

SELECTED KEY TERMS

The following terms and additional boldface terms in the chapter are defined in the Glossary



angiotensin
antidiuretic hormone (ADH)
cystitis
dialysis
erythropoietin
excretion
glomerular filtrate
glomerulonephritis
glomerulus
hemodialysis
kidney
micturition
nephron
pyelonephritis
renin
urea
ureter
urethra
urinalysis
urinary bladder
urine

LEARNING OUTCOMES

After careful study of this chapter, you should be able to:

1. List the systems that eliminate waste and name the substances eliminated by each
2. Describe the parts of the urinary system and give the functions of each
3. Trace the path of a drop of blood as it flows through the kidney
4. Describe a nephron
5. Describe the components and functions of the juxtaglomerular (JG) apparatus
6. Name the four processes involved in urine formation and describe the action of each
7. Identify the role of ADH in urine formation
8. Describe the process of micturition
9. Name three normal and six abnormal constituents of urine
10. List the common disorders of the urinary system
11. List six signs of chronic renal failure
12. Explain the principle and the purpose of kidney dialysis
13. Show how word parts are used to build words related to the urinary system (See Word Anatomy at the end of the chapter)



chapter

22

The Urinary System

Excretion

The urinary system is also called the *excretory system* because one of its main functions is **excretion**, removal and elimination of metabolic waste products from the blood. It has many other functions as well, including regulation of the volume, acid–base balance (pH), and electrolyte composition of body fluids.

Although the focus of this chapter is the urinary system, certain aspects of other systems are also discussed, because body systems work interdependently to maintain homeostasis (internal balance). The systems active in excretion and some of the substances they eliminate are the following:

- ▶ The **urinary system** excretes water, nitrogen-containing waste products, and salts. These are all constituents of the urine.
- ▶ The **digestive system** eliminates water, some salts, and bile in addition to digestive residue, all of which are contained in the feces. The liver is important in elimi-

nating the products of red blood cell destruction and in breaking down certain drugs and toxins.

- ▶ The **respiratory system** eliminates carbon dioxide and water. The latter appears as vapor, as can be demonstrated by breathing on a windowpane.
- ▶ The skin, or **integumentary system**, excretes water, salts, and very small quantities of nitrogenous wastes. These all appear in perspiration, although water also evaporates continuously from the skin without our being conscious of it.

Checkpoint 22-1: The main function of the urinary system is to eliminate waste. What are some other systems that eliminate waste?

Organs of the Urinary System

The main parts of the urinary system, shown in [Figure 22-1](#), are as follows:

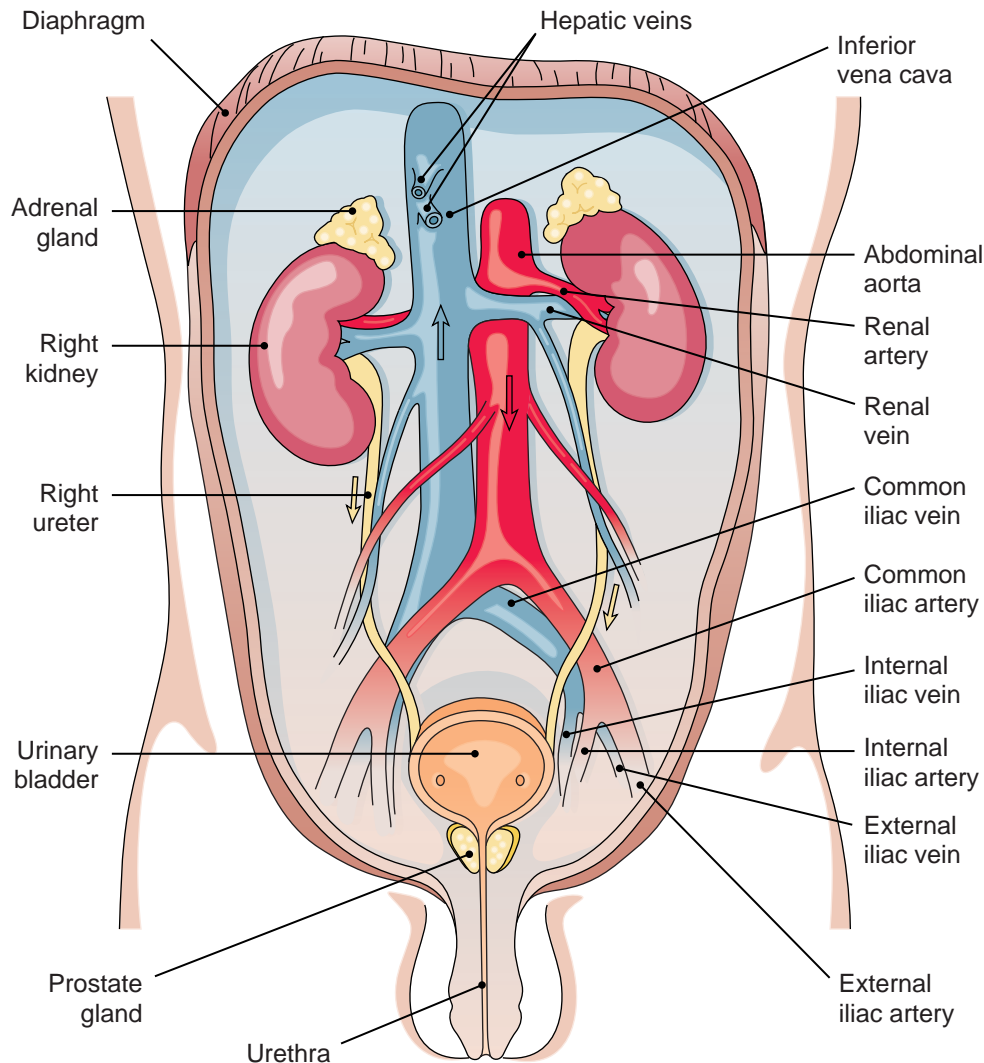


Figure 22-1 Male urinary system, showing blood vessels. **ZOOMING IN** ♦ What vessel supplies blood to the kidney? What vessel drains the kidney?

- ▶ Two **kidneys**. These organs extract wastes from the blood, balance body fluids, and form urine.
- ▶ Two **ureters** (U-re-ters). These tubes conduct urine from the kidneys to the urinary bladder.
- ▶ A single **urinary bladder**. This reservoir receives and stores the urine brought to it by the two ureters.
- ▶ A single **urethra** (u-RE-thrah). This tube conducts urine from the bladder to the outside of the body for elimination.

Checkpoint 22-2: What are the organs of the urinary system?

▶ The Kidneys

The kidneys lie against the back muscles in the upper abdomen at about the level of the last thoracic and first three lumbar vertebrae. The right kidney is slightly lower than the left to accommodate the liver. Each kidney is firmly enclosed in a membranous **renal capsule** made of fibrous connective tissue. In addition, there is a protective layer of fat called the **adipose capsule** around the organ. An outermost layer of fascia (connective tissue) anchors the kidney to the peritoneum and abdominal wall. The kidneys, as well as the ureters, lie posterior to the peritoneum. Thus, they are not in the peritoneal cavity but rather in an area known as the **retroperitoneal** (ret-ro-per-ih-to-NE-al) space.

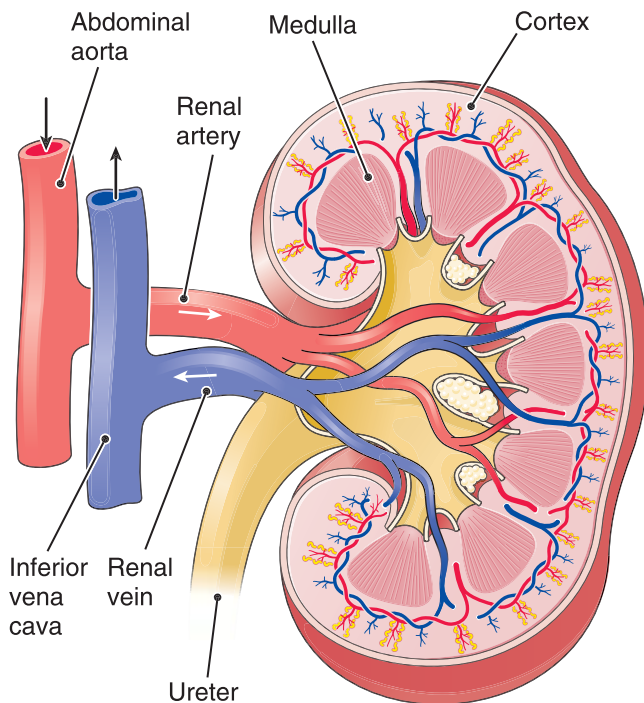


Figure 22-2 Blood supply and circulation of the kidney. **ZOOMING IN** ♦ What vessel supplies blood to the renal artery? What vessel receives blood from the renal vein?

Blood Supply to the Kidney

The kidney's blood supply is illustrated in [Figure 22-2](#). Blood is brought to the kidney by a short branch of the abdominal aorta called the **renal artery**.

After entering the kidney, the renal artery subdivides into smaller and smaller branches, which eventually make contact with the functional units of the kidney, the **nephrons** (NEF-ronz). Blood leaves the kidney by vessels that finally merge to form the **renal vein**, which carries blood into the inferior vena cava for return to the heart.

Checkpoint 22-3: The kidneys are located in the retroperitoneal space. Where is this space?

Checkpoint 22-4: What vessel supplies blood to the kidney and what vessel drains blood from the kidney?

Structure of the Kidney

The kidney is a somewhat flattened organ about 10 cm (4 inches) long, 5 cm (2 inches) wide, and 2.5 cm (1 inch) thick ([Fig. 22-3](#)). On the medial border there is a notch called the **hilum**, where the renal artery, the renal vein, and the ureter connect with the kidney. The lateral border is convex (curved outward), giving the entire organ a bean-shaped appearance.

The kidney is divided into two regions: the renal cortex and the renal medulla ([Fig. 22-3](#)). The **renal cortex** is the kidney's outer portion. The **renal medulla** contains the tubes in which urine is formed and collected. These tubes form a number of cone-shaped structures called **renal pyramids**. The tips of the pyramids point toward the **renal pelvis**, a funnel-shaped basin that forms the upper end of the ureter. Cuplike extensions of the renal pelvis surround the tips of the pyramids and collect urine; these extensions are called **calyces** (KA-lih-seze; singular, **calyx**, KA-lik). The urine that collects in the pelvis then passes down the ureters to the bladder.

Checkpoint 22-5: What are the outer and inner regions of the kidney called?

