CHAPTER 48

DIGESTIVE AND EXCRETORY SYSTEMS

This is a scanning electron micrograph of a filtration membrane in the human kidney. (SEM 3060×)

SECTION 1 *Nutrients*

SECTION 2 *Digestive System*

SECTION 3 *Urinary System*

SECTION 3

URINARY SYSTEM

The body must rid itself of the waste products of cellular activity. The process of removing metabolic wastes, called ***excretion,*** *is just as vital as digestion in maintaining the body's internal environment. Thus, the urinary system not only excretes wastes but also helps maintain homeostasis by regulating the content of water and other substances in the blood.*

OBJECTIVES

- **Identify** the major parts of the kidney.
- **Relate** the structure of a nephron to its function.
- **Explain** how the processes of filtration, reabsorption, and secretion help maintain homeostasis.
- **Summarize** the path in which urine is eliminated from the body.
- **List** the functions of each of the major excretory organs.

VOCABULARY

excretion
renal cortex
renal medulla
renal pelvis
urea
ammonia
urine
nephron
Bowman's capsule
glomerulus
renal tubule
filtration
reabsorption
secretion
loop of Henle
ureter
urinary bladder
urethra

KIDNEYS

The main waste products that the body must eliminate are carbon dioxide, from cellular respiration, and nitrogenous compounds, from the breakdown of proteins. The lungs excrete most of the carbon dioxide, and nitrogenous wastes are eliminated by the kidneys. The excretion of water is necessary to dissolve wastes and is closely regulated by the kidneys, the main organs of the urinary system.

Humans have two bean-shaped kidneys, each about the size of a clenched fist. The kidneys are located one behind the stomach and the other behind the liver. Together, they regulate the chemical composition of the blood.

Structure

Figure 48-15 shows the three main parts of the kidney. The **renal cortex,** the outermost portion of the kidney, makes up about a third of the kidney's tissue mass. The **renal medulla** is the inner two-thirds of the kidney. The **renal pelvis** is a funnel-shaped structure in the center of the kidney. Also, notice in Figure 48-15 that blood enters the kidney through a renal artery and leaves through a renal vein. The renal artery transports nutrients and wastes to the kidneys. The nutrients are used by kidney cells to carry out their life processes. One such process is the removal of wastes brought by the renal artery.

The most common mammalian metabolic waste is **urea** (yoo-REE-uh), a nitrogenous product made by the liver. Nitrogenous wastes are initially brought to the liver as **ammonia,** a chemical compound of nitrogen so toxic that it could not remain long in the body without harming cells. The liver removes ammonia from the blood and converts it into the less harmful substance urea. The urea enters the bloodstream and is then removed by the kidneys.

internet connect

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Topic: Urinary System
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NEPHRONS

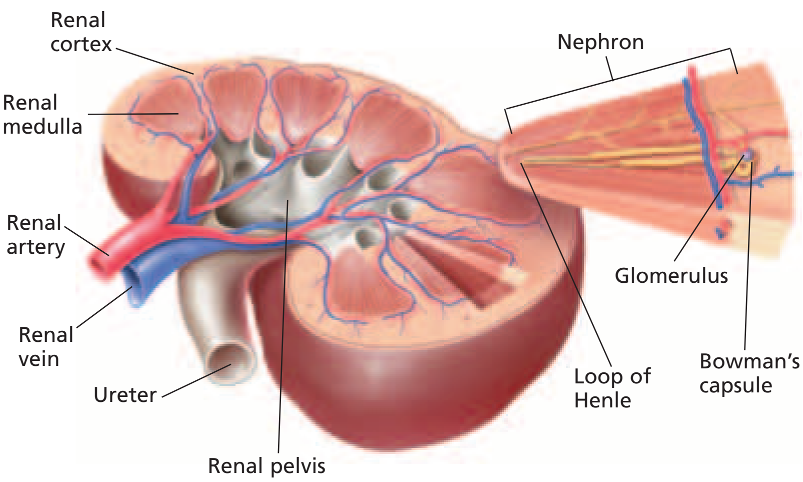
The substances removed from the blood by the kidneys—toxins, urea, water, and mineral salts—form an amber-colored liquid called **urine.** Urine is made in structures called **nephrons** (NEF-RAHNZ), the functional units of the kidney. Nephrons are tiny tubes in the kidneys. One end of a nephron is a cup-shaped capsule surrounding a tight ball of capillaries that retains cells and large molecules in the blood and passes wastes dissolved in water through the nephron. The cup-shaped capsule is called **Bowman's capsule.** Within each Bowman's capsule, an arteriole enters and splits into a fine network of capillaries called a **glomerulus** (gloh-MER-yoo-luhs).

