This color-enhanced image was made with an electron microscope, so the objects it depicts are extremely small. Do you know what they are? This incredible photo shows red blood cells leaking out of a ruptured blood vessel.

Blood vessels are part of the circulatory system, the “highway” system of the human body that transports materials to all of its cells. Red blood cells carry some of these materials, so they are a little like trucks on a highway. In this chapter, you will learn more about capillaries, red blood cells, and other structures of the circulatory system.
23.1 The Circulatory System

Lesson Objectives

- Explain how the heart pumps blood throughout the body.
- Compare different types of blood vessels and their roles.
- Outline pathways of the pulmonary and systemic circulations.
- Define cardiovascular disease, and list its risk factors.
- Describe blood, blood components, and blood pressure.

Vocabulary

**antigen** molecule that the immune system identifies as foreign and responds to by forming antibodies

**artery** type of blood vessel that carries blood away from the heart toward the lungs or body

**atherosclerosis** condition in which plaque builds up inside arteries

**blood** fluid connective tissue that circulates throughout the body through blood vessels

**blood pressure** force exerted by circulating blood on the walls of blood vessels

**blood type** genetic characteristic associated with the presence or absence of antigens on the surface of red blood cells

**capillary** smallest type of blood vessel that connects very small arteries and veins

**cardiovascular disease (CVD)** any disease that affects the heart or blood vessels

**circulatory system** organ system consisting of the heart, blood vessels, and blood that transports materials around the body

**heart attack** blockage of blood flow to heart muscle tissues that may result in the death of cardiac muscle fibers

**hypertension** high blood pressure

**plasma** golden-yellow fluid part of blood that contains many dissolved substances and blood cells

**platelet** cell fragment in blood that helps blood clot
pulmonary circulation  part of the circulatory system that carries blood between the heart and lungs

red blood cell  type of cell in blood that contains hemoglobin and carries oxygen

systemic circulation  part of the circulatory system that carries blood between the heart and body

vein  type of blood vessel that carries blood toward the heart from the lungs or body

white blood cell  type of cell in blood that defends the body against invading microorganisms or other threats in blood or extracellular fluid

Introduction

The circulatory system can be compared to a system of interconnected, one-way roads that range from superhighways to back alleys. Like a network of roads, the job of the circulatory system is to allow the transport of materials from one place to another. As described in Figure 23.1, the materials carried by the circulatory system include hormones, oxygen, cellular wastes, and nutrients from digested food. Transport of all these materials is necessary to maintain homeostasis of the body. The main components of the circulatory system are the heart, blood vessels, and blood. Each of these components is described in detail below.

![FIGURE 23.1](image)
The function of the circulatory system is to move materials around the body.

The Heart

The heart is a muscular organ in the chest. It consists mainly of cardiac muscle tissue and pumps blood through blood vessels by repeated, rhythmic contractions. The heart has four chambers, as shown in Figure 23.2: two upper
atria (singular, atrium) and two lower ventricles. Valves between chambers keep blood flowing through the heart in just one direction. For an animation of the structures of the heart, go to this link: http://www.byrnehealthcare.com/animations/SutterAnatomy.htm.

**Blood Flow Through the Heart**

Blood flows through the heart in two separate loops, which are indicated by the arrows in Figure 23.2. You can also watch an animation of the heart pumping blood at this link: http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_pumping.html.

a. Blood from the body enters the right atrium of the heart. The right atrium pumps the blood to the right ventricle, which pumps it to the lungs. This loop is represented by the blue arrows in Figure 23.2.

b. Blood from the lungs enters the left atrium of the heart. The left atrium pumps the blood to the left ventricle, which pumps it to the body. This loop is represented by the red arrows in Figure 23.2.

**Heartbeat**

Unlike skeletal muscle, cardiac muscle contracts without stimulation by the nervous system. Instead, specialized cardiac muscle cells send out electrical impulses that stimulate the contractions. As a result, the atria and ventricles normally contract with just the right timing to keep blood pumping efficiently through the heart. You can watch an animation to see how this happens at this link: http://www.nhlbi.nih.gov/health/dci/Diseases/hhw/hhw_electrical.html.
Blood Vessels

Blood vessels form a network throughout the body to transport blood to all the body cells. There are three major types of blood vessels: arteries, veins, and capillaries. All three are shown in Figure 23.3 and described below.

- **Arteries** are muscular blood vessels that carry blood away from the heart. They have thick walls that can withstand the pressure of blood being pumped by the heart. Arteries generally carry oxygen-rich blood. The largest artery is the aorta, which receives blood directly from the heart.
- **Veins** are blood vessels that carry blood toward the heart. This blood is no longer under much pressure, so many veins have valves that prevent backflow of blood. Veins generally carry deoxygenated blood. The largest vein is the inferior vena cava, which carries blood from the lower body to the heart.
- **Capillaries** are the smallest type of blood vessels. They connect very small arteries and veins. The exchange of gases and other substances between cells and the blood takes place across the extremely thin walls of capillaries.

**Blood Vessels and Homeostasis**

Blood vessels help regulate body processes by either constricting (becoming narrower) or dilating (becoming wider). These actions occur in response to signals from the autonomic nervous system or the endocrine system. Constriction occurs when the muscular walls of blood vessels contract. This reduces the amount of blood that can flow through the vessels (see Figure 23.4). Dilation occurs when the walls relax. This increases blood flows through the vessels. Constriction and dilation allow the circulatory system to change the amount of blood flowing to different organs. For example, during a fight-or-flight response, dilation and constriction of blood vessels allow more blood to flow to...
skeletal muscles and less to flow to digestive organs. Dilation of blood vessels in the skin allows more blood to flow to the body surface so the body can lose heat. Constriction of these blood vessels has the opposite effect and helps conserve body heat.

**Blood Vessels and Blood Pressure**

The force exerted by circulating blood on the walls of blood vessels is called **blood pressure**. Blood pressure is highest in arteries and lowest in veins. When you have your blood pressure checked, it is the blood pressure in arteries that is measured. High blood pressure, or **hypertension**, is a serious health risk but can often be controlled with lifestyle changes or medication. You can learn more about hypertension by watching the animation at this link: http://www.healthcentral.com/high-blood-pressure/introduction-47-115.html.

**Pulmonary and Systemic Circulations**

The circulatory system actually consists of two separate systems: pulmonary circulation and systemic circulation. You can watch animations of both systems at the following link. http://www.pbs.org/wnet/redgold/journey/phase2_a1.html

**Pulmonary Circulation**

**Pulmonary circulation** is the part of the circulatory system that carries blood between the heart and lungs (the term pulmonary means “of the lungs”). It is illustrated in Figure 23.5. Deoxygenated blood leaves the right ventricle through pulmonary arteries, which transport it to the lungs. In the lungs, the blood gives up carbon dioxide and picks up oxygen. The oxygenated blood then returns to the left atrium of the heart through pulmonary veins.
Systemic Circulation

**Systemic circulation** is the part of the circulatory system that carries blood between the heart and body. It is illustrated in Figure 23.6. Oxygenated blood leaves the left ventricle through the aorta. The aorta and other arteries transport the blood throughout the body, where it gives up oxygen and picks up carbon dioxide. The deoxygenated blood then returns to the right atrium through veins.

