Unit 10

HUMAN BIOLOGY

CHAPTERS

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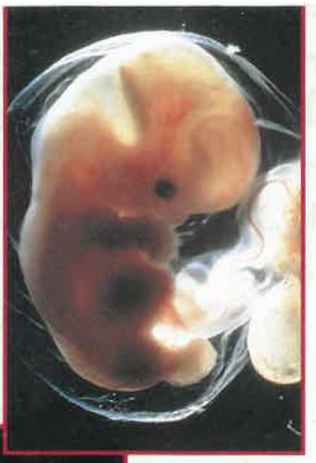
> *"The human body is marvelous. It can move freely, act deliberately, and survive under the most variable conditions. Its construction is complex and its requirements many."*

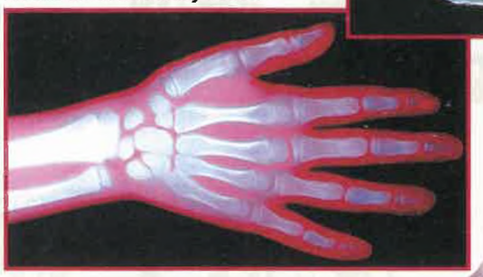
From "Exploring Man," from *Behold Man: A Photographic Journey of Discovery Inside the Body,* by Lennart Nilsson in collaboration with Jan Lindberg. English translation copyright © 1974 by Albert Bonniers Förlag, Stockholm. Reprinted by permission of *Little, Brown and Company.*

Near-perfect coordination of the many organ systems enables humans to play soccer and carry out daily activities.



At six weeks old, this developing human embryo, right, weighs less than 1 g. By eight weeks, all of the major organ systems will be recognizable.

This X ray of a child's hand, below, reveals the hand's many bones.

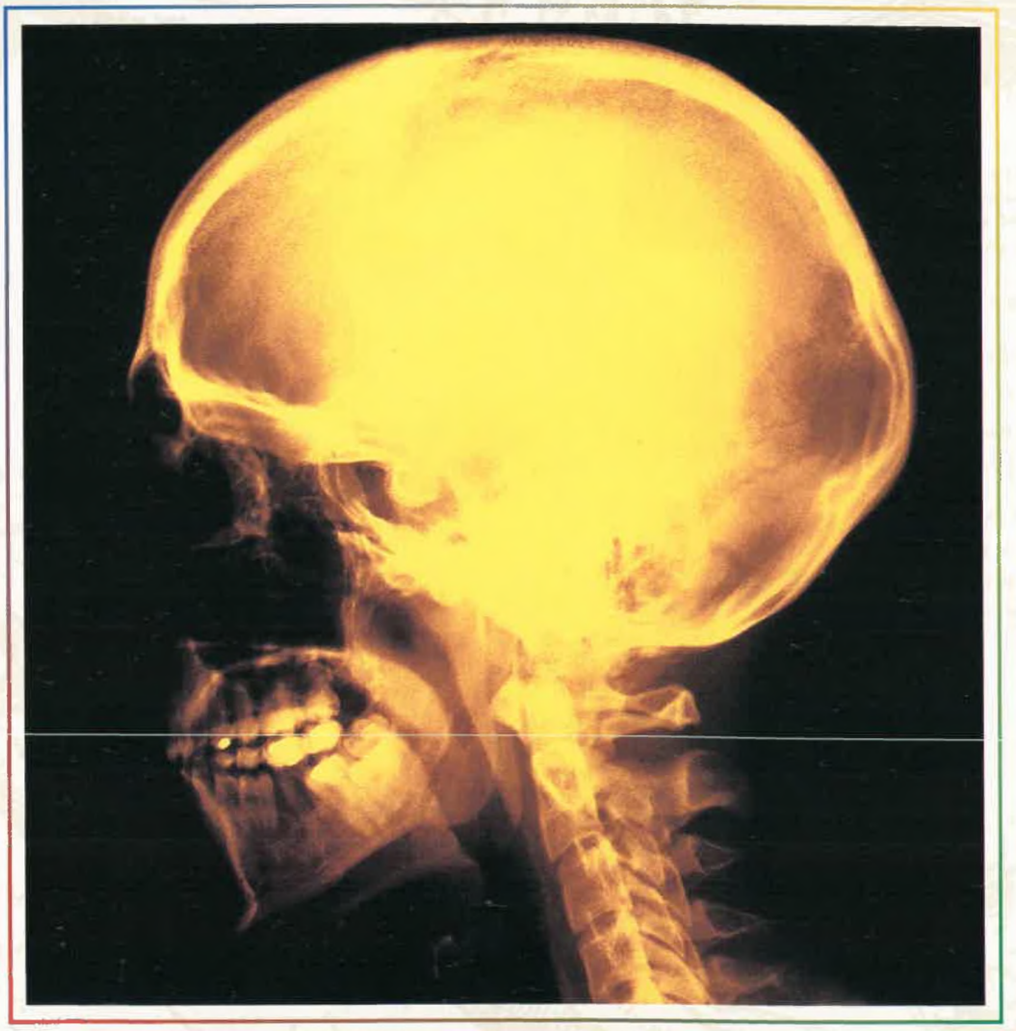


This researcher, like other scientists around the world, spends many hours in the lab each day searching for safe drugs that can be used to treat human ailments.

Red blood cells within a blood vessel

CHAPTER 46

SKELETAL, MUSCULAR, AND INTEGUMENTARY SYSTEMS



This X ray shows a color-enhanced image of the human skull, mandible, teeth, and neck.

FOCUS CONCEPT: ***Structure and Function***

As you read about bones, muscles, and skin, note how their structures are related to their functions in the human body.

SECTION 46-1

THE HUMAN BODY PLAN

The human body begins to take shape during the earliest stages of embryonic development. While the embryo is a tiny hollow ball of dividing cells, it begins forming the tissues and organs that compose the human body. By the end of its third week, the human embryo has bilateral symmetry and is developing vertebrate characteristics that will support an upright body position.

OBJECTIVES

- List and describe the four types of tissues that make up the human body.
- Explain how tissues, organs, and organ systems are organized.
- Summarize the functions of the primary organ systems in the human body.
- Name and locate four human body cavities, and describe the organs that each contains.

BODY TISSUES

In Chapter 4 you learned that a tissue is a collection of cells that are similar in structure and that work together to perform a particular function. The human body has four main types of tissues: muscle, nervous, epithelial, and connective.

Muscle Tissue

Muscle tissue is composed of cells that can contract. Every function that muscle tissue performs—from creating a facial expression to keeping the eyes in focus—is carried out by groups of muscle cells that contract in a coordinated fashion. The human body has three types of muscle tissue: skeletal, smooth, and cardiac. **Skeletal muscle** moves the bones in your trunk, limbs, and face. **Smooth muscle** handles body functions that you cannot control consciously, such as the movement of food through your digestive system. **Cardiac muscle,** found in your heart, pumps blood through your body. Figure 46-1a, on the following page, shows cells of skeletal muscle tissue.

Nervous Tissue

Nervous tissue contains cells that receive and transmit messages in the form of electrical impulses. These cells, called **neurons** (NOO-rahnz), are specialized to send and receive messages from muscles, glands, and other neurons throughout the body. Nervous tissue makes up your brain, spinal cord, and nerves. It is also found in parts of sensory organs, such as the retina in your eye. Nervous tissue provides sensation of the internal and external environment, and it integrates sensory information. Coordination of voluntary and involuntary activities and regulation of some body processes are also accomplished by nervous tissue. Figure 46-1b, on the following page, shows cells of nervous tissue.

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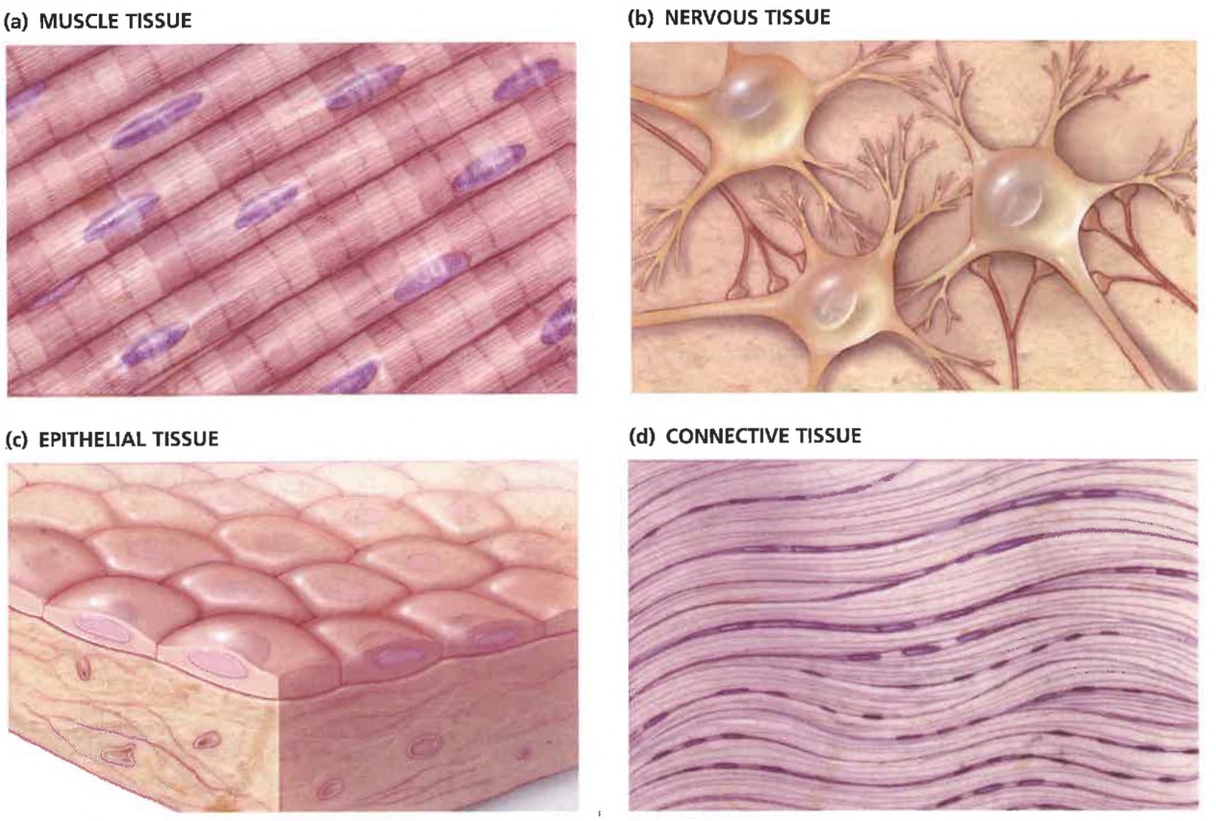


FIGURE 46-1

These four drawings show representative cells of the four main types of tissues in the human body: (a) muscle tissue, (b) nervous tissue, (c) epithelial tissue, and (d) connective tissue.

Epithelial Tissue

Epithelial (ep-uh-THEE-lee-uhl) **tissue** consists of layers of cells that line or cover all internal and external body surfaces. Each epithelial layer is formed from cells that are tightly bound together, providing a protective barrier for these surfaces. Epithelial tissue is found in various thicknesses and arrangements, depending on where it is located. For example, the epithelial tissue that lines blood vessels is a single layer of flattened cells through which substances can easily pass, but the epithelial tissue that lines the windpipe consists of a layer of cilia-bearing cells and mucus-secreting cells that act together to trap inhaled particles. The most easily observed epithelial tissue, the body's outer layer of skin, consists of sheets of dead, flattened cells that cover and protect the underlying living layer of skin. Figure 46-1c shows cells of epithelial tissue.

Connective Tissue

Connective tissue binds, supports, and protects structures in the body. Connective tissues are the most abundant and diverse of the four types of tissue, and include bone, cartilage, tendons, fat, blood, and lymph. These tissues are characterized by cells that are embedded in large amounts of an intercellular substance called **matrix.** Matrix can be solid, semisolid, or liquid. Bone cells are surrounded by a hard, crystalline matrix containing the mineral calcium. The cells in cartilage, tendons, and fat are surrounded by a semisolid fibrous matrix. Blood and lymph cells are suspended in a liquid matrix. Figure 46-1d shows cells of connective tissue.

ORGANS AND ORGAN SYSTEMS

An organ consists of various tissues that work together to carry out a specific function. The stomach, a saclike organ in which food is mixed with digestive enzymes, is composed of the four types of tissues. A single organ, such as the stomach, usually does not function in isolation. Rather, groups of organs interact in an organ system. For example, in the digestive system, the stomach, small intestine, liver, and pancreas all work together to break down food into molecules the body can use for energy. Table 46-1 lists the body's organ systems and names their major structures and functions. As you study the table, think about the ways in which the different organ systems work together to function in an efficient, integrated manner.

TABLE 46-1 *Summary of Organ Systems*

System	Major structures	Functions
Skeletal	bones	provides structure; supports and protects internal organs
Muscular	muscles (skeletal, cardiac, and smooth)	provides structure; supports and moves trunk and limbs; moves substances through body
Integumentary	skin, hair, nails	protects against pathogens; helps regulate body temperature
Cardiovascular	heart, blood vessels, blood	transports nutrients and wastes to and from all body tissues
Respiratory	air passages, lungs	carries air into and out of lungs, where gases (oxygen and carbon dioxide) are exchanged
Immune	lymph nodes and vessels, white blood cells	provides protection against infection and disease
Digestive	mouth, esophagus, stomach, liver, pancreas, small and large intestines	stores and digests food; absorbs nutrients; eliminates waste
Excretory	kidneys, ureters, bladder, urethra, skin, lungs	eliminates waste; maintains water and chemical balance
Nervous	brain, spinal cord, nerves, sense organs, receptors	controls and coordinates body movements and senses; controls consciousness and creativity; helps monitor and maintain other body systems
Endocrine	glands (such as adrenal, thyroid, and pancreas), hypothalamus	maintains homeostasis; regulates metabolism, water and mineral balance, growth and sexual development, and reproduction
Reproductive	ovaries, uterus, mammary glands (in females), testes (in males)	produces ova and milk in females, sperm in males, and offspring after fertilization

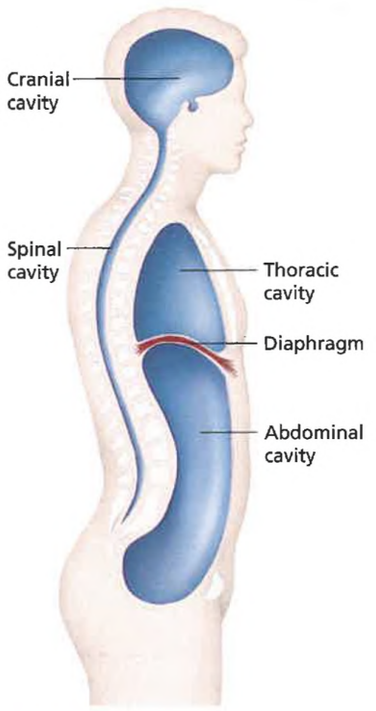


FIGURE 46-2
The human body has four main cavities that house and protect delicate internal organs.