The Nephron As is the case with most organs, the most fascinating aspect of the kidney is too small to be seen with the naked eye. This basic unit, which actually does the kidney's work, is the **nephron** ([Fig. 22-4](#)). The nephron is essentially a tiny coiled tube with a bulb at one end. This bulb, known as the **glomerular** (Bowman) **capsule**, surrounds a cluster of capillaries called the **glomerulus** (glo-MER-u-lus) (pl., glomeruli [glo-MER-u-li]). Each kidney contains about 1 million nephrons; if all these coiled tubes were separated, straightened out, and laid end to end, they would span some 120 kilometers (75 miles)! [Figure 22-5](#) is a microscopic view of kidney tissue showing several glomeruli, each surrounded by a

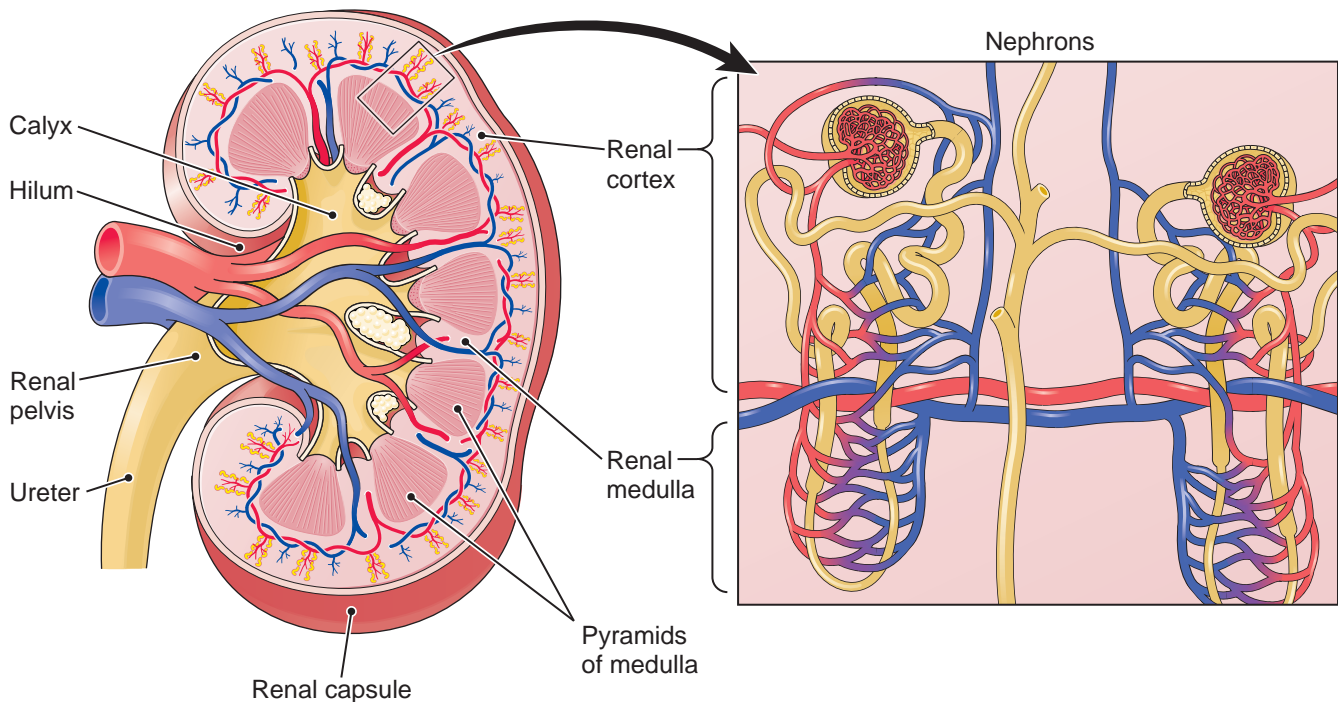


Figure 22-3 Longitudinal section through the kidney showing its internal structure (left) and an enlarged diagram of nephrons (right). Each kidney contains more than 1 million nephrons. **ZOOMING IN** ♦ What is the outer region of the kidney called? What is the inner region of the kidney called?

glomerular capsule. This figure also shows sections through the tubular portions of the nephrons.

A small blood vessel, the **afferent arteriole**, supplies the glomerulus with blood; another small vessel, called the **efferent arteriole**, carries blood from the glomerulus. When blood leaves the glomerulus, it does not head immediately back toward the heart. Instead, it flows into a capillary network that surrounds the nephron's tubular portion. These **peritubular capillaries**, are named for their location.

The tubular portion of the nephron consists of several parts. The coiled part leading from the glomerular capsule is called the **proximal convoluted tubule (PCT, or just proximal tubule)**. The tubule then uncoils to form a hairpin-shaped segment called the **loop of Henle**. The first part of the loop, which carries fluid toward the medulla, is the **descending limb** (see Fig. 22-4). The part that continues from the loop's turn and carries fluid away from the medulla, is the **ascending limb**. Continuing from the ascending limb, the tubule coils once again into the **distal convoluted tubule (DCT, or just distal tubule)**, so called because it is farther along the tubule from the glomerular capsule than is the PCT. The distal end of each tubule empties into a collecting duct, which then continues through the medulla toward the renal pelvis.

The glomerulus, glomerular capsule, and the proximal and distal convoluted tubules of the nephron are within the renal cortex. The loop of Henle and collecting duct extend into the medulla (see Fig. 22-3).

Checkpoint 22-6: What is the functional unit of the kidney called?

Checkpoint 22-7: What name is given to the coil of capillaries in the glomerular (Bowman) capsule?

The Juxtaglomerular (JG) Apparatus The first portion of the DCT curves back toward the glomerulus to pass between the afferent and efferent arterioles (Fig. 22-6). At the point where the DCT makes contact with the afferent arteriole, there are specialized cells in each that together make up the **juxtaglomerular (juks-tah-glo-MER-u-lar) (JG) apparatus**. The JG apparatus helps to regulate kidney function. When blood pressure falls too low for the kidneys to function effectively, cells in the wall of the afferent arteriole secrete the enzyme **renin (RE-nin)**, which raises blood pressure by a mechanism described later.

Functions of the Kidney

The kidneys are involved in the following processes:

- Excretion of unwanted substances, such as cellular metabolic waste, excess salts, and toxins. One product of amino acid metabolism is nitrogen-containing waste material, a chief form of which is **urea (u-RE-ah)**. After synthesis in the liver, urea is transported in the blood to the kidneys for elimination. The kidneys have a specialized mechanism for the elimination of urea and other nitrogenous (ni-TROJ-en-us) wastes.

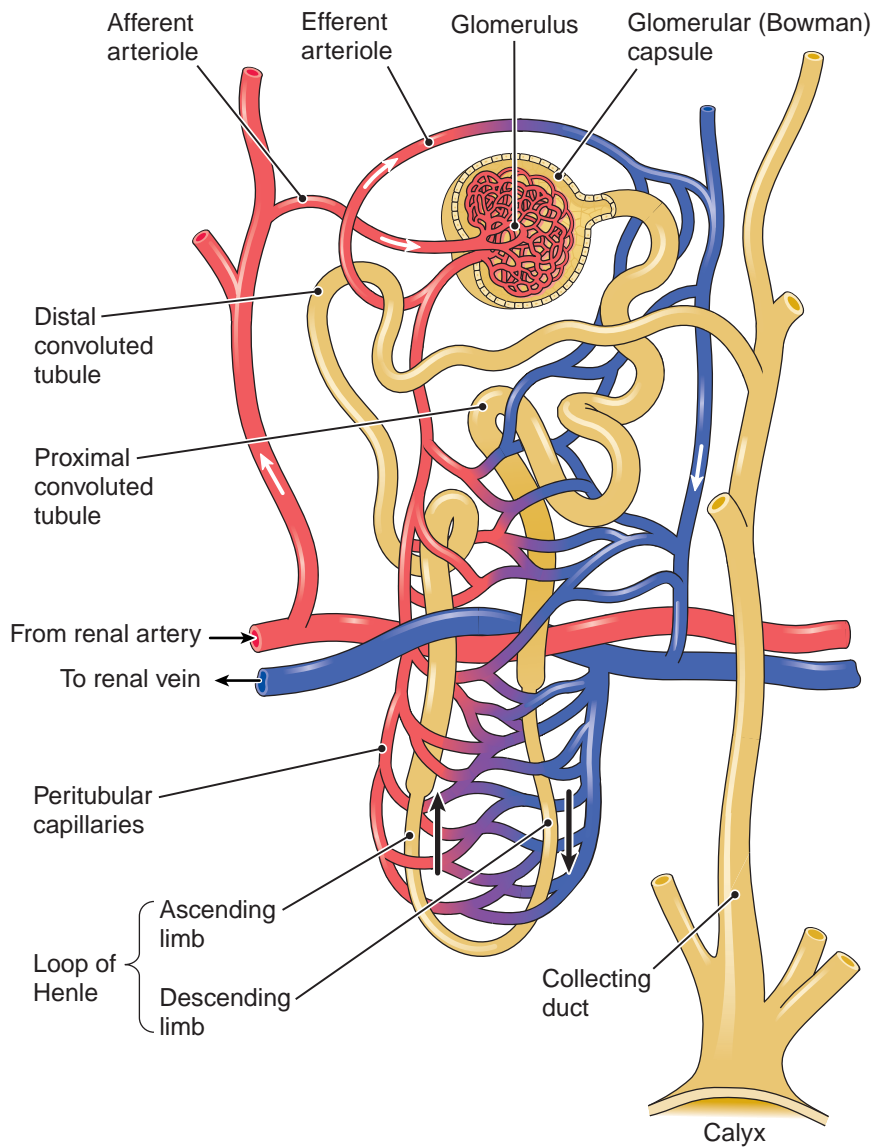


Figure 22-4 A nephron and its blood supply. The nephron regulates the proportions of water, waste, and other materials according to the body's constantly changing needs. Materials that enter the nephron can be returned to the blood through the surrounding capillaries. **ZOOMING IN** ♦ Which of the two convoluted tubules is closer to the glomerular capsule? Which convoluted tubule is farther away?

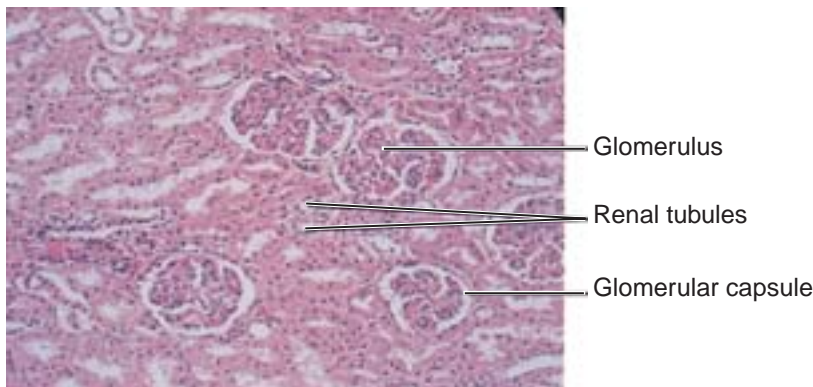


Figure 22-5 Microscopic view of the kidney. (Courtesy of Dana Morse Bittus and B. J. Cohen.)