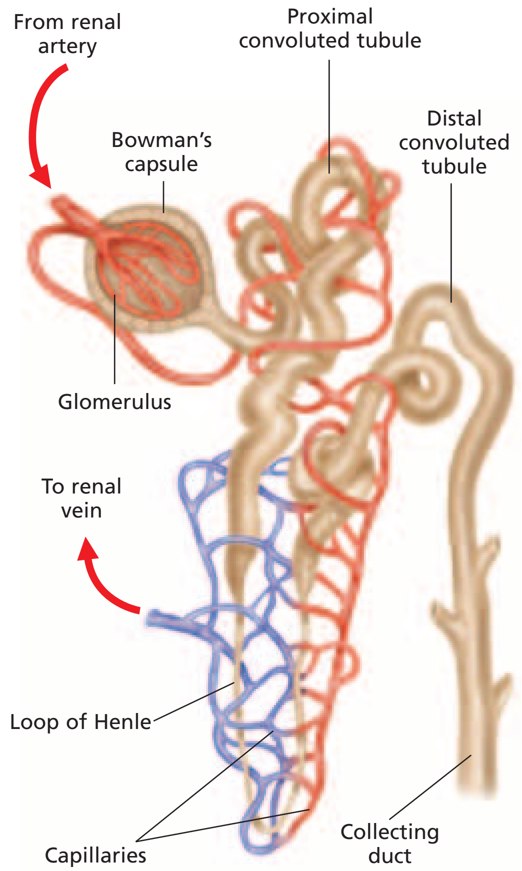
Take a close look at the structure of the nephron, shown in Figure 48-15. Notice the close association between a nephron of the kidney and capillaries of the circulatory system. Initially, fluid passes from the glomerulus into a Bowman's capsule of the nephron. As the fluid travels through the nephron, nutrients that passed into the Bowman's capsule are reabsorbed into the bloodstream. What normally remains in the nephron are waste products and some water, which form urine that passes out of the kidney.

Each kidney consists of more than a million nephrons. If they were stretched out, the nephrons from both kidneys would extend for 80 km (50 mi). As you read about the structure of a nephron, locate each part in Figure 48-15.

FIGURE 48-15

The outer region of the kidney, the renal cortex, contains structures that filter blood brought by the renal artery. The inner region, or renal medulla, consists of structures that carry urine, which empties into the funnel-shaped renal pelvis. The renal vein transports the filtered blood back to the heart.





Each nephron has a cup-shaped structure, called a Bowman's capsule, that encloses a bed of capillaries. This capillary bed, called a glomerulus, receives blood from the renal artery. Fluids are forced from the blood through the capillary walls and into the Bowman's capsule. The material filtered from the blood then flows through the **renal tubule,** which consists of three parts: the proximal convoluted tubule, the loop of Henle, and the distal convoluted tubule. Blood remaining in the glomerulus then flows through a network of capillaries. The long and winding course of both the renal tubule and the surrounding capillaries provides a large surface area for the exchange of materials.

As the filtrate flows through a nephron, its composition is modified by the exchange of materials among the renal tubule, the capillaries, and the extracellular fluid. Various types of exchanges take place in the different parts of the renal tubule. To understand how the structure of each part of the nephron is related to its function, we will examine the three major processes that take place in the nephron: filtration, reabsorption, and secretion. Figure 48-16 shows the site of each of these processes in the nephron.

Word Roots and Origins

glomerulus

from the Latin *glom*, meaning "little ball of yarn"

FILTRATION

Materials from the blood are forced out of the glomerulus and into the Bowman's capsule during a process called **filtration.** Blood in the glomerulus is under relatively high pressure. This pressure forces water, urea, glucose, vitamins, and salts through the thin capillary walls of the glomerulus and into the Bowman's capsule. About one-fifth of the fluid portion of the blood filters into the Bowman's capsule. The rest remains in the capillaries, along with proteins and cells that are too large to pass through the capillary walls. In a healthy kidney, the filtrate—the fluid that enters the nephron—does not contain large protein molecules.