Integration of Organ Systems

An even higher level of organization is the integration of organ systems. Each organ system has organs associated with it according to the organ's primary function. However, the boundaries are not always well defined. For example, nearly all of the juices produced by the pancreas are designed to aid in digestion. But because the pancreas produces vitally important hormones, it is also considered a component of the endocrine system. Each organ system carries out its own specific function, but for the organism to survive, the organ systems must work together. For example, nutrients from the digestive system are distributed by the circulatory system. The efficiency of the circulatory system depends on nutrients from the digestive system and oxygen from the respiratory system. An organism, whether it is a worm, a bird, or a human, is much more than an assembly of tissues. It is an integrated, whole being.

BODY CAVITIES

Many organs and organ systems in the human body are housed in compartments called body cavities. These cavities protect delicate internal organs from injuries and from the daily wear and tear of walking, jumping, or running. The body cavities also permit organs such as the lungs, the urinary bladder, and the stomach to expand and contract while remaining securely supported. As shown in Figure 46-2, the human body has four main body cavities, each of which contains one or more organs. The **cranial cavity** encases the brain. The **spinal cavity,** extending from the cranial cavity to the base of the spine, surrounds the spinal cord.

The two main cavities in the trunk of the human body are separated by a wall of muscle called the **diaphragm** (DIE-uh-FRAM). The upper compartment, or **thoracic** (thoh-RAS-ik) **cavity,** contains the heart, the esophagus, and the organs of the respiratory system—the lungs, trachea, and bronchii. The lower compartment, or **abdominal** (ab-DAHM-uh-nuhl) **cavity,** contains organs of the digestive, reproductive, and excretory systems.

SECTION 46-1 REVIEW

1. Name the four types of tissues in the human body, and give an example of each.
2. How do muscle tissue and nervous tissue differ?
3. How are bone, cartilage, tendons, fat, blood, and lymph tissues structurally similar?
4. How are tissues, organs, and organ systems organized in the body?
5. Locate the thoracic and abdominal cavities, and describe the organs each cavity contains. What structure separates these cavities from each other?
6. **CRITICAL THINKING** Describe how the skeletal, muscular, nervous, respiratory, and circulatory systems function in a person swimming laps in a pool.

SKELETAL SYSTEM

The adult human body consists of approximately 206 bones, which are organized into an internal framework called the ***skeleton.*** *Because the human skeleton is an internal structure, biologists refer to it as an endoskeleton. The variation in size and shape among the bones that make up the skeleton reflects their different roles in the body.*

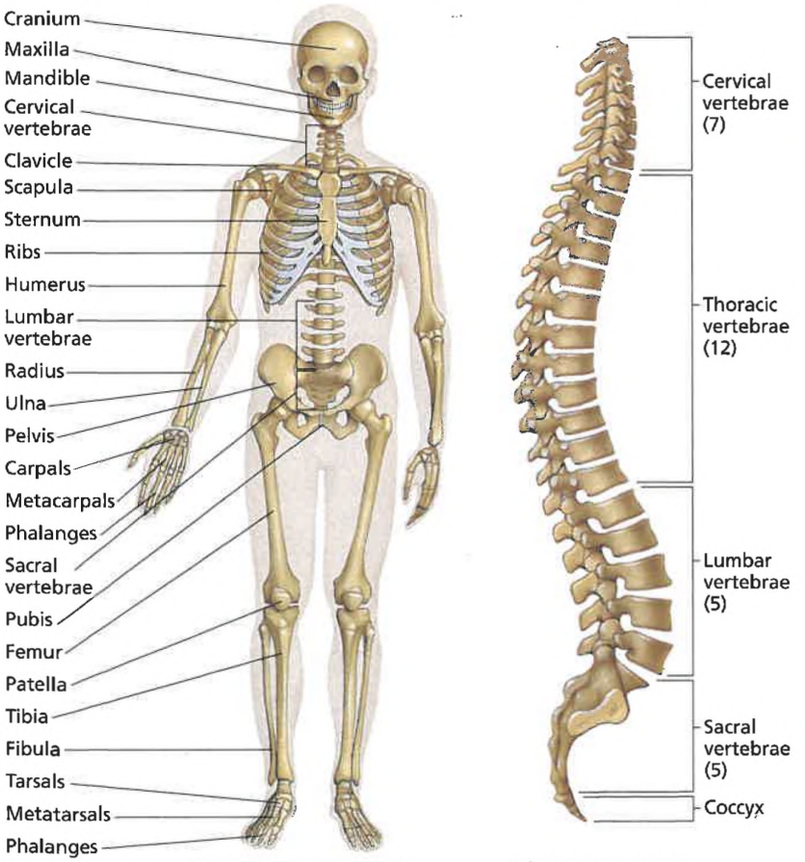
SECTION 46-2

OBJECTIVES

- Distinguish between the axial skeleton and the appendicular skeleton.
- Explain the function and structure of bones.
- Summarize how bones develop and elongate.
- List three types of joints, and give an example of each.
- Describe a common disorder that affects the skeletal system.

THE SKELETON

As shown in Figure 46-3, the human skeleton is composed of two parts—the axial skeleton and the appendicular skeleton. The bones of the skull, ribs, spine, and sternum form the **axial skeleton.** The bones of the arms and legs, along with the scapula, clavicle, and pelvis, make up the **appendicular** (AP-uhn-DIK-yuh-luhr) **skeleton.**



(a) HUMAN SKELETON (b) HUMAN SPINE

FIGURE 46-3
(a) The skeleton is the framework on which the rest of the body is built. (b) Like a stack of segmented tubes, the vertebrae of the spinal column offer strong protection for the spinal cord, yet they permit the trunk to bend and twist.

The bones that make up the skeleton function in a variety of ways. Bones provide a rigid framework against which muscles can pull, give shape and structure to the body, and support and protect delicate internal organs. Notice, for example, that the ribs curve to form a cage that contains the heart and lungs. Similarly, bones in the skull form the cranium, a dome-shaped case that protects the brain. Bones also store minerals, such as calcium and phosphorus, which play vital roles in important metabolic processes. In addition, the internal portion of many bones produces red blood cells and certain types of white blood cells.

BONE STRUCTURE

Despite their number and size, bones make up less than 20 percent of the body's mass. The reason for their having relatively little mass can be better understood by looking at bone structure. Bones are not dry, rigid structures, as they may appear in a museum exhibit. They are moist, living tissues. As shown in Figure 46-4, a long bone consists of a porous central canal surrounded by a ring of dense material. The bone's surface is covered by a tough membrane called the **periosteum** (PER-ee-AHS-tee-uhm). This membrane contains a network of blood vessels, which supply nutrients, and nerves, which signal pain.

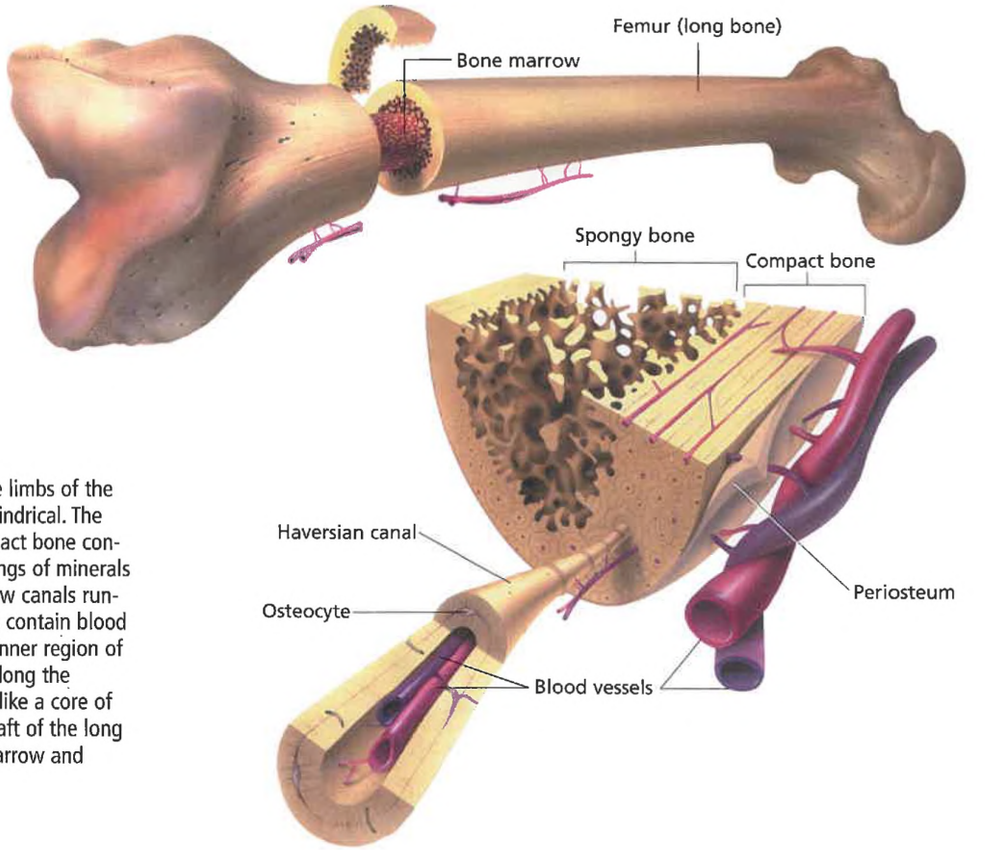
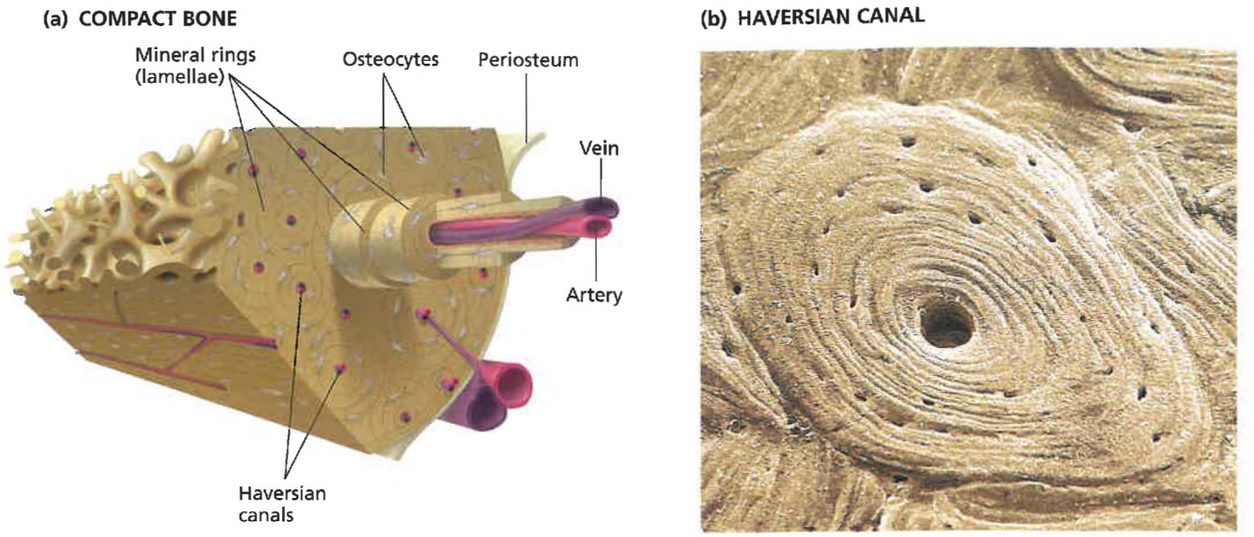


FIGURE 46-4

Long bones, found in the limbs of the body, are hollow and cylindrical. The outer shell of hard compact bone consists of closely packed rings of minerals and protein fibers. Narrow canals running through these rings contain blood vessels and nerves. The inner region of spongy bone stretches along the length of the long bone like a core of rigid lace. The central shaft of the long bone contains yellow marrow and blood vessels.



Under the periosteum is a hard material called **compact bone.** A thick layer of compact bone enables the shaft of the long bone to endure the large amount of stress it receives upon impact with a solid object. In the cross section shown in Figure 46-5a, notice that compact bone is composed of cylinders of mineral crystals and protein fibers called lamellae. In the center of each cylinder is a narrow channel called a **Haversian** (huh-VER-shuhn) **canal,** as shown in Figure 46-5b. Blood vessels run through interconnected Haversian canals, creating a network that carries nourishment to the living bone tissue. Several layers of protein fibers wrap around each Haversian canal. Embedded within the gaps between the protein layers are living bone cells called **osteocytes** (AHS-tee-uh-SIETS).

Inside the compact bone is a network of connective tissue called **spongy bone.** Although its name suggests that it is soft, this tissue is hard and strong. As shown in Figure 46-4, spongy bone has a latticework structure that consists of bony spikes. It is arranged along points of pressure or stress, making bones both light and strong.

Many bones also contain a soft tissue called **bone marrow,** which can be either red or yellow. Red bone marrow—found in spongy bone, the ends of long bones, ribs, vertebrae, the sternum, and the pelvis—produces red blood cells and certain types of white blood cells. Yellow bone marrow fills the shafts of long bones. It consists mostly of fat cells and serves as an energy reserve. It can also be converted to red bone marrow and produce blood cells when severe blood loss occurs.

Injury and Repair

Despite their strength, bones will crack or even break if they are subjected to extreme loads, sudden impacts, or stresses from unusual directions. The crack or break is referred to as a **fracture.** If circulation is maintained and the periosteum survives, healing will occur even if the damage to the bone is severe.

FIGURE 46-5

The cross section in (a) shows the internal structure of compact bone. A micrograph of a Haversian canal (380×) surrounded by lamellae in compact bone is shown in (b).

Eco Connection

Bones of Lead

Millions of Americans have been exposed to lead in the environment. Following exposure to lead, the kidneys excrete most of the metal. But 7 to 10 percent of the remaining lead in the body is stored in bone and can stay there for a lifetime. The rapid bone uptake of lead acts as a detoxifying mechanism. But lead is not permanently locked in bone. As people age, bone degeneration may occur, releasing lead into the bloodstream. Even very small concentrations of lead in the bloodstream can cause damage to kidneys, which in turn can cause high blood pressure.

The United States has outlawed the addition of lead to gasoline, water pipes, and paint. As a result, people who are now under age 25 may not accumulate as much lead in their bones as people from earlier generations.