Cardiovascular Disease

Diseases of the heart and blood vessels, called **cardiovascular diseases (CVD)**, are very common. The leading cause of CVD is atherosclerosis.

Atherosclerosis

**Atherosclerosis** is the buildup of plaque inside arteries (see Figure 23.7). Plaque consists of cell debris, cholesterol, and other substances. Factors that contribute to plaque buildup include a high-fat diet and smoking. As plaque builds up, it narrows the arteries and reduces blood flow. You can watch an animation about atherosclerosis at these links: [http://www.youtube.com/watch?v=f Lonh7ZesKs](http://www.youtube.com/watch?v=fLonh7ZesKs) and [http://www.youtube.com/watch?v=qRK7-DCDKEA](http://www.youtube.com/watch?v=qRK7-DCDKEA).

Coronary Heart Disease

Atherosclerosis of arteries that supply the heart muscle is called coronary heart disease. This disease may or may not have symptoms such as chest pain. As the disease progresses, there is an increased risk of heart attack. A **heart attack** occurs when the blood supply to part of the heart muscle is blocked and cardiac muscle fibers die. Coronary heart disease is the leading cause of death of adults in the U.S.
FIGURE 23.6
The systemic circulation carries blood between the heart and body.

FIGURE 23.7
The fatty material inside the artery on the right is plaque. Notice how much narrower the artery has become. Less blood can flow through it than the normal artery.
Preventing Cardiovascular Disease

Many factors may increase the risk of developing coronary heart disease and other CVDs. The risk of CVDs increases with age and is greater in males than females at most ages. Having a close relative with CVD also increases the risk. These factors cannot be controlled, but other risk factors can, including smoking, lack of exercise, and high-fat diet. By making healthy lifestyle choices, you can reduce your risk of developing CVD.

Blood

Blood is a fluid connective tissue. It circulates throughout the body through blood vessels by the pumping action of the heart. Blood in arteries carries oxygen and nutrients to all the body’s cells. Blood in veins carries carbon dioxide and other wastes away from the cells to be excreted. Blood also defends the body against infection, repairs body tissues, transports hormones, and controls the body’s pH.

Composition of Blood

The fluid part of blood is called plasma. It is a watery golden-yellow liquid that contains many dissolved substances and blood cells. Types of blood cells in plasma include red blood cells, white blood cells, and platelets (see Figure 23.8). You can learn more about blood and its components by watching the animation What Is Blood? at this link: http://www.apan.net/meetings/busan03/materials/ws/education/demo-los/blood-rlo/whatisblood.swf.

• The trillions of red blood cells in blood plasma carry oxygen. Red blood cells contain hemoglobin, a protein with iron that binds with oxygen.
• White blood cells are generally larger than red blood cells but far fewer in number. They defend the body in various ways. For example, white blood cells called phagocytes swallow and destroy microorganisms and debris in the blood.
• Platelets are cell fragments involved in blood clotting. They stick to tears in blood vessels and to each other, forming a plug at the site of injury. They also release chemicals that are needed for clotting to occur.
An overview of red blood cells can be viewed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/36/fLKOBQ6cZHA (16:30).

Hemoglobin is discussed in detail at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/38/LWtXthfG9_M (14:34).

Blood Type

Blood type is a genetic characteristic associated with the presence or absence of certain molecules, called antigens, on the surface of red blood cells. The most commonly known blood types are the ABO and Rhesus blood types.

- ABO blood type is determined by two common antigens, often referred to simply as antigens A and B. A person may have blood type A (only antigen A), B (only antigen B), AB (both antigens), or O (no antigens).

- Rhesus blood type is determined by one common antigen. A person may either have the antigen (Rh\(^+\)) or lack the antigen (Rh\(^-\)).

Blood type is important for medical reasons. A person who needs a blood transfusion must receive blood that is the same type as his or her own. Otherwise, the transfused blood may cause a potentially life-threatening reaction in the patient’s bloodstream.

Lesson Summary

- The heart contracts rhythmically to pump blood to the lungs and the rest of the body. Specialized cardiac muscle cells trigger the contractions.
- Arteries carry blood away from the heart, veins carry blood toward the heart, and capillaries connect arteries and veins.
- The pulmonary circulation carries blood between the heart and lungs. The systemic circulation carries blood between the heart and body.
- A disease that affects the heart or blood vessels is called a cardiovascular disease (CVD). The leading cause of CVD is atherosclerosis, or the buildup of plaque inside arteries. Healthy lifestyle choices can reduce the risk of developing CVD.
- Blood is a fluid connective tissue that contains a liquid component called plasma. It also contains dissolved substances and blood cells. Red blood cells carry oxygen, white blood cells defend the body, and platelets help blood clot.

23.1. The Circulatory System
Lesson Review Questions

Recall

1. Describe how blood flows through the heart.
2. What controls heartbeat?
3. How do arteries differ from veins?
4. What is blood pressure? What is hypertension?
5. List factors that increase the risk of cardiovascular disease.
6. Identify three types of blood cells and their functions.

Apply Concepts

7. To take your pulse, you press your fingers against an artery near the surface of the body. What are you feeling and measuring when you take your pulse? Why can’t you take your pulse by pressing your fingers against a vein?
8. People with type O blood are called “universal donors” because they can donate blood to anyone else, regardless of their ABO blood type. Explain why.

Think Critically

9. Compare and contrast the pulmonary and systemic circulations.
10. Explain the role of blood vessels in homeostasis.

Points to Consider

An important function of the circulatory system is transporting oxygen to cells.

- Do you know where blood gets the oxygen cells it needs?
- How do you think blood is able to give up its oxygen to cells?
Lesson Objectives

- Define respiration, and explain how it differs from cellular respiration.
- Identify the organs of the respiratory system.
- Outline the processes of ventilation, gas exchange, and gas transport.
- Describe the role of gas exchange in homeostasis.
- Explain how the rate of breathing is regulated.
- Identify diseases of the respiratory system.

Vocabulary

**asthma**  respiratory system disease in which air passages of the lungs periodically become too narrow, making breathing difficult

**emphysema**  lung disease, usually caused by smoking, in which walls of alveoli break down, so less gas can be exchanged in the lungs

**larynx**  organ of the respiratory system between the pharynx and trachea that is also called the voice box because it allows the production of vocal sounds

**lung**  organ of the respiratory system in which gas exchange takes place between the blood and the atmosphere

**pharynx**  long, tubular organ that connects the mouth and nasal cavity with the larynx through which air and food pass

**pneumonia**  disease in which the alveoli of the lungs become inflamed and filled with fluid as a result of infection or injury

**respiration**  exchange of gases between the body and the outside air

**respiratory system**  organ system that brings oxygen into the body and releases carbon dioxide into the atmosphere

**trachea**  long, tubular organ of the respiratory system, also called the wind pipe, that carries air between the larynx and lungs

**ventilation**  process of carrying air from the atmosphere into the lungs
Introduction

Red blood cells are like trucks that transport cargo on a highway system. Their cargo is oxygen, and the highways are blood vessels. Where do red blood cells pick up their cargo of oxygen? The answer is the lungs. The lungs are organs of the respiratory system. The respiratory system is the body system that brings air containing oxygen into the body and releases carbon dioxide into the atmosphere.

