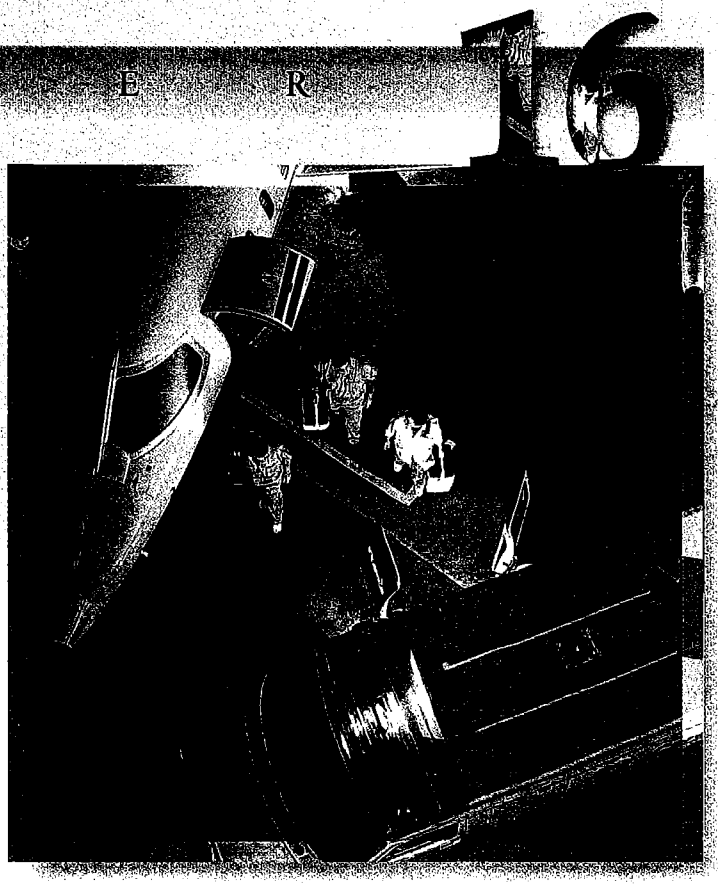
CHAPTER 16

Urinary System and Excretion

Chapter Concepts



We now know how to preserve organs so they can be transported from one city to another for transplant operations.

The plane arrived as expected. Paramedics were ready to rush an insulated container from the aircraft to the operating room of a nearby hospital. Brushing aside the ice in the container, a surgeon plucks out a fist-sized reddish mass—a kidney. Within hours the organ, which has replaced the diseased kidneys inside a young girl's body, is busy producing urine. The transplanted organ, if not rejected, should save the girl from a difficult life of being periodically hooked up to dialysis machines. Rejection is unlikely because it has already been determined that the tissues of the donor are very compatible with those of the recipient.

A kidney is absolutely essential for a healthy life because it helps regulate the pH and the water-salt balance of blood, and it excretes nitrogenous wastes. By regulating the amount of salt and water in the blood, a kidney helps keep blood pressure within a normal range. By excreting nitrogenous wastes, it rids the body of toxic substances. One kidney alone is all we need, and therefore the donor of a kidney will suffer no ill consequences, except the trauma of abdominal surgery. This chapter will detail exactly how a kidney performs its life-preserving functions.

16.1 Urinary System

The urinary system consists of the organs labeled in Figure 16.1. This figure also traces the path of urine. This section discusses the organs of the urinary system, urination, and the functions of the urinary system.

Urinary Organs

The **kidneys** are the primary organs of the urinary system. They are found on either side of the vertebral column, just below the diaphragm. They lie in depressions against the deep muscles of the back beneath the peritoneum, the lining of the abdominal cavity. Although they are somewhat protected by these muscles and by the lower rib cage, the kidneys can be damaged by blows to the back.

The kidneys are bean-shaped and reddish-brown in color. The fist-sized organs are covered by a tough capsule of fibrous connective tissue overlaid by adipose tissue. The concave side of a kidney has a depression called the hilum. The **renal artery** enters and the **renal vein** and ureters exit a kidney at the hilum.

The **ureters,** which extend from the kidneys to the bladder, are small muscular tubes about 25 cm long. Peristalsis moves urine within the ureters, and peristaltic contractions cause urine to enter the bladder at a rate of about five jets per minute.

The **urinary bladder,** which can hold up to 600 ml of urine, is a hollow, muscular organ that gradually expands as urine enters. A sphincter is a circular muscle that encloses a tube. Two sphincters are found in close proximity where the urethra exits the bladder. When these sphincters are closed, urination does not take place.

