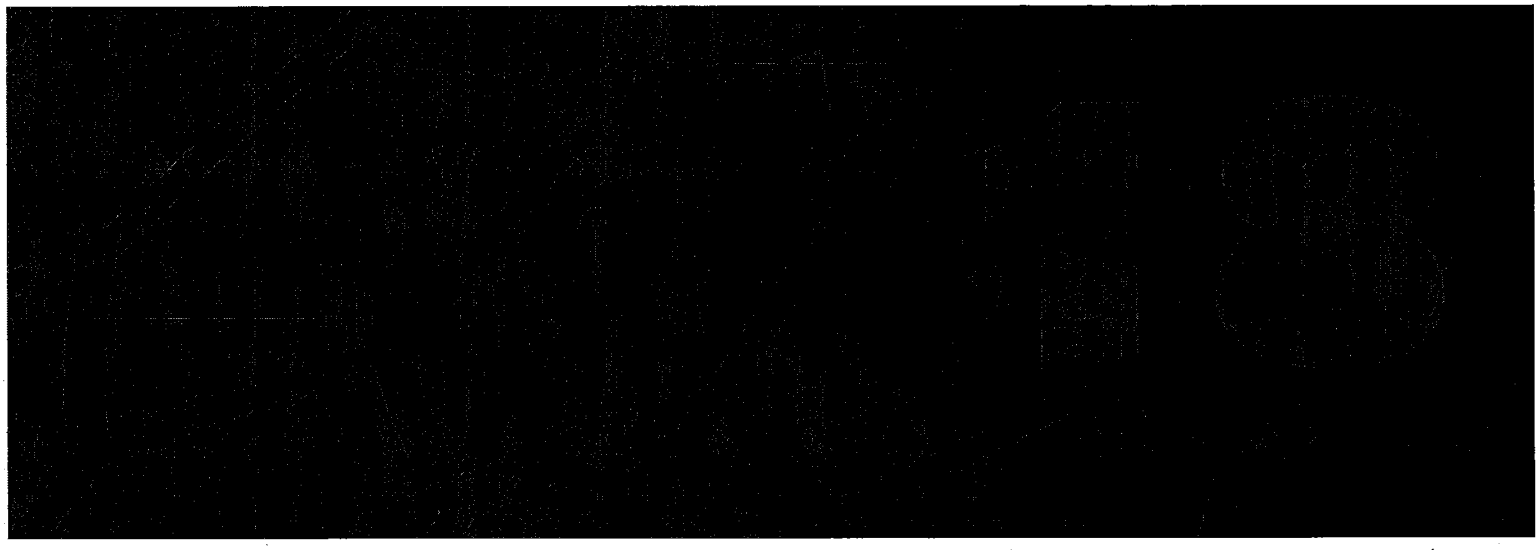
The Urinary System

CHAPTER OBJECTIVES

After studying this chapter, you should be able to:

1. Define the functions of the urinary system.
2. Name the external layers of the kidney.
3. Define the following internal parts of the kidneys: *cortex, medulla, medullary pyramids, renal papillae, renal columns,* and *major* and *minor calyces.*
4. Name the parts of a nephron and describe the flow of urine through this renal tubule.
5. List the functions of the nephrons.
6. Explain how urine flows down the ureters.
7. Describe micturition and the role of stretch receptors in the bladder.
8. Compare the length and course of the male urethra to the female urethra.
9. Name the normal constituents of urine.