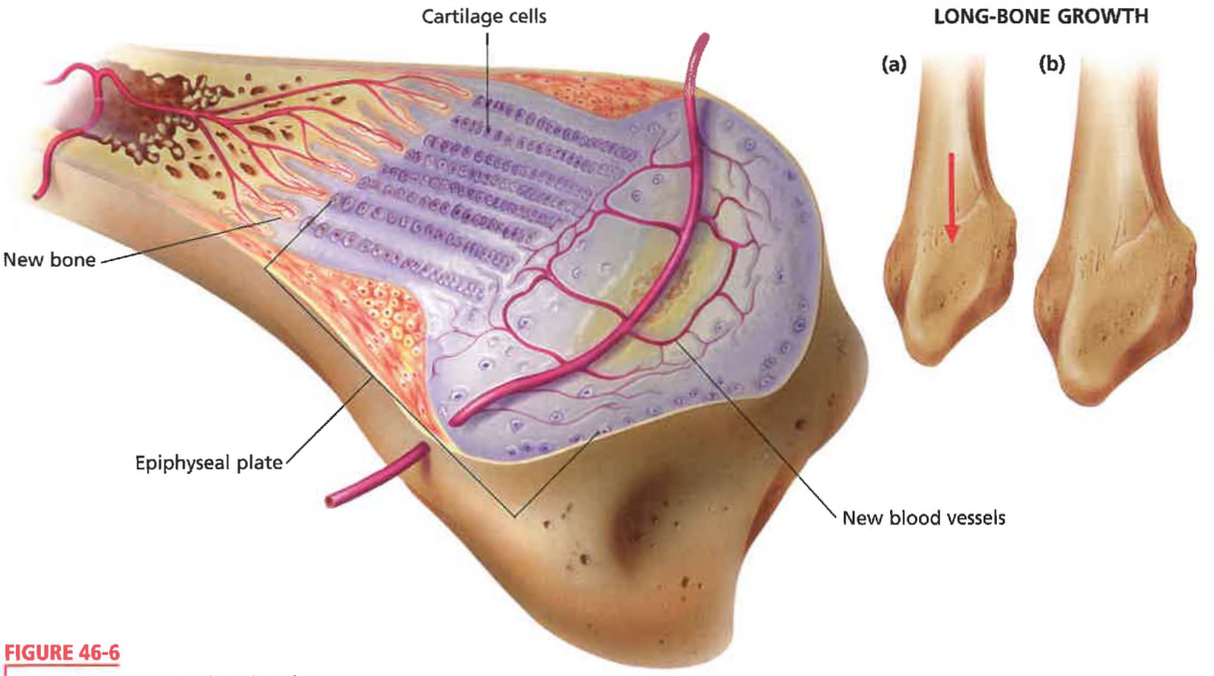


FIGURE 46-6

The epiphyseal plate, found at the ends of long bones, such as the femur shown above, is the site of bone elongation. This region is rich with cartilage cells, which divide, enlarge, and push older cells toward the middle of the bone shaft. As older cells move back, they are replaced by new bone cells, forming new regions of bone. A long bone (a) will grow in length, circumference, and density in this manner, as shown in (b).

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BONE DEVELOPMENT

Most bones develop from cartilage, a tough but flexible connective tissue. In the second month of fetal development, much of the skeleton is made of cartilage. During the third month, osteocytes begin to develop and release minerals that lodge in the spaces between the cartilage cells, turning the cartilage to bone. The process by which cartilage slowly hardens into bone as a result of the deposition of minerals is called **ossification** (AHS-uh-fuh-KAY-shuhn). Most fetal cartilage is eventually replaced by bone. However, some cartilage remains, lending flexibility to the areas between bones, at the end of the nose, in the outer ear, and along the inside of the trachea.

A few bones, such as some parts of the skull, develop directly into hard bone without forming cartilage first. In these cases, the osteocytes are initially scattered randomly throughout the embryonic connective tissue but soon fuse into layers and become flat plates of bone. In the skull, suture lines can be seen where the plates of bone meet.

Bone Elongation

Bones continue to develop after a person's birth. Between early childhood and late adolescence, bone cells gradually replace the cartilage in long bones of limbs, such as the arms and legs. Bone elongation takes place near the ends of long bones in an area known as the **epiphyseal** (EP-uh-FIZ-ee-uhl) **plate.** As shown in Figure 46-6, the epiphyseal plate is composed of cartilage cells that divide and form columns, pushing older cells toward the middle of the bone. As these older cells die, they are replaced by new bone cells.

Growth continues until bone has replaced all the cartilage in the epiphyseal plate. At this point, bones no longer elongate, and a person is considered to have reached full height.

JOINTS

The place where two bones meet is known as a **joint.** Three kinds of joints are found in the human body—fixed, semimovable, and movable. Examples of these joints are shown in Figure 46-7.

Joint Function

Fixed joints prevent movement. They are found in the skull, where they securely connect the bony plates and permit no movement of those bones. A small amount of connective tissue in a fixed joint helps absorb impact to prevent the bones from breaking.

Semimovable joints permit limited movement. For example, semimovable joints hold the bones of the vertebral column in place and allow the body to bend and twist. The vertebrae of the spine are separated by disks of cartilaginous tissue. These tough, springy disks compress and absorb shocks that could damage the fragile spinal cord. Semimovable joints are also found in the rib cage, where long strands of cartilage connect the upper seven pairs of ribs to the sternum, allowing the chest to expand during breathing.

Most of the joints in the body are **movable joints.** These joints enable the body to perform a wide range of movements and activities. Movable joints include hinge, ball-and-socket, pivot, saddle, and gliding joints. An example of a **hinge joint** is found in the elbow, which allows you to move your forearm forward and backward, like a hinged door. An example of a **ball-and-socket joint** is the shoulder joint, which enables you to move your arm up, down, forward, and backward, as well as to rotate it in a complete circle. The joint formed by the top two vertebrae of your spine is an example of a **pivot joint;** it allows you to turn your head from side to side, as when shaking your head "no." The **saddle joint,** found at the base of each thumb, allows you to rotate your thumbs and helps you grasp objects with your hand. Finally, **gliding joints** allow bones to slide over one another. Examples are the joints between the small bones of your foot, which allow your foot to flex when you walk.

Joint Structure

Joints, such as the knee, are often subjected to a great deal of pressure and stress, but their structure is well suited to meet these demands. As in all movable joints, the parts of the bones that come in contact with each other are covered with cartilage, which protects the bones' surface from friction. Tough bands of connective tissue, called **ligaments,** hold the bones of the joint in place. The surfaces of the joints that are subjected to a great deal of pressure are lined with tissue that secretes a lubricating substance called

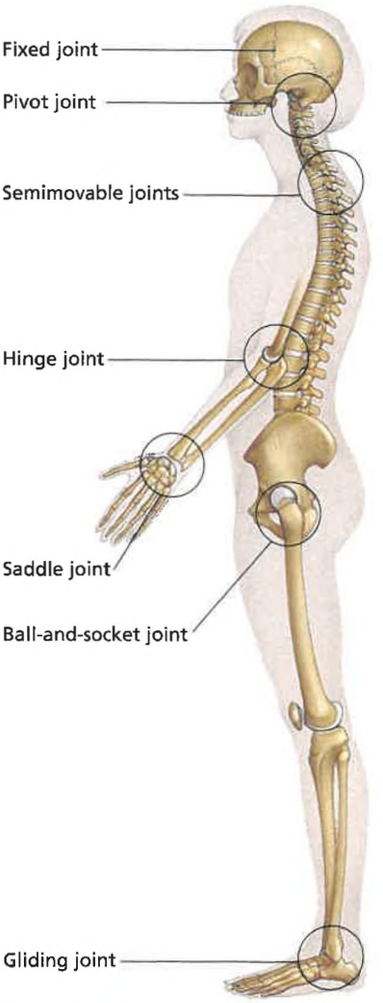
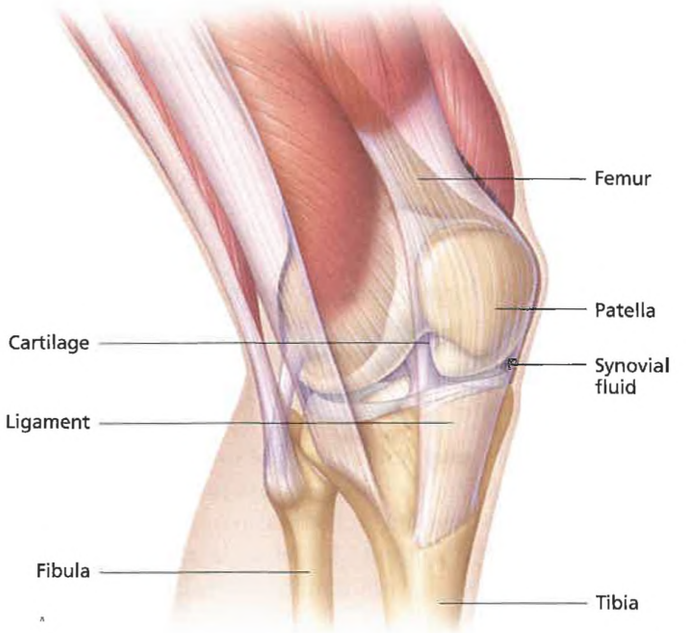


FIGURE 46-7
In addition to fixed joints and semimovable joints, the human body has five types of movable joints: pivot, hinge, saddle, ball-and-socket, and gliding.

FIGURE 46-8

The knee is a movable joint formed by the ends of the femur and the fibula. Many cordlike ligaments stabilize the joint, especially during movement. Pads of cartilage protect the ends of bones and act as shock absorbers. Like many joints in the body, the knee is a synovial joint. It contains membranes that secrete synovial fluid, which lubricates and nourishes the tissues inside the joint.



synovial (sih-NOH-vee-uhl) **fluid.** Synovial fluid helps protect the ends of bones from damage by friction. Figure 46-8 shows the internal structures of the synovial knee joint.

Sometimes these protective structures are not enough to prevent a joint from becoming injured. Of all the joints in the body, the knee joint is the most susceptible to injury because it carries the body's weight and relies on many ligaments for stability.

The term *arthritis* is used to describe several types of disorders that cause painful, swollen joints. There are two forms of arthritis that affect joints. **Rheumatoid arthritis** develops when the immune system begins to attack body tissues. The joints become inflamed, swollen, stiff, and deformed. **Osteoarthritis** is a degenerative joint disease in which the cartilage covering the surface of bone becomes thinner and rougher. As a result, bone surfaces rub against each other, causing severe discomfort.

SECTION 46-2 REVIEW

1. Name the two main parts of the human skeleton, and list the bones that form them.
2. What are five functions of bones?
3. How do compact bone and spongy bone differ in structure and function?
4. When do most of the bones in the body begin to ossify? When does this process end?
5. What are the three major types of joints in the human body? Describe the function of each type and give an example.
6. **CRITICAL THINKING** What is the advantage of a cartilaginous skeleton during prenatal development?

SECTION 46-3

MUSCULAR SYSTEM

Muscles make up the bulk of the body and account for about one-third of its weight. Their ability to contract not only enables the body to move, but also provides the force that pushes substances, such as blood and food, through the body. Without the muscular system, none of the other organ systems would be able to function.

OBJECTIVES

- Distinguish between the three types of muscle tissues.
- Describe the structure of skeletal muscle fibers.
- Explain how skeletal muscles contract.
- Explain how muscles move bones.

MUSCLE TYPES

A muscle is tissue that can contract in a coordinated fashion and includes muscle tissue, blood vessels, nerves, and connective tissue. Recall that the human body has three types of muscle tissues: skeletal, smooth, and cardiac.

Skeletal muscle is responsible for moving parts of the body, such as the limbs, trunk, and face. Skeletal muscle tissue is made up of elongated cells called **muscle fibers.** Each muscle fiber contains many nuclei and is crossed by light and dark stripes, called **striations,** as shown on the following page in Figure 46-10a. Skeletal muscle fibers are grouped into dense bundles called **fascicles.** A

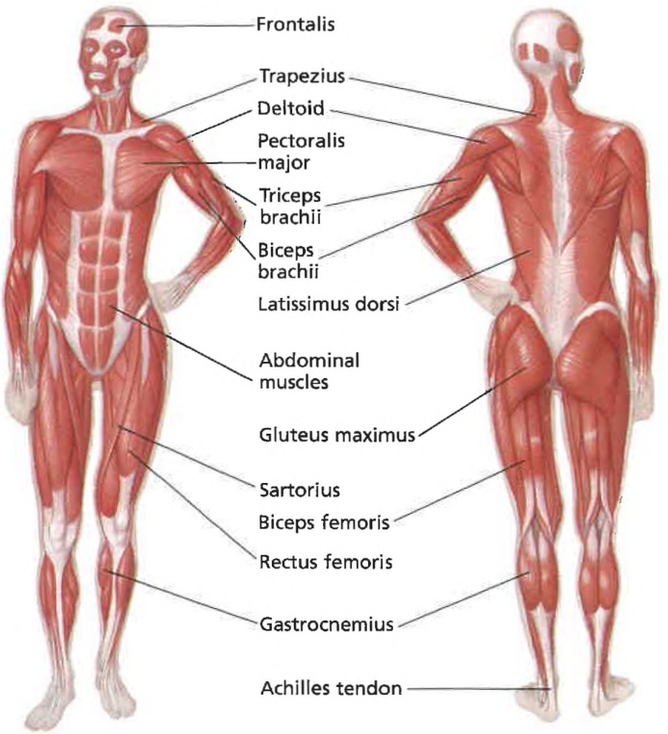
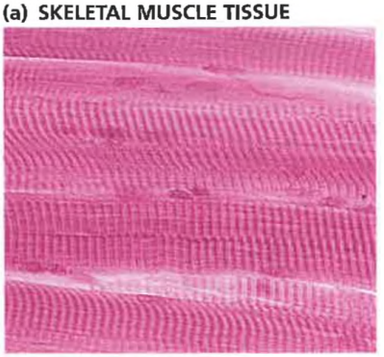
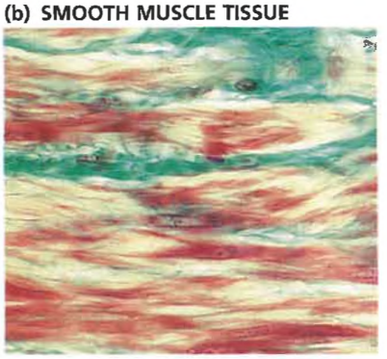


FIGURE 46-9
Skeletal muscle tissue is shown in these diagrams of some of the major muscles in the human body.

(a) SKELETAL MUSCLE TISSUE



(b) SMOOTH MUSCLE TISSUE



(c) CARDIAC MUSCLE TISSUE

FIGURE 46-10

These light micrographs show the three types of muscle tissue. Skeletal muscle tissue (a) has a striped appearance when viewed under a microscope (430×). Smooth muscle tissue (b) is found in the digestive tract, the uterus, the bladder, and the blood vessels (400×). Cardiac muscle tissue (c) is found only in the heart (270×). Its interconnected fibers allow impulses to spread rapidly.

group of fascicles are bound together by connective tissue to form a muscle. Because their contractions can usually be consciously controlled, skeletal muscles are described as **voluntary muscles.**

Smooth muscle forms the muscle layers found in the walls of the stomach, intestines, blood vessels, and other internal organs. Individual smooth muscle cells are spindle-shaped, have a single nucleus, and interlace to form sheets of smooth muscle tissue, as shown in Figure 46-10b. Notice that smooth muscle lacks the striations found in skeletal muscle tissue. Smooth muscle fibers are surrounded by connective tissue, but the connective tissue does not unite to form tendons as it does in skeletal muscles. Because most of its movements cannot be consciously controlled, smooth muscle is referred to as **involuntary muscle.**

Cardiac muscle, shown in Figure 46-10c, makes up the walls of the heart. Cardiac muscle shares some characteristics with both skeletal muscle and smooth muscle. As with skeletal muscle, cardiac muscle tissue is striated; as with smooth muscle, it is involuntary and each cell has one nucleus. A bundle of specialized muscle cells in the upper part of the heart sends electrical signals through cardiac muscle tissue, causing the heart to rhythmically contract and pump blood throughout the body.