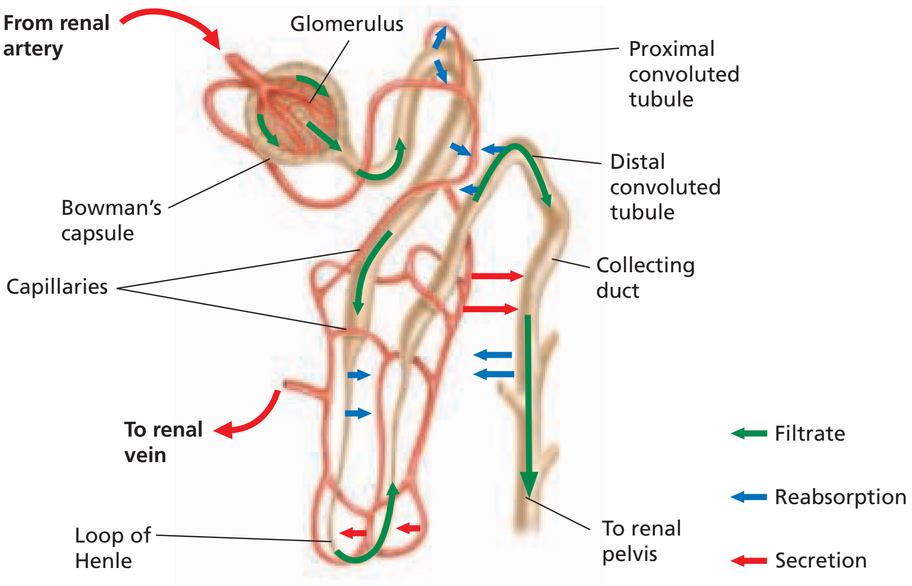


FIGURE 48-16

Color-coded arrows indicate where in the nephron the filtrate travels, and where reabsorption and secretion occur.

REABSORPTION AND SECRETION

The body needs to retain many of the substances that were removed from the blood by filtration. Thus, as the filtrate flows through the renal tubule, these materials return to the blood by being selectively transported through the walls of the renal tubule and into the surrounding capillaries. This process is called **reabsorption.** Most reabsorption occurs in the proximal convoluted tubule. In this region, about 75 percent of the water in the filtrate returns to the capillaries by osmosis. Glucose and minerals, such as sodium, potassium, and calcium, are returned to the blood by active transport. Some additional reabsorption occurs in the distal convoluted tubule.

When the filtrate reaches the distal convoluted tubule, some substances pass from the blood into the filtrate through a process called **secretion.** These substances include wastes and toxic materials. The pH of the blood is adjusted by hydrogen ions that are secreted from the blood into the filtrate.

Formation of Urine

The fluid and wastes that remain in the distal convoluted tubule form urine. The urine from several renal tubules flows into a collecting duct. Notice in Figure 48-17 that the urine is further concentrated in the collecting duct by the osmosis of water through the wall of the duct. This process allows the body to conserve water. In fact, osmosis in the collecting duct, together with reabsorption in other parts of the tubule, returns to the blood about 99 of every 100 mL (about 3.4 oz) of water in the filtrate.

Eco Connection

Kidneys and Pollution

According to data from the U.S. Environmental Protection Agency, indoor areas, where we spend up to 90 percent of our time, contain substances that may be hazardous to our health. Because of their function in excretion, kidneys often are exposed to hazardous chemicals that have entered the body through the lungs, skin, or gastrointestinal tract. Household substances that, in concentration, can damage kidneys include paint, varnishes, furniture oils, glues, aerosol sprays, air fresheners, and lead.

Many factors in our environment are difficult to control, but the elimination of pollutants from our indoor living areas is fairly simple. The four steps listed below may help reduce the effects of many indoor pollutants.

1. Identify sources of pollutants in your home.
2. Eliminate the sources, if possible.
3. Seal off those sources that cannot be eliminated.
4. Ventilate to evacuate pollutants and bring in fresh air.