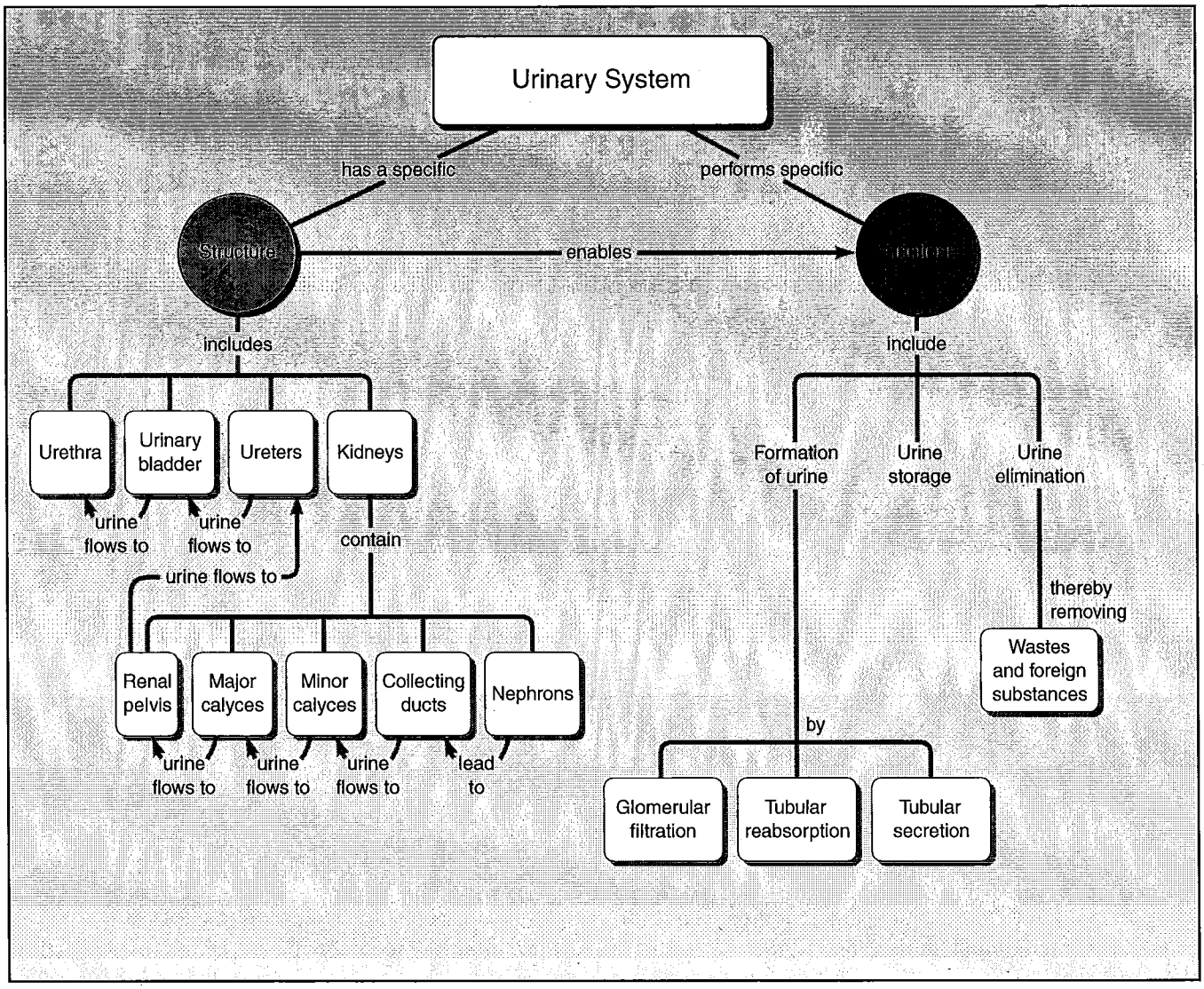


KEY TERMS

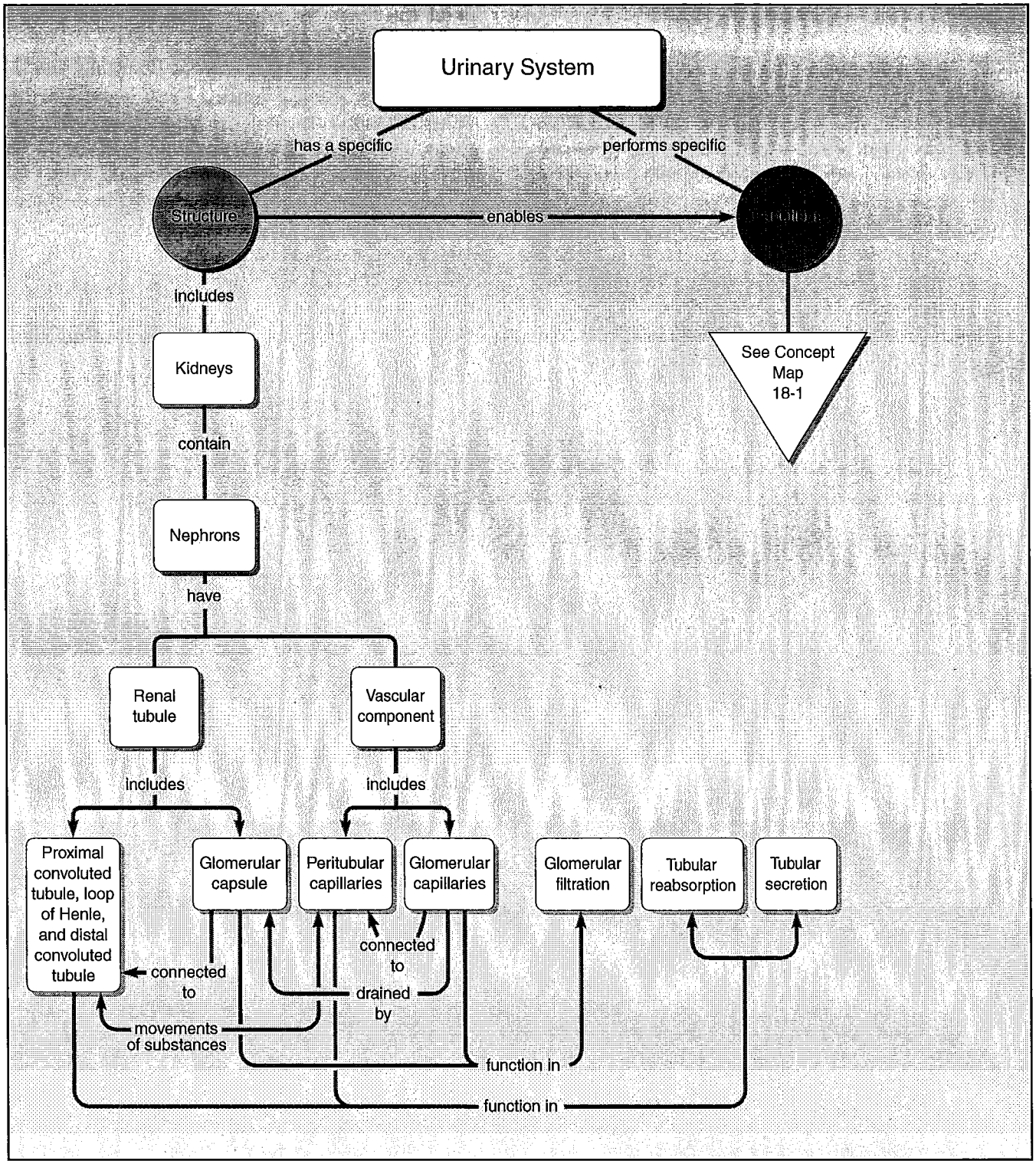
INTRODUCTION

As the body metabolizes the various foods and nutrients taken in through the digestive tract, body cells produce metabolic wastes in the form of carbon dioxide gas, heat, and water. The breakdown of proteins into amino acids and the subsequent metabolism of the amino acids produces nitrogenous wastes like ammonia. The harmful ammonia is converted by liver enzymes into less harmful urea. In addition, the body accumulates excess ions of sodium, chloride, potassium, hydrogen, sulfate, and phosphate.

It is the role of the urinary system to maintain a balance of these products and to remove excesses from the blood. This system helps to keep the body in homeostasis by both removing and restoring selected amounts of solutes and water from the blood. See Concept Maps 18-1 and 18-2: The Urinary System. The **urinary** (**YOO**-rih-nair-ee) **system** consists of two kidneys, two ureters, the urinary bladder, and the urethra (Figure 18-1). The kidneys regulate the composition and volume of the blood and remove wastes from the blood in the form of urine. The urine consists of the metabolic waste urea, excess water, excess ions, and toxic wastes that may have been consumed with food. Urine is excreted from each kidney through the kidney ureter. It is then stored in the urinary bladder, until it is expelled from the body through the urethra.



CONCEPT MAP 18-1. The Urinary System. (*© Cengage Learning 2012*)



CONCEPT MAP 18-2. The Urinary System. (*© Cengage Learning 2012*)

The kidneys are extremely efficient organs and are crucial in maintaining homeostasis in the body. A person can function very well with only one kidney, as we know from hearing about kidney donations among family members. In fact, as long as at least one-third of the kidney is functional, a person can survive. However, if kidney failure occurs, death is inevitable without medical treatment through kidney dialysis. Other systems of the

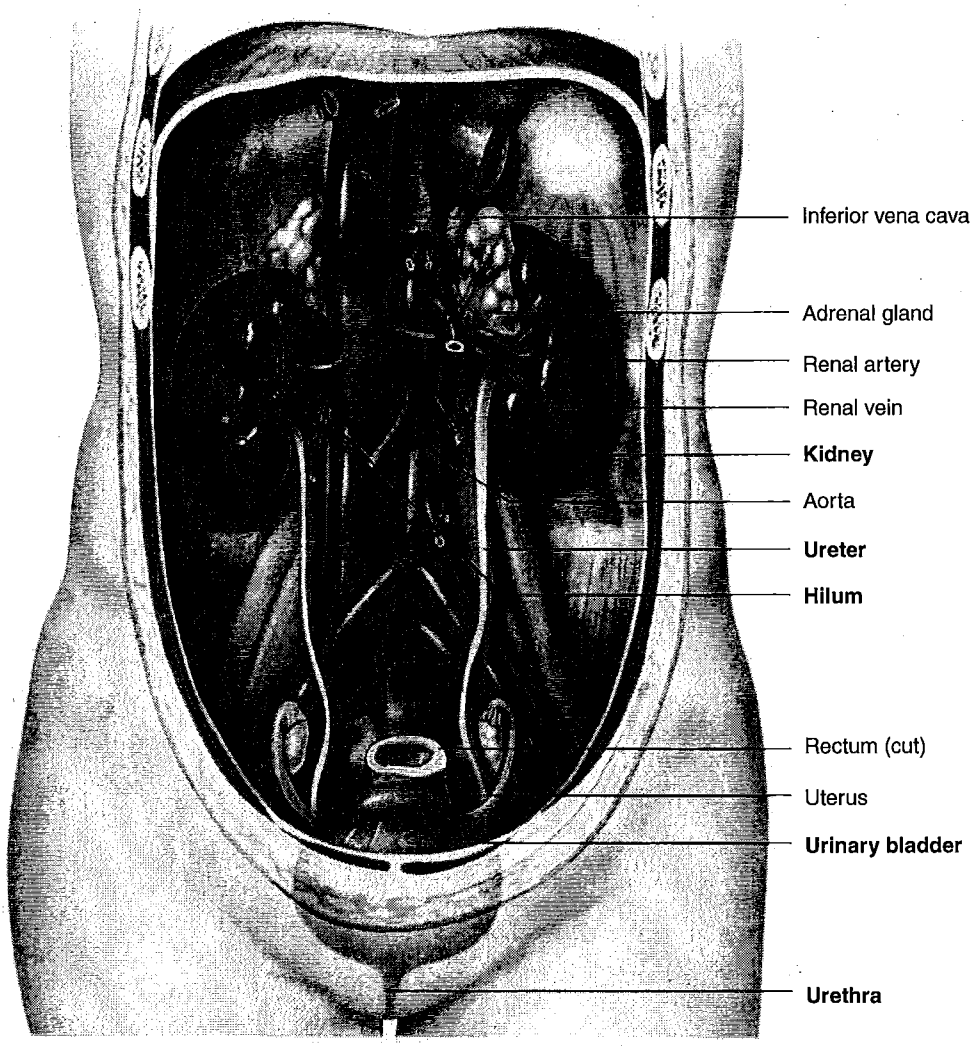


FIGURE 18-1. The organs of the urinary system of a female. (*© Cengage Learning 2012*)

body also participate in waste excretion. The respiratory system excretes carbon dioxide gas and water vapor. The integumentary system excretes dissolved wastes (e.g., urea) in perspiration. The digestive system excretes indigestible materials, like plant fiber, and some bacteria.

FUNCTIONS OF THE URINARY SYSTEM

The major role of maintaining homeostasis with respect to the composition and volume of blood and body fluids is controlled by the kidneys, which perform various functions:

- **Excretion:** The kidneys filter large amounts of fluid from the bloodstream. They are the major excretory organs of the body because they eliminate nitrogenous wastes, drugs, and toxins from the body. Although the skin, liver, intestines, and lungs also eliminate wastes, they cannot compensate if the kidneys fail. In addition, the kidneys can reabsorb needed substances and return them to the blood.
- **Maintain blood volume and concentration:** The kidneys control blood volume by regulating the proper balance in the blood between salts and water. They regulate the volume of urine produced. They also regulate the concentration of ions in body fluids and blood, so the proper balance of sodium, chloride, potassium, calcium, and phosphate ions is maintained.
- **pH regulation:** The kidneys control the proper balance of hydrogen ions in the blood, thus helping

to regulate the proper pH levels in the body along with buffers in the blood and the respiratory system.

- **Blood pressure:** The kidneys produce the enzyme **renin** (**REN**-in), which helps adjust filtration pressure.
- **Erythrocyte concentration:** The kidneys produce **erythropoietin** (eh-**rith**-roh-**POY**-eh-tin), a hormone that stimulates red blood cell production in red bone marrow. They help regulate the concentration of erythrocytes in the blood in cases of chronic hypoxia (inadequate oxygen in tissue cells).
- **Vitamin D production:** The kidneys convert vitamin D to its active form (calciferol). Vitamin D is important for normal bone and teeth development. It also helps control calcium and phosphorus metabolism. The kidneys participate, along with the liver and the skin, in vitamin D synthesis.

THE EXTERNAL ANATOMY OF THE KIDNEYS

The **kidneys** are paired organs that are reddish in color and resemble kidney beans in shape. They are about the size of a closed fist. They are located just above the waist between the parietal peritoneum and the posterior wall of the abdomen. This placement of the kidneys is also referred to as retroperitoneal. The right kidney is slightly lower than the left because of the large area occupied by the liver (see Figure 18-1).

The average adult kidney measures about 11.25 cm (4 inches) long, 5.0 to 7.5 cm (2–3 inches) wide and 2.5 cm (1 inch) thick. Near the center of the concave border of the kidney is a notch called the **hilum** (**HIGH**-lum) through which the ureter leaves the kidney. Blood vessels, nerves, and lymph vessels also enter and exit the kidney through this hilum. The hilum is the entrance to a cavity in the kidney called the **renal sinus,** which consists of connective tissue and fat.