Respiration

The job of the respiratory system is the exchange of gases between the body and the outside air. This process, called respiration, actually consists of two parts. In the first part, oxygen in the air is drawn into the body and carbon dioxide is released from the body through the respiratory tract. In the second part, the circulatory system delivers the oxygen to body cells and picks up carbon dioxide from the cells in return. The use of the word respiration in relation to gas exchange is different from its use in the term cellular respiration. Recall that cellular respiration is the metabolic process by which cells obtain energy by “burning” glucose. Cellular respiration uses oxygen and releases carbon dioxide. Respiration by the respiratory system supplies the oxygen and takes away the carbon dioxide.

An overview of breathing is shown at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/35/SPGRkexI_cs (20:33).

Organs of the Respiratory System

The organs of the respiratory system that bring air into the body are shown in Figure 23.9. Refer to the figure as you read below about the passage of air through these organs. You can also watch a detailed animation of the respiratory system at this link: http://www.youtube.com/watch?v=HiT621PrrO0.

Journey of a Breath of Air

Take in a big breath of air through your nose. As you inhale, you may feel the air pass down your throat and notice your chest expand. Now exhale and observe the opposite events occurring. Inhaling and exhaling may seem like simple actions, but they are just part of the complex process of respiration, which includes these four steps:

a. Ventilation
b. Pulmonary gas exchange
c. Gas transport
d. Peripheral gas exchange
Ventilation

Respiration begins with **ventilation**. This is the process of moving air in and out of the lungs. The **lungs** are the organs in which gas exchange takes place between blood and air.

- Air enters the respiratory system through the nose. As the air passes through the nasal cavity, mucus and hairs trap any particles in the air. The air is also warmed and moistened so it won’t harm delicate tissues of the lungs.
- Next, the air passes through the **pharynx**, a long tube that is shared with the digestive system. A flap of connective tissue called the epiglottis closes when food is swallowed to prevent choking.
- From the pharynx, air next passes through the **larynx**, or voice box. The larynx contains vocal cords, which allow us to produce vocal sounds.
- After the larynx, air moves into the **trachea**, or wind pipe. This is a long tube that leads down to the chest.
- In the chest, the trachea divides as it enters the lungs to form the right and left bronchi. The bronchi contain cartilage, which prevents them from collapsing. Mucus in the bronchi traps any remaining particles in air. Tiny hairs called cilia line the bronchi and sweep the particles and mucus toward the throat so they can be expelled from the body.
- Finally, air passes from the bronchi into smaller passages called bronchioles. The bronchioles end in tiny air sacs called alveoli.
Pulmonary Gas Exchange

Pulmonary gas exchange is the exchange of gases between inhaled air and the blood. It occurs in the alveoli of the lungs. Alveoli (singular, alveolus) are grape-like clusters surrounded by networks of thin-walled pulmonary capillaries. After you inhale, there is a greater concentration of oxygen in the alveoli than in the blood of the pulmonary capillaries, so oxygen diffuses from the alveoli into the blood across the capillaries (see Figure 23.10). Carbon dioxide, in contrast, is more concentrated in the blood of the pulmonary capillaries than in the alveoli, so it diffuses in the opposite direction. This link has an animation of pulmonary gas exchange: http://www.youtube.com/watch?v=Z1h29R82mVc#38;NR=1.

**FIGURE 23.10**
Alveoli are tiny sacs in the lungs where gas exchange takes place.

Gas Transport

After the blood in the pulmonary capillaries becomes saturated with oxygen, it leaves the lungs and travels to the heart. The heart pumps the oxygen-rich blood into arteries, which carry it throughout the body. Eventually, the blood travels into capillaries that supply body tissues. These capillaries are called peripheral capillaries.

Peripheral Gas Exchange

The cells of the body have a much lower concentration of oxygen than does the oxygenated blood in the peripheral capillaries. Therefore, oxygen diffuses from the peripheral capillaries into body cells. Carbon dioxide is produced by cells as a byproduct of cellular respiration, so it is more concentrated in the cells than in the blood of the peripheral capillaries. As a result, carbon dioxide diffuses in the opposite direction.
Back to the Lungs

The carbon dioxide from body cells travels in the blood from the peripheral capillaries to veins and then to the heart. The heart pumps the blood to the lungs, where the carbon dioxide diffuses into the alveoli. Then, the carbon dioxide passes out of the body through the other structures of the respiratory system, bringing the process of respiration full circle.

Gas Exchange and Homeostasis

Gas exchange is needed to provide cells with the oxygen they need for cellular respiration. Cells cannot survive for long without oxygen. Gas exchange is also needed to carry away carbon dioxide waste. Some of the carbon dioxide in the blood dissolves to form carbonic acid, which keeps blood pH within a normal range.

Blood pH may become unbalanced if the rate of breathing is too fast or too slow. When breathing is too fast, blood contains too little carbon dioxide and becomes too basic. When breathing is too slow, blood contains too much carbon dioxide and becomes too acidic. Clearly, to maintain proper blood pH, the rate of breathing must be regulated.

Regulation of Breathing

To understand how breathing is regulated, you first need to understand how breathing occurs.

How Breathing Occurs

Inhaling is an active movement that results from the contraction of a muscle called the diaphragm. The diaphragm is large, sheet-like muscle below the lungs (see Figure 23.11). When the diaphragm contracts, the ribcage expands and the contents of the abdomen move downward. This results in a larger chest volume, which decreases air pressure inside the lungs. With lower air pressure inside than outside the lungs, air rushes into the lungs. When the diaphragm relaxes, the opposite events occur. The volume of the chest cavity decreases, air pressure inside the lungs increases, and air flows out of the lungs, like air rushing out of a balloon. You can watch an animation showing how breathing occurs at this link: http://www.youtube.com/watch?v=hp-gCvW8PRY#38;feature=related.

Control of Breathing

The regular, rhythmic contractions of the diaphragm are controlled by the brain stem. It sends nerve impulses to the diaphragm through the autonomic nervous system. The brain stem monitors the level of carbon dioxide in the blood. If the level becomes too high, it “tells” the diaphragm to contract more often. Breathing speeds up, and the excess carbon dioxide is released into the air. The opposite events occur when the level of carbon dioxide in the blood becomes too low. In this way, breathing keeps blood pH within a narrow range.

Diseases of the Respiratory System

When you have a cold, your nasal passages may become so congested that it’s hard to breathe through your nose. Many other diseases also affect the respiratory system, most of them more serious than the common cold. The following list includes just a sample of respiratory system diseases.