- ♦ Maintenance of water balance. Although the amount of water gained and lost in a day can vary tremendously, the kidneys can adapt to these variations, so that the volume of body water remains remarkably stable from day to day.
- ♦ Regulation of the acid–base balance of body fluids. Acids are constantly being produced by cellular metabolism. Certain foods can yield acids or bases, and people may also ingest antacids, such as bicarbonate. However, if the body is to function normally, the pH of body fluids must remain in the range of 7.35 to 7.45 (see Chapter 21).
- ♦ Regulation of blood pressure. The kidneys depend on blood pressure to filter the blood. If blood pressure falls too low for effective filtration, the cells of the JG apparatus release renin. This enzyme activates **angiotensin** (an-je-o-TEN-sin), a blood protein that causes blood vessels to constrict, thus raising blood pressure (Table 22-1). Angiotensin also stimulates the adrenal cortex to produce the hormone **aldosterone**, which promotes retention of sodium and water, also raising blood pressure.
- ♦ Regulation of red blood cell production. When the kidneys do not get enough oxygen, they produce the hormone **erythropoietin** (eh-rith-ro-POY-eh-tin) (EPO), which stimulates the red cell production in the bone marrow. EPO made by genetic engineering is now available to treat severe anemia, such as occurs in the end stage of kidney failure.

Checkpoint 22-8: What substance is produced by the JG apparatus and under what conditions is it produced?

Formation of Urine

The following explanation of urine formation describes a complex process, involving many back-and-forth exchanges between the bloodstream and the kidney tubules. As fluid filtered from the blood travels slowly through the twists and turns of the nephron, there is ample time for exchanges to take place. These processes together allow the kidney to “fine tune” body fluids as they adjust the composition of the urine.

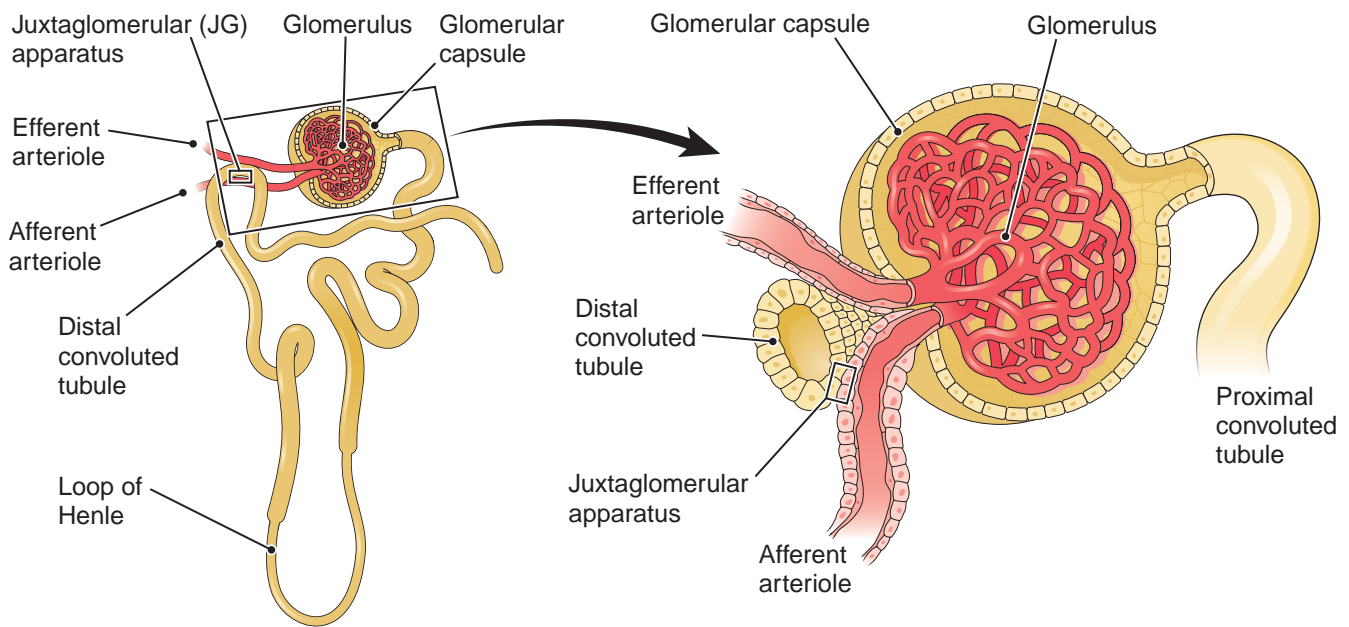


Figure 22-6 Structure of the juxtaglomerular (JG) apparatus. Note how the distal convoluted tubule contacts the afferent arteriole (right). Cells in these two structures make up the JG apparatus. **ZOOMING IN ♦** The JG apparatus is made up of cells from which two structures?

Glomerular Filtration The process of urine formation begins with the glomerulus in the glomerular capsule. The walls of the glomerular capillaries are sievelike and permit the free flow of water and soluble materials through them. Like other capillary walls, however, they are impermeable (im-PER-me-able) to blood cells and large protein molecules, and these components remain in the blood (Fig. 22-7).

Because the diameter of the afferent arteriole is slightly larger than that of the efferent arteriole (see Fig. 22-7), blood can enter the glomerulus more easily than it can leave. Thus, blood pressure in the glomerulus is about three to four times higher than it is in other capil-

laries. To understand this effect, think of placing your thumb over the end of a garden hose as water comes through. As you make the diameter of the opening smaller, water is forced out under higher pressure. As a result of increased fluid (hydrostatic) pressure in the glomerulus, materials are constantly being pushed out of the blood and into the nephron's glomerular capsule. As described in Chapter 3, movement of water and dissolved materials through a membrane under pressure is called **filtration**. This movement of materials under pressure from the blood into the capsule is therefore known as **glomerular filtration**.

The fluid that enters the glomerular capsule, called

Table 22-1 Substances that Affect Renal Function

SUBSTANCE	SOURCE	ACTION
Renin (RE-nin)	Enzyme produced by renal cells when blood pressure falls too low for effective filtration	Activates angiotensin in the blood
Angiotensin (an-je-o-TEN-sin)	Protein in the blood that is activated by renin	Causes constriction of blood vessels to raise blood pressure; also stimulates release of aldosterone from the adrenal cortex
Aldosterone (al-DOS-ter-one)	Hormone released from the adrenal cortex under effects of angiotensin	Promotes reabsorption of sodium and water in the kidney to conserve water and increase blood pressure
Antidiuretic hormone (an-te-di-u-RET-ik) (ADH)	Made in the hypothalamus and released from the posterior pituitary; released when blood becomes too concentrated	Promotes reabsorption of water from the distal convoluted tubule and collecting duct to concentrate the urine and conserve water

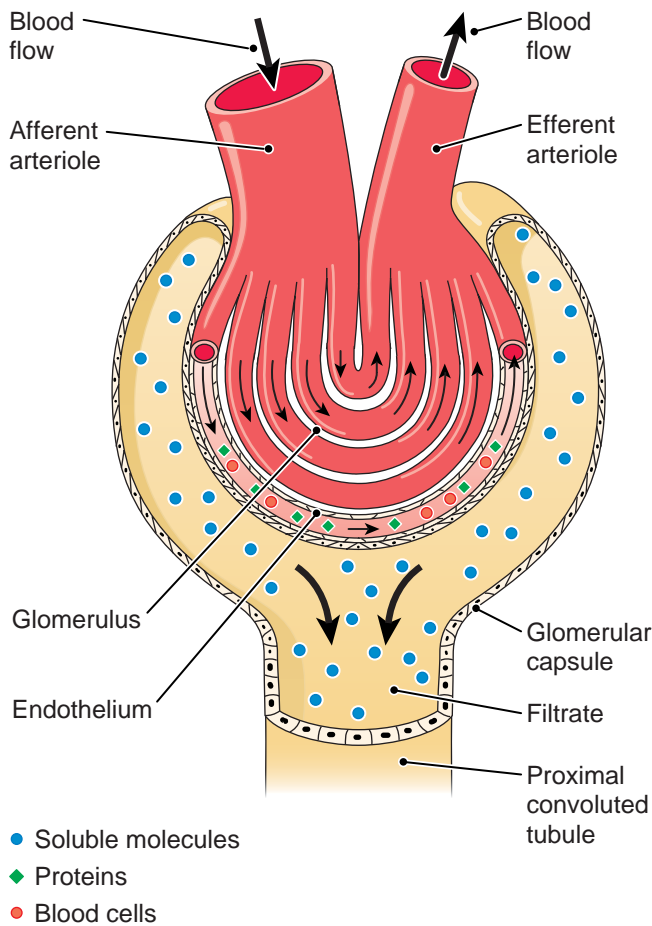


Figure 22-7 Filtration process in the formation of urine. Blood pressure inside the glomerulus forces water and dissolved substances into the glomerular (Bowman) capsule. Blood cells and proteins remain behind in the blood. The smaller diameter of the efferent arteriole maintains the hydrostatic (fluid) pressure. **ZOOMING IN** ♦ Which arteriole associated with the glomerulus has the wider diameter?

the **glomerular filtrate**, begins its journey along the tubular system of the nephron. In addition to water and the normal soluble substances in the blood, other substances, such as vitamins and drugs, also may be filtered and become part of the glomerular filtrate.

Checkpoint 22-9: The first step in urine formation is glomerular filtration. What is glomerular filtration?

Tubular Reabsorption The kidneys form about 160 to 180 liters of filtrate day. However, only 1 to 1.5 liters of urine are eliminated daily. Clearly, most of the water that enters the nephron is not excreted with the urine, but rather, is returned to the circulation. In addition to water, many other substances the body needs, such as nutrients and ions, pass into the nephron as part of the filtrate, and these also must be returned. Therefore, the process of filtration that occurs in the glomerular capsule

is followed by a process of **tubular reabsorption**. As the filtrate travels through the nephron's tubular system, water and other needed substances leave the tubule and enter the surrounding tissue fluid, or interstitial fluid (IF). They move by several processes previously described in Chapter 3, including:

- ♦ **Diffusion.** The movement of substances from an area of higher concentration to an area of lower concentration (following the concentration gradient)
- ♦ **Osmosis.** Diffusion of water through a semipermeable membrane.
- ♦ **Active transport.** Movement of materials through the plasma membrane against the concentration gradient using energy and transporters

The substances that leave the nephron and enter the interstitial fluid then enter the peritubular capillaries and return to the circulation. In contrast, most of the urea and other nitrogenous waste materials are kept within the tubule to be eliminated with the urine. Box 22-1 presents additional information on tubular reabsorption in the nephron.

