidney.

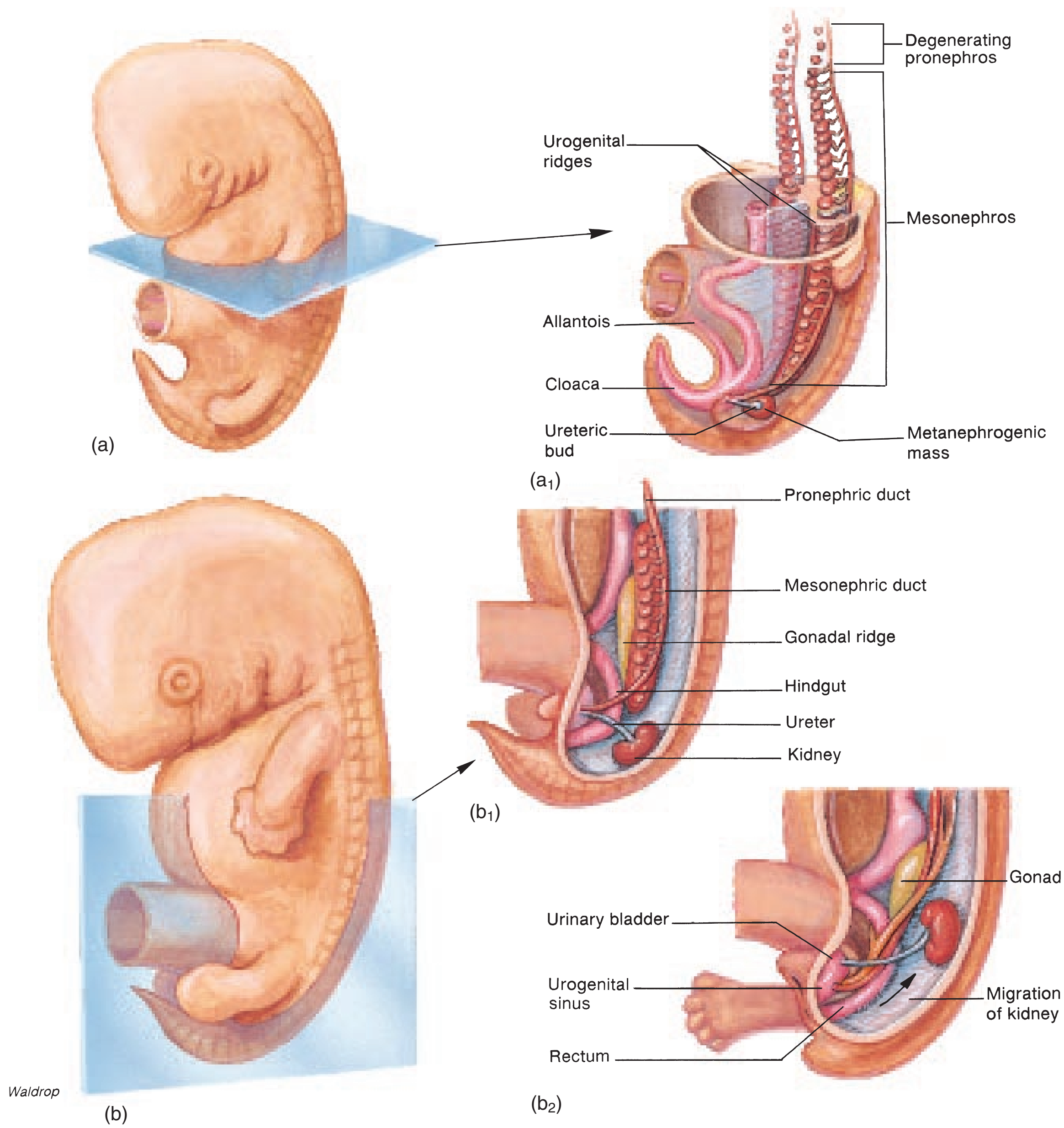


EXHIBIT I The embryonic development of the kidney. (*a*) An anterolateral view of an embryo at 5 weeks showing the position of a transverse cut depicted in (a_1). During the sixth week (b and b_1), the kidney is forming in the pelvic region and the mesonephric duct and gonadal ridge are prominent. The kidney begins migrating during the seventh week (b_2), and the urinary bladder and gonad are formed.