Three layers of tissue surround each kidney. The innermost layer is the **renal capsule.** It is a smooth, transparent, fibrous connective tissue membrane that connects with the outermost covering of the ureter at the hilum. It functions as a barrier against infection and trauma to the kidney. The second layer, on top of the renal capsule, is the **adipose capsule.** It is a mass of fatty tissue that protects the kidney from blows. It also firmly holds the kidney in place in the abdominal cavity. The outermost layer is the **renal fascia** (**REE**-nal **FASH**-ee-ah), which consists of a thin layer of fibrous connective tissue that also anchors the kidneys to their surrounding structures and to the abdominal wall.

THE INTERNAL ANATOMY OF THE KIDNEYS

A frontal section through a kidney will reveal an outer area called the **cortex** and an inner area known as the **medulla** (Figure 18-2). In a freshly dissected kidney, the cortex would be reddish in color and the medulla reddish-brown. Within the medulla are 8 to 18 striated, triangular structures called the **renal pyramids.** The striated appearance is caused by an aggregation of straight tubules and blood vessels. The bases of the pyramids face the cortex and their tips, called the **renal papillae** (**REE**-nal pah-**PILL**-ee), point toward the center of the kidney.

The cortex is the smooth textured area that extends from the renal capsule to the bases of the renal pyramids. It also extends into the spaces between the pyramids. This cortical substance in between the renal pyramids is called the **renal columns.** Together, the cortex and the renal pyramids make up the **parenchyma** (par-**EN**-kih-mah) of the kidney. Structurally, this parenchyma consists of millions of microscopic collecting tubules called nephrons (**NEFF**-ronz). The nephrons are the functional units of the kidney. They regulate the composition and volume of blood and form the urine.

A funnel-shaped structure called the **minor calyx** (**MYE**-nohr **KAY**-liks) surrounds the tip of each renal pyramid. There can be 8 to 18 minor calyces. Each minor calyx collects urine from the ducts of the pyramids. Minor calyces join to form **major calyces.** There are two or three major calyces in the kidney. The major calyces join together to form the large collecting funnel called the **renal pelvis,** which is found in the renal sinus. It is the renal pelvis that eventually narrows to form the ureter (**YOO**-reh-ter). Urine drains from the tips of the renal pyramids into the calyces. It then collects in the renal pelvis and leaves the kidney through the ureter.

THE ANATOMY OF THE NEPHRONS

The functional units of the kidney are the **nephrons.** There are two types of nephrons: Juxtamedullary nephrons have loops of Henle that extend deep into the medulla; cortical nephrons have loops of Henle

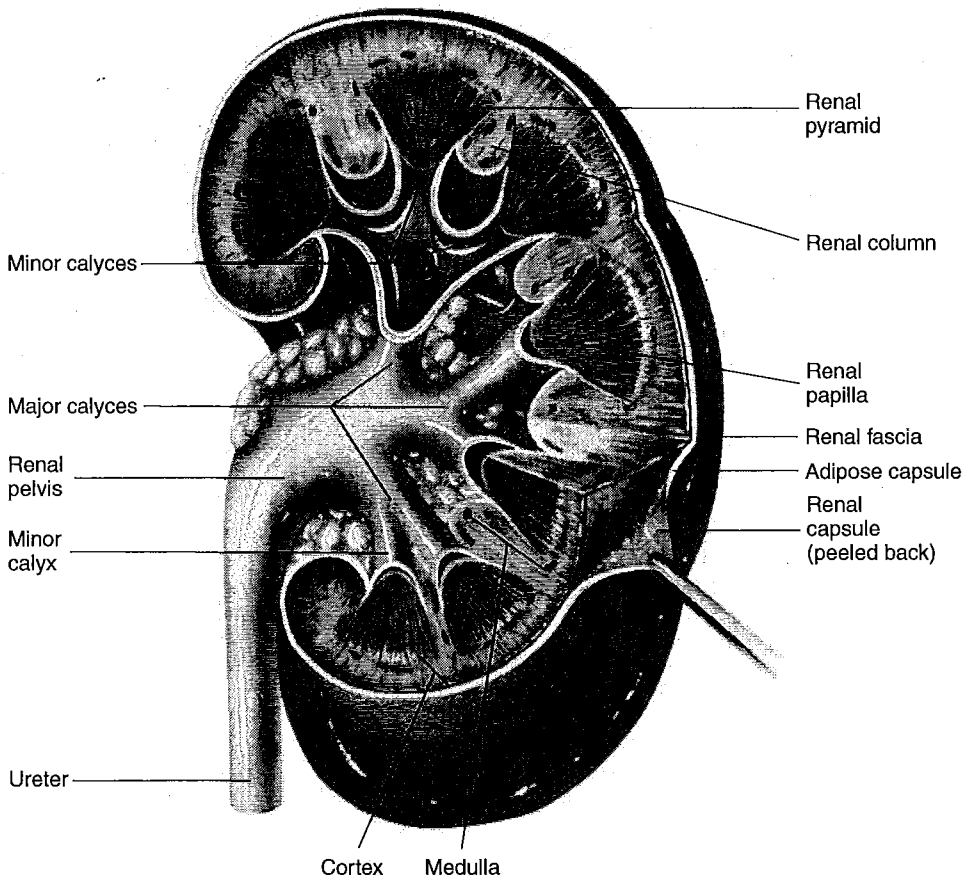


FIGURE 18-2. The internal anatomy of a kidney. (*© Cengage Learning 2012*)

that do not extend deep into the medulla. Basically, a nephron is a microscopic renal tubule, which functions as a filter, and its vascular (surrounding blood vessels) component (Figure 18-3). The nephron begins as a double-walled globe known as **Bowman's glomerular capsule.** This is located in the cortex of the kidney. The innermost layer of the capsule is known as the visceral layer and consists of epithelial cells called **podocytes** (**POH**-doh-sightz). This visceral layer of podocytes surrounds a capillary network known as the **glomerulus** (glom-**AIR**-you-lus). The outer wall of Bowman's glomerular capsule is known as the parietal layer. A collecting space separates the inner visceral layer from the outer parietal layer of the capsule. Together, Bowman's glomerular capsule and the enclosed glomerulus make up what is called a **renal corpuscle.**

The visceral layer of Bowman's capsule and the endothelial capillary network of the glomerulus form an **endothelial-capsular membrane,** which is the site of filtration of water and solutes from the blood. This filtered fluid now moves into the **renal tubule.**

Bowman's capsule opens into the first part of the renal tubule, called the **proximal convoluted tubule,** located in the cortex. The next section of the tubule is called the **descending limb of Henle,** which narrows in diameter as it dips into the medulla of the kidney. The tubule then bends into a U-shaped structure known as the **loop of Henle.** As the tubule straightens, it increases in diameter and ascends toward the cortex of the kidney. Here it is called the **ascending limb of Henle.** In the cortex, the tubule again becomes convoluted and is now called the **distal convoluted tubule.** The distal convoluted tubule ends by merging with a large straight **collecting duct.** In the medulla, collecting ducts connect with the distal tubules of other nephrons. The collecting ducts now pass through the renal pyramids and open into the calyces of the pelvis through a number of larger **papillary ducts,** which empty urine into the renal pelvis.

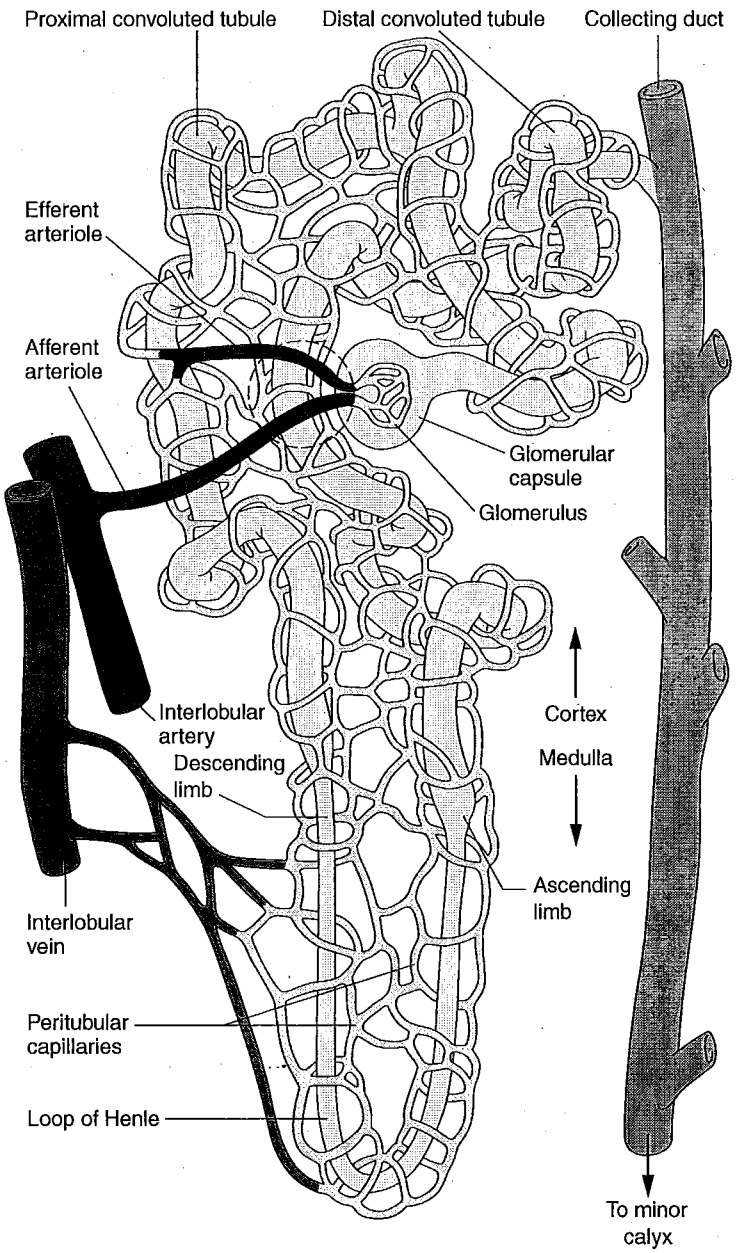


FIGURE 18-3. The anatomy of a nephron, the functional unit of a kidney. (*© Cengage Learning 2012*)

To facilitate filtration, most of the descending limb has thin walls of simple squamous epithelium, and the rest of the nephron and collecting duct is composed of simple cuboidal epithelium. The proximal tubule, ascending limb of Henle, and the collecting duct transport molecules and ions across the wall of the nephron. The descending limb of Henle is highly permeable to water and solutes (Figure 18-4).