Tubular Secretion Before the filtrate leaves the body as urine, the kidney makes final adjustments in composition by the process of **tubular secretion**. In this process, some substances are actively moved from the blood into the nephron. Potassium ions are moved into the urine by this process. Importantly, the kidneys regulate the acid–base (pH) balance of body fluids by the active secretion of hydrogen ions. Some drugs, such as penicillin, also are actively secreted into the nephron for elimination.

Concentration of the Urine The amount of water that is eliminated with the urine is regulated by a complex mechanism within the nephron that is influenced by **antidiuretic hormone (ADH)**, a hormone released from the posterior pituitary gland (see Table 22-1). The process is called the **countercurrent mechanism** because it involves fluid traveling in opposite directions within the ascending and descending limbs of Henle's loop. The countercurrent mechanism is illustrated in Figure 22-8. Its essentials are as follows:

As the filtrate passes through Henle's loop, electrolytes, especially sodium, are actively pumped out by the nephron's cells, resulting in an increased concentration of the interstitial fluid. Because the ascending limb of Henle's loop is not very permeable to water, the filtrate at this point becomes increasingly dilute (see Fig. 22-8). As the filtrate then passes through the more permeable DCT and collecting duct, the concentrated fluids around the nephron draw water out to be returned to the blood. (Remember, according to the laws of osmosis, water follows salt.) In this manner, the urine becomes more concentrated as it leaves the nephron and its volume is reduced.

Box 22-1 Clinical Perspectives

Transport Maximum

The kidney works efficiently to return valuable substances to the blood after glomerular filtration. However, the carriers that are needed for active transport of these substances can become overloaded, and there is also a limit to the amount of each substance that can be reabsorbed in a given time period. The limit of this rate of reabsorption is called the **transport maximum (T_m)**, or tubular maximum, and it is measured in milligrams (mg) per minute. For example, the T_m for glucose is approximately 375 mg/minute.

If a substance is present in excess in the blood, it may ex-

ceed its transport maximum and then, because it cannot be totally reabsorbed, some will be excreted in the urine. Thus, the transport maximum determines the **renal threshold**—the plasma concentration at which a substance will begin to be excreted in the urine, which is measured in mg per deciliter (dL). For example, if the concentration of glucose in the blood exceeds its renal threshold (180 mg/dL), glucose will begin to appear in the urine, a condition called **glycosuria**. The most common cause of glycosuria is uncontrolled diabetes mellitus.

The hormone ADH makes the walls of the DCT and collecting tubule more permeable to water, so that more water will be reabsorbed and less will be excreted with the urine. The release of ADH from the posterior pituitary

is regulated by a feedback system. As the blood becomes more concentrated, the hypothalamus triggers more ADH release from the posterior pituitary; as the blood becomes more dilute, less ADH is released. In the disease diabetes insipidus, there is inadequate secretion of ADH from the hypothalamus, which results in the elimination of large amounts of dilute urine accompanied by excessive thirst.

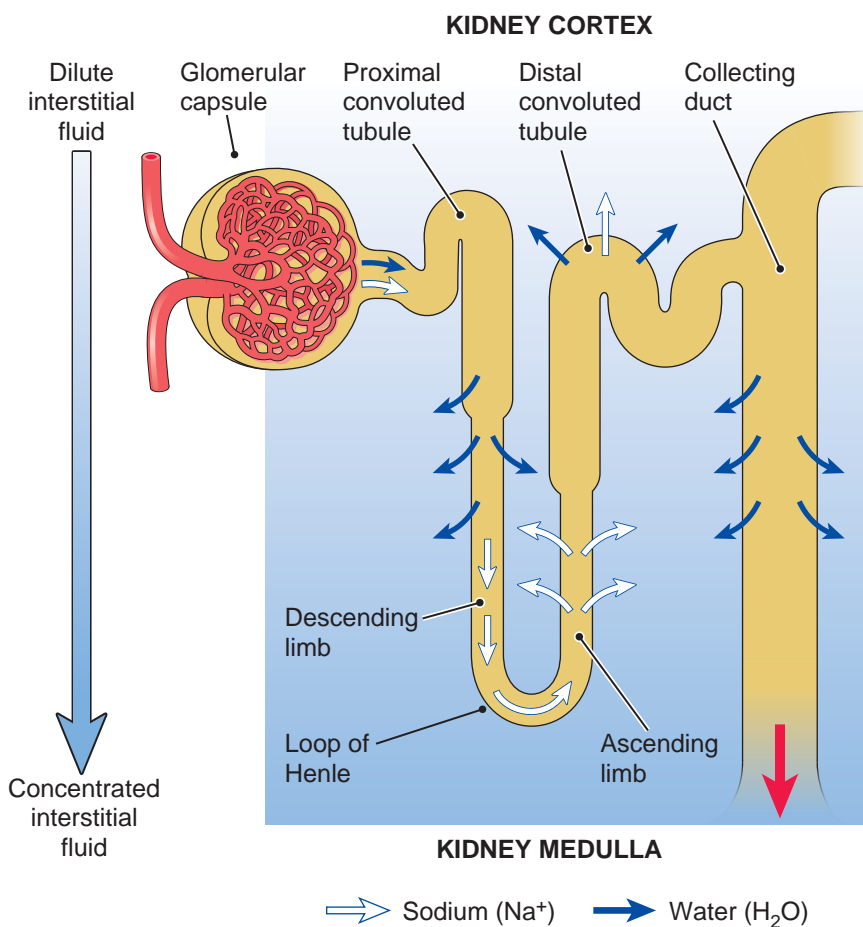


Figure 22-8 Countercurrent mechanism for concentration of urine. Concentration is regulated by means of intricate exchanges of water and electrolytes, mainly sodium, in the loop of Henle, distal convoluted tubule, and collecting duct. The intensity of color shows changing concentrations of the interstitial fluid and filtrate.

Summary of Urine Formation

The processes involved in urine formation are summarized below and illustrated in Figure 22-9.

1. Glomerular filtration allows all diffusible materials to pass from the blood into the nephron.
2. Tubular reabsorption moves useful substances back into the blood while keeping waste products in the nephron to be eliminated in the urine.
3. Tubular secretion moves additional substances from the blood into the nephron for elimination. Movement of hydrogen ions is one means by which the pH of body fluids is balanced.
4. The countercurrent mechanism concentrates the urine and reduces the volume excreted. The pituitary hormone ADH allows more water to be reabsorbed from the nephron.

Checkpoint 22-10: What are the four processes involved in the formation of urine?

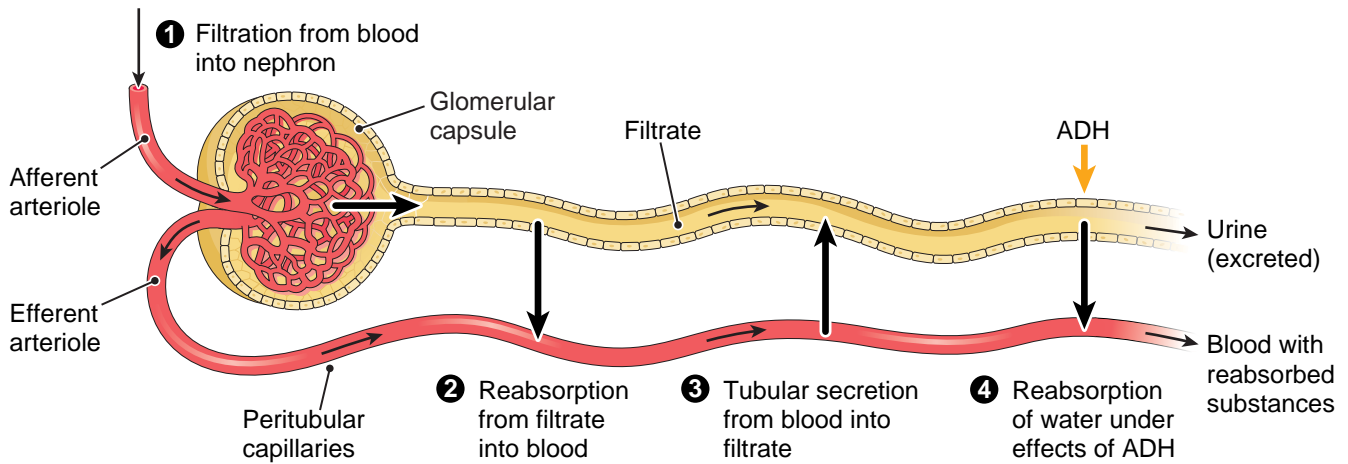


Figure 22-9 Summary of urine formation in a nephron.

The Ureters

Each of the two ureters is a long, slender, muscular tube that extends from the kidney down to and through the inferior portion of the urinary bladder (see Fig. 22-1). The ureters, which are located posterior to the peritoneum and, at the distal portion, below the peritoneum, are entirely extraperitoneal. Their length naturally varies with the size of the individual, and they may be anywhere from 25 cm to 32 cm (10–13 inches) long. Nearly 2.5 cm (1 inch) of the ureter's distal portion enters the bladder by passing obliquely (at an angle) through the inferior bladder wall. Because of the oblique direction the ureter takes through the wall, a full bladder compresses the ureter and prevents the backflow of urine.

The wall of the ureter includes a lining of epithelial cells, a relatively thick layer of involuntary muscle, and finally, an outer coat of fibrous connective tissue. The epithelium is the transitional type, which flattens from a cuboidal shape as the tube stretches. This same type of epithelium lines the renal pelvis, the bladder, and the proximal portion of the urethra. The ureteral muscles are capable of the same rhythmic contraction (peristalsis) that occurs in the digestive system. Urine is moved along the ureter from the kidneys to the bladder by gravity and by peristalsis at frequent intervals.

The Urinary Bladder

When it is empty, the urinary bladder (Fig. 22-10) is located below the parietal peritoneum and posterior to the pubic joint. When filled, it pushes the peritoneum upward and may extend well into the abdominal cavity proper. The urinary bladder is a temporary reservoir for urine, just as the gallbladder is a storage sac for bile.

The bladder wall has many layers. It is lined with mucous membrane containing transitional epithelium. The

bladder's lining, like that of the stomach, is thrown into folds called *rugae* when the organ is empty. Beneath the mucosa is a layer of connective tissue, followed by a three-layered coat of involuntary muscle tissue that can stretch considerably. Finally, there is an incomplete coat of peritoneum that covers only the superior portion of the bladder.