The **pronephros** (*pro-nef′ros*) develops during the fourth week after conception and persists only through the sixth week. Of the three developmental kidneys, it is the most superior in position on the urogenital ridge and is connected to the embryonic **cloaca** by the **pronephric duct.** Although the pronephros is nonfunctional and degenerates in humans, most of its duct is used by the mesonephric kidney (exhibit I), and a portion of it is important in the formation of the metanephros.

The **mesonephros** (*mez′′ŏ-nef′ros*) develops toward the end of the fourth week as the pronephros becomes vestigial. The mesonephros forms from an intermediate portion of the urogenital ridge and functions throughout the embryonic period of development.

Although the **metanephros** (*met′′ă-nef′ros*) begins its formation during the fifth week, it does not become functional until immediately before the start of the fetal stage of development, at the end of the eighth week. The paired metanephric kidneys continue to form urine throughout fetal development. The urine is expelled through the urinary system into the amniotic fluid.

The metanephros develops from two mesodermal sources (exhibit II). The glomerular part of the kidney forms from a specialized caudal portion of the urogenital ridge called the **metanephrogenic mass.** The tubular drainage portion of the kidneys forms as a diverticulum that emerges from the wall of the mesonephric duct near the cloaca. This diverticulum, known as the **ureteric** (*yoo′′rĕ-ter′ik*) **bud,** expands into the metanephrogenic mass to form the drainage pathway for urine. The stalk of the ureteric bud develops into the ureter, whereas the expanded terminal portion forms the renal pelvis, calyces, and papillary ducts. A combination of the ureteric bud and metanephrogenic mass forms the other tubular channels within the kidney.

Once the metanephric kidneys are formed, they begin to migrate from the pelvis to the upper posterior portion of the abdomen. The renal blood supply develops as the kidneys become positioned in the posterior body wall.

The development of the kidneys illustrates the concept that ontogeny (embryonic development) recapitulates phylogeny (evolution). This means that the development of the three kidney types follows an evolutionary pattern. The larvae of a few of the more primitive vertebrates have functional pronephric kidneys. Adult fishes and amphibians have mesonephric kidneys, whereas adult reptiles, birds, and mammals have metanephric kidneys.

The urinary bladder develops from the urogenital sinus, which is connected to the embryonic umbilical cord by the fetal membrane called the allantois (exhibit I). By the twelfth week, the two ureters are emptying into the urinary bladder, the urethra is draining, and the connection of the urinary bladder to the allantois has been reduced to a supporting structure called the **urachus** (*yoo′ră-kus*).

Occasionally a *patent urachus* is present in a newborn and is discovered when urine is passed through the umbilicus, especially if there is a urethral obstruction. Usually, however, it remains undiscovered until an enlarged prostate in an elderly male obstructs the urethra and forces urine through the patent urachus and out the umbilicus (navel).