BLOOD AND NERVE SUPPLY TO THE NEPHRONS

Because the nephrons are mainly responsible for removing wastes from the blood and regulating its electrolytes (which are responsible for the acid or alkaline components of blood) and fluid content, they are richly supplied with blood vessels. The **right** and **left renal arteries** (see Figure 18-1) transport one-quarter of the total cardiac

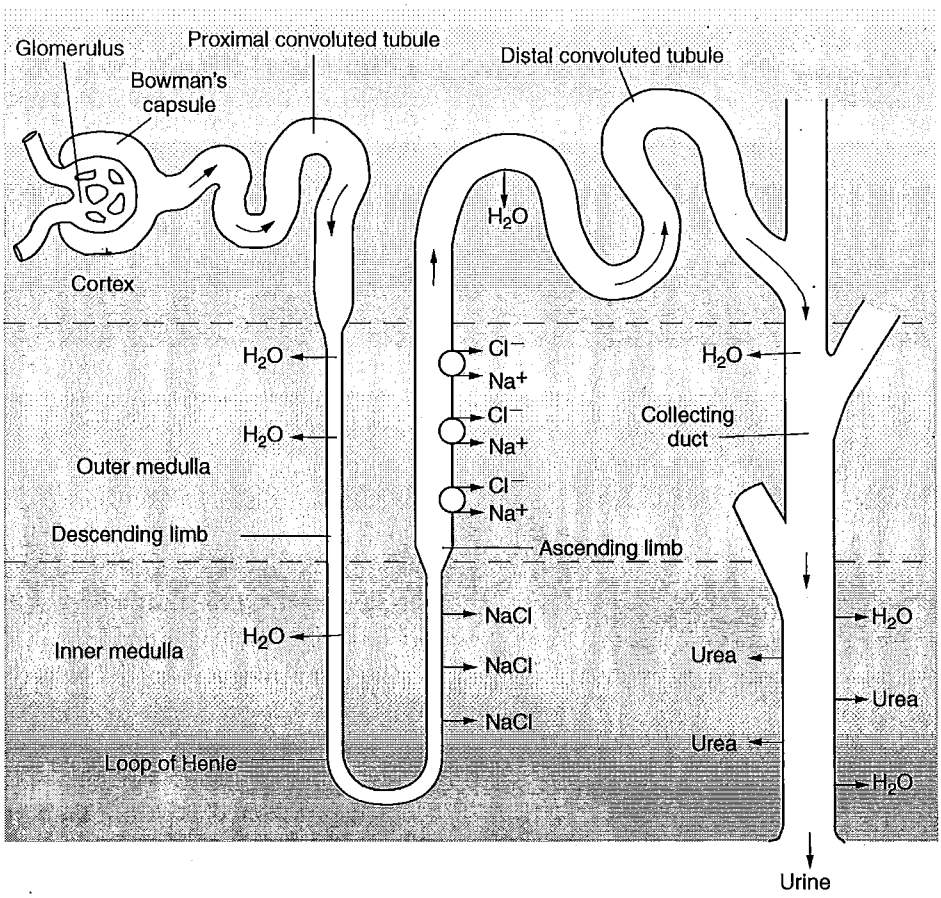


FIGURE 18-4. The flow of materials from the filtered blood in the kidney. (*© Cengage Learning 2012*)

output directly to the kidneys. About 1200 mL of blood passes through the kidneys every minute. This amounts to blood being filtered of wastes approximately 60 times a day.

Just before or immediately after entering the hilum, the renal artery divides into several branches that enter the parenchyma of the kidney in between the renal pyramids. In the renal columns, these branches are called the **interlobar arteries** (Figure 18-5). At the base of the pyramids, the interlobar arteries arch between the cortex and the medulla. Here they are called the **arcuate arteries.** Branches of the arcuate arteries produce a series of interlobular arteries (see Figure 18-3) that enter the cortex and divide into afferent arterioles. Each **afferent arteriole** takes blood from the renal artery to Bowman's glomerular capsule, where the arteriole divides into the tangled capillary network known as the glomerulus.

The glomerular capillaries then reunite to form an **efferent arteriole** that carries blood away from the glomerular capsule. Each efferent arteriole further divides to form a network of capillaries called the **peritubular capillaries,** which surround the convoluted tubules of the nephron. Eventually, the peritubular capillaries reunite to form an **interlobular vein.** The filtered blood then drains into the **arcuate vein** at the base of the pyramid. From the arcuate veins, the blood travels through the **interlobar veins** that run between the pyramids in the renal columns. The interlobar veins unite at the single **right** and **left renal vein** that leave the right and left kidney at the hilum.

The nerve supply to the kidney comes from the **renal plexus** of the autonomic nervous system. Sympathetic neurons, using norepinephrine, innervate the blood vessels of the kidneys. This stimulation causes constriction of the arteries, resulting in a decrease in blood flow and a decrease in filtrate formation. Thus, there is a decrease in urine formation. Urine volume production increases in

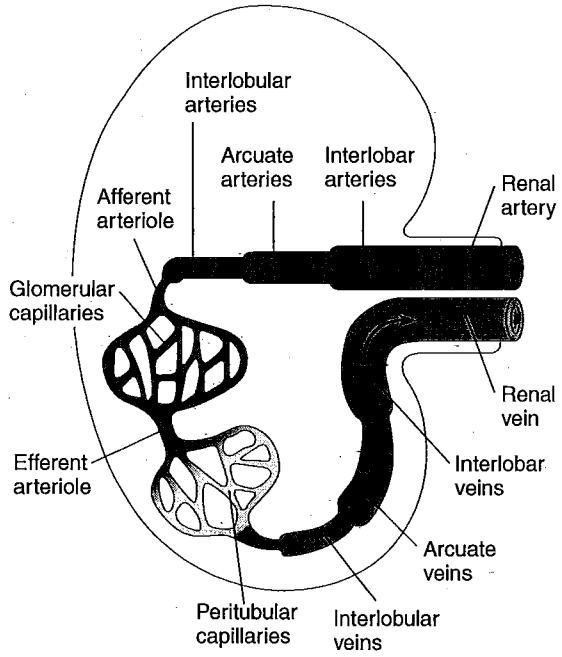


FIGURE 18-5. Blood flow through the kidney. (*© Cengage Learning 2012*)

response to a decrease in sympathetic innervation to the renal arteries.

Trauma or increased physical activity causes an increase in sympathetic stimulation, resulting in low levels of urine production.

PHYSIOLOGY OF THE NEPHRONS

The nephrons carry out a number of important functions. They control blood concentration and volume by removing selected amounts of water and solutes, they help regulate blood pH, they remove toxic wastes from the blood, and they stimulate red blood cell production in red bone marrow by producing a hormone called erythropoietin. The eliminated materials are collectively called **urine**. Urine is formed by three processes in the nephrons: glomerular filtration, tubular reabsorption, and tubular secretion (see Figure 18-6).

In *glomerular filtration*, the glomerulus filters water and certain dissolved substances from the plasma of blood. This process of glomerular filtration results in increased blood pressure. This increased pressure forces the fluid to filter from the blood. The dissolved substances include: positively charged ions of sodium, potassium, calcium, and magnesium; negatively charged ions of chloride, bicarbonate, sulfate, and phosphate; and glucose, urea, and uric acid. This filtrate is mainly water with some of the same components as the blood plasma. No large proteins are filtered. Both kidneys filter about 45 gallons of blood plasma per day. Yet only a small portion of the glomerular filtrate leaves the kidneys as urine. Most fluid gets reabsorbed in the renal tubules and reenters the plasma.