When the bladder is empty, the muscular wall becomes thick, and the entire organ feels firm. As the blad-

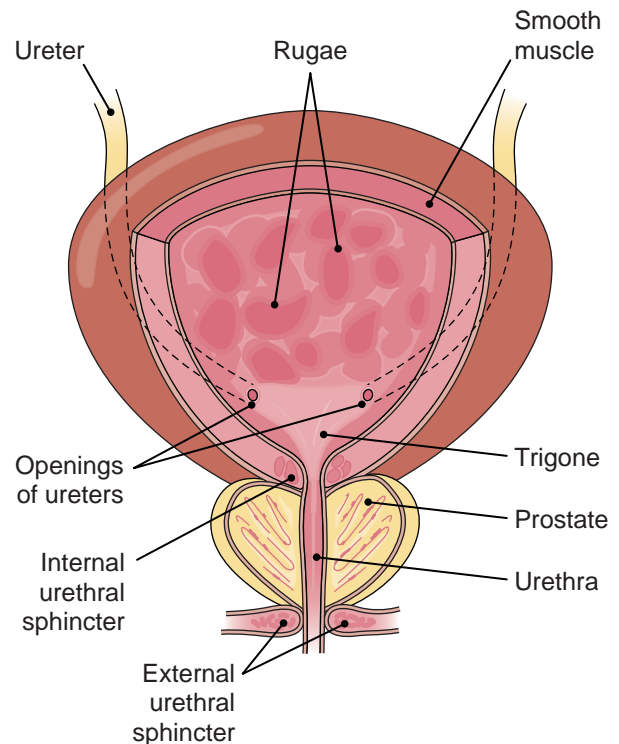


Figure 22-10 Interior of the male urinary bladder. The trigone is a triangular region in the floor of the bladder marked by the openings of the ureters and the urethra. **ZOOMING IN** ♦ What gland does the urethra pass through in the male?

der fills, the muscular wall becomes thinner, and the organ may increase from a length of 5 cm (2 inches) up to as much as 12.5 cm (5 inches) or even more. A moderately full bladder holds about 470 mL (1 pint) of urine.

The **trigone** (TRI-gone) is a triangular-shaped region in the floor of the bladder. It is marked by the openings of the two ureters and the urethra (see Fig. 22-10). As the bladder fills with urine, it expands upward, leaving the trigone at the base stationary. This stability prevents stretching of the ureteral openings and the possible back flow of urine into the ureters.

► The Urethra

The **urethra** is the tube that extends from the bladder to the outside (see Fig. 22-1) and is the means by which the bladder is emptied. The urethra differs in men and women; in the male, it is part of both the reproductive system and the urinary system, and it is much longer than is the female urethra.

The male urethra is about 20 cm (8 inches) in length. Proximally, it passes through the prostate gland, where it is joined by two ducts carrying male germ cells (spermatozoa) from the testes and glandular secretions. From here, it leads to the outside through the **penis** (PE-nis), the male organ of copulation. The male urethra serves the dual purpose of conveying semen with the germ cells and draining the bladder.

The urethra in the female is a thin-walled tube about 4 cm (1.5 inches) long. It is located posterior to the pubic joint and is embedded in the muscle of the vagina's anterior wall. The external opening, called the **urinary meatus** (me-A-tus), is located just anterior to the vaginal opening between the labia minora. The female urethra drains the bladder only and is entirely separate from the reproductive system.

Urination

The process of expelling (voiding) urine from the bladder is called **urination** or **micturition** (mik-tu-RISH-un). This process is controlled both voluntarily and involuntarily with the aid of two rings of muscle (sphincters) that surround the urethra (see Fig. 22-10). Near the bladder's outlet is an involuntary **internal urethral sphincter** formed by a continuation of the smooth muscle of the bladder wall. Below this muscle is a voluntary **external urethral sphincter** formed by the muscles of the pelvic floor. By learning to control the voluntary sphincter, one can gain control over emptying of the bladder.

As the bladder fills with urine, stretch receptors in its wall send impulses to a center in the lower part of the spinal cord. Motor impulses from this center stimulate contraction of the bladder wall, forcing urine outward as both the internal and external sphincters are made to relax. In the infant, this emptying occurs automatically as

a simple reflex. Early in life, a person learns to control urination from higher centers in the brain until the time is appropriate, a process known as *toilet training*. The impulse to urinate will override conscious controls if the bladder becomes too full.

The bladder can be emptied voluntarily by relaxing the muscles of the pelvic floor and increasing the pressure in the abdomen. The resulting increased pressure in the bladder triggers the spinal reflex that leads to urination.

Checkpoint 22-11: What is the name of the tube that carries urine from the kidney to the bladder?

Checkpoint 22-12: What is the name of the tube that carries urine from the bladder to the outside?

► The Urine

Urine is a yellowish liquid that is approximately 95% water and 5% dissolved solids and gases. The pH of freshly collected urine averages 6.0, with a range of 4.5 to 8.0. Diet may cause considerable variation in pH.

The amount of dissolved substances in urine is indicated by its **specific gravity**. The specific gravity of pure water, used as a standard, is 1.000. Because of the dissolved materials it contains, urine has a specific gravity that normally varies from 1.002 (very dilute urine) to 1.040 (very concentrated urine). When the kidneys are diseased, they lose the ability to concentrate urine, and the specific gravity no longer varies as it does when the kidneys function normally.

Normal Constituents

Some of the dissolved substances normally found in the urine are the following:

- **Nitrogenous waste products**, including urea, uric acid, and **creatinine** (kre-AT-ih-nin)
- **Electrolytes**, including sodium chloride (as in common table salt) and different kinds of sulfates and phosphates. Electrolytes are excreted in appropriate amounts to keep their blood concentration constant.
- **Pigment**, mainly yellow pigment derived from certain bile compounds. Pigments from foods and drugs also may appear in the urine.

Abnormal Constituents

Examination of urine, called a **urinalysis** (u-rin-AL-ih-sis) (UA), is one of the most important parts of a medical evaluation. A routine urinalysis includes observation of color and turbidity (cloudiness) as well as measurement of pH and specific gravity. Laboratories also test for a variety of abnormal components, including:

- **Glucose** is usually an important indicator of diabetes mellitus, in which the cells do not adequately metabo-

lize blood sugar. The excess glucose, which cannot be reabsorbed, is excreted in the urine. The presence of glucose in the urine is known as **glycosuria** (gli-ko-SU-re-ah) or glucosuria.

- ▶ **Albumin.** The presence of this protein, which is normally retained in the blood, may indicate a kidney disorder, such as glomerulonephritis. Albumin in the urine is known as **albuminuria** (al-bu-mih-NU-re-ah).
- ▶ **Blood** in the urine is usually an important indicator of urinary system disease, including nephritis. Blood in the urine is known as **hematuria** (hem-ah-TU-re-ah).
- ▶ **Ketones** (KE-tones) are produced when fats are incompletely oxidized; ketones in the urine are seen in diabetes mellitus and starvation.
- ▶ **White blood cells** (pus) are evidence of infection; they can be seen by microscopic examination of a centrifuged specimen. Pus in the urine is known as **pyuria** (pi-U-re-ah).
- ▶ **Casts** are solid materials molded within the microscopic kidney tubules. They consist of cells or proteins and, when present in large number, they usually indicate disease of the nephrons.

More extensive tests on urine may include analysis for drugs, enzymes, hormones, and other metabolites as well as cultures for microorganisms. Normal values for common urine tests are given in Appendix 4, Table 1.

Disorders of the Urinary System

The kidney is more prone to disorders than any other portion of the urinary system.

Kidney Disorders

Kidney disorders may be acute or chronic. Acute conditions usually arise suddenly, most frequently as the result of infection with inflammation of the nephrons. These diseases commonly run a course of a few weeks and are followed by complete recovery. Chronic conditions arise slowly and are often progressive, with gradual loss of kidney function.

Acute glomerulonephritis (glo-mer-u-lo-nef-RI-tis), also known as acute *poststreptococcal glomerulonephritis*, is the most common disease of the kidneys. This condition usually occurs in children about 1 to 4 weeks after a streptococcal throat infection. Antibodies formed in response to the streptococci attach to the glomerular membrane and cause injury. These damaged glomeruli allow protein, especially albumin, to filter into the glomerular capsule and ultimately to appear in the urine (albuminuria). They also allow red blood cells to filter into the urine (hematuria). Usually, the patient recovers without permanent kidney damage. In adult patients, the disease is more likely to become chronic, with a gradual decrease in the number of functioning nephrons, leading to chronic renal failure.

Pyelonephritis (pi-el-o-nef-RI-tis), an inflammation of the renal pelvis and the tissue of the kidney, may be either acute or chronic. In acute pyelonephritis, the inflammation results from a bacterial infection. Bacteria most commonly reach the kidney by ascending along the lining membrane from an infection in the distal part of the urinary tract (see Fig. 23-15 in Chapter 23). More rarely, bacteria are carried to the kidney by the blood.

Acute pyelonephritis is often seen in people with partial obstruction of urine flow with stagnation (urinary stasis). It is most likely to occur in pregnant women and in men with an enlarged prostate, because the prostate surrounds the first portion of the urethra in males. Other causes of stasis include neurogenic bladder, which is bladder dysfunction resulting from neurologic lesions, as seen in diabetes mellitus, and structural defects in the area where the ureters enter the bladder. Pyelonephritis usually responds to the administration of antibiotics, fluid replacement, rest, and fever control.

Chronic pyelonephritis, a more serious disease, is frequently seen in patients with urinary tract stasis or back flow. It may be caused by persistent or repeated bacterial infections. Progressive damage of kidney tissue is evidenced by high blood pressure, continual loss of protein in the urine, and dilute urine.

Hydronephrosis (hi-dro-nef-RO-sis) is the distention of the renal pelvis and calyces with accumulated fluid as a result of urinary tract obstruction. The most common causes of obstruction, in addition to pregnancy or an enlarged prostate, are a kidney stone that has formed in the pelvis and dropped into the ureter, a tumor that presses on a ureter, and scars due to inflammation. Prompt removal of the obstruction may result in complete recovery. If the obstruction is not removed, the kidney will be permanently damaged.

A **polycystic** (pol-e-SIS-tik) **kidney** is one in which many fluid-containing sacs develop in the active tissue and gradually destroy it by pressure. This disorder may run in families, and treatment has not proved very satisfactory, except for the use of dialysis machines or kidney transplantation.

Tumors of the kidneys usually grow rather slowly, but rapidly invading types are occasionally found. Blood in the urine and dull pain in the kidney region are warnings that should be heeded at once. Surgical removal of the kidney offers the best chance of cure because most renal cancers do not respond to chemotherapy or radiation.

Kidney Stones Kidney stones, or **calculi** (KAL-ku-li), are made of substances, such as calcium salts or uric acid, that precipitate out of the urine instead of remaining in solution. They usually form in the renal pelvis, but may also form in the bladder.