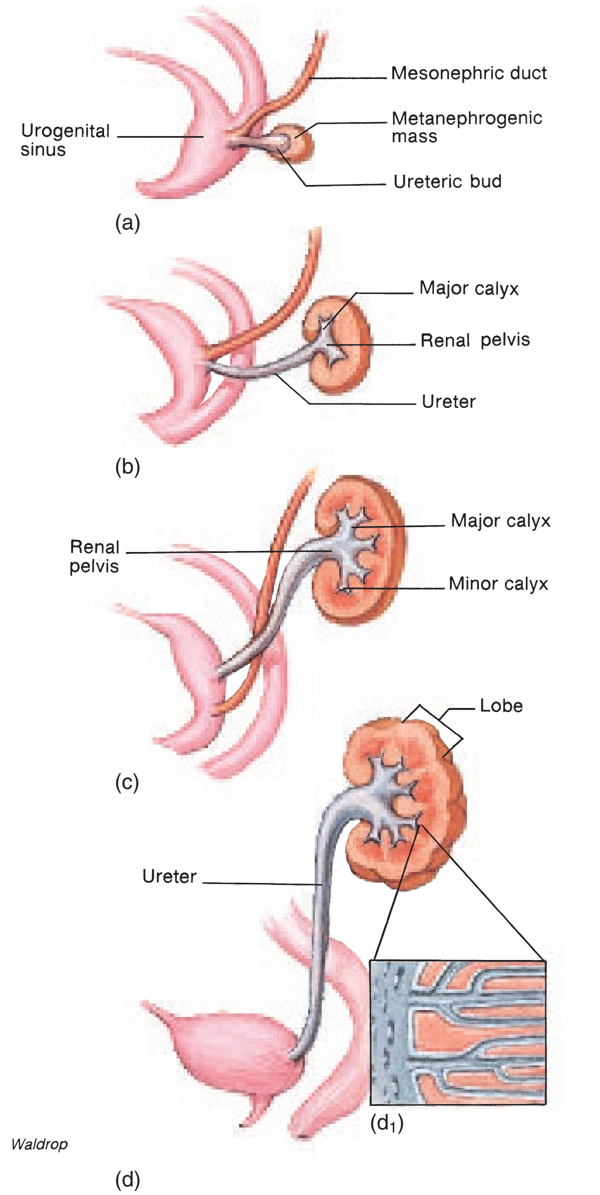


EXHIBIT II The development of the matanephric kidney (*a*) at 4 weeks, (*b*) 5 weeks, (*c*) 7 weeks, and (*d*) at birth. (d_1) A magnified view of the arrangement of papillary ducts within a papilla.

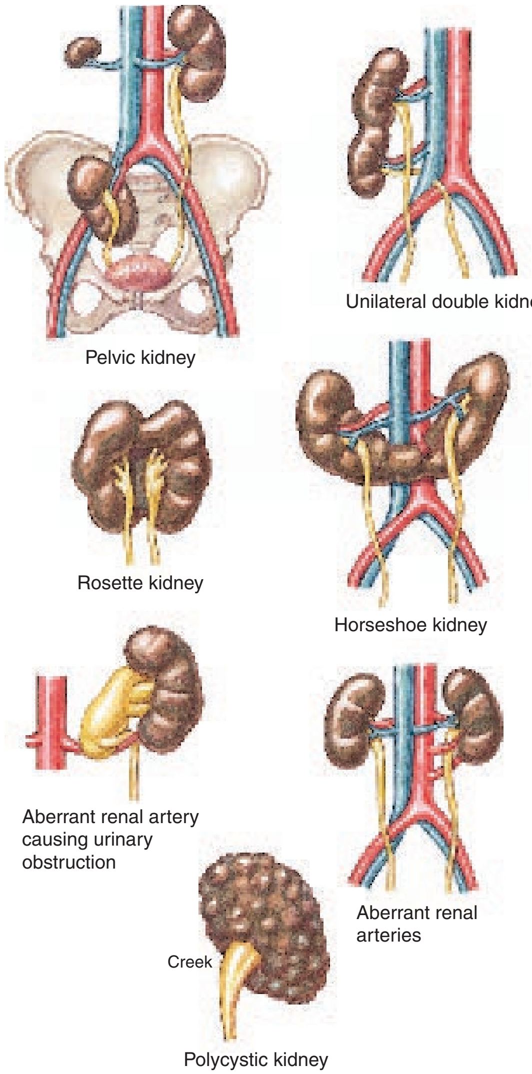


FIGURE 19.17 Congenital anomalies involving the kidneys.

Kidneys

Common malformations of the kidneys are illustrated in figure 19.17. One common deformity is **renal agenesis** (*ă-jen′ĕ-sis*), the unilateral absence of a kidney as a result of failure of a uretic bud to develop. **Renal ectopia** is the condition in which one or both kidneys are in an abnormal position. Generally, this condition occurs when a kidney remains in the pelvic area. **Horseshoe kidney** refers to a fusion of the kidneys across the midline. The incidence of this asymptomatic condition is about 1 in 600.

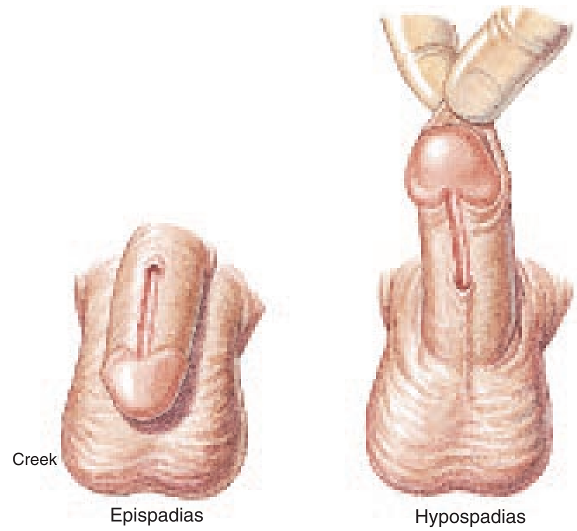


FIGURE 19.18 Epispadias and hypospadias of the male urethra.