MUSCLE STRUCTURE

A muscle fiber is a single, multinucleated muscle cell. A muscle may be made up of hundreds or even thousands of muscle fibers, depending on the muscle's size. Although muscle fibers make up most of the muscle tissue, a large amount of connective tissue, blood vessels, and nerves are also present. Like all body cells, muscle cells are soft and easy to injure. Connective tissue covers and supports each muscle fiber and reinforces the muscle as a whole.

The health of a muscle depends on a sufficient nerve and blood supply. Each skeletal muscle fiber has a nerve ending that controls its activity. Active muscles use a lot of energy and therefore require a continuous supply of oxygen and nutrients, which are supplied by arteries. Muscles produce large amounts of metabolic waste that must be removed through veins.

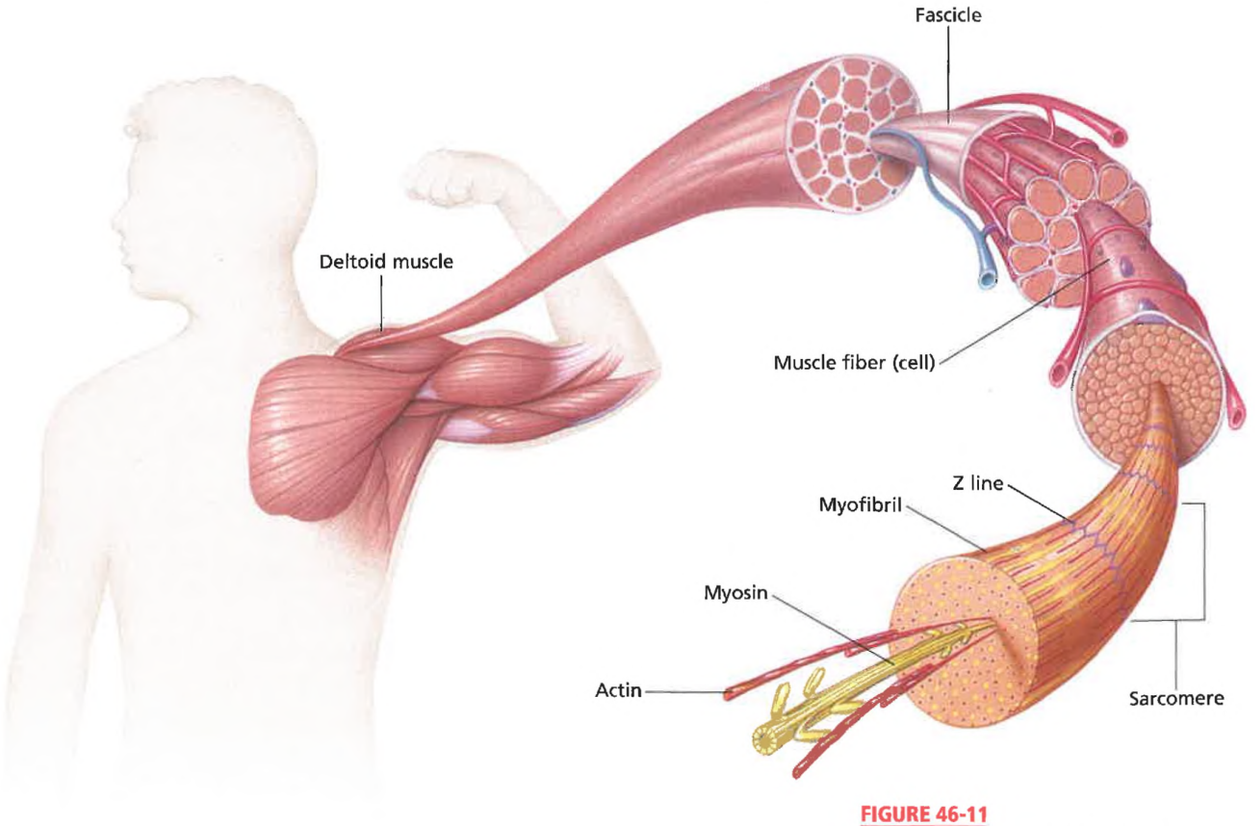


FIGURE 46-11

Skeletal muscles consist of densely packed groups of elongated cells, called fascicles, that are held together by connective tissue. Muscle fibers consist of protein filaments called myofibrils. Two types of filaments are found in muscle fibers—actin and myosin. The complementary structures of actin and myosin interact to contract and relax muscles.

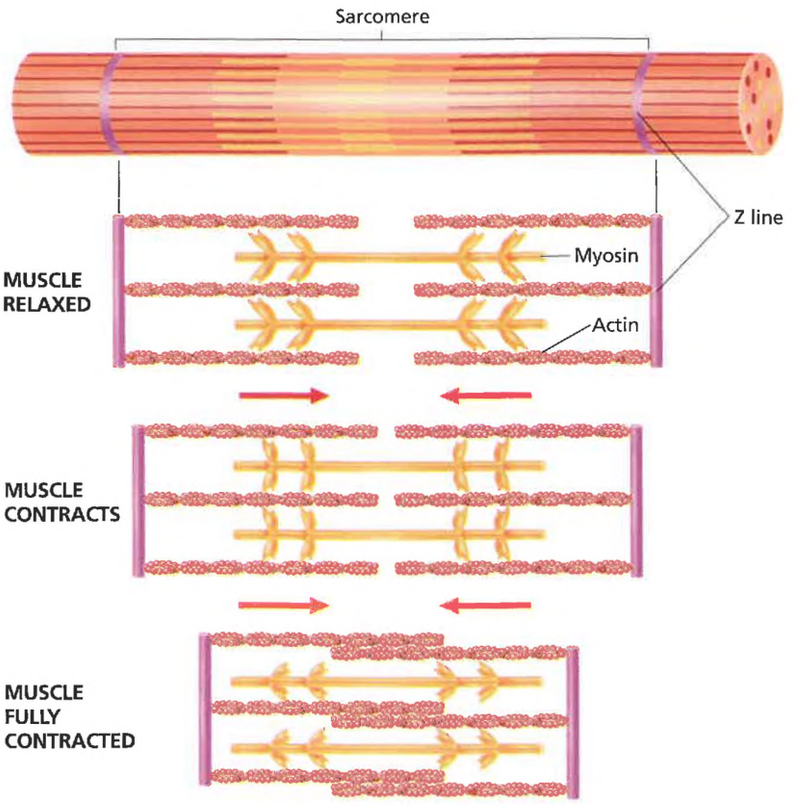
A muscle fiber, such as the one shown in Figure 46-11, consists of bundles of threadlike structures called **myofibrils** (MIE-oh-FIE-bruhlz). Each myofibril is made up of two types of protein filaments—thick ones and thin ones. Thick filaments are made of the protein **myosin** (MIE-uh-suhn), and thin filaments are made of the protein **actin.** Myosin and actin filaments are arranged to form an overlapping pattern, which gives muscle tissue its striated appearance. Thin actin filaments are anchored at their endpoints to a structure called the **Z line.** The region from one Z line to the next is called a **sarcomere** (SAHR-kuh-MIR).

Muscular Contraction

The sarcomere is the functional unit of muscle contraction. When a muscle contracts, myosin filaments and actin filaments interact to shorten the length of a sarcomere. Myosin filaments have extensions shaped like oval "heads." Actin filaments look like a twisted strand of beads. When a nerve impulse stimulates a muscle fiber to contract, the heads at the end of the myosin filaments attach to points between the beads of the actin filaments. The myosin heads then bend inward, pulling the actin filaments with them. The myosin heads then let go, bend back into their original position, attach to a new point on the actin filament, and pull again. This action shortens the length of the

FIGURE 46-12

In a relaxed muscle, the actin and myosin filaments overlap. During a muscle contraction, the filaments slide past each other and the zone of overlap increases. As a result, the length of the sarcomere shortens.



sarcomere. The synchronized shortening of sarcomeres along the full length of a muscle fiber causes the whole fiber, and hence the muscle, to contract. Figure 46-12 shows the structures of the sarcomere.

Like all cellular activities, muscle contraction requires energy, which is supplied by ATP. This energy is used to detach the myosin heads from the actin filaments. Because myosin heads must attach and detach a number of times during a single muscle contraction, muscle cells must have a continuous supply of ATP. Without ATP, the myosin heads would remain attached to the actin filaments, keeping a muscle permanently contracted.

Muscle contraction is an all-or-none response—either the fibers contract or they remain relaxed. How, then, are you able to contract your muscles tightly enough to lift a dumbbell or gently enough to lift a pen? The force of a muscle contraction is determined by the number of muscle fibers that are stimulated. As more fibers are activated, the force of the contraction increases.

Some muscles, such as the muscles that hold the body in an upright position and maintain posture, are nearly always at least partially contracted. However, prolonged contraction may cause the muscle to use up all its available energy, become overly tired, and begin to cramp. To prevent this from happening, the nervous system automatically stimulates different muscle fibers alternately in the muscle, allowing some to be at rest while others are working to maintain the body's posture.

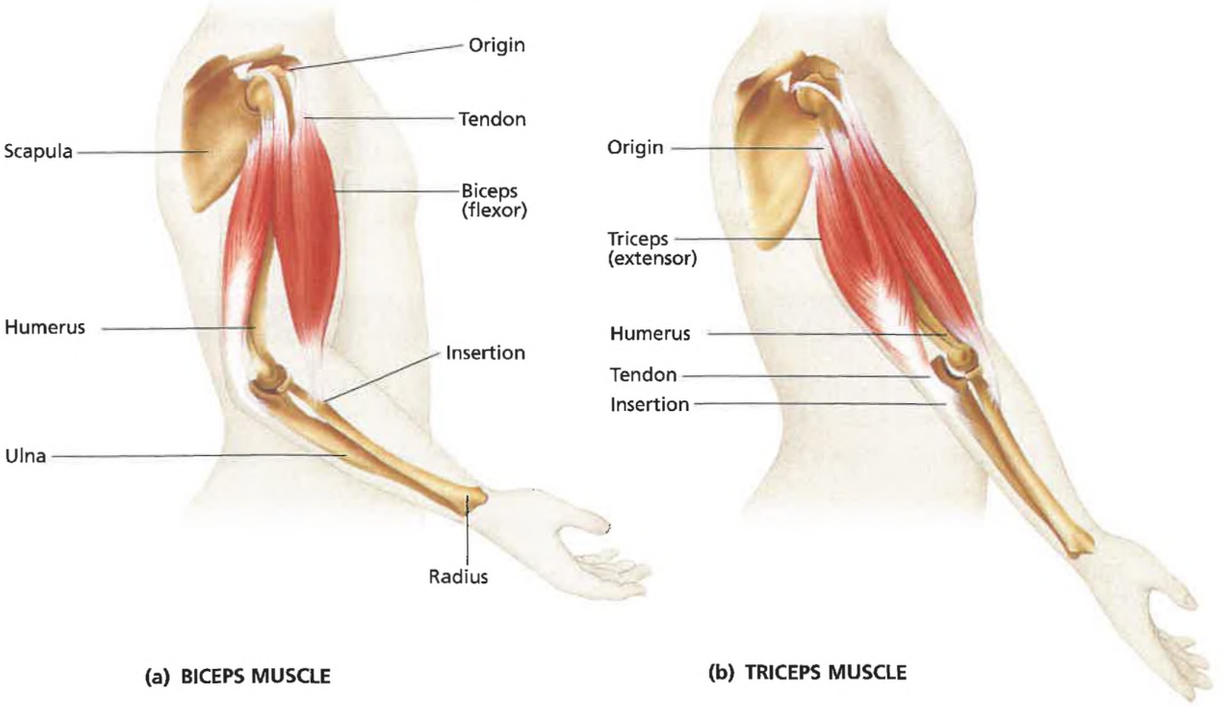
MUSCULAR MOVEMENT OF BONES

Generally, skeletal muscles are attached to one end of a bone, stretch across a joint, and are fastened to the end of another bone. Muscles are attached to the outer membrane of bone, either directly or by a tough fibrous cord of connective tissue called a **tendon.** For example, as shown in Figure 46-13, one end of the large biceps muscle in the arm is connected by tendons to the radius and ulna in the forearm, while the other end of the muscle is connected to the scapula in the shoulder. When the biceps muscle contracts, the forearm flexes upward while the scapula remains stationary. The point where the muscle attaches to the stationary bone—in this case, the scapula—is called the **origin.** The point where the muscle attaches to the moving bone—in this case the bones in the forearm—is called the **insertion.**

Most skeletal muscles are arranged in opposing pairs. One muscle in a pair moves a limb in one direction; the other muscle moves it in the opposite direction. Muscles move bones by pulling them, not by pushing them. For example, when the biceps muscle contracts, the elbow bends. The biceps muscle is known as a **flexor,** a muscle that bends a joint. Contraction of the triceps muscle in the upper arm straightens the limb. The triceps muscle is an example of an **extensor,** a muscle that straightens a joint. To bring about a smooth movement, one muscle in a pair must relax while the opposing muscle contracts.

FIGURE 46-13

Skeletal muscles, such as the biceps and triceps muscles in the upper arm, are connected to bones by tendons. (a) When the biceps muscle contracts, the elbow bends. (b) When the triceps muscle contracts, the elbow straightens.



(a) BICEPS MUSCLE

(b) TRICEPS MUSCLE

MUSCLE FATIGUE

internetconnect

SCILINKS NSTA

TOPIC: Muscle fatigue
GO TO: www.scilinks.org
KEYWORD: HM920

Muscle cells store glycogen, which is used as a source of energy after blood-delivered glucose is exhausted. The breakdown of glycogen releases large amounts of energy, but sometimes even those reserves are used up, especially in athletes who participate in sports that require sustained exertion. During prolonged and vigorous exertion, fat molecules are utilized for energy. Fat molecules contain a greater concentration of potential energy than any other molecule in the body. When energy availability fails to keep pace with its use, muscle fatigue sets in and controlled muscle activity ceases, even though the muscle may still receive nerve stimulation to move. **Muscle fatigue** is the physiological inability of a muscle to contract. Muscle fatigue is a result of a relative depletion of ATP. When ATP is absent, a state of continuous contraction occurs. An example of depletion of ATP is when a marathon runner collapses during a race, suffering from severe muscle cramps.

FIGURE 46-14

These athletes are in the process of repaying their oxygen debts. Oxygen debt occurs frequently after strenuous, sustained exertion.

Oxygen Debt

Oxygen is used during cellular respiration in the synthesis of ATP. Large amounts of oxygen are needed to maintain the rate of maximum ATP production required to sustain strenuous exercise. However, after several minutes of exertion, the circulatory system and the respiratory system are not able to bring in enough oxygen to meet the demands of energy production. Oxygen levels in the body become depleted. This temporary lack of oxygen availability is called **oxygen debt.** Oxygen debt leads to an accumulation of metabolic wastes in the muscle fibers. The presence of this waste produces the soreness you may experience after prolonged exercise. Oxygen debt is what causes an athlete to spend a minute or two in rapid, deep breathing after strenuous exercise, as the athletes shown in Figure 46-14 are doing. The oxygen debt is repaid quickly as additional oxygen becomes available, but muscle soreness may persist until all of the metabolic wastes that have accumulated in the muscle fibers are carried away or converted.