The causes of stone formation include dehydration, stasis (stagnation) of the urine, and infection of the uri-

nary tract. The stones may vary in size from tiny grains resembling bits of gravel up to large masses that fill the renal pelvis and extend into the calyces. The latter are described as **staghorn calculi**.

There is no way of dissolving these stones because substances that could do so would also destroy kidney tissue. Sometimes, instruments can be used to crush small stones and thus allow them to be expelled with the urine, but more often, surgical removal is required. A **lithotripter** (LITH-o-trip-tor), literally a “stone-cracker,” is a device that employs external shock waves to shatter kidney stones. The procedure is called **lithotripsy** (LITH-o-trip-se).

Renal Failure Acute renal failure may result from a medical or surgical emergency or from toxins that damage the tubules. This condition is characterized by a sudden, serious decrease in kidney function accompanied by electrolyte and acid–base imbalances. Acute renal failure occurs as a serious complication of other severe illness and may be fatal.

Chronic renal failure results from a gradual loss of nephrons. As more and more nephrons are destroyed, the kidneys gradually lose the ability to perform their normal functions. As the disease progresses, nitrogenous waste products accumulate to high levels in the blood, causing a condition known as **uremia** (u-RE-me-ah). In many cases, there is a lesser decrease in renal function, known as **renal insufficiency**, that produces fewer symptoms.

Two of the characteristic signs and symptoms of chronic renal failure are the following:

- ▶ **Dehydration** (de-hi-DRA-shun). Excessive loss of body fluid may occur early in renal failure, when the kidneys cannot concentrate the urine and large amounts of water are eliminated.
- ▶ **Edema** (eh-DE-mah). Accumulation of fluid in the tissue spaces may occur late in chronic renal disease, when the kidneys cannot eliminate water in adequate amounts.
- ▶ **Electrolyte imbalance**, including retention of sodium and accumulation of potassium
- ▶ **Hypertension** may occur as the result of fluid overload and the increased production of renin (see Box 22-2).
- ▶ **Anemia** occurs when the kidneys cannot produce the hormone erythropoietin to activate red blood cell production in bone marrow.
- ▶ **Uremia** (u-RE-me-ah), an excess of nitrogenous waste products in the blood. When these levels are very high, urea can be changed into ammonia in the stomach and intestine and cause ulcerations and bleeding.

Checkpoint 22-13: What is the difference between acute and chronic kidney disorders?

Renal Dialysis and Kidney Transplantation

Dialysis (di-AL-ih-sis) means “the separation of dissolved molecules based on their ability to pass through a semi-permeable membrane” (Fig. 22-11 A). Molecules that can pass through the membrane move from an area of greater concentration to one of lesser concentration. In patients who have defective kidney function, the accumulation of urea and other nitrogenous waste products can be reduced by passage of the patient’s blood through a dialysis machine. The principle of “molecules leaving the area of greater concentration” thus operates to remove wastes from the blood. The fluid in the dialysis machine, the dialysate, can be adjusted to regulate the flow of substances out of the blood.

There are two methods of dialysis in use: hemodialysis (blood dialysis) and peritoneal dialysis (dialysis in the

Box 22-2 A Closer Look

The Renin-Angiotensin Pathway: The Kidneys’ Route to Blood Pressure Control

In addition to forming urine, the kidneys play an integral role in regulating blood pressure. When blood pressure drops, cells of the juxtaglomerular apparatus secrete the enzyme renin into the blood. Renin acts on another blood protein, **angiotensinogen**, which is manufactured by the liver. Renin converts angiotensinogen into **angiotensin I** by cleaving off some amino acids from the end of the protein. Angiotensin I is then converted into **angiotensin II** by yet another enzyme called angiotensin-converting enzyme (ACE), which is manufactured by capillary endothelium, especially in the lungs. Angiotensin II increases blood pressure in four ways:

1. It increases cardiac output and stimulates vasoconstriction.
2. It stimulates the release of aldosterone, a hormone that acts on the kidneys’ distal convoluted tubules to increase

sodium reabsorption, and secondarily, water reabsorption.

3. It stimulates the release of antidiuretic hormone, which acts directly on the distal convoluted tubules to increase water reabsorption.
4. It stimulates thirst centers in the hypothalamus, resulting in increased fluid consumption.

The combined effects of angiotensin II produce a dramatic increase in blood pressure. In fact, angiotensin II is estimated to be four to eight times more powerful than norepinephrine, another potent stimulator of hypertension, and thus is a good target for blood pressure-controlling drugs. One class of drugs used to treat hypertension is the **ACE inhibitors** (angiotensin-converting enzyme inhibitors), which control blood pressure by blocking the production of angiotensin II.

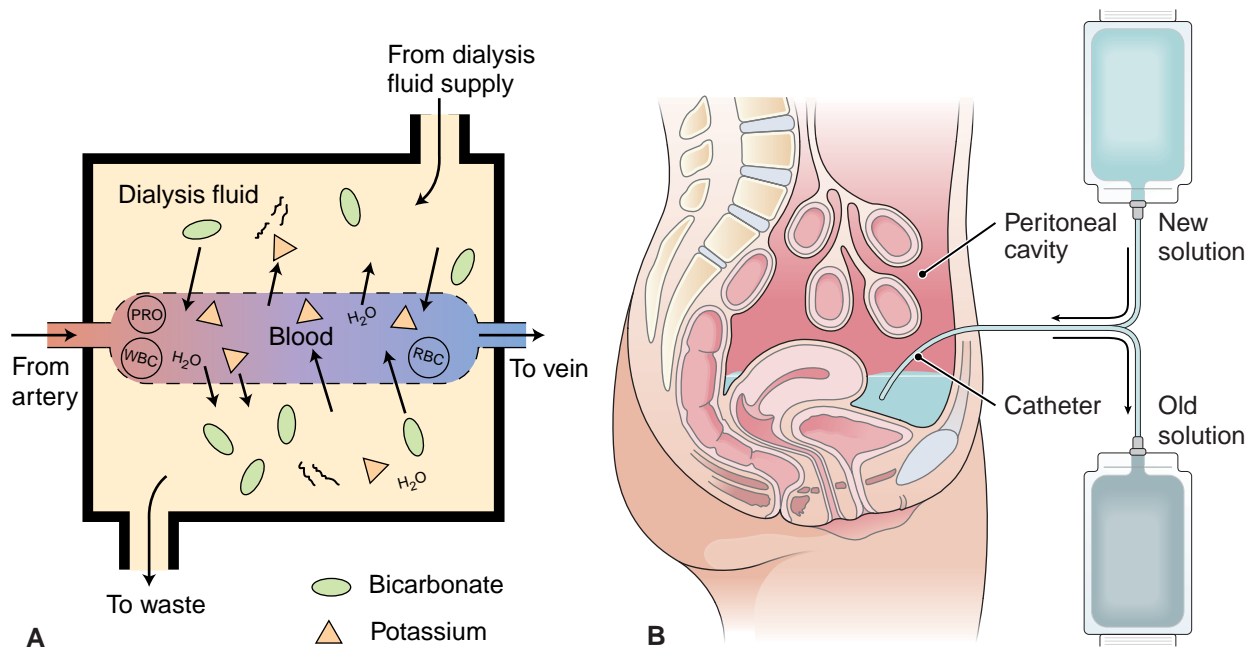


Figure 22-11 A hemodialysis system and a peritoneal dialysis system. (A) In hemodialysis, a cellophane membrane separates the blood compartment and dialysis fluid compartment. This membrane is porous enough to allow all of the constituents except the plasma proteins (PRO) and blood cells (WBC, RBC) to diffuse between the two compartments. (B) In peritoneal dialysis, a semipermeable membrane richly supplied with blood vessels lines the peritoneal cavity. With dialysate dwelling in the peritoneal cavity, waste products diffuse from the network of blood vessels into the dialysate. (A, Reprinted with permission from Porth CM. *Pathophysiology*. 7th ed. Philadelphia: Lippincott Williams & Wilkins, 2004; B, reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

abdominal cavity). In hemodialysis, the dialysis membrane is made of cellophane or other synthetic material. In peritoneal dialysis, the surface area of the peritoneum acts as the membrane (see Fig. 22-11 B). Dialysis fluid is introduced into the peritoneal cavity and then periodically removed along with waste products. This procedure may be done at intervals through the day or during the night.

A 1973 amendment to the Social Security Act provides federal financial assistance for people who have chronic renal disease and require dialysis. Most hemodialysis is performed in freestanding clinics. Treatment time has been reduced; a typical schedule involves 2 to 3 hours, three times a week. Access to the bloodstream has been made safer and easier through surgical establishment of a permanent exchange site (shunt). Peritoneal dialysis also has been improved and simplified, enabling patients to manage treatment at home. (Box 22-3 gives an overview of what to expect in a career as a hemodialysis technician.)

The final option for treatment of renal failure is kidney transplantation. Surgeons have successfully performed many of these procedures. Kidneys have so much extra functioning tissue that the loss of one kidney normally poses no problem to the donor. Records show that transplantation success is greatest when surgeons use a kidney from a living donor who is closely related to the patient. Organs from deceased donors have also proved

satisfactory in many cases. The problem of tissue rejection (the rejection syndrome) is discussed in Chapter 17.

Disorders of the Ureters

Abnormalities in structure of the ureter include subdivision at the renal pelvis and constricted or abnormally narrow parts, called **strictures** (STRICK-tures). Abnormal pressure from tumors or other outside masses may cause ureteral narrowing. Obstruction also may be caused by stones from the kidneys, or kinking of the tube because of a dropping of the kidney, a condition known as **renal ptosis** (TO-sis). In cases of **ureterocele** (u-RE-ter-o-sele), the end of the ureter bulges into the bladder (Fig. 22-12). The result is urinary obstruction that leads to distention of the ureter (hydroureter) and renal pelvis (hydronephrosis). The usual cause of ureterocele is a congenital (present at birth) narrowing of the ureteral opening.

Ureteral Stones The passage of a small stone along the ureter causes excruciating pain, called *renal colic*. Relief of this pain usually requires morphine or an equally powerful drug. The first “barber surgeons,” operating without benefit of anesthesia, were permitted by their patients to cut through the skin and the muscles of the back to remove stones from the ureters. “Cutting for stone” in this way was relatively successful, despite the lack of sterile technique,

Box 22-3 • Health Professions

Hemodialysis Technician

A hemodialysis technician, also called a renal technician or a nephrology technician, specializes in the safe and effective delivery of renal dialysis therapy to patients suffering from kidney failure. Before treatment begins, the technician prepares the dialysis solutions and ensures that the dialysis machine is clean, sterile, and in proper working order. The technician measures and records the patient's weight, temperature, and vital signs, inserts a catheter into the patient's arm, and connects the dialysis machine to it. During dialysis, the technician monitors the patient for adverse reactions and guards against any equipment malfunction. After the treatment is completed, the technician again measures and records

the patient's weight, temperature, and vital signs. To perform these duties, hemodialysis technicians need a thorough understanding of anatomy and physiology. Most technicians in the United States receive their training from a college or technical school, and many states require that the technician be certified.