Ureters

Duplication of the ureters and the associated renal pelvis is a frequent anomaly of the urinary tract. Unilateral duplication occurs in 1 in 200 births, whereas bilateral duplication occurs in 1 in 1,200 births. Occasionally there is partial duplication, which increases the propensity for urinary infections. A completely duplicated ureter frequently opens into areas other than the urinary bladder requiring surgical correction.

Urinary Bladder

Protrusion of the posterior wall of the urinary bladder, called **exstrophy of the urinary bladder,** occurs when the wall of the perineum fails to close. Associated with this condition, which occurs in about 1 in 40,000 births, are defective urethral sphincter muscles.

Urethra

The most common anomaly of the urethra is **hypospadias** (*hi″pospād′e-as*), a condition in which the urethra of the male opens on the underside of the penis instead of at the tip of the glans penis (fig. 19.18). There is a similar defect in the female in which the urethra opens into the vagina. **Epispadias** is a failure of closure on the dorsum of the penis. Hypospadias and epispadias can be corrected surgically.

Symptoms and Diagnosis of Urinary Disorders

Normal micturition is painless. **Dysuria** (*dis-yur′e-ă*), or painful urination, is a sign of a urinary tract infection or obstruction of the urethra—as in an enlarged prostate in a male. **Hematuria**

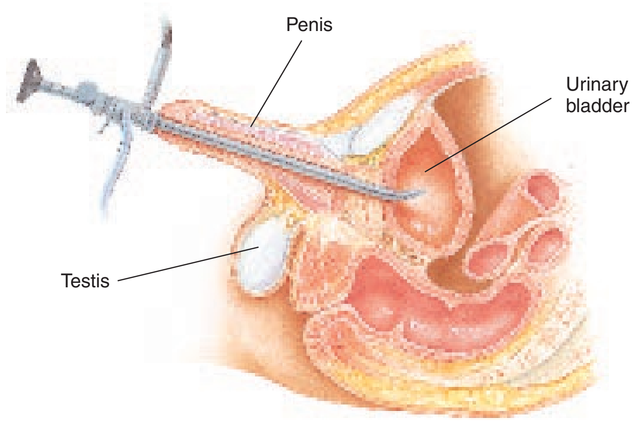


FIGURE 19.19 Cystoscopic examination of a male.

means blood in the urine and is usually associated with trauma. **Bacteriuria** means bacteria in the urine, and **pyuria** is the term for pus in the urine, which may result from a prolonged infection. **Oliguria** is a scanty output of urine, whereas **polyuria** is an excessive output. Low blood pressure and kidney failure are two causes of oliguria. **Uremia** (*yoo-re'me-ă*) is a condition in which substances ordinarily excreted in the urine accumulate in the blood. **Enuresis** (*en''yŭ-re'sis*), or **incontinence,** is the inability to control micturition. It may be caused by psychological factors or by structural impairment.

The palpation and inspection of urinary organs is an important aspect of physical assessment. The right kidney is palpable in the supine position; the left kidney usually is not. The distended urinary bladder is palpable along the superior pelvic rim.

The urinary system may be examined using radiographic techniques. An **intravenous pyelogram** (*pi'ĕ-lŏgram*) (**IVP**) permits radiographic examination of the kidneys following the injection of radiopaque dye. In this procedure, the dye that has been injected intravenously is excreted by the kidneys so that the renal pelvises and the outlines of the ureters and urinary bladder can be observed in a radiograph.

Cystoscopy (*sĭ-stos'kŏ-pe*) is the inspection of the inside of the urinary bladder using an instrument called a cystoscope (fig. 19.19). By means of this technique, tissue samples can be obtained, as well as urine samples from each kidney prior to mixing in the urinary bladder. Once the cystoscope is in the urinary bladder, the ureters and pelvis can be viewed through urethral catheterization and inspected for obstructions.

A **renal biopsy** is a diagnostic test for evaluating certain types and stages of kidney diseases. The biopsy is performed either through a skin puncture (closed biopsy) or through a surgical incision (open biopsy).

Urinalysis is a simple but important laboratory aspect of a physical examination. The voided urine specimen is tested for color, specific gravity, chemical composition, and for the presence of microscopic bacteria, crystals, and casts. *Casts* are accumulations of proteins that leaked through the glomeruli and were pushed through the tubules, like toothpaste through a tube.