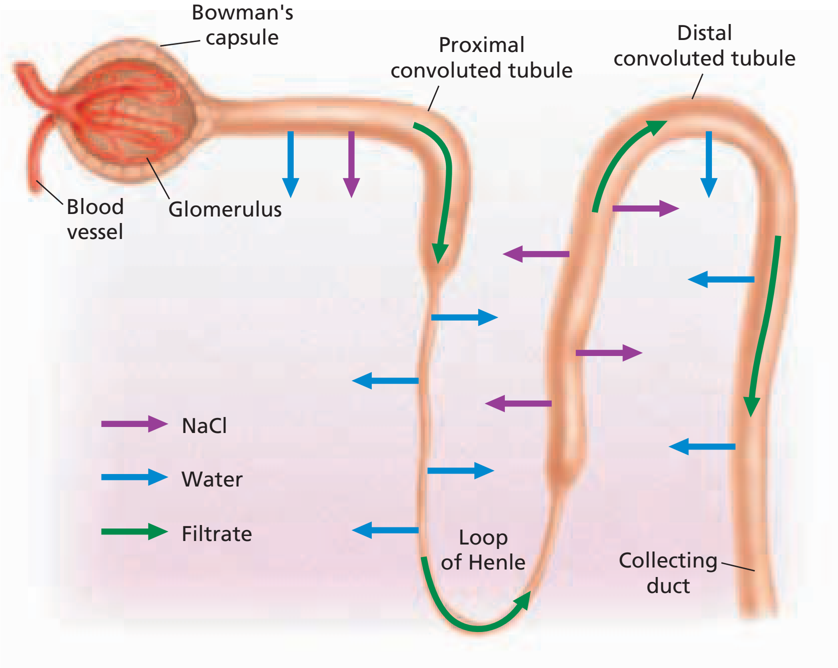


FIGURE 48-17

The sodium chloride that is actively transported out of the loop of Henle makes the extracellular environment surrounding the collecting duct hypertonic. Thus, water moves out of the collecting duct by osmosis into this hypertonic environment, increasing the concentration of urine.

The Loop of Henle

The function of the **loop of Henle** (HEN-lee) is closely related to that of the collecting duct. Water moves out of the collecting duct because the concentration of sodium chloride is higher in the fluid surrounding the collecting duct than it is in the fluid inside the collecting duct. This high concentration of sodium chloride is created and maintained by the loop of Henle. Cells in the wall of the loop transport chloride ions from the filtrate to the fluid between the loops and the collecting duct. Positively charged sodium ions follow the chloride ions into the fluid. This process ensures that the sodium chloride concentration of the fluid between the loops and the collecting duct remains high and thus promotes the reabsorption of water from the collecting duct.

ELIMINATION OF URINE

Urine from the collecting ducts flows through the renal pelvis and into a narrow tube called a **ureter** (yoo-REET-uhr). A ureter leads from each kidney to the **urinary bladder,** a muscular sac that stores urine. Muscular contractions of the bladder force urine out of the body through a tube called the **urethra** (yoo-REE-thruh). Locate the ureters, urinary bladder, and urethra in Figure 48-18.

At least 500 mL (17 oz) of urine must be eliminated every day because this amount of fluid is needed to remove potentially toxic materials from the body and to maintain homeostasis. A normal adult eliminates from 1.5 L (1.6 qt) to 2.3 L (2.4 qt) of urine a day, depending on the amount of water taken in and the amount of water lost through respiration and perspiration.

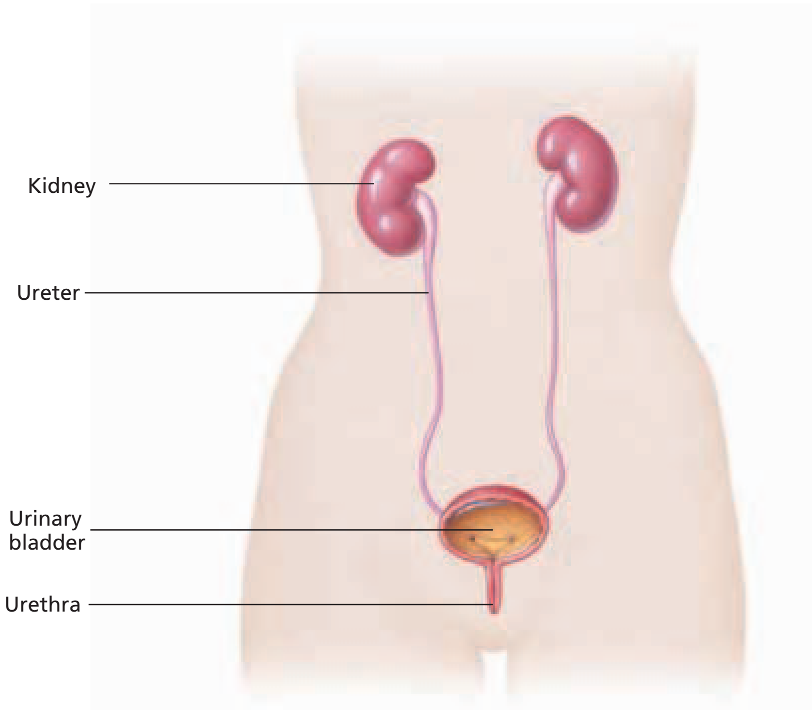


FIGURE 48-18

Urine travels from each kidney through a ureter to the urinary bladder, where it is stored until it is eliminated from the body through the urethra.