The **urethra,** which extends from the urinary bladder to an external opening, is a different length in females and males. In females, the urethra is only about 4 cm long. As mentioned in the Health Focus on page 304, the short length of the female urethra makes bacterial invasion easier and helps explain why females are more prone to urinary tract infections than males. In males, the urethra averages 20 cm when the penis is flaccid (limp, nonerect). As the urethra leaves the male urinary bladder, it is encircled by the prostate gland. In older men, enlargement of the prostate gland can restrict urination. A surgical procedure can usually correct the condition and restore a normal flow of urine.

In females, the reproductive and urinary systems are not connected. In males, the urethra carries urine during urination and sperm during ejaculation. This double function of the urethra in males does not alter the path of urine (Fig. 16.1).

Only the urinary system, consisting of the kidneys, the ureter, the urinary bladder, and the urethra, holds urine.

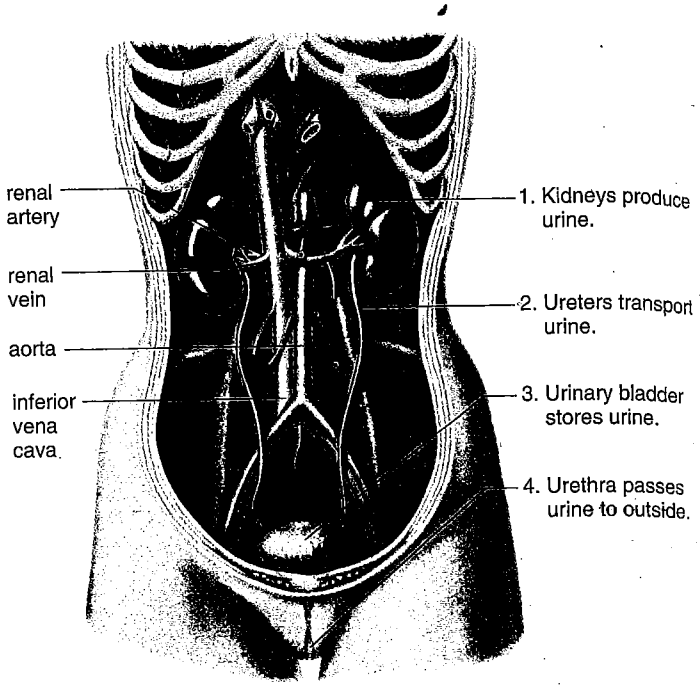


Figure 16.1 The urinary system.
Urine is found only within the kidneys, the ureters, the urinary bladder, and the urethra.

Urination

When the urinary bladder fills to about 250 ml of urine stretch receptors send sensory nerve impulses to the spina cord. Subsequently, motor nerve impulses from the spina cord cause the urinary bladder to contract and the sphinc ters to relax so that urination is possible (Fig. 16.2). In olde children and adults, the brain controls this reflex, delayin urination until a suitable time.

Functions of the Urinary System

The function of the urinary system is to produce urine an conduct it to outside the body. The kidneys produce urine and the other organs of the system store urine or conduct i toward the outside of the body.

Excretion is the removal of metabolic wastes from th body. People sometimes confuse the terms excretion an defecation, but they do not refer to the same proces Defecation refers to the elimination of feces from the bod and is a function of the digestive system. Excretion, o the other hand, refers to the elimination of metaboli wastes, which are the products of metabolism. For exan ple, the undigested food and bacteria that make up fec have never been a part of the functioning of the bod while the substances excreted in urine were once metab lites in the body.

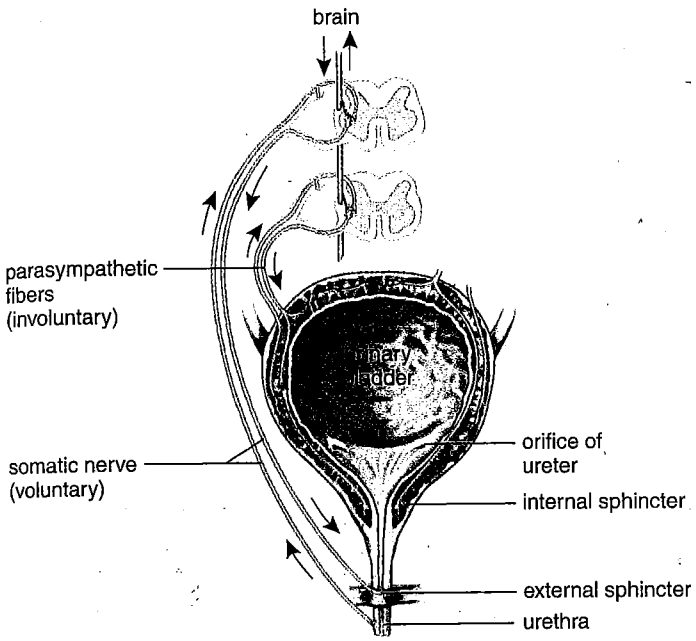


Figure 16.2 Urination.
As the bladder fills with urine, sensory impulses go to the spinal cord and then to the brain. The brain can override the urge to urinate. When urination occurs, motor nerve impulses cause the bladder to contract and an internal sphincter to open. Nerve impulses also cause an external sphincter to open.