Hemodialysis technicians work in a variety of settings such as hospitals, clinics, and patients' homes. As populations age, the incidence of kidney disease is expected to rise, as will the need for hemodialysis. For more information about this career, contact the National Association of Nephrology Technicians.

because the approach through the back avoided the peritoneal cavity and the serious risk of peritonitis.

Modern surgery employs a variety of instruments for removal of stones from the ureter, including endoscopes similar to those described in Chapter 19. The transurethral route through the urethra and urinary bladder and then into the ureter, as well as entrance through the skin and muscles of the back, may be used to remove calculi from the kidney pelvis or from the ureter.

Checkpoint 22-14: What is the scientific name for stones, as may occur in the urinary tract?

Disorders Of the Bladder

A full (distended) bladder lies in an unprotected position in the lower abdomen, and a blow may rupture it, neces-

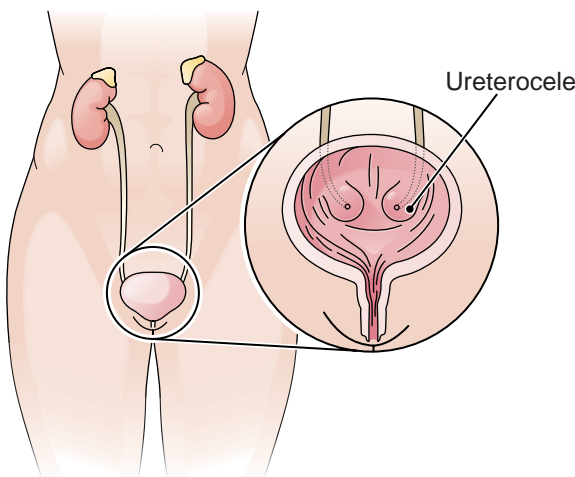


Figure 22-12 Ureterocele. The ureter bulges into the bladder. The resulting obstruction causes urine to back up into the ureter and renal pelvis. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

sitating immediate surgical repair. Blood in the urine is a rather common symptom of infection or tumors, which may involve the bladder.

Cystitis Inflammation of the bladder, called **cystitis** (sis-TI-tis), is 10 times as common in women as in men. This may be due, at least in part, to the very short urethra of the female compared with that of the male. The usual path of infection is that bacteria ascend from the outside through the urethra into the bladder (see Fig. 23-15 in Chapter 23). The common contaminants are colon bacteria, such as *E. coli*, carried to the urethra from the anus. Urinary stasis and catheterization to remove urine from the bladder are other possible sources of infection. Pain, urgency to urinate, and urinary frequency are common symptoms of cystitis.

Another type of cystitis, called **interstitial cystitis**, may cause pelvic pain with discomfort before and after urination. The tissues below the mucosa are involved. The disease can be diagnosed only with the use of a **cystoscope**, a type of endoscope used to examine the bladder (Fig. 22-13). Because no bacteria are involved, antibiotics are not effective treatment and may even be harmful.

Obstruction by an enlarged prostate gland in a male or from pregnancy may lead to urinary stasis and cystitis. Reduction of a person's general resistance to infection, as in diabetes, may also lead to cystitis. The danger of cystitis is that the infection may ascend to other parts of the urinary tract.

Tumors Tumors of the bladder, which are most prevalent in men older than 50 years of age, include benign papillomas and various kinds of cancer. About 90% of bladder tumors arise from the epithelial lining. Possible causes include toxins (particularly certain aniline dyes), chronic infestations (schistosomiasis), heavy cigarette smoking, and the presence of urinary stones, which may develop and increase in size within the bladder.

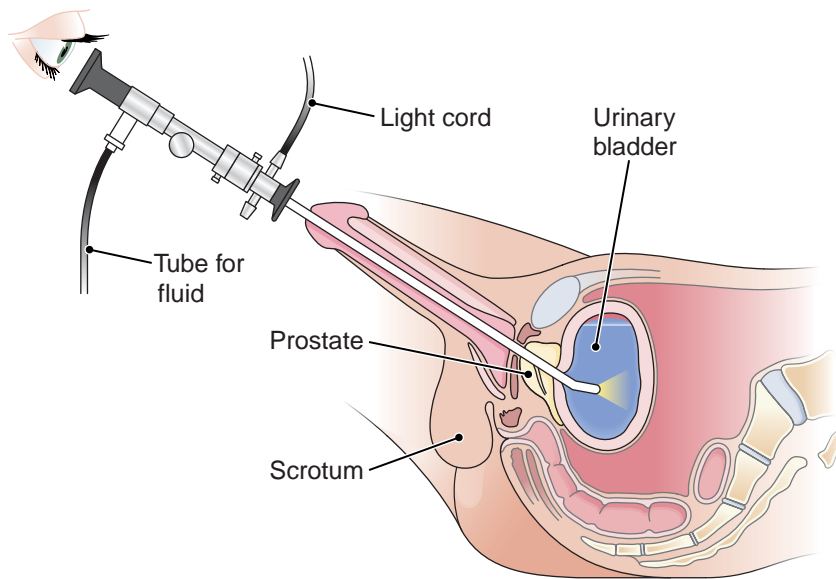


Figure 22-13 Cystoscopy. A lighted cystoscope is introduced through the urethra into the bladder of a male subject. Sterile fluid is used to inflate the bladder. The cystoscope is used to examine the bladder, remove specimens for biopsy, and remove tumors. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

Blood in the urine (hematuria) and frequent urination, in the absence of pain or fever, are early signs of a bladder tumor. A cystoscopic examination (see Fig. 22-13) and biopsy should be performed as soon as these signs are detected. Treatment includes removal of the tumor, which may be done cystoscopically, and localized chemotherapy. More serious cases may require irradiation. Removal before the tumor invades the muscle wall gives the best prognosis.

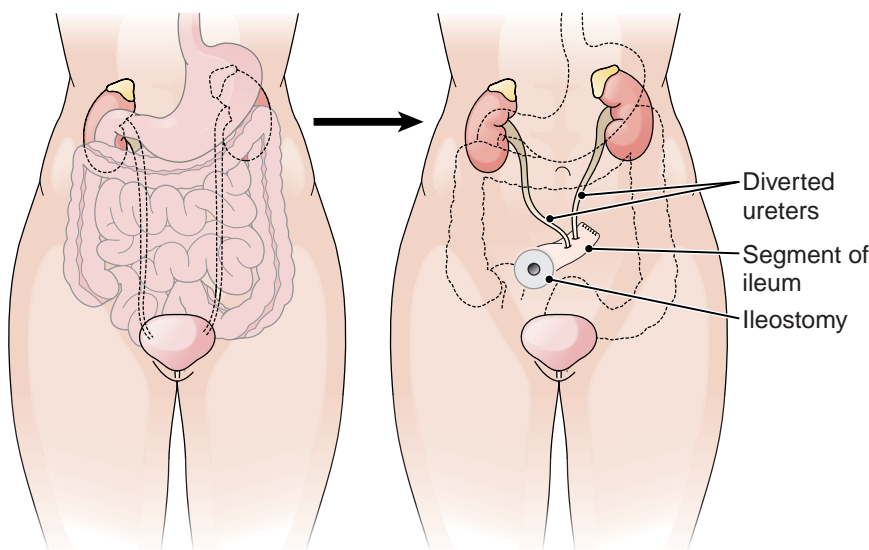


Figure 22-14 Ileal conduit. The ureters are vented through a segment of the ileum to open at the body surface through an ileostomy. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

If it is necessary to remove the bladder in a cystectomy (sis-TEK-to-me), the ureters must be vented elsewhere. They may be diverted to the body surface through a segment of the ileum, a procedure known as an ileal conduit (Fig. 22-14), or diverted to some other portion of the intestine. Alternatively, surgeons may create a bladder out of a section of the colon.

Urinary Incontinence Urinary incontinence (in-KON-tin-ens) refers to an involuntary loss of urine. The condition may originate with a neurologic disorder, trauma to the spinal cord, weakness of the pelvic muscles, impaired bladder function or medications. Different forms of urinary incontinence have specific names:

- ▶ Stress incontinence is due to urethral incompetence that allows small amounts of urine to be released when an activity increases pressure in the abdomen. These activities include coughing, sneezing, laughing, lifting or exercising.
- ▶ Urge incontinence, also called overactive bladder, results from an inability to control bladder contractions once the sensation of bladder fullness is perceived.
- ▶ Overflow incontinence is due to neurologic damage or urinary obstruction that causes the bladder to overfill. Excess pressure in the bladder results in involuntary loss of urine.
- ▶ Enuresis (en-u-RE-sis) is involuntary urination, usually during the night (bed-wetting)

Some treatment approaches to incontinence include muscle exercises, dietary changes, biofeedback, medication, surgery or, in serious cases, self-catheterization.

Checkpoint 22-15: What is the term for inflammation of the bladder?

Disorders of the Urethra

Congenital anomalies may involve the urethra as well as other parts of the urinary tract. The opening of the urethra to the outside may be too small, or the urethra itself may be narrowed. Occasionally, an abnormal valve-like structure is found at the point where

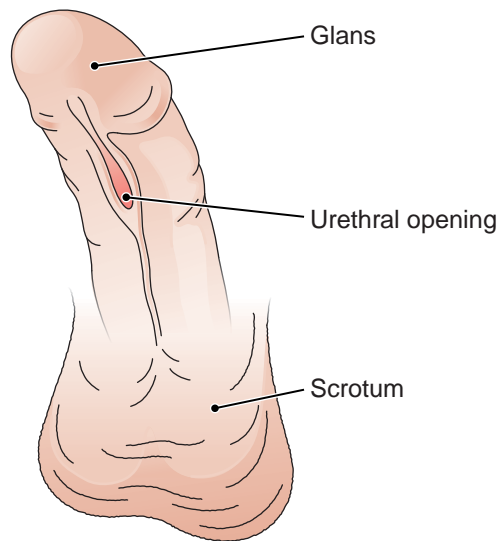


Figure 22-15 Hypospadias. A ventral view of the penis is shown here. (Reprinted with permission from Cohen BJ. *Medical Terminology*. 4th ed. Philadelphia: Lippincott Williams & Wilkins, 2004.)

the urethra enters the bladder. If it is not removed surgically, it can cause back pressure of the urine, with serious consequences. There is also a condition in the male in which the urethra opens on the undersurface of the penis instead of at the end. This is called **hypospadias** (hi-po-SPA-de-as) (Fig. 22-15).