SECTION 46-3 REVIEW

1. What are the three main types of muscle tissues found in the body, and what are their functions?
2. Why is smooth muscle referred to as involuntary muscle?
3. What is a muscle fiber? Why does it appear striated?
4. What are actin and myosin, and how are they organized in a muscle? How do they interact during a muscle contraction?
5. How do muscle pairs work together to move a limb?
6. **CRITICAL THINKING** Rigor mortis is a condition in which all the body muscles become rigid shortly after a person dies. Why does rigor mortis develop?

Research Notes

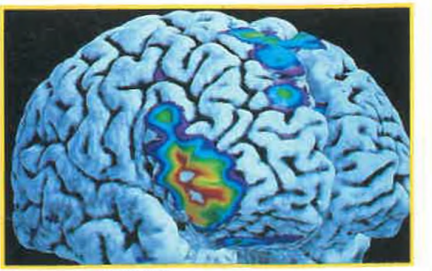
Looking Inside the Human Body

In 1895, the development of X-ray equipment provided physicians a way to look inside the body at images of dense tissue, such as bones. Modern imaging techniques rely on computers. For example, computerized tomography (CT) uses a focused beam of low-dose X rays to obtain cross-sectional images of structures in the body. Tomography is the X-ray technique used to image only a specific "slice" or plane of tissue. Computerized tomography can differentiate tissues of various densities. Another technology, magnetic resonance imaging (MRI), creates images of soft tissues by using radio waves emitted by the nuclei of hydrogen atoms activated by a magnetic scanner.

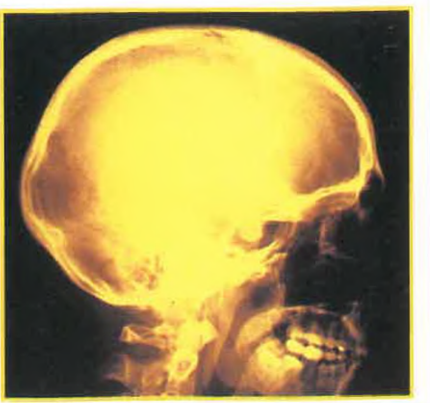
Still another and newer imaging technology is positron emission technology, or PET. Positrons are positively charged particles that result from the disintegration of radioisotopes. Michael M. TerPogossian and his colleagues at Johns Hopkins suggested using short-lived radioisotopes in medical research in 1966. They then developed scanners to detect the positrons released by radioisotopes that had been injected into a patient's bloodstream. As electronic and computer technology improved, biomedical engineers redesigned scanning equipment to create three-dimensional images from the positron emissions. Positron emission technology is often used in evaluating brain metabolism. It is also used to map areas of the brain involved in memory, sensation, perception, speech, and information processing. In addition, positron emission technology provides clues to the physiological and neurochemical basis of medical psychiatric disorders, such as depression.

A new holographic imaging system combines images obtained by computerized tomography or magnetic resonance scanners and displays an accurate three-dimensional image of the anatomical structures being viewed. A holograph is a method of photography that uses laser light. A three-dimensional image is produced when the holograph is viewed under visible light. The transparent but solid-seeming image floats in front of the holographic film and can be moved around or reversed so that it can be studied from all sides. Computer point-and-click methods allow viewers to focus on specific areas of the image. Physicians can make surgical plans by studying the actual appearance of a patient's organs, as shown in the 3-D PET scan of a brain that highlights the verbal center in (a). Compare the 3-D PET scan with the X ray of the same part of the body in (b). The X ray may not be as helpful as the 3-D PET scan is when a physician must diagnose an illness or injury of the brain.

Some of the newest techniques are interactive. On the Internet, for example, medical students and researchers can view a "Visible Man" made up of thousands of computerized tomography cross sections. They can use the images to test theories or study the relationships of various anatomical structures. An explosion in technology has provided medicine with new techniques, such as virtual reality. Virtual reality is a computer simulation of a system that allows the user to perform operations on the system and that shows the effects of those operations. Doctors are beginning to use virtual reality to navigate through a patient's computerized tomography images when planning for surgery or other treatments.



(a) 3-D PET SCAN



(b) X RAY

SECTION

46-4

OBJECTIVES

- Describe the functions of the skin.
- Distinguish between the two layers that form the skin.
- Compare the structure of hair with that of nails.
- Identify two types of glands found in the skin, and describe their functions.

INTEGUMENTARY SYSTEM

The integumentary system, consisting of the skin, hair, and nails, acts as a barrier to protect the body from the outside world. It also functions to retain body fluids, protect against disease, eliminate waste products, and regulate body temperature.

SKIN

The skin is one of the human body's largest organs. Subjected to a lifetime of wear and tear, the layers of skin are capable of repairing themselves. Skin contains sensory devices that monitor the external environment, and mechanisms that rid the body of wastes. The skin is composed of two layers—the epidermis and the dermis.

Epidermis

The **epidermis,** or outer layer of skin, is composed of many sheets of flattened, scaly epithelial cells. Its layers are made of mostly dead cells. These cells are exposed to the dangers of the external environment. Scraped or rubbed away on a daily basis, they are replaced by new cells made in the rapidly dividing lower layers. The cells of the epidermis are filled with a protein called **keratin,** which gives skin its rough, leathery texture and its waterproof quality.

There is a great variety in skin color among humans. The color of skin is mainly determined by a brown pigment called **melanin** (MEL-uh-nin), which is produced by cells in the lower layers of the epidermis. Melanin absorbs harmful ultraviolet radiation. The amount of melanin produced in skin depends on two factors: heredity and the length of time the skin is exposed to ultraviolet radiation. Increased amounts of melanin in a person's skin occurs in response to injury of the skin by ultraviolet radiation. All people, but especially people with light skin, need to minimize exposure to the sun and protect themselves from its ultraviolet radiation, which can damage the DNA in skin cells and lead to deadly forms of skin cancer.

Dermis

The **dermis,** the inner layer of skin, is composed of living cells and many kinds of specialized structures, such as sensory neurons, blood vessels, muscle fibers, hair follicles, and glands. Sensory neurons make it possible for you to sense many kinds of conditions and signals from the environment, such as heat and pressure. Blood vessels provide nourishment to the living cells and help regulate body

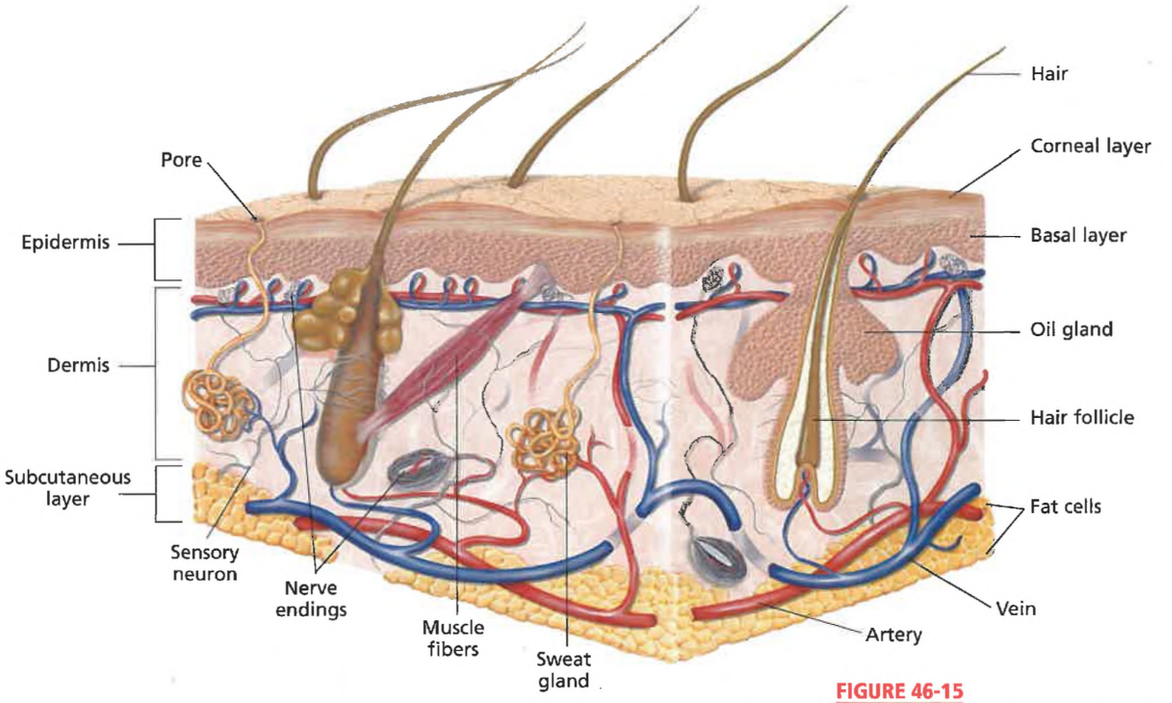


FIGURE 46-15

Skin is composed of two layers: the epidermis and the dermis. The epidermis consists of dead, flattened cells that are shed and replaced every day. The dermis contains a variety of specialized structures that carry out essential life processes, such as protecting the body from infectious diseases and regulating body temperature.

temperature. Tiny muscle fibers attached to hair follicles contract and pull hair upright when you are cold or afraid, producing what are commonly called goose bumps. Glands produce sweat, which helps cool your body, and oil, which helps soften your skin. A layer of fat cells lies below the dermis. These cells act as energy reserves; add a protective, shock-absorbing layer; and insulate the body against heat loss. Study the structures of the skin in Figure 46-15.

Nails and Hair

Nails, which protect the ends of the fingers and toes, form from nail roots under skin folds at their base and sides. As new cells form, the nail grows longer. Like hair, nails are composed primarily of keratin. The nail body is about 0.5 mm (0.02 in.) thick, and growth continues throughout life. Nails grow at about 1 mm (0.04 in.) per week. Nails rest on a bed of tissue filled with blood vessels, giving the nails a pinkish color. The structure of a fingernail can be seen in Figure 46-16.

Changes in the shape, structure, and appearance of the nails may be an indicator of a disease somewhere in the body. They may turn yellow in patients with chronic respiratory disorders, or they may grow concave in certain blood disorders.

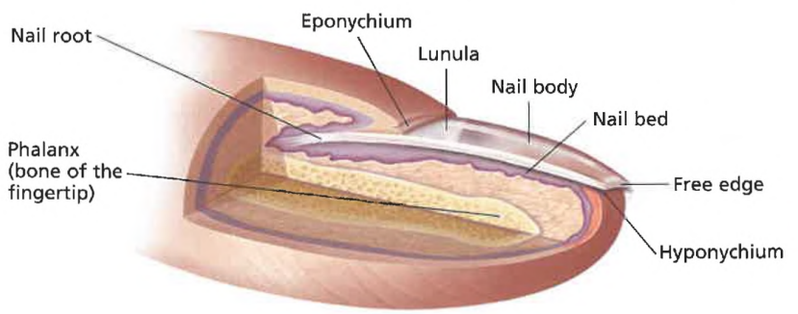


FIGURE 46-16

This illustration of the structure of a fingernail shows that the nail root, from which the nail is constantly regenerated, is protected well beneath the surface of the finger, next to the bone of the fingertip.

FIGURE 46-17
Skin acts as a temperature-controlling device. It contains millions of sweat glands that secrete microscopic droplets of water. The water droplets help cool the body when its temperature rises, such as after a rigorous workout.

Hair, which protects and insulates the body, is produced by a cluster of cells at the base of deep dermal pits called **hair follicles.** The shaft of the hair that extends beyond the skin is composed of dead, keratin-filled cells that overlap like roof shingles. Glands associated with hair follicles secrete oil, which prevents hair from drying out and breaking off. Most individual hairs grow for several years and then fall out. However, hair on the scalp can grow continuously for many years.

Hair color is the result of the presence of the pigment melanin in the hair shaft. Black, brown, and yellow variants of melanin combine in an almost infinite number of proportions to determine an individual's hair color. Hair color is influenced by hereditary factors and may vary over different areas of the body.

Glands

The skin contains **exocrine glands,** glands that release secretions through ducts. The main exocrine glands of the skin are the sweat glands and the oil glands.

The skin functions as an excretory organ by releasing excess water, salts, and urea through the **sweat glands.** By releasing excess water, the skin also helps regulate body temperature. When the body's temperature rises, circulation increases, and the skin becomes warm and flushed, as shown in Figure 46-17. The sweat glands then release sweat. As the water in sweat evaporates, the skin is cooled.

Oil glands, found in large numbers on the face and scalp, secrete a fatty substance known as **sebum.** Oil glands are usually connected by tiny ducts to hair follicles. Sebum coats the surface of the skin and the shafts of hairs, preventing excess water loss and lubricating and softening the skin and hair. Sebum is also mildly toxic to some bacteria. If the ducts of oil glands become clogged with excessive amounts of sebum, dead cells, and bacteria, the skin disorder **acne** can result. The production of sebum is controlled by hormones. During adolescence, high levels of sex hormones increase the activity of the skin's oil glands, often resulting in skin eruptions called acne. Although it is difficult to prevent, acne can sometimes be controlled with meticulous skin care.

SECTION 46-4 REVIEW

1. What are the names and functions of the two layers of skin?
2. What is melanin? Why can sunbathing be considered dangerous?
3. Why is the dermis considered the living layer of skin?
4. In what two ways are hair and nails similar?
5. What are the functions of the two types of exocrine glands found in the dermis?
6. **CRITICAL THINKING** Why are third-degree burns—which destroy the epidermis and dermis of the skin—over large regions of the body often fatal?

CHAPTER 46 REVIEW

SUMMARY/VOCABULARY

46-1

- A tissue is a collection of cells that work together to perform a particular function.
- The human body has four main types of tissue: muscle, nervous, epithelial, and connective.
- An organ consists of various tissues that work together to carry out a specific function.
- An organ system is a group of organs interacting to perform a life process.
- Many organs and organ systems in the human body are housed in body cavities.

Vocabulary

abdominal cavity (908)
cardiac muscle (905)
connective tissue (906)
cranial cavity (908)
diaphragm (908)
epithelial tissue (906)
matrix (906)
muscle tissue (905)
neuron (905)
nervous tissue (905)
skeletal muscle (905)
smooth muscle (905)
spinal cavity (908)
thoracic cavity (908)

46-2

- The human skeleton is composed of the axial skeleton (skull, ribs, spine, and sternum) and the appendicular skeleton (arms and legs, scapula, clavicle, and pelvis).
- Bones support muscles and organs, give structure to the body, protect internal organs, store minerals, and manufacture blood cells.
- Bones are made up of minerals, protein fibers, and cells called osteocytes. Most consist of compact and spongy bone and may contain bone marrow.
- Most bones develop from cartilage through a process called ossification.
- Bone elongation occurs near the ends of long bones, at the epiphyseal plate.
- The human body has three types of joints—fixed, semimovable, and movable.