23.2. The Respiratory System
• **Asthma** is a disease in which the air passages of the lungs periodically become too narrow, often with excessive mucus production. This causes difficulty breathing, coughing, and chest tightness. An asthma attack may be triggered by allergens, strenuous exercise, stress, or other factors. You can learn more about asthma by watching the animation at this link: http://www.youtube.com/watch?v=S04dci7NTPk#38;feature=rated.

• **Pneumonia** is a disease in which some of the alveoli of the lungs fill with fluid so gas exchange cannot occur. Symptoms usually include coughing, chest pain, and difficulty breathing. Pneumonia may be caused by an infection or injury of the lungs.

• **Emphysema** is a lung disease in which walls of the alveoli break down so less gas can be exchanged in the lungs (see Figure 23.12). This causes shortness of breath. The damage to the alveoli is usually caused by smoking and is irreversible.

**Cigarette Health Warnings**

Beginning in September 2012, the U.S. Food and Drug Administration will require larger, more prominent cigarette health warnings on all cigarette packaging and advertisements in the United States. These warnings are a significant advancement in communicating the dangers of smoking. These new cigarette health warnings contains nine different warnings that will increase awareness of the specific health risks associated with smoking, such as death, addiction, lung disease, cancer, stroke and heart disease. These warnings include:

- cigarettes are addictive
- tobacco smoke can harm your children
- cigarettes cause fatal lung disease
- cigarettes cause cancer
- cigarettes cause strokes and heart disease
- smoking during pregnancy can harm your baby
- smoking can kill you
- tobacco smoke causes fatal lung disease in nonsmokers
- quitting smoking now greatly reduces serious risks to your health.
Alveoli Changes in Lung Diseases

Pneumonia

Healthy

Emphysema

See http://www.fda.gov/TobaccoProducts/Labeling/CigaretteWarningLabels/default.htm for additional information.

Lesson Summary

- Respiration is the process in which gases are exchanged between the body and the outside air. The lungs and other organs of the respiratory system bring oxygen into the body and release carbon dioxide into the
atmosphere.

- Respiration begins with ventilation, the process of moving air into and out of the lungs. Gas exchange in the lungs takes place across the thin walls of pulmonary arteries in tiny air sacs called alveoli. Oxygenated blood is transported by the circulatory system from lungs to tissues throughout the body. Gas exchange between blood and body cells occurs across the walls of peripheral capillaries.

- Gas exchange helps maintain homeostasis by supplying cells with oxygen, carrying away carbon dioxide waste, and maintaining proper pH of the blood.

- Breathing occurs due to repeated contractions of a large muscle called the diaphragm. The rate of breathing is regulated by the brain stem. It monitors the level of carbon dioxide in the blood and triggers faster or slower breathing as needed to keep the level within a narrow range.

- Diseases of the respiratory system include asthma, pneumonia, and emphysema.

Lesson Review Questions

Recall

1. What is respiration? What is ventilation?
2. How is respiration different from cellular respiration?
3. Outline the pathway of a breath of air from the nose to the alveoli.
4. Describe how pulmonary gas exchange occurs.
5. Identify three diseases of the respiratory system, and state what triggers or causes each disease.

Apply Concepts

6. Sometimes people who are feeling anxious breathe too fast and become lightheaded. This is called hyperventilation. Hyperventilation can upset the pH balance of the blood, resulting in blood that is too basic. Explain why.

Think Critically

7. Compare and contrast pulmonary and peripheral gas exchange.
8. Explain why contraction of the diaphragm causes the lungs to fill with air.
9. Explain how the rate of breathing is controlled.

Points to Consider

Oxygen is just one substance transported by the blood. The blood also transports nutrients such as glucose.

- What are nutrients? What other substances do you think might be nutrients?
- Where do you think nutrients enter the bloodstream? How might this occur?
Lesson Objectives

- Identify the organs and functions of the digestive system.
- Outline the roles of the mouth, esophagus, and stomach in digestion.
- Explain how digestion and absorption occur in the small intestine.
- List functions of the large intestine.
- Describe common diseases of the digestive system.
- Identify classes of nutrients and their functions in the human body.
- Explain how to use MyPyramid and food labels as tools for balanced eating.

Vocabulary

absorption  process in which substances such as nutrients pass into the blood stream

bile  fluid produced by the liver and stored in the gall bladder that is secreted into the small intestine to help digest lipids and neutralize acid from the stomach

body mass index (BMI)  estimate of the fat content of the body calculated by dividing a person’s weight (in kilograms) by the square of the person’s height (in meters)

chemical digestion  chemical breakdown of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood

digestion  process of breaking down food into nutrients that can be absorbed by the blood

digestive system  organ system that breaks down food, absorbs nutrients, and eliminates any remaining waste

eating disorder  mental illness in which people feel compelled to eat in a way that causes physical, mental, and emotional health problems

elimination  process in which waste passes out of the body

esophagus  long, narrow digestive organ that passes food from the pharynx to the stomach

feces  solid waste that remains after food is digested and is eliminated from the body through the anus

gall bladder  sac-like organ that stores bile from the liver and secretes it into the duodenum of the small intestine
gastrointestinal (GI) tract  organs of the digestive system through which food passes during digestion, including the mouth, esophagus, stomach, and small and large intestines

large intestine  organ of the digestive system that removes water from food waste and forms feces

liver  organ of digestion and excretion that secretes bile for lipid digestion and breaks down excess amino acids and toxins in the blood

macronutrient  nutrient such as carbohydrates, proteins, lipids, or water that is needed by the body in relatively large amounts

mechanical digestion  physical breakdown of chunks of food into smaller pieces by organs of the digestive system

micronutrient  nutrient such as a vitamin or mineral that is needed by the body in relatively small amounts

mineral  chemical element such as calcium or potassium that is needed in relatively small amounts for proper body functioning

MyPlate  visual guideline for balanced eating, replacing MyPyramid in 2011

MyPyramid  visual dietary guideline that shows the relative amounts of foods in different food groups that should be eaten each day

nutrient  substance the body needs for energy, building materials, or control of body processes

obesity  condition in which the body mass index is 30.0 kg/m$^2$ or greater

peristalsis  rapid, involuntary, wave-like contraction of muscles that pushes food through the GI tract and urine through the ureters

small intestine  long, narrow, tube-like organ of the digestive system where most chemical digestion of food and virtually all absorption of nutrients take place

stomach  sac-like organ of the digestive system between the esophagus and small intestine in which both mechanical and chemical digestion take place

villi  microscopic, finger-like projections in the mucous membrane lining the small intestine that form a large surface area for the absorption of nutrients

vitamin  organic compound needed in small amounts for proper body functioning

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**Introduction**

The respiratory and circulatory systems work together to provide cells with the oxygen they need for cellular respiration. Cells also need glucose for cellular respiration. Glucose is a simple sugar that comes from the food we eat. To get glucose from food, digestion must occur. This process is carried out by the digestive system.
Overview of the Digestive System

The digestive system consists of organs that break down food and absorb nutrients such as glucose. Organs of the digestive system are shown in Figure 23.14. Most of the organs make up the gastrointestinal tract. The rest of the organs are called accessory organs.