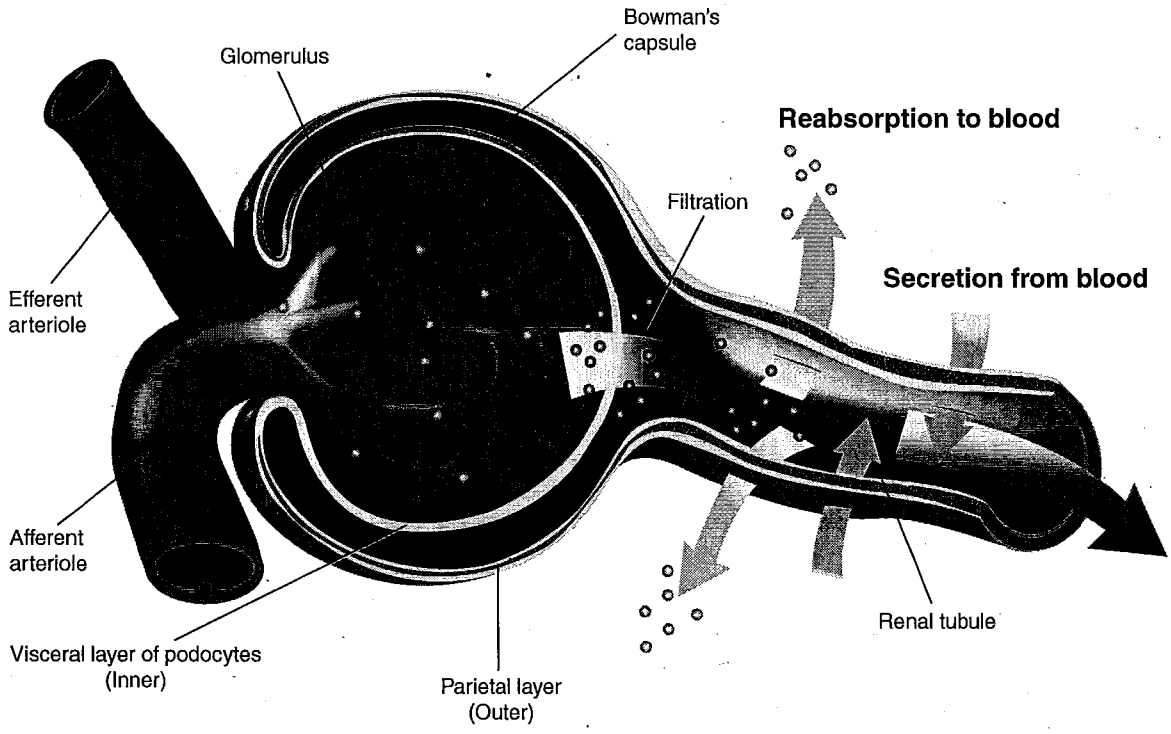


FIGURE 18-6. The main functions of the nephrons: filtration, reabsorption, and secretion. (*© Cengage Learning 2012*)

The *tubular reabsorption* process transports substances out of the tubular fluid and back into the blood of the peritubular capillary. This reabsorption occurs throughout the renal tubule, but the majority of reabsorption occurs in the proximal convoluted tubule. Active transport reabsorbs glucose while osmosis rapidly reabsorbs water. Active transport reabsorbs amino acids, creatine, lactic acid, uric acid, citric acid, and ascorbic acid. Active transport also reabsorbs phosphate, calcium, sulfate, sodium, and potassium ions. Chloride ions and other negatively charged ions are reabsorbed by electrochemical attraction. The descending limb of Henle reabsorbs water by osmosis. The ascending limb reabsorbs sodium, potassium, and chloride ions by active transport. The distal convoluted tubule reabsorbs sodium ions by active transport and water by osmosis. The collecting ducts of the nephrons also will reabsorb water by osmosis. About 95% of water is reabsorbed back into the bloodstream. Hormones, such as vasopressin and aldosterone, are essential to help control this process.

In *tubular secretion*, substances will move from the plasma in the peritubular capillary into the fluid of the renal tubule. The amount of a certain substance excreted into the urine may eventually exceed the amount originally filtered from the blood plasma in the glomerulus. The proximal convoluted tubule actively secretes penicillin, creatinine, and histamine into the tubular fluid. The entire renal tubule actively secretes hydrogen ions ($H+$), thus helping to regulate the pH of the body fluids. The distal convoluted tubule and the collecting duct secrete potassium ions ($K+$).

Urine consists of water and solutes that the kidneys either eliminate or retain in the body to maintain homeostasis. Urine is about 95% water with urea, uric acid, some amino acids, and electrolytes. The daily production of urine is between 0.6 and 2.5 liters per day. This depends on a person's fluid intake, environmental temperature and humidity, respiratory rates, body temperature, and emotional conditions. Urine production of 56 mL an hour is considered normal; 30 mL an hour indicates possible kidney failure.

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HEALTH ALERT

PREVENTING URINARY TRACT INFECTIONS

Urinary tract infections, referred to as UTIs, are more common in women than in men. The bacterium *Escherichia coli* is a commensalistic bacterium that is part of our normal intestinal contents and is a necessary component of the digestive system. *E. coli* is harmless long as it remains in the intestine. However, if it is transferred from the anal area to the urethra, it leads to infection of the urinary system. Since the anus and urethral opening are closer in females than in males, and since the urethra is much shorter in females than in males, bacteria can easily enter the urinary bladder, grow and reproduce, and cause much pain and annoyance.

There are a number of ways to prevent UTIs. Drinking 3 to 4 quarts of fluid daily, besides helping to prevent kidney stones, will cause one to urinate every 2 to 3 hours. This will flush out any invading bacteria and buildup of urine that is needed for the growth of bacteria. In addition, drinking cranberry juice and eating blueberries helps decrease any bacterial growth in the bladder. Good personal hygiene is also essential to preventing bacterial contamination of the urinary system from the anal area. Women should be taught to wipe from front to back and to wash from front to back. Thoroughly washing hands with hot water and soap after toilet use is also very important. Frequent urination flushes out the system and helps retard the growth of any bacteria. Thus, both men and women should be conscious of the necessity for fluid intake and hygiene to prevent UTIs. ■

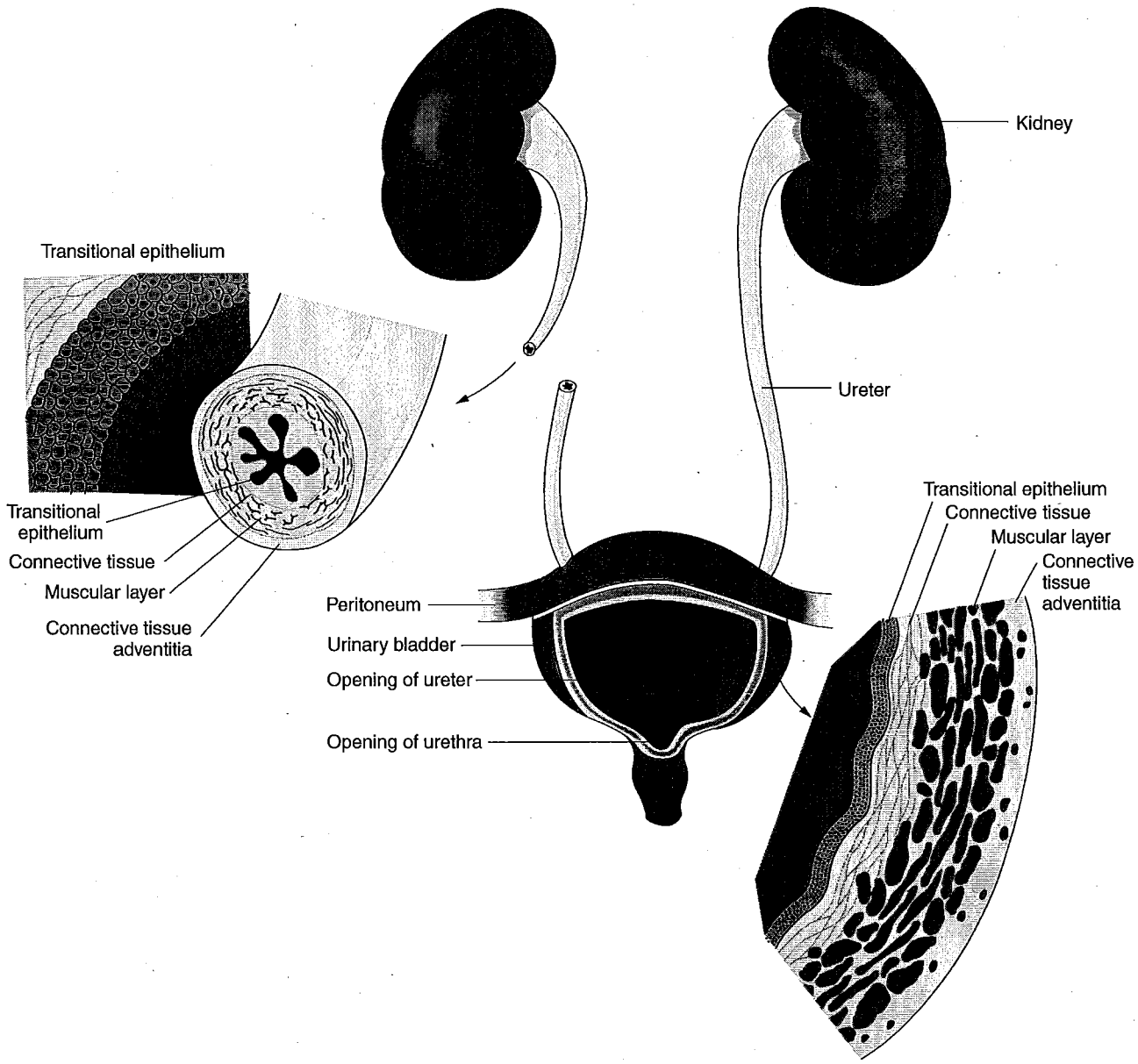

FIGURE 18-7. The two ureters and the urinary bladder in a female. (*© Cengage Learning 2012*)

THE URETERS: ANATOMY AND FUNCTION

The body has two **ureters** (**YOO**-reh-terz), each one descending from a kidney. Each ureter is basically an extension of the pelvis of a kidney and extends about 25 to 30 cm (10 to 12 inches) down to the urinary bladder (Figure 18-7). Each begins as the funnel-shaped renal pelvis and descends parallel on each side of the vertebral column to the bladder. They connect to the urinary bladder posteriorly.