Infections of the Urinary Organs

Urinary tract infections (UTIs) are a significant cause of illness and are also a major factor in the development of chronic renal failure. Females are more susceptible to urinary tract infections than are males because the urethra is shorter in females and the urethral and anal openings are closer together. The incidence of infection increases directly with sexual activity and aging in both sexes.

Infections of the urinary tract are named according to the infected organ. An infection of the urethra is called **urethritis** (*yoo''re-thri'tis*) and involvement of the urinary bladder is **cystitis** (*sis-ti'tis*). Cystitis is frequently a secondary infection from some other part of the urinary tract. **Nephritis** is inflammation of the kidney tissue. **Glomerulonephritis** (*glo-mer''yŭ-lo-nĕfri'tis*) is inflammation of the glomeruli. Glomerulonephritis may occur following an upper respiratory tract infection because antibodies produced against streptococci bacteria can produce an autoimmune inflammation in the glomeruli. This inflammation may permanently change the glomeruli and figure significantly in the development of chronic renal disease and renal failure.

Any interference with the normal flow of urine, such as from a renal stone or an enlarged prostate in a male, causes stagnation of urine in the renal pelvis and may lead to pyelitis. **Pyelitis** is an inflammation of the renal pelvis and its calyces. **Pyelonephritis** is inflammation involving the renal pelvis, the calyces, and the tubules of the nephron within one or both kidneys. Bacterial invasion from the blood or from the lower urinary tract is another cause of both pyelitis and pyelonephritis.

Trauma to the Urinary Organs and Functional Impairments

Trauma

A sharp blow to a lumbar region of the back may cause a contusion or rupture of a kidney. Symptoms of kidney trauma include hematuria and pain in the upper abdominal quadrant and flank on the injured side.

Pelvic fractures from accidents may result in perforation of the urinary bladder and urethral tearing. On a long automobile trip, it is advisable to stop to urinate at regular intervals because an attached seat belt over the region of a full urinary bladder can cause rupture of the urinary bladder in even a relatively minor accident. Urethral injuries are more common in men than in women because of the position of the urethra in the penis. In a straddle injury, for example, a man walking along a raised beam may slip and compress his urethra and penis between the hard surface and his pubic arch, rupturing the urethra.

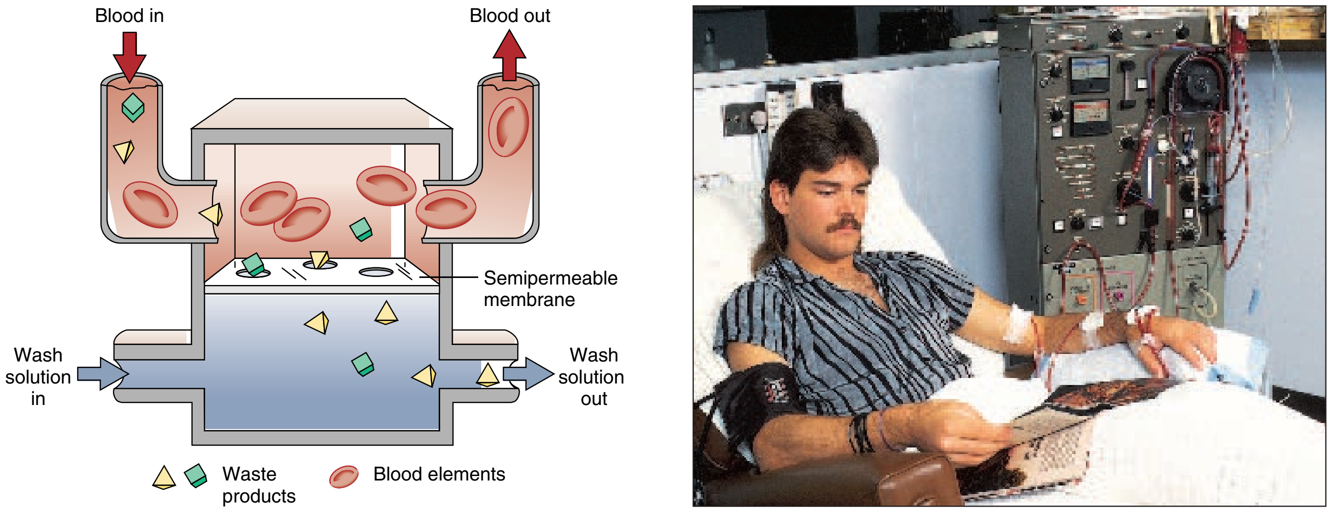


FIGURE 19.20 The hemodialysis process.