Vocabulary

appendicular skeleton (909)
axial skeleton (909)
ball-and-socket joint (913)
bone marrow (911)
compact bone (911)
epiphyseal plate (912)
fixed joint (913)
fracture (911)
gliding joint (913)
Haversian canal (911)
hinge joint (913)
joint (913)
ligament (913)
movable joint (913)
ossification (911)
osteoarthritis (914)
osteocyte (911)
periosteum (910)
pivot joint (913)
rheumatoid arthritis (914)
saddle joint (913)
semimovable joint (913)
skeleton (909)
spongy bone (911)
synovial fluid (914)

46-3

- The human body has three types of muscle tissues—skeletal muscle, smooth muscle, and cardiac muscle.
- Skeletal muscles consist of groups of muscle fibers that contain threadlike myofibrils. Each myofibril is made up of two types of protein filaments, thin actin filaments and thick myosin filaments.
- A sarcomere is the fundamental unit of a muscle contraction. During a muscle contraction, myosin and actin filaments interact to shorten the length of a sarcomere.
- Most skeletal muscles are arranged in opposing pairs.

Vocabulary

actin (917)
extensor (919)
fascicle (915)
flexor (919)
insertion (919)
involuntary muscle (916)
muscle fatigue (920)
muscle fiber (915)
myofibril (917)
myosin (917)
origin (919)
oxygen debt (920)
sarcomere (917)
striation (915)
tendon (919)
voluntary muscle (916)
Z line (917)

46-4

- *Skin, hair, and nails act as barriers that protect the body from the environment.*
- *Skin is composed of two layers: the epidermis (composed of dead, keratin-filled cells) and the dermis (composed of living cells and a variety of structures).*
- *Hair and nails are composed of the protein* keratin; they grow from a bed of rapidly dividing cells.
- Sweat glands produce sweat, which evaporates and helps cool the body. Oil glands secrete sebum, which helps soften the skin and prevents hair from drying out.

Vocabulary

acne (924)
dermis (922)
epidermis (922)
exocrine gland (924)
hair follicle (924)
keratin (922)
melanin (922)
oil gland (924)
sebum (924)
sweat gland (924)

REVIEW

Vocabulary

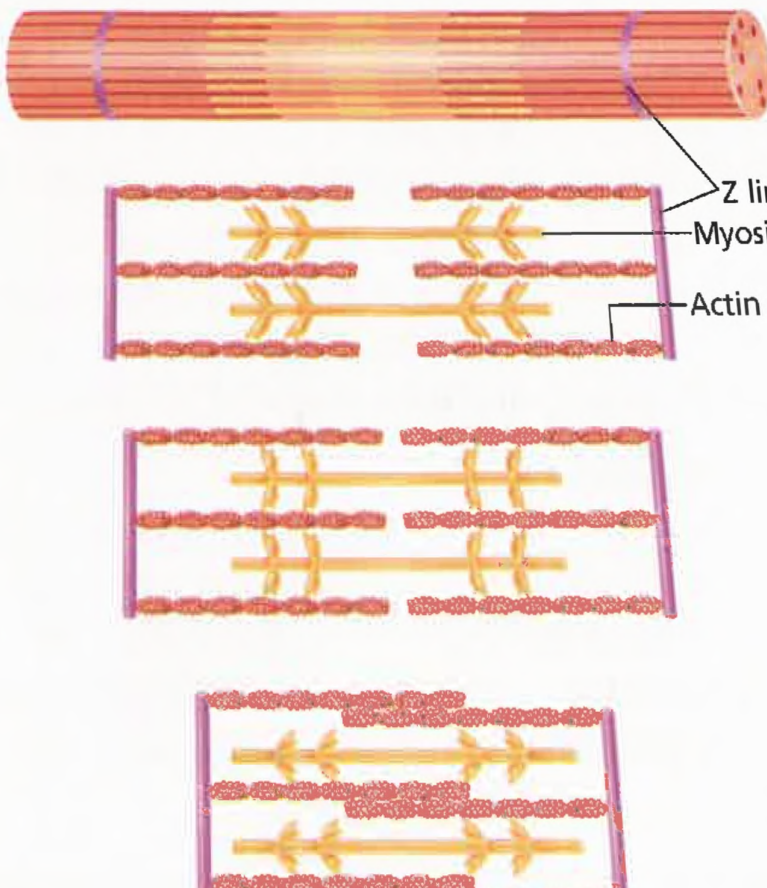
1. *What is epithelial tissue?*
2. *Distinguish between compact bone and spongy bone.*
3. *Describe the components of a sarcomere.*
4. *Describe how skeletal muscle, smooth muscle, and cardiac muscle differ.*
5. *What is the difference between the epidermis and the dermis?*

Multiple Choice

6. *The thoracic cavity contains the (a) brain (b) organs of the digestive system (c) organs of the respiratory system (d) spine.*
7. *The cells of connective tissue are embedded in a substance called (a) marrow (b) matrix (c) synovial fluid (d) keratin.*
8. *The periosteum is a membrane that (a) covers the bone (b) produces red blood cells (c) contains marrow (d) protect the ends of long bones.*
9. *During ossification (a) cartilage replaces bone cells (b) bones become more porous (c) bone replaces cartilage (d) marrow is produced.*
10. *Hinge joints allow (a) gliding movement (b) circular movement (c) no movement (d) back-and-forth movement.*
11. *Cardiac muscle is (a) voluntary muscle (b) involuntary muscle (c) a type of smooth muscle (d) found in the lungs.*
12. Actin and myosin are types of protein found in (a) cartilage (b) bone cells (c) hair and nails (d) muscle cells.
13. Red bone marrow (a) acts as an energy reserve (b) cushions the ends of bones (c) produces red and white blood cells (d) contains melanin.
14. The bones of a joint are held in place by (a) tendons (b) the epiphyseal plate (c) sarcomeres (d) ligaments.
15. The dermis (a) contains nerves and blood vessels (b) contains keratin (c) is the top layer of skin (d) is made up of dead cells.

Short Answer

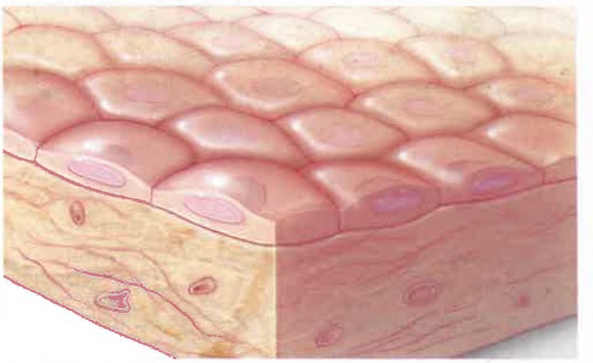
16. Identify the structure in the figure below. Describe the components of this structure, and explain how it changes during a muscle contraction.



17. What is the relationship between cells and organ systems?
18. What is a body cavity? What organs are found in the abdominal cavity?
19. What are five functions of the skeletal system?
20. Explain the role Haversian canals play in compact bone.
21. What is red bone marrow? Where is it produced and what is its function?
22. Describe the cause and symptoms of the disease rheumatoid arthritis.
23. Compare the functions of tendons and ligaments.
24. What substance prevents the hair and skin from drying out? Where is this substance produced?
25. What is melanin? What is its role in the body?

CRITICAL THINKING

1. Young thoroughbred horses that are raced too early in life have an increased risk of breaking the bones in their legs. What can you infer about the process of ossification in horses?
2. Red bone marrow produces red blood cells. How are these cells transported to the rest of the body?
3. During a normal birth, a baby passes through the mother's pelvis. A woman's pelvis has a larger diameter and is more oval-shaped than a man's pelvis. In addition, a newborn's skull bones are not completely ossified. How are these skeletal properties advantageous to the birthing process?
4. The walls of blood vessels are encircled by a single layer of smooth muscle. The walls of the stomach and small intestine have a layer of circular smooth muscle and a layer of longitudinal smooth muscle. How do these muscle arrangements reflect the functions of each structure?
5. Oil glands secrete an oily substance that helps keep the skin soft and flexible. They also secrete fatty acids, which help kill bacteria. How can their function be affected if you wash your skin too frequently?
6. Examine the drawing of epithelial cells below. The flat epithelial cells of the skin overlap each other much like shingles on a roof do. How does this arrangement enable these cells to perform their protective function?



EXTENSION

1. The knee is a joint covered by the patella, or kneecap. Find out what function the kneecap serves. Research and write a report about an athlete who has suffered an injury to the patella. Report the cause of and treatment for the injury.
2. Read "Musical Muscles" in *Discover*, August 1999, on page 25. What are vocal cords? How do vocal cords make sound? Describe the damage that singers often do to their vocal cords. What is the condition called, and how is it treated?
3. Choose a form of exercise, such as running, cycling, or weight training. Write a report about the types of skills that are necessary for the exercise and the long-term effects it has on the body.

Dehydrating and Demineralizing Bone

OBJECTIVES

- Determine the amount of water and minerals in bone.
- Identify structures in bone cells.

PROCESS SKILLS

- observing
- identifying
- calculating

MATERIALS

- safety goggles
- lab apron
- gloves
- bones (2)
- drying oven
- balance
- specimen tag
- tongs
- 250 mL beaker
- wax pencil
- gauze, circular piece
- hot pad
- 500 mL beakers (2)
- 300 mL of 1 M hydrochloric acid
- glass plate or parafilm
- prepared bone slides
- compound microscope
- lens paper
- resealable plastic bag
- permanent marker

Background

1. Dehydration is the process of removing the water from a substance.
2. Demineralization is the process of removing the minerals from a substance.

TABLE A DEHYDRATION OF BONE

Mass before drying	Mass after drying	Percentage of bone mass lost

PART A Dehydrating a Bone

1. In your lab report, prepare a data table similar to Table A.
2.  Put on safety goggles, a lab apron, and gloves. Wear this protective gear during all parts of this investigation.
3. Obtain a bone from your teacher. Test the flexibility of the bone by trying to bend and twist it.
4. Place the bone on a balance. Measure the mass of the bone to the nearest 0.1 g, and record it in your data table. Then use a permanent marker to write the initials of each member of your group on a specimen tag, and tie the tag to the bone.
5. Place the bone in a drying oven at 100°C for 30 minutes. While the bone is in the oven, complete Part C.
6.  CAUTION **Do not touch hot objects with your bare hands. Use insulated gloves and tongs as appropriate.** Using tongs, remove the bone from the oven and place it on a heatproof pad to cool for 10 minutes.
7. Use tongs to place the cooled bone on the balance. Measure the mass of the bone to the nearest 0.1 g, and record it in your data table.
8. Use the equation below to calculate the percentage of the bone's mass that was lost during heating.

$$\text{Percentage mass lost} = \frac{\text{mass before heating} - \text{mass after heating}}{\text{mass before heating}} \times 100$$

PART B Demineralizing a Bone

9. In your lab report, prepare a data table similar to Table B.
10. Obtain a second bone from your teacher. Test the flexibility of the bone by trying to bend and twist it.

TABLE B DEMINERALIZATION OF A BONE

Mass before demineralizing	Mass after demineralizing and drying	Percentage of bone mass lost

11. Place the bone on a balance. Measure the mass of the bone, and record it in your data table.
12. CAUTION **Glassware is fragile. Notify your teacher promptly of any broken glass or cuts. Do not clean up broken glass or spills unless your teacher tells you to do so.** Using a wax pencil, label a 500 mL beaker "1 M HCl." Also label the beaker with the initials of all group members. Place a piece of gauze in the bottom of the beaker.
13. CAUTION **If you get an acid on your skin or clothing, wash it off at the sink immediately while calling to your teacher.** Place the bone on top of the gauze in the beaker, and add enough 1 M HCl to cover the bone. Use a glass plate or parafilm to cover the beaker.
14. Place the beaker under a fume hood, and allow the bone to soak in the acid until it softens and becomes spongy. This should take 5–7 days. Periodically use tongs to test the hardness of the bone. *Note: Do not touch the bone with your fingers while it is soaking in acid. Rinse the tongs with water thoroughly each time you finish testing the bone.*
15. When the bone becomes spongy, use tongs to carefully remove it from the beaker, and rinse it under running water for two minutes.
16. After the bone has been thoroughly rinsed, test the bone for hardness by twisting and bending it with your fingers. *Note: Be sure you are wearing gloves.*
17. Then use a permanent marker to write the initials of each member of your group on a specimen tag, and tie the tag to the bone. Place the bone in a drying oven at 100°C for 30 minutes.
18. CAUTION **Do not touch hot objects with your bare hands. Use insulated gloves and tongs as appropriate.** Using tongs, remove the bone from the oven and place it on a heat-proof pad to cool for 10 minutes.
19. Use tongs to place the cooled bone on the balance. Measure the mass of the bone to the nearest 0.1 g, and record it in your data table.
20. Use the equation below to calculate the percentage of the bone's mass that was lost through demineralization and dehydration.

$$\text{Percentage of mass lost} = \frac{\text{mass before demineralizing} - \text{mass after demineralizing and drying}}{\text{mass before demineralizing}} \times 100$$

PART C Observing Prepared Slides of Bone

21. Using a compound light microscope, focus on a prepared slide of bone using low power, and then switch to high power. Locate a Haversian canal, the darkly stained circle in the center of a set of lamellae. Find the darkly stained osteocytes between the lamellae.
22. In your lab report, draw and label the following bone structures: Haversian canal, lamella, osteocyte.