Quick Lab

Analyzing Kidney Filtration

Materials disposable gloves, lab apron, safety goggles, 20 mL of test solution, 3 test tubes, filter, beaker, 15 drops each of biuret and Benedict's solution, 2 drops IKI solution, 3 pipets, wax marker pen

Procedure

1. Put on your gloves, lab apron, and safety goggles.
2. Put 15 drops of the test solution into each of the test tubes. Label the test tubes "Protein," "Starch," and "Glucose."
3. Add 15 drops of biuret solution to the test tube labeled "Protein." Record your observations.
4. Add 15 drops of Benedict's solution to the test tube labeled "Glucose." Record your observations.
5. Add two drops of IKI solution to the test tube labeled "Starch." Record your observations.
6. Discard the tested solutions, and rinse your test tubes as your teacher directs.
7. Pour the remaining test solution through a filter into a beaker. Using the test solution from the beaker, repeat steps 3–5.

Analysis Which compounds passed through the filter paper? If some did not, explain why. How does the filtration of this activity resemble the activity of the kidney?

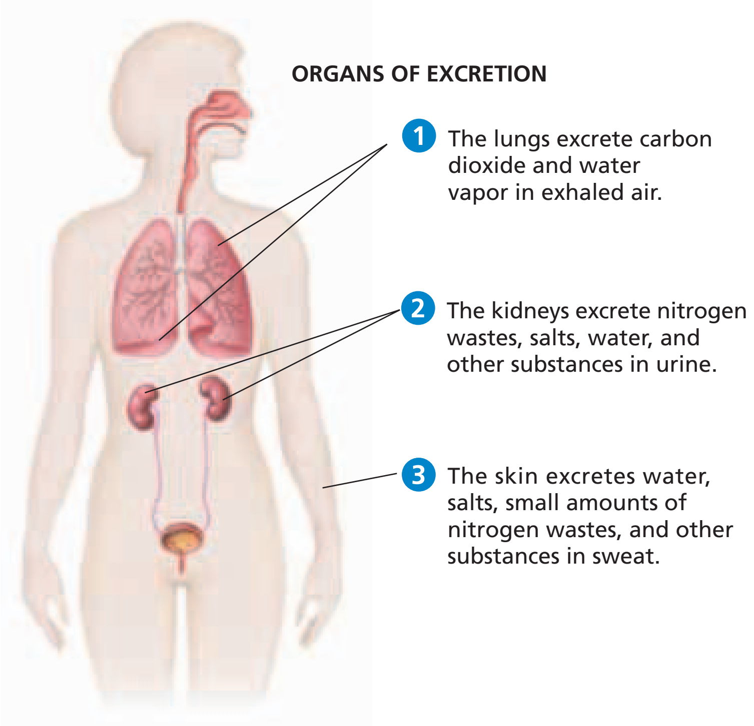


FIGURE 48-19

The lungs, the kidneys, and the skin all function as excretory organs. The main excretory products are carbon dioxide, nitrogen wastes (urea), salts, and water.

THE EXCRETORY ORGANS

Although the kidneys, lungs, and skin belong to different organ systems, they all have a common function: waste excretion.

The kidneys are the primary excretory organs of the body. They play a vital role in maintaining the homeostasis of body fluids.

The lungs are the primary site of carbon dioxide excretion. The lungs carry out detoxification, altering harmful substances so that they are not poisonous. The lungs are also responsible for the excretion of the volatile substances in onions, garlic, and other spices.

The skin helps the kidneys control the salt composition of the blood. Some salt, water, nitrogen waste and other substances are excreted through perspiration. A person working in extreme heat may lose water through perspiration at the rate of 1 L per hour. This amount of perspiration represents a loss of about 10 to 30 g of salt per day. Both the water and salt must be replenished to maintain normal body functions.

Figure 48-19 summarizes some waste substances and the organ(s) that excrete them. Notice that undigested food is not in the figure. Undigested food is not excreted in the scientific sense; it is eliminated, meaning it is expelled as feces from the body without ever passing through a membrane or being subjected to metabolic processes. The term *excretion* correctly refers to the process during which substances must pass through a membrane to leave the body.

SECTION 3 REVIEW

1. Illustrate and label the major parts of the kidney.
2. Explain how the structure of a nephron relates to its function.
3. Describe three processes carried out in the kidney that help maintain homeostasis.
4. Identify five of the structures through which urine is eliminated.
5. Explain the function of each of the organs involved in excretion.

CRITICAL THINKING

6. **Relating Concepts** Explain why a high concentration of protein in the urine may indicate damaged kidneys.
7. **Recognizing Relationships** Why would there be a decrease in urine output if a person had lost a large amount of blood?
8. **Analyzing Concepts** Given the definition of *excretion,* why do you think the large intestine is not classified as a major excretory organ?