Obstruction

The urinary system can become obstructed anywhere along the tract. Calculi (stones) are the most common cause, but blockage can also come from trauma, strictures, tumors or cysts, spasms or kinks of the ureters, or congenital anomalies. If not corrected, an obstruction causes urine to collect behind the blockage and generate pressure that may cause permanent functional and anatomic damage to one or both kidneys. As a result of pressure buildup in a ureter, a distended ureter, or **hydroureter,** develops. Dilation in the renal pelvis is called **hydronephrosis.**

Urinary stones (calculi) are generally the result of infections or metabolic disorders that cause the excretion of large amounts of organic and inorganic substances (see fig. 19.12). As the urine becomes concentrated, these substances may crystalize and form granules in the renal calyces. The granules then serve as cores for further precipitation and development of larger calculi. This becomes dangerous when a calculus grows large enough to cause an obstruction. The calculus also causes intense pain when it passes through the urinary tract.

Renal Failure and Hemodialysis

Renal output of 50 to 60 cc of urine per hour is considered normal. If the output drops to less than 30 cc per hour, it may indicate renal failure—the loss of the kidney's ability to maintain fluid and electrolyte balance and to excrete waste products. Renal failure can be either acute or chronic. **Acute renal failure** is the sudden loss of kidney function caused by shock and hemorrhage, thrombosis, or other physical trauma to the kidneys. The kidneys may sustain a 90% loss of their nephrons through tissue death and still continue to function without apparent difficulty. If a patient suffering acute renal failure is stabilized, the nephrons have an excellent capacity to regenerate.

A person with **chronic renal failure** cannot sustain life independently. Chronic renal failure is the end result of kidney disease in which the kidney tissue is progressively destroyed. As renal tissue continues to deteriorate, the options for sustaining life are *hemodialysis (he''mo-di-al'-ĭsis)* or *kidney transplantation*.

Hemodialysis equipment is designed to filter the wastes from the blood of a patient who has chronic renal failure. The patient's blood is pumped through a tube from the radial artery and passes through a machine, where it is cleansed and then returned to the body through a vein (fig. 19.20). The cleaning process involves pumping the blood past a semipermeable cellophane membrane that separates the blood from an isotonic solution containing molecules needed by the body (such as glucose). Waste products diffuse out of the blood through the membrane, while glucose and other molecules needed by the body remain in the blood.

More recent hemodialysis techniques include the use of the patient's own peritoneal membranes for filtering. Dialysis fluid is introduced into the peritoneal cavity, and then, after a period of time, discarded after wastes have accumulated. This procedure, called *continuous ambulatory peritoneal dialysis (CAPD)*, can be performed several times a day by the patients themselves on an outpatient basis.

Urinary Incontinence

The inability to voluntarily retain urine in the urinary bladder is known as *urinary incontinence*. It has a number of causes and may be temporary or permanent. Emotional stress is a cause of temporary incontinence in adults. Permanent incontinence may result from neurological trauma, various urinary diseases, tissue damage within the urinary bladder or urethra, or weakness of the pelvic floor muscles. Remarkable advances have been made in treating permanent urinary incontinence through the implantation of an artificial urethral sphincter.

Clinical Case Study Answer

The hematuria experienced by the patient is probably the result of laceration caused by the upper abdominal knife wound. The lower right quadrant stab most likely did not violate the urinary tract. The course of blood seen in the catheter begins and proceeds as follows: abdominal aorta → right renal artery → smaller parenchymal artery → through the lacerated vessel(s) → into the lacerated urinary collecting system, either at the calyx or the renal pelvis or proximal right ureter → urinary bladder → into catheter. During the operation, the surgeon should keep in mind that in 2% to 4% of the population only one kidney is present. If, therefore, she is prompted to remove the damaged kidney, she should first confirm the presence of a second functioning kidney. If a second kidney is not present, every effort should be made to correct the problem without performing a nephrectomy, which would consign the patient to chronic hemodialysis or kidney transplant.