Analysis and Conclusions

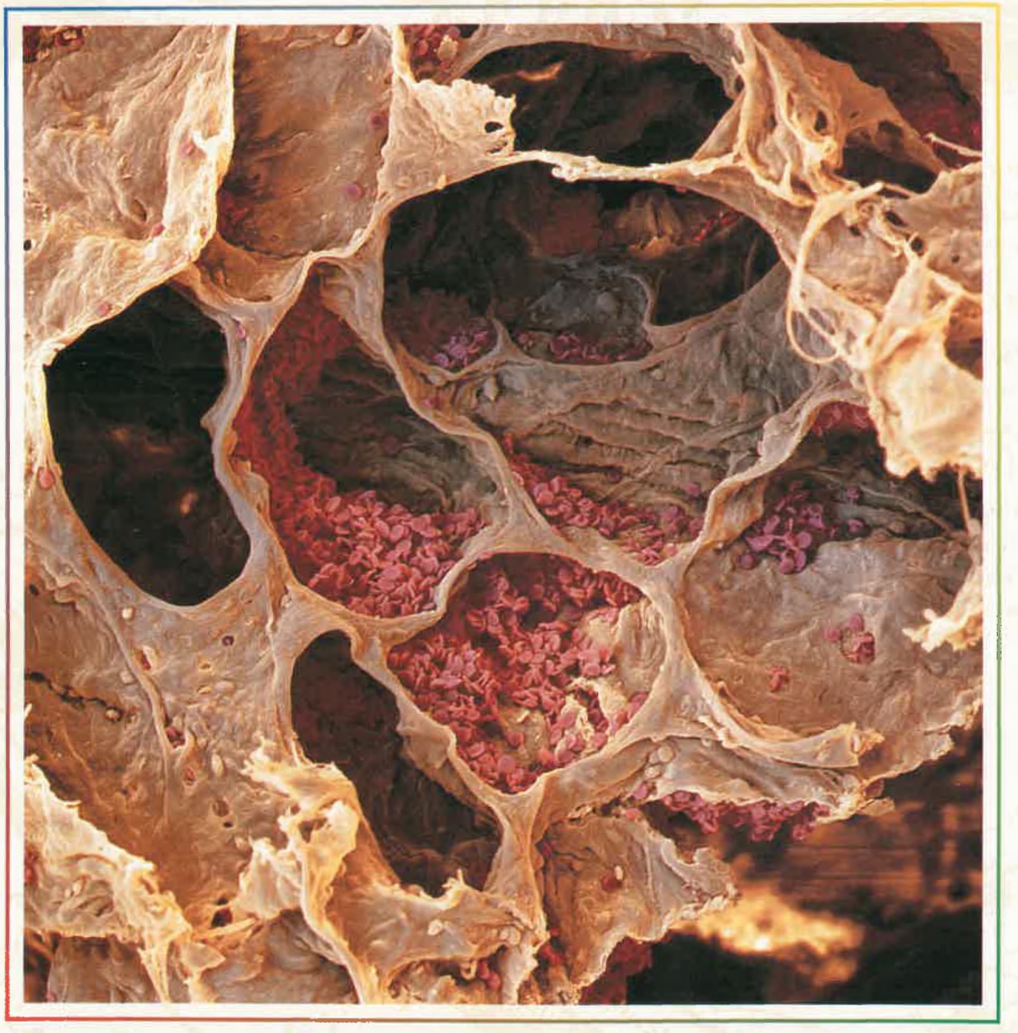
1. What effect did water loss have on the bone? What effect did mineral loss have on the bone?
2. Why did you have to dehydrate the bone before measuring its mass in Part B?
3. What percentage of bone is water? What percentage of bone is mineral?
4. If you were to prepare a slide using the dehydrated and demineralized bone, what do you think it would look like?
5. What happened when the demineralized bone was dried? Why do you think this happened?
6. If a person's diet lacked calcium, how could this affect his or her bones?

Further Inquiry

Research the differences in the amount and distribution of compact bone and spongy bone among bones from various parts of the human skeleton. Discover whether there are any other differences in the internal structure of different types of bones.

CHAPTER 47

CIRCULATORY AND RESPIRATORY SYSTEMS



This photograph shows the air sacs of a human lung. (SEM 780×)

FOCUS CONCEPT: ***Structure and Function***

As you read, note how the structural features of the organs in the circulatory and respiratory systems are related to the transport and exchange of materials.

SECTION 47-1

THE CIRCULATORY SYSTEM

Most of the cells in the human body are not in direct contact with the external environment. The circulatory system acts as a transport service for these cells. Two fluids move through the circulatory system: blood and lymph. The blood, heart, and blood vessels form the ***cardiovascular system.*** *The lymph, lymph nodes, and lymph vessels form the* ***lymphatic system.*** *The cardiovascular system and lymphatic system collectively make up the* ***circulatory system.***

OBJECTIVES

- Describe the structure and function of the human heart.
- Trace the flow of blood through the heart and body.
- Distinguish between arteries, veins, and capillaries in terms of their structure and function.
- Distinguish between pulmonary circulation and systemic circulation.
- Describe the functions of the lymphatic system.

THE HEART

The central organ of the cardiovascular system is the heart, the muscular organ that pumps blood through an intricate network of blood vessels. The heart beats more than 2.5 billion times in an average life span. Yet this organ that does so much work is slightly larger than a fist. The heart lies within the thoracic (chest) cavity, behind the sternum (breastbone) and between the two lungs. A tough, saclike membrane called the **pericardium** surrounds the heart and secretes a fluid that reduces friction as the heart beats.

Notice in Figure 47-1 that a **septum** vertically divides the heart into two sides. The right side pumps blood to the lungs, and the left side pumps blood to the other parts of the body. Each side of the heart is divided into an upper and lower chamber. Each upper chamber is called an **atrium,** and each lower chamber is called a **ventricle.**

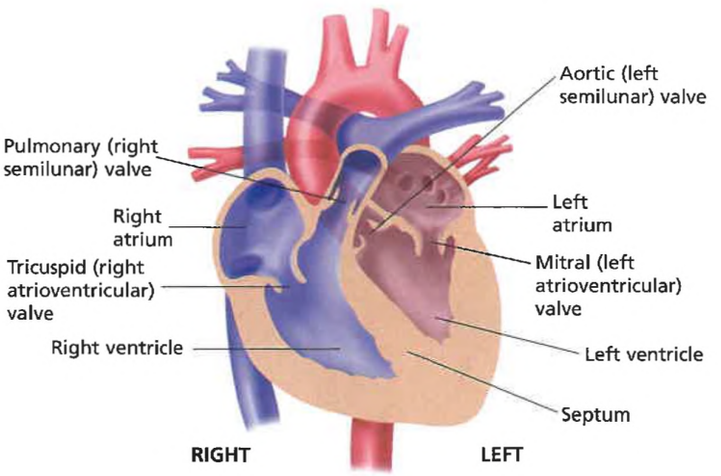


FIGURE 47-1
The septum prevents mixing of blood from the two sides of the heart, and the valves ensure that blood flows in only one direction.

Quick Lab

Determining Heart Rate

Materials stopwatch or clock with second hand

Procedure

1. Have your partner find the pulse in your wrist and count your heartbeats for 15 seconds while you are seated. Calculate your resting heart rate in beats per minute.
2. Have your partner count your heartbeats for 15 seconds while you are standing. Calculate your heart rate in beats per minute.
3. Have your partner count your heartbeats for 15 seconds while you are lying down. Calculate your heart rate in beats per minute.

Analysis What causes your pulse? What causes the change in your heart rate in each position?

A one-way valve separates each atrium from the ventricle beneath it. These valves are called **atrioventricular** (AY-tree-oh-ven-TRIH-kyuh-luhr) **(AV) valves.** They consist of flaps of tissue that open in only one direction. The AV valve on the right side is called the **tricuspid valve.** The **mitral valve,** also called the bicuspid valve, is on the left. As the ventricles pump, blood pressure closes the AV valves, preventing blood from flowing backward from the ventricles to the atria.

From the ventricles, blood flows out of the heart into large vessels. A **semilunar** (semee-LOON-uhr) **(SL) valve** separates the ventricles from these large vessels on each side of the heart. The SL valve on the right side is known as the **pulmonary valve,** and the SL valve on the left side is known as the **aortic valve.** The SL valves prevent blood from flowing back into the ventricles when the heart relaxes.

Circulation in the Heart

Refer to Figure 47-2 to trace the path of the blood as it circulates through the heart. Blood returning to the heart from parts of the body other than the lungs has a high concentration of carbon dioxide and a low concentration of oxygen. This deoxygenated blood enters the right atrium. Notice in Figure 47-2 that the flow of blood on the right side of the heart is illustrated with a blue arrow representing deoxygenated blood, which has a deep bluish-red color.

The right atrium pumps the deoxygenated blood into the right ventricle. The muscles of the right ventricle contract and force the blood into the pulmonary arteries, which lead to the lungs. In the lungs, the carbon dioxide diffuses out of the blood and oxygen diffuses into the blood. The oxygenated blood returns to the left

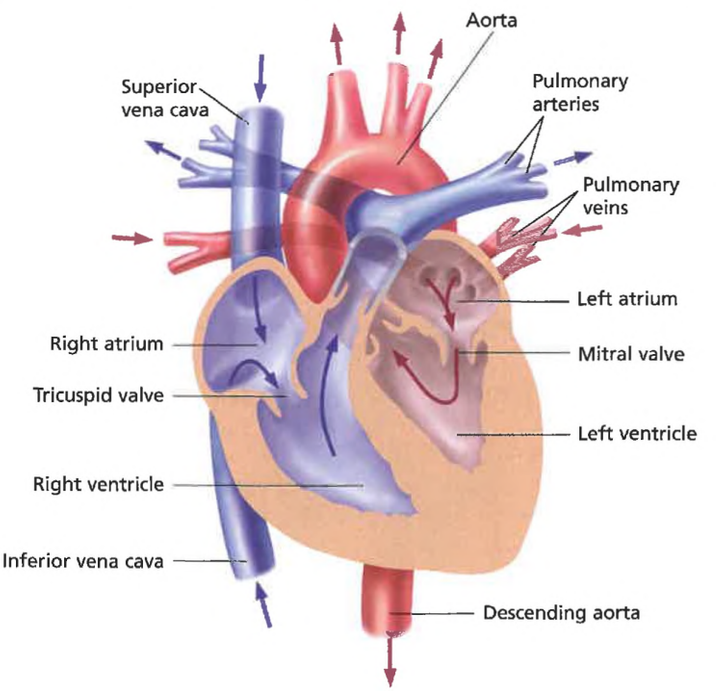


FIGURE 47-2

Trace the path of blood through the heart. Which side of the heart contains deoxygenated blood? Notice that illustrations of a heart are drawn as if the heart were in a person facing you, that is, the left side of the heart is shown on the right as you face it, and the right side of the heart is on the left as you face it.

atrium of the heart. Notice in Figure 47-2 that the flow of blood on the left side of the heart is illustrated with a red arrow representing oxygenated blood, which has a bright red color.

The oxygenated blood is then pumped into the left ventricle. Contraction of the muscular walls of the left ventricle force the blood into a large blood vessel called the **aorta.** From the aorta, blood is transported to all parts of the body except the lungs. The left ventricle is the thickest chamber of the heart because it has to do the most work to pump blood to all parts of the body.

Control of the Heartbeat

The heart consists of muscle cells that contract in waves. When the first group of cells are stimulated, they in turn stimulate neighboring cells. Those cells then stimulate more cells. This chain reaction continues until all the cells contract. The wave of activity spreads in such a way that the atria and the ventricles contract in a steady rhythm. The first group of heart-muscle cells that get stimulated lie in an area of the heart known as the sinoatrial node, shown in Figure 47-3.

The **sinoatrial** (SIEN-oh-AY-tree-uhl) **(SA) node** is a group of specialized heart-muscle cells located in the right atrium. These muscle cells spontaneously initiate their own electrical impulse and contract. The SA node is often called the **pacemaker** because it regulates the rate of contraction of the entire heart. The electrical impulse initiated by the SA node subsequently reaches another special area of the heart, known as the **atrioventricular (AV) node.** The AV node is located in the septum between the atria, as shown in Figure 47-3. The AV node relays the electrical impulse to the muscle cells that make up the ventricles. As a result, the ventricles contract a fraction of a second after the atria, completing one full heartbeat. In an average adult at rest, the heart beats about 70 times each minute.

A heartbeat has two phases. Phase one, called **systole** (SIS-tohl), occurs when the ventricles contract, closing the AV valves and opening the SL valves to pump blood into the two major vessels that exit the heart. Phase two, called **diastole** (DIE-a-stohl), occurs when the ventricles relax, allowing the back pressure of the blood to close the SL valves and opening the AV valves. The closing of these two heart valves results in the characteristic *lubb dup* sound we call a heartbeat. If one of the valves fails to close properly, some blood may flow backward, creating a different sound, which is known as a heart murmur.

Blood Vessels

The circulatory system is known as a closed system because the blood is contained within either the heart or the blood vessels at all times. This type of system differs from an open system, in which blood leaves the vessels and circulates within tissues throughout the organism's body. The blood vessels that are part of the closed circulatory system of humans form a vast network to help keep the blood flowing in one direction.

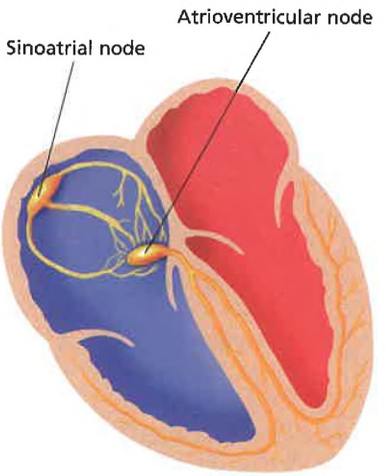


FIGURE 47-3

Two areas of specialized tissue, known as nodes, control the heartbeat. A person whose SA node is defective can have an operation to implant an artificial pacemaker. An artificial pacemaker can also help a defective AV node. Why is the term *artificial pacemaker* appropriate?

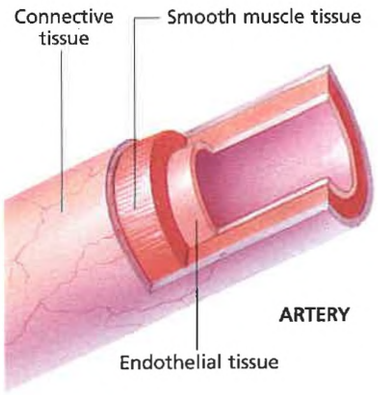


FIGURE 47-4

Notice the thick muscular layer of an artery. The layers of the artery wall are separated by elastic tissue. This tissue provides strength, preventing systolic pressure from bursting the artery.

Arteries and Blood Pressure

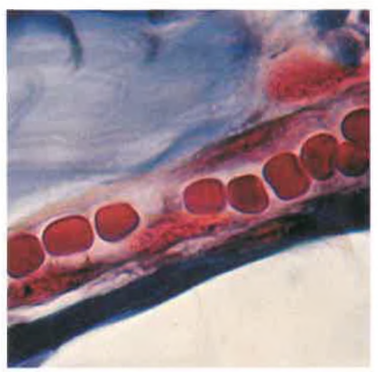
Each beat of the heart forces blood through blood vessels. The large, muscular vessels that carry blood away from the heart are called **arteries.** As shown in Figure 47-4, the thick walls of the arteries have three layers: an inner endothelial layer, a middle layer of smooth muscle, and an outer layer of connective tissue. This structure gives arteries a combination of strength and elasticity, which allows them to stretch as pressurized blood enters from the heart. You can feel this stretching of arteries—it is your pulse.

Contraction of the heart propels the blood through the arteries with considerable force. The force that blood exerts against the walls of a blood vessel is known as **blood pressure.** Blood pressure is always highest in the two main arteries that leave the heart. It is usually measured in the artery that supplies blood to the arm. To measure blood pressure, a trained person inflates a cuff that is placed around a person's arm, temporarily stopping the flow of blood through the artery. Connected to the cuff is a gauge containing a column of mercury (Hg) that rises as the pressure in the cuff increases. The trained person then releases the air in the cuff slowly while listening to the artery with a stethoscope and watching the column of mercury. The first sounds of blood passing through the artery mean that the ventricles have pumped with enough force to momentarily overcome the pressure exerted by the cuff. This is known as the **systolic pressure,** or the pressure of the blood when the ventricles contract. In a normal adult, the systolic pressure is about 120 mm of Hg for males and 110 mm of Hg for females. Continuing to release the air in the cuff, the trained person next listens for the disappearance of sound, which indicates a steady flow of blood through the artery in the arm. At this point, the pressure of the blood is sufficient to keep the arteries open constantly even with the ventricles relaxed. This is known as **diastolic pressure.** In a normal adult, the diastolic pressure is about 80 mm of Hg for males and 70 mm of Hg for females.