Urethritis, which is characterized by inflammation of the mucous membrane and the glands of the urethra, is much more common in men than in women. It is often caused by infection with gonococci or chlamydias, although many other bacteria may be involved.

“Straddle” injuries to the urethra are common in men. This type of injury occurs when, for example, a man walking along a raised beam slips and lands with the beam between his legs. Such an accident may catch the urethra between the hard surfaces of the beam and the pubic arch and rupture the urethra. In accidents in which the bones of the pelvis are fractured, rupture of the urethra is fairly common.

► The Effects of Aging

Even without kidney disease, aging causes the kidneys to lose some of their ability to concentrate urine. With aging, progressively more water is needed to excrete the same amount of waste. Older people find it necessary to drink more water than young people, and they eliminate larger amounts of urine (polyuria), even at night (nocturia).

Beginning at about 40 years of age, there is a decrease in the number and size of the nephrons. Often, more than half of them are lost before the age of 80 years. There may be an increase in blood urea nitrogen (BUN) without serious symptoms. Elderly people are more susceptible than young people to urinary system infections. Childbearing may cause damage to the musculature of the pelvic floor, resulting in urinary tract problems in later years.

Enlargement of the prostate, common in older men, may cause obstruction and back pressure in the ureters and kidneys. If this condition is untreated, it will cause permanent damage to the kidneys. Changes with age, including decreased bladder capacity and decreased muscle tone in the bladder and urinary sphincters, may predispose to incontinence. However, most elderly people (60% in nursing homes, and up to 85% living independently) have no incontinence.

Word Anatomy

Medical terms are built from standardized word parts (prefixes, roots, and suffixes). Learning the meanings of these parts can help you remember words and interpret unfamiliar terms.

WORD PART	MEANING	EXAMPLE
The Kidneys		
retro-	backward, behind	The <i>retroperitoneal</i> space is posterior to the peritoneal cavity.
ren/o	kidney	The <i>renal</i> artery carries blood to the kidney.
nephro-	kidney	The <i>nephron</i> is the functional unit of the kidney.
juxta-	next to	The <i>juxtaglomerular</i> apparatus is next to the glomerulus.
The Ureters		
extra-	beyond, outside of	The ureters are <i>extraperitoneal</i> .
Disorders of the Urinary System		
pyel/o	renal pelvis	<i>Pyelonephritis</i> is inflammation of the nephrons and renal pelvis.
cyst/o	sac, bladder	A <i>polycystic</i> kidney develops many fluid-containing sacs.
dia-	through	<i>Dialysis</i> is the separation (-lysis) of molecules based on their ability to pass through a semipermeable membrane.
-cele	swelling, enlarged space	A <i>uterocele</i> is formed as the end of the ureter bulges into the bladder.
trans-	across, through	A <i>transurethral</i> route is through the urethra.
The Effects of Aging		
noct/i	night	<i>Nocturia</i> is excessive urination at night.

Summary

I. Excretion- removal and elimination of metabolic waste

- A. Systems that eliminate waste
1. Urinary- removes waste from blood
 - a. Other functions- regulates blood volume, pH, and electrolytes
 2. Digestive system—eliminates water, salts, bile with digestive residue
 3. Respiratory system—eliminates carbon dioxide, water
 4. Skin—eliminates water, salts, nitrogen waste

II. Organs of the urinary system

- a. Kidneys (2)
- b. Ureters (2)
- c. Urinary bladder (1)
- d. Urethra (1)

III. Kidneys

1. In upper abdomen against the back
 2. In retroperitoneal space (posterior to the peritoneum)
- A. Blood supply
- a. Renal artery—carries blood to kidney from aorta
 - b. Renal vein—carries blood from kidney to inferior vena cava
- B. Structure of the kidney
1. Cortex—outer portion
 2. Medulla—inner portion
 3. Pelvis
 - a. Upper end of ureter
 - b. Calyces—cuplike extensions that receive urine
 4. Nephron
 - a. Functional unit of kidney
 - b. Parts
 - (1) Glomerular (Bowman) capsule—around glomerulus
 - (2) Proximal convoluted tubule (PCT)
 - (3) Loop of Henle- descending and ascending limbs
 - (4) Distal convoluted tubule (DCT)
 - c. Blood supply to nephron
 - (1) Afferent arteriole—enters glomerular capsule
 - (2) Glomerulus—coil of capillaries in glomerular capsule
 - (3) Efferent arteriole—leaves glomerular capsule
 - (4) Peritubular capillaries—surround nephron
 - (5) Juxtaglomerular apparatus
 - a. Consists of cells in afferent arteriole and distal convoluted tubule
 - b. Releases renin to regulate blood pressure via angiotensin
- C. Functions of the kidney
1. Excretion of waste, excess salts, toxins
 2. Water balance
 3. Acid–base balance (pH)
 4. Regulation of blood pressure
 5. Releases hormone erythropoietin (EPO)- stimulates red blood cell production

D. Formation of urine

1. Glomerular filtration—driven by blood pressure in glomerulus
 - a. Water and soluble substances forced out of blood and into glomerular capsule
 - b. Blood cells and proteins remain in blood
 - c. Glomerular filtrate—material that leaves blood and enters the nephron
2. Tubular reabsorption
 - a. Most of filtrate leaves nephron by diffusion, osmosis and active transport
 - b. Returns to blood through peritubular capillaries
3. Tubular secretion—materials moved from blood into nephron for excretion
4. Concentration of urine
 - a. Countercurrent mechanism—method for concentrating urine based on movement of ions and permeability of tubule
 - (1) ADH
 - (a) Hormone from posterior pituitary
 - (b) Promotes reabsorption of water

IV. The ureters—carry urine from the kidneys to the bladder

V. Urinary bladder

- a. Stores urine until it is eliminated
- b. Trigone—triangular region in base of bladder; remains stable as bladder fills

VI. Urethra—carries urine out of body

1. Male urethra—20 cm long; carries both urine and semen
 2. Female urethra—4 cm long; opening anterior to vagina
- A. Urination (micturition)
1. Both voluntary and involuntary
 2. Sphincters
 - a. Internal urethral sphincter—involuntary (smooth muscle)
 - b. External urethral sphincter—voluntary (skeletal muscle)
 3. Stretch receptors in bladder wall signal reflex emptying
 4. Can be controlled through higher brain centers

VII. Urine

1. pH averages 6.0
 2. Specific gravity—measures dissolved substances
- A. Normal constituents—water, nitrogenous waste, electrolytes, pigments
- B. Abnormal constituents—glucose, albumin, blood, ketones, white blood cells, casts

VIII. Disorders of the urinary system

- A. Kidney disorders
1. Examples
 - a. Acute glomerulonephritis—damages glomeruli
 - b. Pyelonephritis—inflammation of kidney and renal pelvis

- c. Hydronephrosis—distention with obstructed fluids
 - d. Polycystic kidney—fluid-containing sacs develop
 - e. Tumors
 - 2. Kidney stones- calculi
 - 3. Renal failure
 - a. Types
 - 1) Acute—results from medical emergency or toxins
 - 2) Chronic—signs include dehydration, electrolyte imbalance, edema, hypertension, anemia, uremia
 - 4. Renal dialysis and kidney transplantation
 - a. Renal dialysis—removes unwanted substances from blood when kidneys fail
- B. Disorders of the ureters**
- 1. Stricture (narrowing)
 - 2. Stones (calculi)
- C. Disorders involving the bladder**
- 1. Cystitis—inflammation; most common in females
 - 2. Tumors
 - 3. Urinary incontinence
- D. Disorders of the urethra**
- 1. Hypospadias—urethra opens on underside of penis
 - 2. Urethritis—inflammation

IX. Effects of aging

- 1. Polyuria—increased elimination of urine
- 2. Nocturia—urination at night
- 3. Incontinence
- 4. Increased blood urea nitrogen (BUN)
- 5. Prostate enlargement

Questions for Study and Review

Building Understanding

Fill in the blanks

1. Each kidney is located outside the abdominal cavity in a _____ space.
2. The renal artery, renal vein, and ureter connect to the kidney at the _____.
3. The part of the bladder marked by the openings of the ureters and urethra is called the _____.
4. The amount of dissolved substances in urine is indicated by its _____.
5. The presence of glucose in the urine is known as _____.

Matching

Match each numbered item with the most closely related lettered item.

- | | |
|---|-------------------------|
| ___ 6. Produced by the kidney in response to low blood pressure | a. urea |
| ___ 7. Stimulates vasoconstriction | b. erythropoietin |
| ___ 8. Produced by the kidney in response to hypoxia | c. antidiuretic hormone |
| ___ 9. Stimulates kidneys to produce concentrated urine | d. renin |
| ___ 10. Produced by the liver during protein catabolism | e. angiotensin |

Multiple choice

- ___ 11. The functional unit of the renal system is the
 - a. renal capsule
 - b. kidney
 - c. nephron
 - d. juxtaglomerular apparatus
- ___ 12. The loop of Henle is located in the renal
 - a. cortex
 - b. medulla
 - c. pelvis
 - d. calyx
- ___ 13. Fluid moves out of the glomerulus by
 - a. filtration
 - b. diffusion
 - c. osmosis
 - d. active transport
- ___ 14. One's ability to delay urination is due to voluntary control of the
 - a. trigone
 - b. internal urethral sphincter
 - c. external urethral sphincter
 - d. urinary meatus
- ___ 15. Pus in the urine is termed
 - a. pyuria
 - b. uremia
 - c. anemia
 - d. enuresis

Understanding Concepts

16. List four organ systems active in excretion. What are the products eliminated by each?
17. Compare and contrast the following terms:
 - a. glomerular capsule and glomerulus
 - b. afferent and efferent arteriole
 - c. proximal and distal convoluted tubule
 - d. ureter and urethra
18. Trace the pathway of a urea molecule from the afferent arteriole to the urinary meatus.
19. Describe the four processes involved in the formation of urine.
20. Compare the male urethra and female urethra in structure and function. Why is cystitis more common in women than in men?

21. List some of the dissolved substances normally found in the urine.
22. Differentiate between the following disorders:
 - a. albuminuria and hematuria
 - b. glomerulonephritis and pyelonephritis
 - c. hydronephrosis and polycystic kidney
 - d. renal ptosis and ureterocele
23. What is meant by the word *dialysis* and how is this principle used for patients with kidney failure? What kinds of membranes are used for hemodialysis? for peritoneal dialysis?

Conceptual Thinking

24. Christie is fourteen years old and suffers from anorexia nervosa. Her parents take her to the hospital after she reports sharp pain in the lumbar region of her back. While there, she is diagnosed with hydronephrosis. What is the relationship between her eating disorder and her renal disorder?
25. A class of antihypertensive drugs called loop diuretics prevents sodium reabsorption in the loop of Henle. How could a drug like this lower blood pressure?

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