The following interactive animation demonstrates the flow of food through the gastrointestinal (GI) system.

23.3. The Digestive System
The Gastrointestinal Tract

The gastrointestinal (GI) tract is a long tube that connects the mouth with the anus. It is more than 9 meters (30 feet) long in adults and includes the esophagus, stomach, and small and large intestines. Food enters the mouth, passes through the other organs of the GI tract, and then leaves the body through the anus. At the following link, you can watch an animation that shows what happens to food as it passes through the GI tract. [http://www.youtube.com/watch?v=QtDgQjOGPJM](http://www.youtube.com/watch?v=QtDgQjOGPJM).

The organs of the GI tract are lined with mucous membranes that secrete digestive enzymes and absorb nutrients. The organs are also covered by layers of muscle that enable peristalsis. **Peristalsis** is an involuntary muscle contraction that moves rapidly along an organ like a wave (see Figure 23.15). You can watch an animation of peristalsis at this link: [http://en.wikipedia.org/wiki/File:Peristalsis.gif](http://en.wikipedia.org/wiki/File:Peristalsis.gif).

![Peristalsis](http://en.wikipedia.org/wiki/File:Peristalsis.gif)

**FIGURE 23.15** Peristalsis pushes food through the GI tract.

Accessory Organs of Digestion

Other organs involved in digestion include the liver, gall bladder, and pancreas. They are called accessory organs because food does not pass through them. Instead, they secrete or store substances needed for digestion.

Functions of the Digestive System

The digestive system has three main functions: digestion of food, absorption of nutrients, and elimination of solid food waste. **Digestion** is the process of breaking down food into components the body can absorb. It consists of two types of processes: mechanical digestion and chemical digestion.

- **Mechanical digestion** is the physical breakdown of chunks of food into smaller pieces. This type of digestion takes place mainly in the mouth and stomach.
- **Chemical digestion** is the chemical breakdown of large, complex food molecules into smaller, simpler nutrient molecules that can be absorbed by the blood. This type of digestion begins in the mouth and stomach but occurs mainly in the small intestine.
After food is digested, the resulting nutrients are absorbed. **Absorption** is the process in which substances pass into the bloodstream, where they can circulate throughout the body. Absorption of nutrients occurs mainly in the small intestine. Any remaining matter from food that cannot be digested and absorbed passes into the large intestine as waste. The waste later passes out of the body through the anus in the process of **elimination**.

### The Start of Digestion: Mouth to Stomach

Does the sight or aroma of your favorite food make your mouth water? When this happens, you are getting ready for digestion.

**Mouth**

The mouth is the first digestive organ that food enters. The sight, smell, or taste of food stimulates the release of digestive enzymes by salivary glands inside the mouth. The major salivary enzyme is amylase. It begins the chemical digestion of carbohydrates by breaking down starch into sugar.

![Interactive Animation](https://www.ck12.org/)

The following interactive animation demonstrates the chewing and swallowing process.

The mouth also begins the process of mechanical digestion. Sharp teeth in the front of the mouth cut or tear food when you bite into it (see **Figure 23.16**). Broad teeth in the back of the mouth grind food when you chew. Food is easier to chew because it is moistened by saliva from the salivary glands. The tongue helps mix the food with saliva and also helps you swallow. After you swallow, the chewed food passes into the pharynx.

**Esophagus**

From the pharynx, the food moves into the esophagus. The **esophagus** is a long, narrow tube that passes food from the pharynx to the stomach by peristalsis. The esophagus has no other digestive functions. At the end of the esophagus, a muscle called a sphincter controls the entrance to the stomach. The sphincter opens to let food into the stomach and then closes again to prevent food from passing back into the esophagus.

**Stomach**

The **stomach** is a sac-like organ in which food is further digested both mechanically and chemically. (To see an animation of how the stomach digests food, go to the link below.) Churning movements of the stomach’s thick, muscular walls complete the mechanical breakdown of food. The churning movements also mix food with digestive fluids secreted by the stomach. One of these fluids is hydrochloric acid. It kills bacteria in food and gives the stomach the low pH needed by digestive enzymes that work in the stomach. The main enzyme is pepsin,
which chemically digests protein. See http://www.youtube.com/watch?v=URHBBE3RKEs#38;feature=related for additional information.

The stomach stores the partly digested food until the small intestine is ready to receive it. When the small intestine is empty, a sphincter opens to allow the partially digested food to enter the small intestine.

The following interactive animation demonstrates the processes that occur in the stomach.

**Digestion and Absorption: The Small Intestine**

The small intestine is a narrow tube about 7 meters (23 feet) long in adults. It is the site of most chemical digestion and virtually all absorption. The small intestine consists of three parts: the duodenum, jejunum, and ileum (see Figure 23.14).

**Digestion in the Small Intestine**

The duodenum is the first and shortest part of the small intestine. Most chemical digestion takes place here, and many digestive enzymes are active in the duodenum (see Table 23.1). Some are produced by the duodenum itself.
Others are produced by the pancreas and secreted into the duodenum. To see animations about digestive enzymes in the duodenum, use these links: http://www.youtube.com/watch?v=bNMnNHqxszc#38;feature=related (0:40) and http://www.youtube.com/watch?v=1xNpXO8gGFM(2:45).

<table>
<thead>
<tr>
<th>Enzyme</th>
<th>What It Digests</th>
<th>Where It Is Made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylase</td>
<td>carbohydrates</td>
<td>pancreas</td>
</tr>
<tr>
<td>Trypsin</td>
<td>proteins</td>
<td>pancreas</td>
</tr>
<tr>
<td>Lipase</td>
<td>lipids</td>
<td>pancreas, duodenum</td>
</tr>
<tr>
<td>Maltase</td>
<td>carbohydrates</td>
<td>duodenum</td>
</tr>
<tr>
<td>Peptidase</td>
<td>proteins</td>
<td>duodenum</td>
</tr>
</tbody>
</table>

The liver is an organ of both digestion and excretion. It produces a fluid called bile, which is secreted into the duodenum. Some bile also goes to the gall bladder, a sac-like organ that stores and concentrates bile and then secretes it into the small intestine. In the duodenum, bile breaks up large globules of lipids into smaller globules that are easier for enzymes to break down. Bile also reduces the acidity of food entering from the highly acidic stomach. This is important because digestive enzymes that work in the duodenum need a neutral environment. The pancreas contributes to the neutral environment by secreting bicarbonate, a basic substance that neutralizes acid.

Absorption in the Small Intestine

The jejunum is the second part of the small intestine, where most nutrients are absorbed into the blood. As shown in Figure 23.17, the mucous membrane lining the jejunum is covered with millions of microscopic, fingerlike projections called villi (singular, villus). Villi contain many capillaries, and nutrients pass from the villi into the bloodstream through the capillaries. Because there are so many villi, they greatly increase the surface area for absorption. In fact, they make the inner surface of the small intestine as large as a tennis court! You can watch an animation of absorption across intestinal villi at this link: http://www.youtube.com/watch?v=P1sDOJM65Bc#38;feature=related.