CHAPTER HIGHLIGHTS

SECTION 1 Nutrients

- The human body needs six nutrients—carbohydrates, proteins, lipids, vitamins, minerals, and water—to grow and function.
- Carbohydrates, found in foods such as breads, provide most of the body's energy. The body quickly processes monosaccharides. Cellulose cannot be digested but is needed for fiber.
- Proteins, found in foods such as meats, help the body grow and repair tissues. Essential amino acids must be obtained from foods.
- Lipids, found in foods such as oils, are used to build cell membranes.
- Vitamins act as coenzymes to enhance enzyme function.
- Minerals are inorganic substances used to build red blood cells and bones and for muscle and nerve functions.
- Water helps regulate body temperature and transports nutrients and wastes.

Vocabulary

nutrient (p. 979)
vitamin (p. 982)
mineral (p. 982)
dehydration (p. 984)

SECTION 2 Digestive System

- Mechanical digestion involves the breaking of food into smaller particles. Chemical digestion involves changing the chemical nature of the food substance.
- The mouth, teeth, and tongue initiate mechanical digestion. Chemical digestion of carbohydrates begins in the mouth.
- The esophagus is a passageway through which food passes from the mouth to the stomach by peristalsis.
- The stomach has layers of muscles that churn the food to assist in mechanical digestion. Pepsin in the stomach begins the chemical digestion of proteins.
- Bile assists in the mechanical digestion of lipids. Enzymes secreted by the pancreas complete the digestion of the chyme.
- The digested nutrients are absorbed through the villi of the small intestine.
- The large intestine absorbs water from the undigested mass. The undigested mass is eliminated as feces through the anus.

Vocabulary

digestion (p. 985)
gastrointestinal tract (p. 985)
saliva (p. 986)
pharynx (p. 986)
epiglottis (p. 986)
peristalsis (p. 987)
gastric fluid (p. 988)
ulcer (p. 988)
cardiac sphincter (p. 988)
chyme (p. 988)
pyloric sphincter (p. 988)
gallbladder (p. 989)
villus (p. 990)
colon (p. 991)

SECTION 3 Urinary System

- Excretion is the removal of metabolic wastes from the body.
- The kidneys are the main organs of excretion and of the urinary system.
- Nephrons are the functional units of the kidneys. Through filtration, reabsorption, and secretion, they remove wastes and return nutrients and water to the blood.
- The urine passes through a ureter and is stored in the urinary bladder until it is eliminated through the urethra.
- Urine must be eliminated from the body to remove toxic materials and to maintain homeostasis.
- The lungs and the skin also play an important role in the excretion of wastes.

Vocabulary

excretion (p. 993)
renal cortex (p. 993)
renal medulla (p. 993)
renal pelvis (p. 993)
urea (p. 993)
ammonia (p. 993)
urine (p. 994)
nephron (p. 994)
Bowman's capsule (p. 994)
glomerulus (p. 994)
renal tubule (p. 995)
filtration (p. 995)
reabsorption (p. 996)
secretion (p. 996)
loop of Henle (p. 997)
ureter (p. 997)
urinary bladder (p. 997)
urethra (p. 997)

Using Vocabulary

1. For each set of terms, choose the one that does not belong, and explain why it does not belong.
   a. *carbohydrate, protein, lipid,* and *mineral*
   b. *pharynx, epiglottis, bolus,* and *esophagus*
   c. *cardiac sphincter, gastric pits, renal medulla,* and *pyloric sphincter*
   d. *absorption, filtration, secretion,* and *reabsorption*
2. Use the following terms in the same sentence: *gallbladder, gastric fluid, pepsin,* and *saliva.*
3. **Word Roots and Origins** The word *protein* is derived from the Greek *proteios,* which means "of prime importance." Using this information, explain why the term *protein* is a good name for the nutrient it describes.