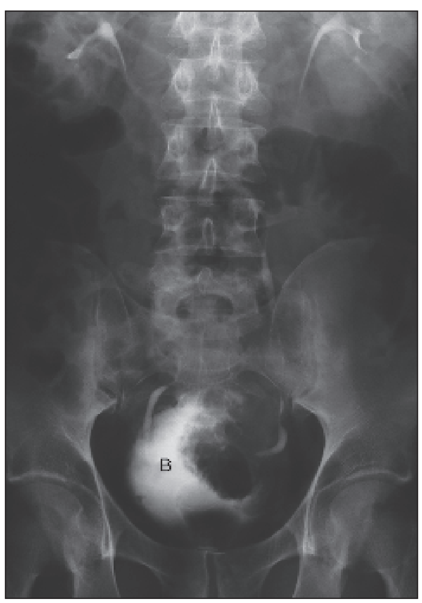
CLINICAL PRACTICUM 19.1

A 41-year-old male presents in your office because his urine has a pink tinge. He also reports an increase in his frequency of urination. The patient denies fever, chills, pain, or foul odor from his urine.

The physical exam is normal. A routine urinalysis reveals red blood cells too numerous to count, no white blood cells, and no bacteria. You order an intravenous urogram (IVU) (*a*), which is an injection of intravenous contrast material for an exam of the urinary system, and CT scan (*b*). (B = bladder.)

QUESTIONS

1. What is the large dark mass (filling defect) seen in the urinary bladder (indicated with the letter B) on the IVU? Is it the source of the bleeding?
2. On the CT, white contrast fills the lumen of the urinary bladder (indicated with an arrow). Why does the patient have increased frequency of urination?
3. Transitional carcinoma has a 5–10% incidence of synchronous tumors. Synchronous tumors are tumors of the same cell type occuring at the same time in separate locations. What other structures must be evaluated for the presence of tumors?



(a)

(b)

CLINICAL PRACTICUM 19.2

A 41-year-old female presents at the emergency room with left lumbar pain that at times radiates to the left groin. She describes the pain as intermittent and crampy, but denies any fever or blood in her urine.

Physical exam shows a nontender abdomen and no evidence of costovertebral angle tenderness. Routine urinalysis shows minimal red blood cells, no white blood cells, and no bacteria. You order an intravenous urogram.

QUESTIONS

1. On the precontrast image, what is the density indicated by the arrow?
2. What effect does this have on the ureter as demonstrated by the postcontrast image?
3. Why is the patient having intermittent pain?

Precontrast image

Postcontrast image

Chapter Summary

Introduction to the Urinary System (p. 676)

1. The urinary system consists of two kidneys, two ureters, the urinary bladder, and the urethra.
2. The urinary system maintains the composition and properties of body fluid, which establishes the extracellular environment. The end product of the urinary system is urine, which is voided from the body during micturition.

Kidneys (pp. 676–684)

1. The kidneys are retroperitoneal, embedded in a renal adipose capsule.
2. Each kidney is contained by a renal capsule and divided into an outer renal cortex and an inner renal medulla.
   (a) The renal medulla is composed of renal pyramids separated by renal columns.
   (b) The renal papillae empty urine into the minor calyces and then into the major calyces, which drain into the renal pelvis. From there, urine flows through the ureter.
3. Each kidney contains more than a million microscopic functional units called nephrons.
   (a) Filtration occurs in the glomeruli, which receive blood from afferent glomerular arterioles.
   (b) Glomerular blood is drained by efferent glomerular arterioles that deliver blood to peritubular capillaries surrounding the nephron tubules.
   (c) The glomerular capsules and distal convoluted tubules are located in the renal cortex.
   (d) The nephron loops are located in the renal medulla.
   (e) Filtrate from the distal convoluted tubules are drained into papillary ducts that extend through the renal medulla to empty urine into the calyces.

Ureters, Urinary Bladder, and Urethra (pp. 684–688)

1. Urine is channeled from the kidneys to the urinary bladder by the ureters and expelled from the urinary bladder through the urethra. The detrusor muscle of the urinary bladder and the sphincter muscles of the urethra are used in the control of micturition.
   (a) Each ureter contains three layers: the mucosa, muscularis, and adventitia.
   (b) The lumen of the urinary bladder is lined by transitional epithelium, which is folded into rugae. These structures enhance the ability of the urinary bladder to distend.
   (c) The urethra has an internal sphincter of smooth muscle and an external sphincter of skeletal muscle.
   (d) The male urethra conducts urine during urination and seminal fluid during ejaculation. The female urethra is much shorter than that of a male and conducts only urine.
   (e) The male urethra is composed of prostatic, membranous, and spongy portions.
2. Micturition is controlled by reflex centers in the second, third, and fourth sacral segments of the spinal cord.