The ileum is the third part of the small intestine. A few remaining nutrients are absorbed here. Like the jejunum, the inner surface of the ileum is covered with villi that increase the surface area for absorption.

23.3. The Digestive System
The Large Intestine and Its Functions

From the small intestine, any remaining food wastes pass into the large intestine. The large intestine is a relatively wide tube that connects the small intestine with the anus. Like the small intestine, the large intestine also consists of three parts: the cecum (or caecum), colon, and rectum. Follow food as it moves through the digestive system at http://www.youtube.com/watch?v=Uzl6M1YIU3w#38;feature=related (1:37).

The digestive system song Where Will I Go can be heard at http://www.youtube.com/watch?v=OYWVbt6t2mw#38;feature=related (3:27).

Absorption of Water and Elimination of Wastes

The cecum is the first part of the large intestine, where wastes enter from the small intestine. The wastes are in a liquid state. As they pass through the colon, which is the second part of the large intestine, excess water is absorbed. The remaining solid wastes are called feces. Feces accumulate in the rectum, which is the third part of the large intestine. As the rectum fills, the feces become compacted. After a certain amount of feces accumulate, they are eliminated from the body. A sphincter controls the anus and opens to let feces pass through.

Bacteria in the Large Intestine

Trillions of bacteria normally live in the large intestine. Most of them are helpful. In fact, we wouldn’t be able to survive without them. Some of the bacteria produce vitamins, which are absorbed by the large intestine. Other functions of intestinal bacteria include:

- Controlling the growth of harmful bacteria.
- Breaking down indigestible food components.
- Producing substances that help prevent colon cancer.
- Breaking down toxins before they can poison the body.

Diseases of the Digestive System

Many diseases can affect the digestive system. Three of the most common are food allergies, ulcers, and heartburn.

- Food allergies occur when the immune system reacts to substances in food as though they were harmful "foreign invaders.” Foods that are most likely to cause allergies are pictured in Figure 23.18. Symptoms of food allergies often include vomiting and diarrhea.
• Ulcers are sores in the lining of the stomach or duodenum that are usually caused by bacterial infections. Symptoms typically include abdominal pain and bleeding. You can see how stomach ulcers develop at this link: http://www.youtube.com/watch?v=4bXZRgJ-1fk.
• Heartburn is a painful burning sensation in the chest caused by stomach acid backing up into the esophagus. The stomach acid may eventually cause serious damage to the esophagus unless the problem is corrected.

Common Food Allergies

FIGURE 23.18
These foods are the most common causes of food allergies.

KQED: Hepatitis C: The Silent Epidemic

Hepatitis C is a virus that causes cirrhosis of the liver and liver cancer. It’s the leading cause for liver transplants in the U.S., and an estimated 4 million Americans have the disease. Current treatments are difficult to tolerate and are often ineffective, but recent breakthroughs from scientists may soon produce a cure for the disease that claims more than 10,000 American lives each year. See http://www.kqed.org/quest/television/hepatitis-c-the-silent-epidemic for additional information.

Food and Nutrients

Did you ever hear the saying, “You are what you eat”? It’s not just a saying. It’s actually true. What you eat plays an important role in your health. Eating a variety of the right types of foods promotes good health and provides
energy for growth and activity. This is because healthful foods are rich in nutrients. **Nutrients** are substances the body needs for energy, building materials, and control of body processes. There are six main classes of nutrients: carbohydrates, proteins, lipids, water, vitamins, and minerals. These six classes are categorized as macronutrients or micronutrients depending on how much of them the body needs.

**Macronutrients**

Nutrients the body needs in relatively large amounts are called **macronutrients**. They include carbohydrates, proteins, lipids, and water. All macronutrients except water can be used by the body for energy. (The energy in food is measured in a unit called a Calorie.) The exact amount of each macronutrient that an individual needs depends on many factors, including gender and age. Recommended daily intakes by teens of three macronutrients are shown in Table 23.2. Based on your gender and age, how many grams of proteins should you eat each day?

**Table 23.2: Recommended Intakes of Macronutrients**

<table>
<thead>
<tr>
<th>Gender/Age</th>
<th>Carbohydrates (g/day)</th>
<th>Proteins (g/day)</th>
<th>Water (L/day) (includes water in food)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males 9–13 years</td>
<td>130</td>
<td>34</td>
<td>2.4</td>
</tr>
<tr>
<td>Males 14–18 years</td>
<td>130</td>
<td>52</td>
<td>3.3</td>
</tr>
<tr>
<td>Females 9–13 years</td>
<td>130</td>
<td>34</td>
<td>2.1</td>
</tr>
<tr>
<td>Females 14–18 years</td>
<td>130</td>
<td>46</td>
<td>2.3</td>
</tr>
</tbody>
</table>

- Carbohydrates include sugars, starches, and fiber. Sugars and starches are used by the body for energy. One gram of carbohydrates provides 4 Calories of energy. Fiber, which is found in plant foods, cannot be digested but is needed for good health.
- Dietary proteins are broken down during digestion to provide the amino acids needed for protein synthesis. Any extra proteins in the diet not needed for this purpose are used for energy or stored as fat. One gram of proteins provides 4 Calories of energy.
- Lipids provide the body with energy and serve other vital functions. One gram of lipids provides 9 Calories of energy. You need to eat small amounts of lipids for good health. However, large amounts can be harmful, especially if they contain saturated fatty acids from animal foods.
- Water is essential to life because biochemical reactions take place in water. Most people can survive only a few days without water.

**Micronutrients**

Nutrients the body needs in relatively small amounts are called **micronutrients**. They include vitamins and minerals. **Vitamins** are organic compounds that are needed by the body to function properly. Several vitamins are described in Table ref table|table:vitamins|below. Vitamins play many roles in good health, ranging from maintaining good vision to helping blood clot. Vitamin B12 is produced by bacteria in the large intestine. Vitamin D is synthesized by the skin when it is exposed to UV light. Most other vitamins must be obtained from foods like those listed in Table 23.3.

**Table 23.3: Vitamins**

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Function</th>
<th>Good Food Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>good vision</td>
<td>carrots, spinach</td>
</tr>
<tr>
<td>B12</td>
<td>normal nerve function</td>
<td>meat, milk</td>
</tr>
<tr>
<td>C</td>
<td>making connective tissue</td>
<td>oranges, red peppers</td>
</tr>
<tr>
<td>D</td>
<td>healthy bones and teeth</td>
<td>salmon, eggs</td>
</tr>
<tr>
<td>E</td>
<td>normal cell membranes</td>
<td>vegetable oils, nuts</td>
</tr>
</tbody>
</table>
TABLE 23.3: (continued)

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Function</th>
<th>Good Food Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>blood clotting</td>
<td>spinach, soybeans</td>
</tr>
</tbody>
</table>

Minerals are chemical elements that are essential for body processes. They include calcium, which helps form strong bones and teeth, and potassium, which is needed for normal nerve and muscle function. Good sources of minerals include green leafy vegetables, whole grains, milk, and meats. Vitamins and minerals do not provide energy, but they are still essential for good health. The needed amounts generally can be met with balanced eating. However, people who do not eat enough of the right foods may need vitamin or mineral supplements.