The kidneys play a central role in homeostasis by regulating the composition of blood, and therefore tissue fluid. As urine is being produced, the kidneys (1) carry out the excretion of metabolic wastes, particularly nitrogenous wastes; (2) maintain the normal water-salt balance of the blood and, as a consequence, the normal blood volume and blood pressure; and (3) maintain the acid-base balance of blood. The kidneys also (4) have a hormonal function, as will be discussed.

Excretion of Metabolic Wastes

The kidneys excrete metabolic wastes, notably nitrogenous wastes. Urea is the primary nitrogenous end product of metabolism in human beings, but humans also excrete some ammonium, creatinine, and uric acid.

Urea is a by-product of amino acid metabolism. The breakdown of amino acids in the liver releases ammonia, which the liver combines with carbon dioxide to produce urea. Ammonia is very toxic to cells, but urea is much less toxic. Because it is less toxic, less water is required to excrete urea.

The metabolic breakdown of creatine phosphate results in **creatinine.** Creatine phosphate is a high-energy phosphate reserve molecule in muscles.

The breakdown of nucleotides, such as those containing adenine and thymine, produces **uric acid.** Uric acid is rather insoluble. If too much uric acid is present in blood, crystals form and precipitate out. Crystals of uric acid sometimes collect in the joints, producing a painful ailment called gout.

Maintenance of Water-Salt Balance

A principal function of the kidneys is to maintain the appropriate water-salt balance of the blood. As we shall see, blood volume is intimately associated with the salt balance of the body. As you know, salts, such as NaCl, have the ability to cause osmosis, the diffusion of water—in this case, into the blood. The more salts there are in the blood, the greater the blood volume and the greater the blood pressure. In this way, the kidneys are involved in regulating blood pressure.

The kidneys also maintain the appropriate level of other ions, such as potassium ions (K^+), bicarbonate ions (HCO_3^-), and calcium ions (Ca^{2+}), in the blood.

Maintenance of Acid-Base Balance

The kidneys regulate the acid-base balance of the blood. In order for us to remain healthy, the blood pH should be just about 7.4. The kidneys monitor and control blood pH, mainly by excreting hydrogen ions (H^+) and reabsorbing the bicarbonate ions (HCO_3^-) as needed to keep blood pH at 7.4. Urine usually has a pH of 6 or lower because our diet often contains acidic foods.

Secretion of Hormones

The kidneys assist the endocrine system in hormone secretion. The kidneys release renin, a substance that leads to the secretion of the hormone aldosterone from the adrenal cortex, the outer portion of the adrenal glands, which lie atop the kidneys. As described later in this chapter, aldosterone promotes the reabsorption of sodium ions (Na^+) by the kidneys.

Whenever the oxygen-carrying capacity of the blood is reduced, the kidneys secrete the hormone **erythropoietin,** which stimulates red blood cell production.

The kidneys also help activate vitamin D from the skin. Vitamin D is the precursor of the hormone calcitriol, which promotes calcium (Ca^{2+}) reabsorption from the digestive tract.

The kidneys are the primary organs of excretion, particularly of nitrogenous wastes. The kidneys are also major organs of homeostasis because they regulate the water-salt balance and the acid-base balance of the blood as well as the secretion of certain hormones.

16.2 Kidney Structure

When a kidney is sliced lengthwise, it is possible to see that many branches of the renal artery and vein reach inside the kidney (Fig. 16.3*a*). If the blood vessels are removed, it is easier to identify the three regions of a kidney. The **renal cortex** is an outer, granulated layer that dips down in between a radially striated, or lined, inner layer called the renal medulla. The **renal medulla** consists of cone-shaped tissue masses called renal pyramids. The **renal pelvis** is a central space, or cavity, that is continuous with the ureter (Fig. 16.3*b*).

Microscopically, the kidney is composed of over one million **nephrons,** sometimes called renal or kidney tubules (Fig. 16.3*c*). The nephrons produce urine and are positioned so that the urine flows into a collecting duct. Several nephrons enter the same collecting duct; the collecting ducts enter the renal pelvis.