Review Activities

Objective Questions

1. Which of the following statements about the renal pyramids is *false?*
   (a) They are located in the renal medulla.
   (b) They contain glomeruli.
   (c) They contain papillary ducts.
   (d) They are supported by renal columns.
2. Renal vessels and the ureter attach at the concave medial border of the kidney called
   (a) the renal pelvis.
   (b) the urachus.
   (c) the calyx.
   (d) the hilum.
3. The renal medulla of the kidney contains
   (a) glomerular capsules.
   (b) glomeruli.
   (c) renal pyramids.
   (d) adipose capsules.
4. Urine flowing from the papillary ducts enters directly into
   (a) the renal calyces.
   (b) the ureter.
   (c) the renal pelvis.
   (d) the distal convoluted tubules.
5. Which of the following statements concerning the kidneys is *false?*
   (a) They are retroperitoneal.
   (b) They each contain 8 to 15 renal pyramids.
   (c) They each have two distinct regions—the renal cortex and renal medulla.
   (d) They are positioned between the third and fifth lumbar vertebrae.
6. A renal stone (calculus), would most likely cause stagnation of urine in which portion of the urinary system?
   (a) the urinary bladder
   (b) the renal column
   (c) the ureter
   (d) the renal pelvis
   (e) the urethra
7. Distention of the urinary bladder is possible because of the presence of
   (a) rugae.
   (b) the trigone.
   (c) the adventitia.
   (d) the transitional epithelium.
   (e) both a and d.
8. The detrusor muscle is located in
   (a) the kidneys.
   (b) the ureters.
   (c) the urinary bladder.
   (d) the urethra.
9. The internal urethral sphincter is innervated by
   (a) sympathetic neurons.
   (b) parasympathetic neurons.
   (c) somatic motor neurons.
   (d) all of the above.
10. Which of the following statements about metanephric kidneys is *true?*
   (a) They become functional at the end of the eighth week.
   (b) They are active throughout fetal development.
   (c) They are the third pair of kidneys to develop.
   (d) All of the above are true.

Essay Questions

1. Describe the location of the kidneys in relation to the abdominal cavity and the peritoneal membranes.
2. Diagram the kidney structures that can be identified in a coronal section.
3. Describe how the kidney is supported against the posterior abdominal wall. How is this support related to the condition called renal ptosis?
4. Trace a drop of blood from an interlobular artery through a glomerulus and into an interlobular vein. List in order all the vessels through which the blood passes. How do structural differences in afferent and efferent glomerular arterioles ensure the high blood pressure needed for filtrate formation?
5. In a male, trace the path of urine from the site of filtration at the renal corpuscle to the outside of the body. List in order all the structures through which the urine passes.
6. What is a nephron? Describe the two types of nephrons found in a kidney. Why are nephrons considered the functional units of the urinary system?
7. Describe the mechanism involved in the passage of urine from the renal pelvis to the urinary bladder.
8. Describe the urinary bladder with regard to position, histological structure, blood supply, and innervation.
9. Compare and contrast the urethra in the male and female.
10. What is the micturition reflex? Discuss the physiological and functional events of a voluntary micturition response.
11. What is a metanephrogenic mass? A ureteric bud? Discuss the sequential development of these embryonic structures to form the urinary system. How can a greater knowledge of this development process lead to a better understanding of congenital abnormalities?
12. Briefly describe the purpose of cytoscopy and urinalysis.
13. List four common congenital malformations of the urinary system. Which of these require surgical correction?
14. Define *dysuria*, *hematuria*, *bacteriuria*, *pyuria*, *oliguria*, *polyuria*, *uremia*, *and enuresis*.

Critical-Thinking Questions

1. Why is it more accurate to refer to the kidneys and associated structures as the urinary system rather than the excretory system?
2. Treatment with sulfa medications such as Gantrisin (sulfisoxazole) and broad-spectrum antibiotics such as tetracycline or ampicillin usually clear up the symptoms of cystitis very quickly. What is the danger of discontinuing the prescribed medication as soon as the symptoms are gone?
3. The neighborhood day-care center won't accept children who are still in diapers. You've tried to toilet train your 15-month-old boy, but you haven't made any progress at all. Should you persist in your efforts, or would it be better to wait? Explain.
4. What functions of a real kidney does an artificial kidney (dialysis machine) fail to duplicate?
5. Your friend's baby is due next month, and she is constantly running to the bathroom to urinate. Can you explain why?
6. Explain why a male should be particularly concerned if he has difficulty voiding urine.