Balanced Eating

Balanced eating is a way of eating that promotes good health. It means eating the right balance of different foods to provide the body with all the nutrients it needs. Fortunately, you don’t need to measure and record the amounts of different nutrients you each day in order to balance your eating. Instead, you can use MyPlate and food labels.

MyPyramid and MyPlate

MyPyramid shows the relative amounts of foods in different food groups you should eat each day (see Figure 23.19). You can visit the MyPyramid Web site (http://www.mypyramid.gov) to learn more about MyPyramid and customize it for your own gender, age, and activity level.

Each food group represented by a colored band in MyPyramid is a good source of nutrients. The key in Figure 23.19 shows the food group each band represents. The wider the band, the more you should eat from that food group. The white tip of MyPyramid represents foods that should be eaten only once in awhile, such as ice cream and potato chips. They contain few nutrients and may contribute excess Calories to the diet. The figure “walking” up the side of MyPyramid represents the role of physical activity in balanced eating. Regular exercise helps you burn any extra energy that you consume in foods and provides many other health benefits. You should be active for about an hour a day most days of the week. The more active you are, the more energy you will use.

In June 2011, the United States Department of Agriculture replaced My Pyramid with MyPlate. MyPlate depicts the relative daily portions of various food groups. See http://www.choosemyplate.gov/ for further information.

The following guidelines accompany MyPlate:

1. Balancing Calories
   - Enjoy your food, but eat less.
   - Avoid oversized portions.

2. Foods to Increase
   - Make half your plate fruits and vegetables.
   - Make at least half your grains whole grains.
   - Switch to fat-free or low-fat (1%) milk.

3. Foods to Reduce
   - Compare sodium in foods like soup, bread, and frozen meals [U+2015] and choose the foods with lower numbers.
   - Drink water instead of sugary drinks.

23.3. The Digestive System
MyPyramid is a visual guideline for balanced eating.

**Figure 23.19**

**Grains:**
At least half should be whole grains.

**Vegetables:**
Include green and yellow vegetables.

**Fruits:**
Consume whole fruits instead of juices.

**Oils:**
Use unsaturated nut and vegetable oils.

**Milk:**
Make low-fat or fat-free choices.

**Meat and Legumes:**
Include fish, beans, and peas.

---

**Food Labels**

Packaged foods are required by law to carry a nutrition facts label, like the one in **Figure 23.21**. The labels show the nutrient content and ingredients of foods. Reading labels can help you choose foods that are high in nutrients you need more of (such as proteins) and low in nutrients you need less of (such as fats).

You should also look for ingredients such as whole grains, vegetables, and fruits. Avoid foods that contain processed ingredients, such as white flour or white rice. Processing removes nutrients. As a result, processed foods generally
supply fewer nutrients than whole foods, even when they have been enriched or fortified with added nutrients.

Weight Gain and Obesity

Any unused energy in food—whether it comes from carbohydrates, proteins, or lipids—is stored in the body as fat. An extra 3,500 Calories of energy results in the storage of almost half a kilogram (1 pound) of stored body fat. People who consistently consume more food energy then they need may become obese. Obesity occurs when the body mass index is 30.0 kg/m² or greater. Body mass index (BMI) is an estimate of the fat content of the body. It is calculated by dividing a person’s weight (in kilograms) by the square of the person’s height (in meters). Obesity
increases the risk of health problems such as type 2 diabetes and hypertension.

**Eating Disorders**

Some people who are obese have an eating disorder, called binge eating disorder, in which they compulsively overeat. An eating disorder is a mental illness in which people feel compelled to eat in a way that causes physical, mental, and emotional health problems. Other eating disorders include anorexia nervosa and bulimia nervosa. Treatments for eating disorders include counseling and medication.

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**Lesson Summary**

- The digestive system consists of organs that break down food, absorb nutrients, and eliminate waste. The breakdown of food occurs in the process of digestion.
- Digestion consists of mechanical and chemical digestion. Mechanical digestion occurs in the mouth and stomach. Chemical digestion occurs mainly in the small intestine. The pancreas and liver secrete fluids that aid in digestion.
- Virtually all absorption of nutrients takes place in the small intestine, which has a very large inner surface area because it is covered with millions of microscopic villi.
- The absorption of water from digestive wastes and the elimination of the remaining solid wastes occur in the large intestine. The large intestine also contains helpful bacteria.
- Digestive system diseases include food allergies, ulcers, and heartburn.
- Nutrients are substances that the body needs for energy, building materials, and control of body processes. Carbohydrates, proteins, lipids, and water are nutrients needed in relatively large amounts. Vitamins and minerals are nutrients needed in much smaller amounts.
- Balanced eating promotes good health. MyPyramid and food labels are two tools that can help you choose the right foods for balanced eating. Eating too much and exercising too little can lead to weight gain and obesity. Some people who are obese have an eating disorder. Eating disorders are mental illnesses that require treatment by health professionals.
Lesson Review Questions

Recall

1. What organs make up the gastrointestinal tract? What are the accessory organs of digestion?
2. Describe peristalsis and its role in digestion.
3. Define mechanical and chemical digestion.
4. Describe functions of the stomach.
5. Where are most nutrients absorbed?
6. What role do villi play in absorption?
7. How do bacteria in the large intestine help keep us healthy?
8. Describe two diseases of the digestive system.
9. What is an eating disorder? Give an example.

Apply Concepts

10. Assume that a person has a disease that prevents the pancreas from secreting digestive enzymes. Explain how digestion might be affected.
11. Aleesha weighs 80 kg and is 1.6 m tall. What is her body mass index? Is she obese?

Think Critically

12. Compare and contrast macronutrients and micronutrients.
13. Explain how to use MyPyramid and food labels to choose foods for balanced eating.

23.3. The Digestive System
Points to Consider

In this lesson, you learned that the large intestine eliminates solid wastes that are left after digestion occurs.

- Wastes are also produced when cells break down nutrients for energy and building materials. How do you think these wastes are removed from the body? Do you think they are eliminated by the large intestine as well?
- Might there be other ways to remove wastes from the body? What about liquid wastes and excess water?
Lesson Objectives

- Define excretion, and identify organs of the excretory system.
- Explain how the urinary system filters blood and excretes wastes.
- Describe the roles of the kidneys in homeostasis.
- Identify kidney diseases, and describe dialysis.