The principal function of the ureters is to transport urine from the renal pelvis into the urinary bladder. The ureters are lined with a mucous coat of transitional epithelium that can stretch. Connective tissue binds the epithelium to a layer of smooth muscle. The urine is carried through the ureters primarily by peristaltic contractions of the smooth muscular walls of the ureters, but gravity and hydrostatic pressure also contribute. The outermost layer of the ureter is composed of connective tissue called the adventitia. Peristaltic waves pass from the kidney to the urinary bladder varying from one to five

waves per minute, depending on the amount of urine formation. Consuming excess liquids will cause more urine formation per unit of time.

THE URINARY BLADDER AND THE MICTURITION REFLEX

The **urinary bladder** is a hollow muscular organ located in the pelvic cavity posterior to the pubic symphysis. It consists of the same tissue layers as the ureters. It is a movable organ held in position by folds of peritoneum (see Figure 18-7). When empty, it resembles a deflated balloon. It assumes a spherical shape when slightly full of urine. As urine volume increases, it becomes pear-shaped and ascends into the abdominal cavity.

The interior of the bladder has three openings, the two openings from the two ureters and the single opening to the urethra that will drain the bladder. A smooth triangular region of the bladder outlined by these openings is called the **trigone** (**TRY**-gohn) (Figure 18-8). Bladder infections tend to develop in this region. The bladder wall contains three layers of smooth muscle collectively known as the **detrusor** (**dee**-**TRUE**-sohr) **muscle.** At the junction of the urinary bladder and urethra, smooth muscle of the bladder wall forms the **internal urinary sphincter,** which is under involuntary control.

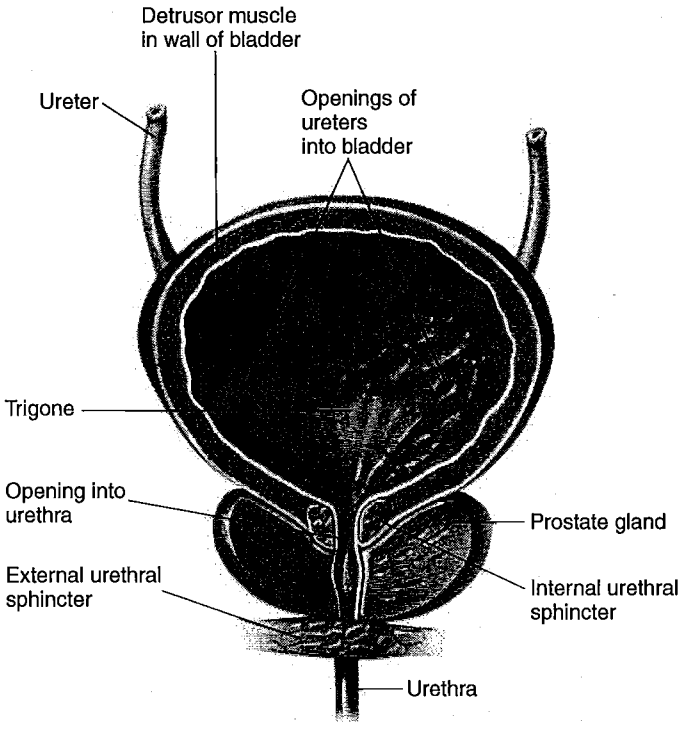

FIGURE 18-8. The anatomy of the urinary bladder in a male. (*© Cengage Learning 2012*)

Urine is expelled from the bladder by an act known as **micturition** (mik-tyoo-**RIH**-shun), commonly referred to as urination or voiding. This response is caused by a combination of involuntary and voluntary nerve impulses. The average capacity of the bladder is approximately 500 mL. When the amount of urine reaches 200 to 400 mL, stretch receptors in the bladder wall transmit nerve impulses to the lower portion of the spinal cord. It is these impulses that initiate a conscious desire to expel urine and an unconscious reflex called the **micturition reflex.** During urination, the detrusor muscle of the bladder contracts as do the muscles of the pelvic floor and abdominal wall. The **external urinary sphincter,** formed of skeletal muscle that surrounds the urethra as it leaves the bladder, must relax and urine then leaves the bladder and moves through the urethra to the outside.

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THE URETHRA: MALE AND FEMALE POSITIONS

The **urethra** (yoo-**REE**-thrah) is a small thin-walled tube leading from the floor of the urinary bladder to the outside of the body. It transports urine by peristalsis. Its position in the two sexes differs slightly as does its function.

In females, it lies directly posterior to the pubic symphysis and is located in the wall of the vagina in an anterior position just above the vaginal opening. Its length is about 3.8 cm (1.5 inches). Its opening to the outside is called the urethral orifice and is located between the clitoris and the vaginal opening.

In males, the urethra is 20 cm (8 inches) long. Directly below the bladder, it passes vertically through the prostate gland. It then passes through the urogenital diaphragm and enters the penis. It opens at the tip of the penis at the urethral orifice. In the male, the urethra has a dual function as part of both the urinary and reproductive systems. It carries urine out of the body and functions as a passageway for semen to be discharged from the body.

COMMON DISEASE, DISORDER, OR CONDITION

DISORDERS OF THE URINARY SYSTEM

KIDNEY STONES

Kidney stones, also known as renal calculi, are composed of the precipitates of uric acid, magnesium or calcium phosphate, or calcium oxalate. They can form in the renal pelvis or in the collecting ducts. When a stone passes through the ureter, it can be very painful with accompanying nausea. The pain radiates from the area of the kidney, abdomen, and pelvis. Most kidney stones will pass on their own. Today, larger ones are pulverized by a process called ultrasound lithotripsy. The patient is placed in water where ultrasound waves are focused on the kidney stones, which are then crushed and easily passed in the urine.

CYSTITIS

Cystitis is an inflammation of the urinary bladder, usually caused by a bacterial infection. The infection causes a frequent urge to urinate, with an accompanying burning sensation during urination. This infection can be treated with antibiotics. Early treatment will prevent the bacteria from ascending into the ureters and causing ureteritis (inflammation of the ureters) and possible kidney infection.

GOUT

Gout is a condition caused by high concentrations of uric acid in the plasma. This condition was once believed to be caused by excess food intake, but it may be inherited. The crystals of uric acid get deposited in joints of the hands and feet, causing inflammation and great pain. Gout is treated with drugs that inhibit uric acid reabsorption. Uric acid forms from the metabolism of certain nitrogen bases in nucleic acids.

GLOMERULONEPHRITIS

Glomerulonephritis (glom-**air**-yoo-loh-neh-**FRYE**-tis) is an inflammation of the kidneys, where the filtration membrane within the renal capsule is infected with bacteria. This can be acute following streptococcal sore throat or scarlet fever infection, or it can be a chronic condition resulting in kidney failure.

RENAL FAILURE

Renal failure can result from almost any condition that interferes with kidney function. As urea and other metabolites accumulate in the blood, acidosis develops and death can occur within 1 to 2 weeks. This type of acute renal failure can result from acute glomerulonephritis or blockage of the renal tubules. Chronic renal failure is caused by damage to so many nephrons that the remaining ones cannot accommodate normal kidney function. It can be caused by chronic glomerulonephritis, tumors, obstructions of the urinary tract, or lack of blood supply to the kidneys caused by arteriosclerosis. The toxic effects of the accumulated metabolic waste products result in coma and eventually death. Renal failure can be treated by a procedure called **hemodialysis.** A dialysis machine filters blood taken from an artery and then returns it to a vein. In this procedure, a machine substitutes for the excretory functions of the kidneys. In peritoneal dialysis, the peritoneum is used as a diffusable membrane to correct an imbalance of electrolytes or fluid in the blood or to remove wastes, toxins, or drugs normally filtered by the kidneys. A catheter is sutured into the peritoneum and connected to inflow and outflow tubing containing dialysate.

HEMATURIA

Hematuria (hee-mah-**TOO**-ree-ah) is blood in the urine, specifically an abundance of red blood cells. This can develop from kidney stones in the system or from bacterial infections of the urinary tract. Inflammation of the bladder, urethra, or the prostate gland can also cause hematuria.

(*continues*)

COMMON DISEASE, DISORDER, OR CONDITION

DISORDERS OF THE URINARY SYSTEM (continued)

OLIGURIA

Oliguria (ol-ig-**YOO**-ree-ah) is a condition in which only a small amount of urine is being produced, less than 500 mL per day. This results in an inability to effectively excrete waste products from the blood. It can be caused by urinary tract obstructions, lesions in the kidney, or imbalances in body electrolytes and fluids.