Macroscopically, a kidney has three regions: the renal cortex, the renal medulla, and the renal pelvis which is continuous with the ureter. Microscopically, a kidney contains over one million nephrons.

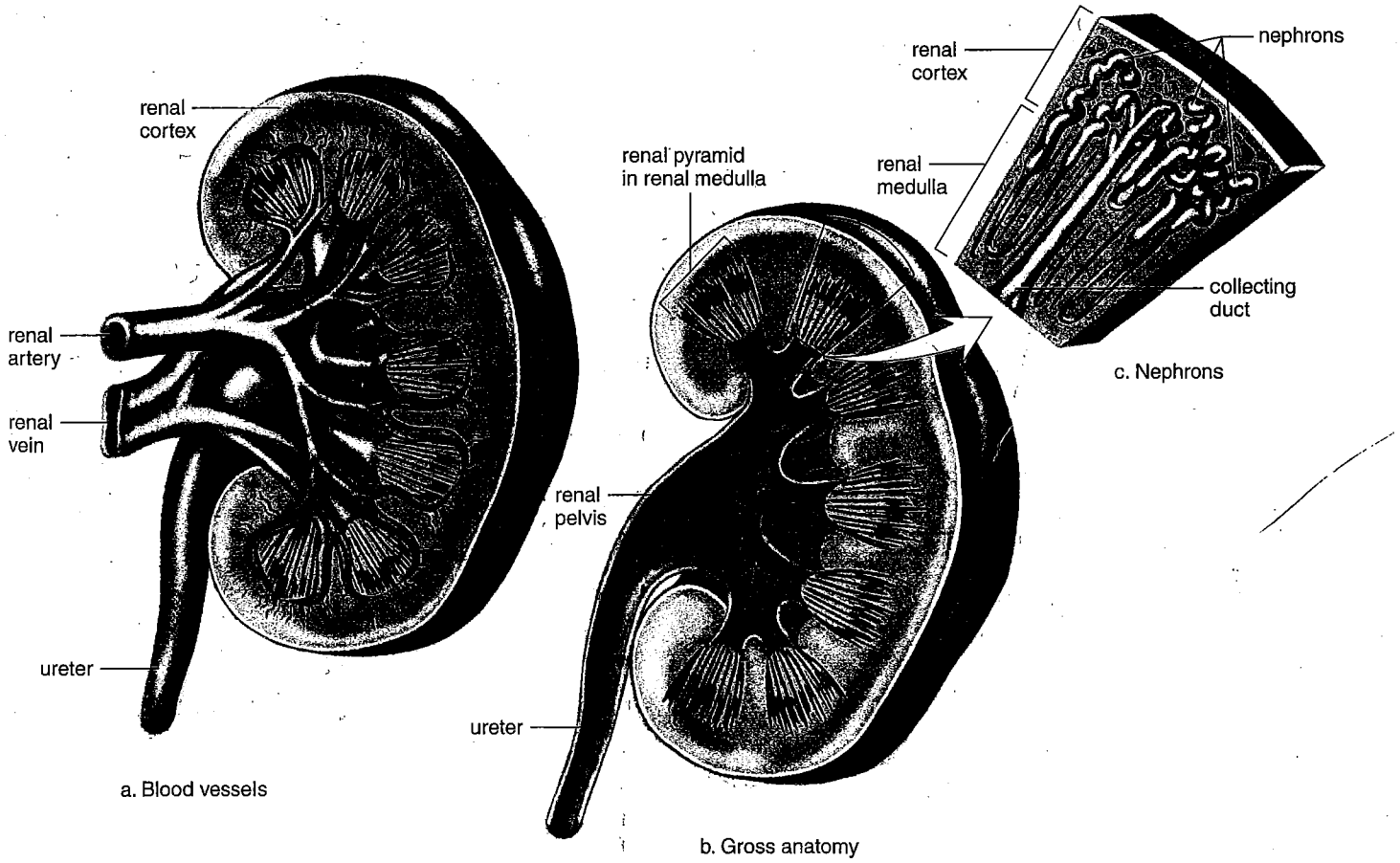


Figure 16.3 Gross anatomy of the kidney.
a. A longitudinal section of the kidney showing the blood supply. Note that the renal artery divides into smaller arteries, and these divide into arterioles. Venules join to form small veins, which join to form the renal vein. **b.** The same section without the blood supply. Now it is easier to distinguish the renal cortex, the renal medulla, and the renal pelvis, which connects with the ureter. The renal medulla consists of the renal pyramids. **c.** An enlargement showing the placement of nephrons.