Vocabulary

**bladder**  hollow, sac-like organ that stores urine until it is excreted from the body

**dialysis**  medical procedure in which blood is filtered through a machine in patients with kidney failure

**excretion**  process of removing wastes and excess water from the body

**excretory system**  organ system that removes wastes and excess water from the body and includes the kidneys, large intestine, liver, skin, and lungs

**kidney failure**  loss of the ability of nephrons of the kidney to function fully

**nephrone**  structural and functional unit of the kidney that filters blood and forms urine

**ureter**  muscular, tube-like organ of the urinary system that moves urine by peristalsis from a kidney to the bladder

**urethra**  muscular, tube-like organ of the urinary system that carries urine out of the body from the bladder; in males, it also carries sperm out of the body

**urinary system**  organ system that includes the kidneys and is responsible for filtering waste products and excess water from the blood and excreting them from the body

**urination**  process in which urine leaves the body through a sphincter at the end of the urethra

**urine**  liquid waste product of the body that is formed by the kidneys and excreted by the other organs of the urinary system
Introduction

If you exercise on a hot day, you are likely to lose a lot of water in sweat. Then, for the next several hours, you may notice that you do not pass urine as often as normal and that your urine is darker than usual. Do you know why this happens? Your body is low on water and trying to reduce the amount of water lost in urine. The amount of water lost in urine is controlled by the kidneys, the main organs of the excretory system.

Excretion

Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis. Although the kidneys are the main organs of excretion, several other organs also excrete wastes. They include the large intestine, liver, skin, and lungs. All of these organs of excretion, along with the kidneys, make up the excretory system. This lesson focuses on the role of the kidneys in excretion. The roles of the other excretory organs are summarized below:

- The large intestine eliminates solid wastes that remain after the digestion of food.
- The liver breaks down excess amino acids and toxins in the blood.
- The skin eliminates excess water and salts in sweat.
- The lungs exhale water vapor and carbon dioxide.

Urinary System

The kidneys are part of the urinary system, which is shown in Figure 23.22. The main function of the urinary system is to filter waste products and excess water from the blood and excrete them from the body.

Kidneys and Nephrons

The kidneys are a pair of bean-shaped organs just above the waist. A cross-section of a kidney is shown in Figure 23.23. The function of the kidney is to filter blood and form urine. Urine is the liquid waste product of the body that is excreted by the urinary system. Nephrons are the structural and functional units of the kidneys. A single kidney may have more than a million nephrons!

The kidney and nephron are discussed at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/57/cc8sUv2SuaY (18:38).

Additional information about the nephron is shown at http://www.youtube.com/user/khanacademy#p/c/7A9646BC5110CF64/58/czY5nyvZ7cU.
FIGURE 23.22
The kidneys are the chief organs of the urinary system.

FIGURE 23.23
Each kidney is supplied by a renal artery and renal vein.
Filtering Blood and Forming Urine

As shown in Figure 23.24, each nephron is like a tiny filtering plant. It filters blood and forms urine in the following steps:

a. Blood enters the kidney through the renal artery, which branches into capillaries. When blood passes through capillaries of the glomerulus of a nephron, blood pressure forces some of the water and dissolved substances in the blood to cross the capillary walls into Bowman’s capsule.

b. The filtered substances pass to the renal tubule of the nephron. In the renal tubule, some of the filtered substances are reabsorbed and returned to the bloodstream. Other substances are secreted into the fluid.

c. The fluid passes to a collecting duct, which reabsorbs some of the water and returns it to the bloodstream. The fluid that remains in the collecting duct is urine.

Excretion of Urine

From the collecting ducts of the kidneys, urine enters the ureters, two muscular tubes that move the urine by peristalsis to the bladder (see Figure 23.22). The bladder is a hollow, sac-like organ that stores urine. When the bladder is about half full, it sends a nerve impulse to a sphincter to relax and let urine flow out of the bladder and into the urethra. The urethra is a muscular tube that carries urine out of the body. Urine leaves the body through another sphincter in the process of urination. This sphincter and the process of urination are normally under conscious control.
Kidneys and Homeostasis

The kidneys play many vital roles in homeostasis. They filter all the blood in the body many times each day and produce a total of about 1.5 liters of urine. The kidneys control the amount of water, ions, and other substances in the blood by excreting more or less of them in urine. The kidneys also secrete hormones that help maintain homeostasis. Erythropoietin, for example, is a kidney hormone that stimulates bone marrow to produce red blood cells when more are needed.

The kidneys themselves are also regulated by hormones. For example, antidiuretic hormone from the hypothalamus stimulates the kidneys to produce more concentrated urine when the body is low on water. Homeostasis and feedback mechanisms are discussed in the following two videos: http://www.youtube.com/watch?v=FTkwJuazIwA#38;p=5D2D42394C49020A#38;playnext=1#38;index=3 (8:24) and http://www.youtube.com/watch?v=kIVix1O6qEI#38;p=5D2D42394C49020A#38;index=5 (8:40).

Kidney Disease and Dialysis

A person can live a normal, healthy life with just one kidney. However, at least one kidney must function properly to maintain life. Diseases that threaten the health and functioning of the kidneys include kidney stones, infections, and diabetes.

- Kidney stones are mineral crystals that form in urine inside the kidney. They may be extremely painful. If they block a ureter, they must be removed so urine can leave the kidney and be excreted.
- Bacterial infections of the urinary tract, especially the bladder, are very common. Bladder infections can be treated with antibiotics prescribed by a doctor. If untreated, they may lead to kidney damage.
- Uncontrolled diabetes may damage capillaries of nephrons. As a result, the kidneys lose much of their ability to filter blood. This is called kidney failure. The only cure for kidney failure is a kidney transplant, but it can be treated with dialysis. Dialysis is a medical procedure in which blood is filtered through a machine (see Figure 23.25).

Lesson Summary

- Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis. Organs of excretion make up the excretory system. They include the kidneys, large intestine, liver, skin, and lungs.
- The kidneys filter blood and form urine. They are part of the urinary system, which also includes the ureters, bladder, and urethra.
- Each kidney has more than a million nephrons, which are the structural and functional units of the kidney. Each nephron is like a tiny filtering plant.
- The kidneys maintain homeostasis by controlling the amount of water, ions, and other substances in the blood. They also secrete hormones that have other homeostatic functions.
- Kidney diseases include kidney stones, infections, and kidney failure due to diabetes. Kidney failure may be treated with dialysis.

23.4. The Excretory System
Lesson Review Questions

Recall

1. What is excretion?
2. List organs of the excretory system and their functions.
3. Describe how nephrons filter blood and form urine.
4. State the functions of the ureters, bladder, and urethra.

Apply Concepts

5. Tom was seriously injured in a car crash. As a result, he had to have one of his kidneys removed. Does Tom need dialysis? Why or why not?

Think Critically

6. Explain how the kidneys maintain homeostasis.
Points to Consider

Infections caused by microorganisms may affect any of the organ systems described in this chapter. For example, you have just read that bacterial infections of the bladder are common.

- What defenses do you think the body has to keep out microorganisms?
- Do you know if there are other defenses against microorganisms if they manage to get inside the body?

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23.5 References

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