POLYURIA

Polyuria (pall-ee-**YOO**-ree-ah) is the production of an excessive amount of urine. This is a result of both diabetes mellitus and diabetes insipidus. It can also occur due to the intake of an excessive amount of fluids and the use of diuretics (drugs that promote the formation and excretion of urine).

PYURIA

Pyuria (pye-**YOO**-ree-ah) is a condition in which there is an excessive number of white blood cells in the urine (pus). It results from a bacterial infection of the urinary tract.

UREMIA

Uremia (yoo-**REE**-mee-ah) is a condition in which there is an excessive amount of urine (specifically urea and nitrogenous waste) in the blood. It is also known as azotemia, a toxic condition produced by renal failure when the kidneys cannot remove the urea from the blood.

POLYCYSTIC KIDNEY DISEASE (PKD)

Polycystic (pol-ee-**SIS**-tic) **kidney disease** or **PKD** is a condition in which the kidneys are abnormally enlarged and contain numerous cysts. There are three forms of this disease. The first is congenital polycystic disease (PKD), which is a rare congenital defect in which all or part of one or both kidneys fail to develop properly. Severe defective development results in death shortly after birth. The second is childhood polycystic disease (PKD), which is a rare condition resulting in death after a few years of age. It develops from kidney and liver failure as well as portal hypertension (increased venous pressure in the hepatic portal circulatory route). The third is adult polycystic disease (PKD), which is characterized by lower back pain and high blood pressure. The kidneys eventually fail resulting in uremia and death. This condition can be acquired or congenital and can involve either one or both kidneys.

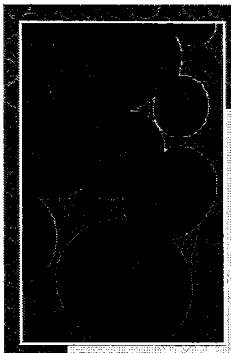
URINARY INCONTINENCE

Urinary incontinence (**YOO**-rih-nair-ee in-**CON**-tin-ens) is a condition in which an individual experiences an uncontrollable and continued flow of urine. It can be caused by neurological dysfunctions resulting in not realizing that the bladder is full, independent contractions of the detrusor muscle of the bladder as a result of surgery (like removal of a cancerous prostate gland), or a disease that affects the nerves of the spinal cord that go to the bladder.

HEALTH ALERT

URINARY TRACT INFECTION (UTI)

Urinary tract infections affect one or more structures of the urinary tract. They are more common in females than in males due to the short length of the urethra in females. Most infections are caused by gram-negative bacteria, most commonly *Escherichia coli* or species of *Klebsiella*, *Pseudomonas*, *Proteus*, or *Enterobacter*. Bacteria can reproduce in the bladder causing UTI in women much easier than in men. By the time a woman urinates and flushes bacteria from the urethra, those bacteria may have already invaded the bladder. The long urethra in males makes it more difficult for the bacteria to get to the bladder. Symptoms of UTI include frequent urination and a burning sensation on urination, accompanied by pain. In severe infections, pus and blood may be visible in the urine. UTI in men may not show typical symptoms. Prevention can be achieved by increasing fluid intake, having good perineal hygiene, and urinating frequently. UTI is treated with antibacterial and antiseptic drugs. ■



AS THE BODY AGES

As we age, the kidneys decrease in size, in fact, beginning as early as age 20. At this age, our kidneys weigh about 260 grams. By age 80, they weigh about 200 grams. This is related to decreased blood flow to the kidneys. After 20 years of age, there is about a 10% decrease in blood flow to the kidneys, occcurring approximately every 10 years. During this time, functional glomeruli decrease, and efferent and afferent arterioles to the glomeruli become twisted and irregular, thus inhibiting normal blood filtration at Bowman's capsule. The kidneys' capacity for absorption decreases as does their ability to secrete various substances. By age 80, almost half of the kidneys' glomeruli have ceased to function.

Kidney diseases are also more common in older adults and include kidney stones, urinary tract infections, and inflammations of the kidney. As the ability to concentrate urine declines with age, and as the sense of thirst diminishes, a more common risk of dehydration occurs with individuals in their golden years.

With aging, the kidneys have a reduced ability to eliminate urea, uric acid, toxins, and creatinine from the blood. Older adults also tend to experience frequent urination at night, excessive daily urination, occasional blood in the urine, and even painful urination. These age-related changes in the kidneys cause the later-in-life acquired conditions of diabetes and high blood pressure to have a greater effect on the functioning of kidneys in older adults. ■

Career FOCUS

There are a number of careers available to individuals with a special interest in the urinary system.

- **Urologists** are physicians who specialize in the study and treatment of disorders of the urinary tract of both women and men and who also specialize in the study of the male genital tract.
- **Dialysis technicians** are allied health professionals who maintain and operate dialysis equipment to treat patients who have various kidney disorders.
- **Nephrologists** are physicians who specialize in the study of the kidney and the treatment of its disorders and pathology.
- **Medical laboratory technicians** are individuals who perform bacteriological tests and microscopic examinations of blood, fluids, and tissues of the body under the supervision of a physician or medical technologist.

BODY SYSTEMS WORKING TOGETHER TO MAINTAIN HOMEOSTASIS: THE URINARY SYSTEM

Integumentary System
- The skin and the kidneys are involved in vitamin D production.
- The skin is a protective barrier and a site for water loss via perspiration.
- The urinary system compensates for water loss caused by perspiration.

Skeletal System
- The lower ribs provide some protection to the kidneys.
- Both the kidneys and bones help maintain calcium levels in the blood.

Muscular System
- Muscles control elimination of urine from the bladder in the voluntary action of micturition.
- Muscle cells produce creatinine as a nitrogenous waste product of metabolism that the kidneys excrete.

Nervous System
- The nervous system controls urine production and micturition.

Endocrine System
- Antidiuretic hormone (ADH) and aldosterone help regulate urine production by influencing renal reabsorption of electrolytes and water.

Cardiovascular System
- Blood volume is controlled by the urinary system.
- Blood pressure controls glomerular filtration.
- Blood carries nutrients and oxygen to and eliminates waste from the urinary tissues.

Lymphatic System
- The kidney helps maintain extracellular fluid composition and volume.
- Lymphatic vessels help maintain blood pressure by returning lymph to the plasma of blood.
- The lymphocytes help protect the urinary structures from infection and cancer.

Digestive System
- The liver transforms toxic ammonia (a by-product of amino acid metabolism) into less harmful urea that is then excreted by the kidneys.
- The kidneys restore fluids lost by the digestive process.

Respiratory System
- The lungs and the kidneys help maintain the proper pH of the body.
- The respiratory system provides the oxygen needed by the cells of the kidneys to function and eliminates the carbon dioxide waste product.

Reproductive System
- The urethra of the male functions as both an organ to eliminate urine from the bladder and as a tube to transfer sperm to the outside.
- The kidneys replace fluid lost from the normal activities of the reproductive system.

SUMMARY OUTLINE

INTRODUCTION

1. The urinary system helps keep the body in homeostasis by removing and restoring selected amounts of solutes and water from the blood.
2. The system consists of two kidneys, two ureters, the bladder, and the urethra.
3. The kidneys are the main filtering organs of the system, producing the urine.
4. Urine consists of urea, excess water, excess ions, and toxic wastes that may have been consumed with food.

FUNCTIONS OF THE URINARY SYSTEM

The kidneys perform six functions as they daily filter the blood:

1. **Excretion.** They are the major excretory organs of the body, filtering large amounts of fluids from the bloodstream, including nitrogenous wastes, drugs, and toxins.
2. **Maintain blood volume and concentration.** They regulate the proper balance of water and dissolved salts by maintaining proper ion concentrations.
3. **pH regulation.** They control the proper hydrogen ion concentration of the blood.
4. **Blood pressure.** They produce the enzyme renin, which helps maintain blood pressure.
5. **Erythrocyte concentration.** They produce the protein hormone erythropoietin, which stimulates red blood cell production.
6. **Vitamin D production.** They convert vitamin D to its active form (calciferol).

THE EXTERNAL ANATOMY OF THE KIDNEYS

1. The kidneys are located just above the waist between the parietal peritoneum and the posterior wall of the abdomen.
2. The hilum is a notch in the concave center of each kidney through which a ureter leaves the kidney and blood vessels, nerves, and lymph vessels enter and exit the kidney.
3. Three layers of tissue surround each kidney.
4. The innermost layer is the renal capsule that acts as a barrier against infection and trauma.
5. The second layer is the adipose capsule, a mass of fatty tissue that protects the kidney from blows.
6. The outermost layer is the renal fascia that anchors the kidney to the abdominal wall.

THE INTERNAL ANATOMY OF THE KIDNEYS

1. The outer area of a kidney is called the cortex.
2. The inner area of a kidney is called the medulla.
3. Within the medulla are striated, triangular structures called the renal pyramids whose bases face the cortex and whose tips are called renal papillae that point to the center of the kidney.
4. The cortical material that extends between the pyramids is called the renal columns.
5. The cortex and renal pyramids make up the parenchyma of the kidney, which is composed of millions of microscopic units called nephrons.
6. The nephrons are the functional units of the kidneys.
7. The tip of each renal pyramid is surrounded by a funnel-shaped structure called a minor calyx, which collects urine from the ducts of the pyramids.
8. Minor calyces join to form a few major calyces. The major calyces join to form the large collecting funnel called the renal pelvis, which narrows to form the ureter.