Understanding Key Concepts

4. **Identify** which of the six nutrients needed by the body are organic and which are inorganic.
5. **State** the daily number of servings needed from each food group in the USDA Food Guide pyramid in order to maintain a healthy diet.
6. **Propose** a vegetarian diet that includes all of the nutrients needed by the human body.
7. **Explain** the role of inorganic nutrients in keeping the body healthy.
8. **Name** the nutrient that makes up more than 90 percent of the fluid part of blood.
9. **Name** the nutrient associated with heart disease when it is consumed in high levels.
10. **List** the organs of the digestive system and their functions.
11. **Contrast** the processes involved in mechanical and chemical digestion.
12. **Describe** how the stomach carries out mechanical digestion.
13. **Identify** the source and function of each major digestive enzyme.
14. **Predict** the problems a person might have if his or her small intestine were not functioning properly.
15. **Identify** the function of the large intestine.
16. **Identify** the major parts of the kidney.
17. **Explain** the relationship between Bowman's capsule, the proximal tubule, the loop of Henle, and the distal tubule.
18. **Identify** the processes that occur in the nephron that maintain homeostasis.
19. **Summarize** how urine is stored and eliminated from the body.
20. **Describe** the function of two organs other than kidneys that are also involved in excretion.
21. **CONCEPT MAPPING** Use the following terms to create a concept map that shows the process of digestion: *bile, chemical digestion, chyme, digestion, liver, mechanical digestion, molar, pancreas, saliva, small intestine,* and *stomach.*

Critical Thinking

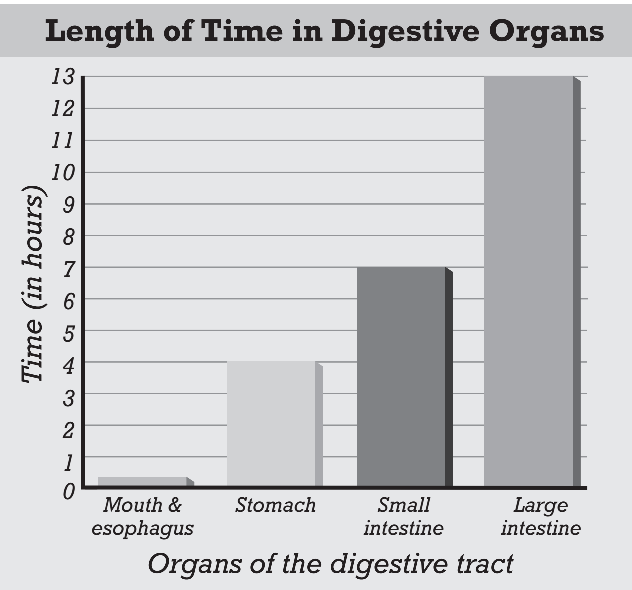
22. **Applying Information** In some countries, many children suffer from a type of malnutrition called *kwashiorkor*. They have swollen stomachs and become increasingly thin until they die. Even when given rice and water, these children still die. What type of nutritional deficiency might these children have?
23. **Analyzing Concepts** Why is it important that the large intestine reabsorb water and not eliminate it?
24. **Predicting Patterns** The loop of Henle functions to conserve water by aiding in reabsorption. Its length varies among mammal species. Would you expect the loop of Henle of an animal such as the beaver, which lives in a watery environment, to be longer or shorter than that found in humans? Explain your answer.
25. **Recognizing Relationships** Look at the pictures of the teeth of different animals. What can you tell about the human diet by comparing the teeth of humans with those of other animals shown here?

Standardized Test Preparation

DIRECTIONS: Choose the letter of the answer choice that best answers the question.

1. What is the primary function of carbohydrates?
   A. to aid in digestion
   B. to break down molecules
   C. to regulate the flow of chyme
   D. to supply the body with energy
2. How can dehydration best be prevented?
   F. by perspiring
   G. by inhaling air
   H. by drinking water
   J. by not drinking water
3. Why is the epiglottis important?
   A. It regulates the flow of chyme.
   B. It prevents food from going down the trachea.
   C. It separates the pharynx from the nasal cavity.
   D. It is the passage through which food travels to the stomach.

INTERPRETING GRAPHICS: The graph below shows the approximate length of time food spends in each digestive organ. Use the graph below to answer the following question.

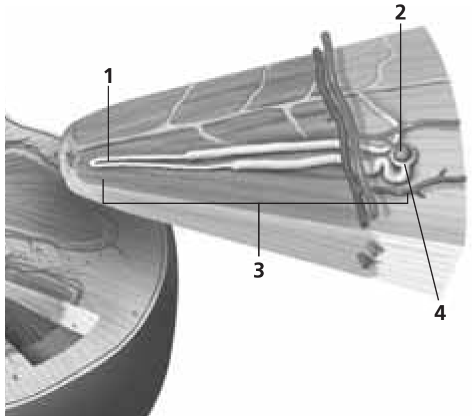


4. Bile breaks up large fat droplets. Approximately how long is the food in the digestive tract before it comes into contact with bile?
   F. 4 hours
   G. 7 hours
   H. 11 hours
   J. 13 hours

DIRECTIONS: Complete the following analogy.