THE ANATOMY OF THE NEPHRONS

1. A nephron is a microscopic renal tubule and its vascular component.
2. The nephron begins as a double-walled globe known as Bowman's glomerular capsule.
3. The innermost layer of the capsule is the visceral layer made of podocytes. These epithelial podocytes surround a capillary network called the glomerulus.
4. The outermost layer of the capsule is called the parietal layer.
5. A renal corpuscle is made up of Bowman's glomerular capsule and the enclosed capillary glomerulus.
6. The visceral layer of Bowman's capsule and the capillary network of the glomerulus form the endothelial-capsular membrane, which filters water and solutes from the blood and moves it into the renal tubule.
7. The first part of the renal tubule is called the proximal convoluted tubule, located in the cortex.
8. The following part is the descending limb of Henle, which narrows as it dips into the medulla. The tubule then bends into the U-shaped loop of Henle.
9. As the loop straightens, it increases in diameter and ascends toward the cortex as the ascending limb of Henle.

10. In the cortex, the renal tubule again becomes convoluted and is known as the distal convoluted tubule, which ends by merging with a large, straight collecting duct.
11. In the medulla, collecting ducts connect with the distal convoluted tubules of a number of nephrons.
12. Collecting ducts now pass through the renal pyramids and open into the calyces of the pelvis through a number of larger papillary ducts. They empty urine into the renal pelvis.

BLOOD AND NERVE SUPPLY TO THE NEPHRONS

1. The right and left renal arteries transport 1200 mL of blood to the kidneys every minute.
2. The arteries branch and pass between the renal pyramids in the renal columns as the interlobar arteries. At the base of the pyramids, they arch as the arcuate arteries found between the cortex and the medulla.
3. Branches of the arcuate arteries become the interlobular arteries, which branch into afferent arterioles in the cortex. Afferent arterioles divide into the capillary network called the glomerulus.
4. Glomerular capillaries reunite to form the efferent arteriole, which exits the capsule of the glomerulus.
5. Efferent arterioles divide to form peritubular capillaries, which surround the convoluted tubules of the nephron.
6. Peritubular capillaries reunite to form an interlobular vein, which connects with the arcuate vein at the base of a pyramid.
7. Arcuate veins connect to interlobar veins found between the pyramids in the renal columns.
8. Interlobar veins unite at the right and left renal veins that exit the right and the left kidney at the hilum.
9. The nerve supply to the kidney is the renal plexus of the autonomic nervous system.

PHYSIOLOGY OF THE NEPHRONS

1. The three major functions of nephrons are to control blood concentration and volume by removing and restoring selected amounts of water and solutes, help regulate blood pH, and remove toxic waste from the blood.
2. Urine forms by glomerular filtration, tubular reabsorption, and tubular secretion, all of which occur in the nephrons.
3. Glomerular filtration removes water and these dissolved substances from the plasma of blood: sodium, potassium, calcium, and magnesium positive ions; negative ions of chloride, bicarbonate, sulfate, and phosphate; and glucose, urea, and uric acid. Ninety-nine percent of the fluid gets reabsorbed in the renal tubules.
4. Tubular reabsorption transports substances from the tubular fluid into the blood of the peritubular capillaries. Active transport reabsorbs glucose, and osmosis reabsorbs water. Active transport reabsorbs positively charged ions, amino acids, creatinine, and lactic, uric, citric, and ascorbic acids. Negatively charged ions are reabsorbed by electrochemical attraction.
5. Tubular secretion moves these substances from the plasma in the peritubular capillary into the fluid of the renal tubule: penicillin and other drugs, creatinine, histamine, hydrogen ions, and potassium ions.
6. Urine consists of 95% water with urea, uric acid, some amino acids, and electrolytes.

THE URETERS: ANATOMY AND FUNCTION

1. Each of the two ureters begins as an extension of the renal pelvis of a kidney and connects to the urinary bladder.
2. The function of the ureters is to transport urine from the renal pelvis to the urinary bladder.
3. Urine moves mainly by peristaltic contractions of the smooth muscle walls, but gravity and hydrostatic pressure also contribute.

THE URINARY BLADDER AND THE MICTURITION REFLEX

1. The urinary bladder is held in position by folds of peritoneum in the pelvic cavity.
2. The two openings from the ureters and the single opening into the urethra outline a smooth triangular region called the trigone.
3. The bladder wall is composed of three layers of smooth muscle called the detrusor muscle.
4. At the junction of the urinary bladder and the urethra is the internal urinary sphincter under involuntary control.
5. Urine is expelled from the bladder by an act known as micturition.
6. The external urinary sphincter, formed by skeletal muscle surrounding the urethra as it leaves the bladder, relaxes and urine leaves the bladder.

7. The bladder can hold 700 to 800 mL of urine. When it reaches 200 to 400 mL, stretch receptors in the bladder wall transmit impulses to the lower spinal cord, which initiate a conscious desire to urinate and an unconscious reflex called the micturition reflex.

THE URETHRA: MALE AND FEMALE POSITIONS

1. The urethra is a small thin-walled tube connecting to the floor of the urinary bladder that leads to the outside.
2. In females, it is located in the wall of the vagina just above the vaginal opening. It is 3.8 cm long and its opening, called the urethral orifice, is located between the clitoris and the vaginal opening.
3. In males, the urethra is 20 cm long, and just below the bladder it passes through the prostate gland and enters the penis, opening at the tip of the male penis as the urethral orifice. In the male, the urethra not only transports urine but also transfers semen to the outside.

REVIEW QUESTIONS

1. Name the organs of the urinary system.
2. Explain six functions of the urinary system.
3. *What other systems of the body perform excretion and what do they excrete?
4. *Explain the role of glomerular filtration, tubular reabsorption, and tubular secretion in the nephron in maintaining homeostasis.
5. Name three functions of the nephrons.
6. *Explain the micturition reflex in terms of changes in the urinary bladder.
7. Compare the length and position of the urethra in the male and in the female.
8. Name the parts of a nephron's renal tubule.
9. Name three constituents of urine.

*Critical Thinking Questions

FILL IN THE BLANK

Fill in the blank with the most appropriate term.

1. Within the medulla of the kidney are 8 to 18 striated triangular structures called _____.
2. The _____ are functional microscopic units of the kidney.
3. Urine is expelled by an act called _____, commonly known as urination or voiding.
4. The innermost layer of the kidney is called the _____, a fibrous connective tissue membrane that is a barrier against infection and trauma to the kidney.
5. A nephron begins as a double-walled globe called _____ capsule.
6. In the medulla, the renal tubule bends into a U-shape known as the loop of _____.
7. The kidneys produce a protein hormone called _____, which stimulates hematopoiesis in red bone marrow.
8. The active form of vitamin D is called _____.
9. Kidneys produce an enzyme called _____, which helps regulate blood pressure.
10. When crystals of uric acid get deposited in the joints of the hands and feet, the condition is called _____.

MATCHING

Place the most appropriate number in the blank provided.

_____ Podocytes	1. Inner region of kidney
_____ Cortex	2. Area in bladder
_____ Medulla	3. Collect urine
_____ Capillary network	4. Bladder wall
	5. Cortical area in medulla
_____ Hilum	6. Epithelial cells in inner wall of Bowman's capsule
_____ Trigone	
_____ Renal column	7. Sympathetic neurons
_____ Detrusor muscle	8. Renal pelvis
	9. Notch through which the ureter leaves the kidney
_____ Renal plexus	
_____ Calyx	10. Outer layer of kidney
	11. Glomerulus
	12. Sphincter muscle

Search and Explore

- Search the Internet with key words from the chapter to discover additional information. Key words might include kidneys, nephrons, urinary system anatomy, or one of the disorders of the urinary system introduced in this chapter.

CASE STUDY

Jennifer Mills, a 20-year-old college student, is on vacation with friends at the beach when she suddenly experiences severe pain that radiates from her left side to her abdomen. In addition, Jennifer feels extremely nauseated and begins to vomit. Her friends take her to the emergency department at the local hospital. Following a CT scan, x-rays, IV fluids for dehydration, and medication for pain, Jennifer is discharged with instructions to follow up with a urologist when she returns home.

Questions

1. What problem do you think is causing Jennifer's severe pain and nausea?
2. Where in the urinary system does this condition develop?
3. How is this problem treated?
4. Describe one activity that will help prevent this disorder from recurring.

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LABORATORY EXERCISE:

THE URINARY SYSTEM

Materials needed: A dissecting kit, your fetal pig, and a dissecting pan

1. Remove your fetal pig from its storage area. You have already opened the abdominal cavity when you performed your dissection for the digestive system. Locate the large paired kidneys, attached dorsally to the abdominal wall behind the intestines. Midpoint on the medial side of each kidney is a depression called the hilum. Note the renal artery and vein entering and leaving the kidney. Find the ureter as it leaves each kidney through this hilum. Follow a ureter as it leaves the kidney. It goes posteriorly under the parietal peritoneum. Follow its reconnection to the urinary bladder, which normally would be found in the posterior ventral part of the abdomen. In your fetal pig, it will be located on the inner surface of the flap of tissue to which the umbilical cord was attached. The urethra arises from the bladder medially between the two ureters and runs posteriorly, parallel to the rectum.
2. Although the kidneys of the fetal pig are small, remove one and cut it in a frontal section. You will be able to observe the cortex, the medulla, and the renal pyramids with their striations.
3. Examine the models of the urinary system provided by your instructor and identify the major organs of the system.