5. lung : alveolus :: kidney :
   A. ureter
   B. nephron
   C. microvillus
   D. glomerulus

INTERPRETING GRAPHICS: The figure below shows a cross section of a kidney. Use the figure to answer the question that follows.



6. Which part of the model represents the loop of Henle?
   F. 1
   G. 2
   H. 3
   J. 4

SHORT RESPONSE

The liver and pancreas are accessory organs of the gastrointestinal tract.

In what two ways do the liver and pancreas differ from other digestive organs?

EXTENDED RESPONSE

When a person's kidneys stop functioning, urea builds up in the blood. For the urea to be removed, the person must be attached to a mechanical kidney, also called a dialysis machine.

Part A What would happen if the person did not have the urea removed from his or her blood?

Part B Using your understanding of how a normal kidney functions, suggest a design for the major components of a dialysis machine.

Test TIP Study of the digestive and urinary systems is often aided by drawing flowcharts of the processes described.

Modeling Human Digestion

OBJECTIVES

- Test a model of digestion in the human stomach.

PROCESS SKILLS

- modeling
- hypothesizing
- observing
- predicting
- inferring

MATERIALS

- safety goggles
- lab apron
- glass-marking pencil
- 5 test tubes with stoppers
- test-tube rack
- scalpel
- cooked egg white
- balance
- 10 mL graduated cylinder
- 1% pepsin solution
- 0.2% hydrochloric acid
- 1% sodium bicarbonate
- distilled water
- red and blue litmus paper
- lined paper
- disposable gloves

Background

1. How is food changed from the chunks you chew with your teeth to the chyme absorbed in your small intestine?
2. What type of organic compound does the enzyme pepsin digest?

PART A Setting Up

1. Label five test tubes 1, 2, 3, 4, and 5, and place them in a test-tube rack.
2. CAUTION **Always cut in a direction away from your body.** Use a scalpel to cut a firm, cooked egg white into fine pieces.
3. Using the balance, measure and place equal amounts (about 6 g) of the fine egg white sample into each test tube, as shown in the illustration above.
4. CAUTION **Put on safety goggles and a lab apron. If you get hydrochloric acid solution on your skin or clothes, wash it off at the sink while calling to your teacher. If you get any solutions in this investigation in your eyes, immediately flush them out at the eyewash station while calling to your teacher.** Use a clean graduated cylinder to add the solutions listed below to the test tubes. Rinse the cylinder between additions so that you do not contaminate the samples.
   - test tube 1—10 mL of water
   - test tube 2—10 mL of pepsin solution
   - test tube 3—10 mL of hydrochloric acid
   - test tube 4—5 mL of pepsin solution and 5 mL of sodium bicarbonate solution
   - test tube 5—5 mL of pepsin and 5 mL of hydrochloric acid

DEGREE OF DIGESTION OF EGG WHITE UNDER VARYING CONDITIONS			
Test-tube number	**Contents**	**pH**	**Degree of digestion**
1	egg white 10 mL water		
2	egg white 10 mL 1% pepsin solution		
3	egg white 10 mL 0.2% hydrochloric acid solution		
4	egg white 5 mL 1% pepsin solution 5 mL 1% sodium bicarbonate solution		
5	egg white 5 mL 1% pepsin solution 5 mL 0.2% hydrochloric acid solution		

5. Stopper and gently shake each test tube.
6. In your lab report, make a data table like the one shown above.
7. In your lab report, write a hypothesis which predicts which test tube will show the most digestion after 48 hours. Explain your reasoning.
8. Label your test-tube rack with your initials. Store the test-tube rack for 48 hours at room temperature. Leave a note on the rack cautioning others not to spill the acids or bases.
9. Clean up your lab materials, and wash your hands before leaving the lab.

PART B Recording the Results

10. After 48 hours, measure the pH of each solution with red and blue litmus paper. Record your results in the data table you created in your lab report.
11. Look for the egg white in each test tube. In your data table, describe the degree to which the egg white has broken down and dissolved in each test tube.
12. Clean up your lab materials, and wash your hands before leaving the lab.

Analysis and Conclusions

1. What conditions caused the greatest digestion of cooked egg white?
2. Which test tube best modeled the chemical composition in the human stomach?
3. What information do test tubes 1, 2, and 3 give you? What do they control?
4. Compare test tubes 4 and 5. What can you conclude about the effects of the chemical environment on the activity of pepsin?
5. List some other foods that pepsin is likely to digest.
6. Do you think that pepsin would digest butter? Explain your answer.

Further Inquiry

Design an experiment to test the digestion of a food containing carbohydrates, such as a potato or an apple.