High blood pressure, or **hypertension,** is a leading cause of death in many countries. Blood pressure that is higher than normal places a strain on the walls of the arteries and increases the chance that a vessel will burst. Because people with chronic high blood pressure often display no external symptoms, hypertension is sometimes referred to as the silent killer.

FIGURE 47-5

The diameter of a capillary is so small that red blood cells must move single file through these vessels, as shown in this photograph (1,200×). All exchange of nutrients and waste between blood and cells occurs across the thin walls of the capillaries.



Capillaries and Veins

Recall that when the left ventricle contracts, it forces blood into the aorta, the body's largest artery. From the aorta, blood travels through a network of smaller arteries, which in turn divide and form even smaller vessels, called **arterioles.** The arterioles branch into a network of tiny vessels, called **capillaries.** A capillary is shown in Figure 47-5.

The network formed by capillaries is so extensive that all of the approximately 100 trillion cells in the body lie within about 125 μm

of a capillary. This close association between capillaries and cells allows for rapid exchange of materials. Capillary walls are only one cell thick; gases and nutrients can diffuse through these thin walls. Wherever the concentration of oxygen or nutrients is higher in the blood than in the surrounding cells, the substance diffuses from the blood into the cells. Wherever the concentrations of carbon dioxide and wastes are higher in the cells than in the blood, these substances diffuse from the cells into the blood.

Blood flows through capillaries that merge to form larger vessels called **venules** (VEN-yoolz). Several venules in turn unite to form a **vein,** a large blood vessel that carries blood to the heart. Veins returning deoxygenated blood from the lower parts of the body merge to form the **inferior vena cava.** Veins returning deoxygenated blood from the upper parts of the body merge to form the **superior vena cava.** Refer back to Figure 47-2 and locate the inferior vena cava and the superior vena cava.

As you can see in Figure 47-6, although the walls of the veins are composed of three layers, like those of the arteries, they are thinner and less muscular. By the time blood reaches the veins, it is under much less pressure than it was in the arteries. With less pressure being exerted in the veins, the blood could flow backward and disrupt the pattern of circulation. To prevent that, valves in the veins help keep the blood flowing in one direction. Many veins pass through skeletal muscle. When these muscles contract, they are able to squeeze the blood through the veins. When these muscles relax, the valves can close, thus preventing the blood from flowing backward. Figure 47-7 shows the structure of a valve in a vein.

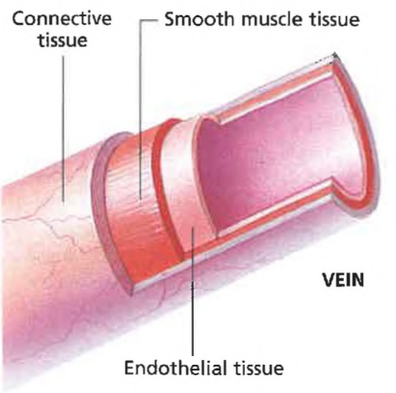


FIGURE 47-6

Like an artery, a vein has three layers. Notice the outer layer of connective tissue, the middle layer of smooth muscle, and the inner layer of endothelial tissue. Compare this figure with Figure 47-4. How do the three layers in a vein compare with those in an artery?

PATTERNS OF CIRCULATION

The English scientist William Harvey (1578–1657) first showed that the heart and the blood vessels form one continuous, closed system of circulation. He also reasoned that this system consists of two primary subsystems: **pulmonary circulation,** in which the blood travels between the heart and lungs, and **systemic circulation,** in which the blood travels between the heart and all other body tissues.

Pulmonary Circulation

Deoxygenated blood returning from all parts of the body except the lungs enters the right atrium, where it is then pumped into the right ventricle. When the right ventricle contracts, the deoxygenated blood is sent through the pulmonary artery to the lungs. The pulmonary artery is the only artery that carries deoxygenated blood. The pulmonary artery branches into two smaller arteries, with one artery going to each lung. These arteries branch into arterioles and then into capillaries in the lungs.

In the lungs, carbon dioxide diffuses out of the capillaries and oxygen diffuses into the capillaries. The oxygenated blood then

FIGURE 47-7

This figure shows the structure of the valves in veins. Many veins have valves to keep the blood flowing in one direction. If these valves fail to close properly, some blood can leak backward and expand a weak area of the vein. This results in a condition known as varicose veins.

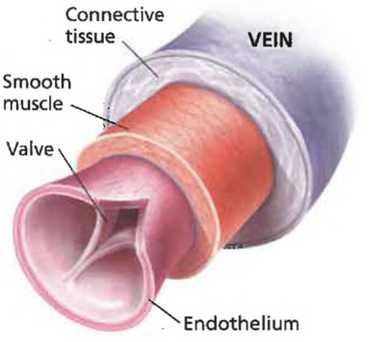
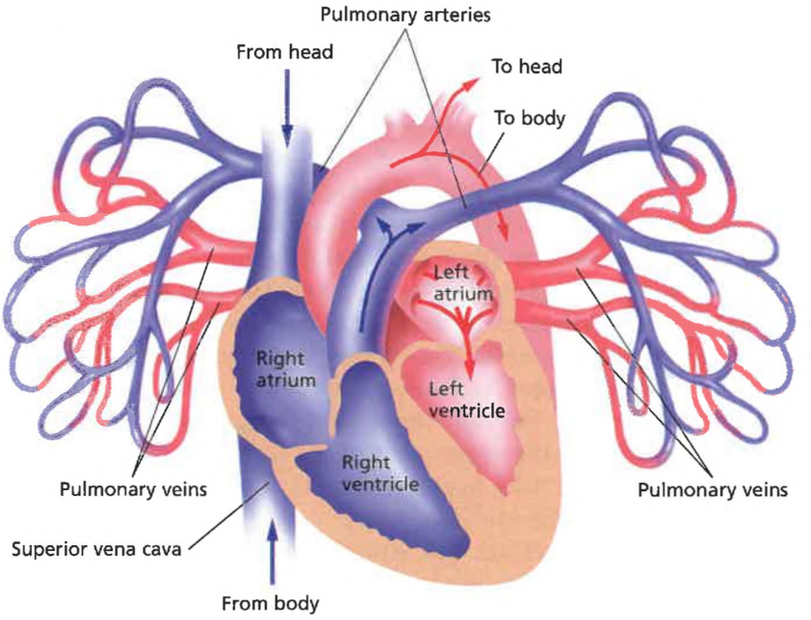


FIGURE 47-8

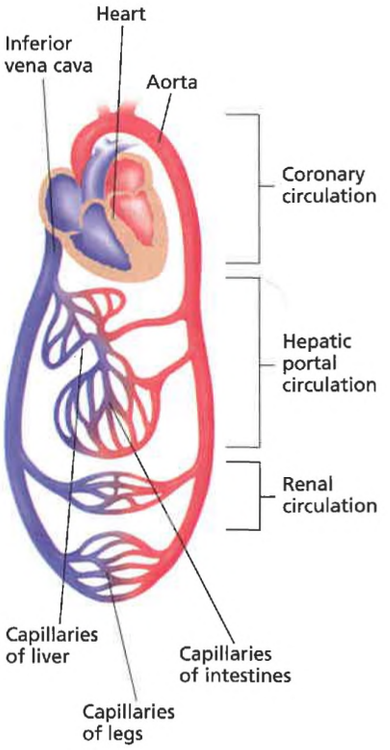
The pulmonary circulation between the heart and the lungs involves the pulmonary arteries and the pulmonary veins. Deoxygenated blood flows from the right side of the heart to the lungs. Oxygenated blood is returned to the left side of the heart from the lungs. This is the opposite of systemic and coronary blood flow, in which oxygen-rich blood flows from the heart and oxygen-poor blood is returned to the heart.



flows into venules, which merge into the **pulmonary veins** that lead to the left atrium of the heart. The pulmonary veins are the only veins that carry oxygenated blood. From the left atrium, blood is pumped into the left ventricle and then to the body through the aorta, supplying the cells with oxygen. In Figure 47-8, trace the path blood takes as it passes through pulmonary circulation.

FIGURE 47-9

Notice three subsystems of systemic circulation. Other subsystems transport blood between the heart and the head, arms, organs, and legs.



Systemic Circulation

Systemic circulation is the movement of blood between the heart and all parts of the body except the lungs. Trace the path blood follows in systemic circulation in Figure 47-9. Notice that oxygenated blood is pumped out of the left ventricle and into the aorta. From the aorta, blood flows into other subsystems of systemic circulation.

Coronary circulation is one subsystem of systemic circulation that supplies blood to the heart itself. The heart muscle is thick, and oxygen and nutrients must be supplied to each cell. If the blood supply to the heart is reduced or cut off, muscle cells will die. This can happen when an artery is blocked by a blood clot or by **atherosclerosis** (ATH-uhr-oh-skler-OH-sis), a disease characterized by the buildup of fatty materials on the interior walls of the coronary artery. If either type of blockage reduces the flow of blood to the heart muscle cells, a heart attack will result.

Renal circulation, another subsystem of systemic circulation, supplies blood to the kidneys. Nearly one-fourth of the blood that is pumped into the aorta by the left ventricle flows to the kidneys. The kidneys filter waste from the blood.

Hepatic portal circulation is a subsystem of systemic circulation. Nutrients are picked up by capillaries in the small intestine and are transported by the blood to the liver. Excess nutrients are stored in the liver for future needs. The liver receives oxygenated blood from a large artery that branches from the aorta.

LYMPHATIC SYSTEM

In addition to the cardiovascular system, the circulatory system also includes the lymphatic system. One function of the lymphatic system is to return fluids that have collected in the tissues to the bloodstream. Fluids diffuse through the capillary walls just as oxygen and nutrients do. Some of these fluids pass into cells, some return to the capillaries, and some remain in the intercellular spaces.

Excess fluid in the tissues moves into the tiny vessels of the lymphatic system; this fluid is called **lymph.** Lymph vessels merge to form larger vessels. The lymph vessels are similar in structure to capillaries, and the larger lymph vessels are similar in structure to veins. However, an important difference exists between blood vessels and lymph vessels. As you learned earlier, blood vessels form a complete circuit so that blood passes from the heart to all parts of the body and then back again to the heart. In contrast, lymph vessels form a one-way system that returns fluids collected in the tissues back to the bloodstream. In addition, the lymphatic system has no pump like the heart. Like the blood in veins, lymph must be moved through the vessels by the squeezing of skeletal muscles. Like veins, the larger lymph vessels have valves to prevent the fluid from moving backward.

Notice in Figure 47-10 that lymph vessels form a vast network that extends throughout the body. The lymph that travels in these vessels is a transparent yellowish fluid, much like the liquid part of the blood. As the lymph travels through these vessels on its way to the heart, it passes through small organs known as lymph nodes. Notice in Figure 47-10 that lymph nodes are like beads on a string. These nodes filter the lymph as it passes, trapping foreign particles, microorganisms, and other tissue debris. Lymph nodes also store **lymphocytes,** white blood cells that are specialized to fight disease. When a person has an infection, the nodes may become inflamed, swollen, and tender because of the increased number of lymphocytes.

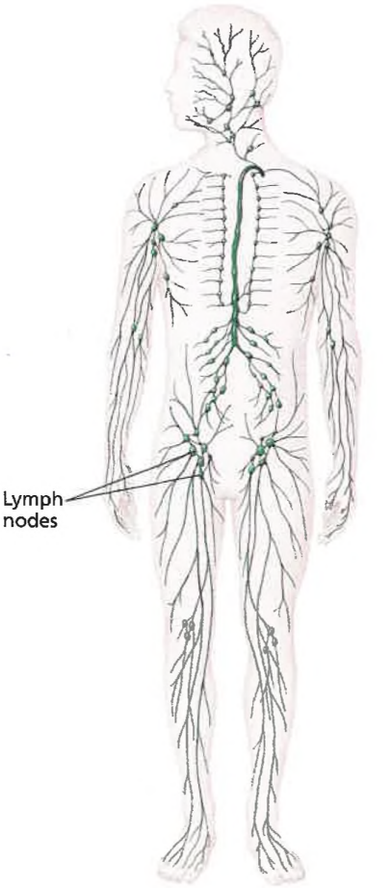


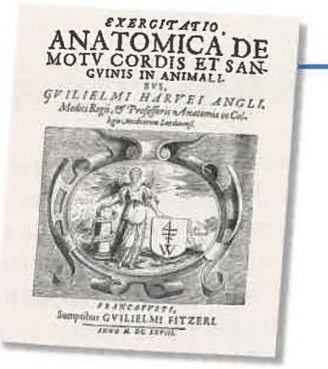
FIGURE 47-10
Like the cardiovascular system, the lymphatic system forms a vast network. Concentrated in certain regions of this network are lymph nodes that contain some of the disease-fighting cells of the immune system.

SECTION 47-1 REVIEW

1. Identify the structure that prevents blood from mixing between the left and right sides of the heart. Explain what prevents blood from flowing from the ventricles backward into the atria.
2. Identify the structure that controls the heartbeat, and describe the process by which it regulates the heartbeat.
3. Outline the path that blood follows in pulmonary circulation.
4. Compare the lymphatic system with the cardiovascular system.
5. In which blood vessels would you expect to find the lowest average blood pressure? Explain your answer.
6. **CRITICAL THINKING** Some babies are born with a hole in the septum between the two atria. Based on what you know about blood flow through the heart, explain why this condition would be harmful to the baby.

Literature & Life

On the Motion of the Heart



This excerpt is from William Harvey's anatomical essay *On the Motion of the Heart and Blood in Animals.* It was first presented in 1628.

The study of medicine in Harvey's time normally consisted of studying the works of ancient Greek doctors and philosophers, not direct observation. Harvey's work as a physician and anatomist was revolutionary because he actually observed the action of the heart and the movement of blood in live animals.

When the chest of a living animal is laid open and the capsule that immediately surrounds the heart is slit up or removed, the organ is seen now to move, now to be at rest; there is a time when it moves, and a time when it is motionless.

These things are more obvious in the colder animals, such as toads, frogs, serpents, small fishes, crabs, shrimps, snails, and shell-fish. They also become more distinct in warm-blooded animals, such as the dog and hog, if they be attentively noted when the heart begins to flag, to move more slowly, and, as it were, to die: the movements then become slower and rarer, the pauses longer, by which it is made much more easy to perceive and unravel what the motions really are, and how they are performed. In the pause, as in death, the heart is soft, flaccid, exhausted, lying, as it were, at rest.

In the motion, and interval in which this is accomplished, three principal circumstances are to be noted:

1. That the heart is erected, and rises upwards to a point, so that at this time it strikes against the breast and the pulse is felt externally.

2. That it is everywhere contracted, but more especially towards the sides so that it looks narrower, relatively longer, more drawn together. The heart of an eel taken

out of the body of the animal and placed upon the table or the hand, shows these particulars; but the same things are manifest in the hearts of all small fishes and of those colder animals where the organ is more conical or elongated.

3. The heart being grasped in the hand, is felt to become harder during its action. Now this hardness proceeds from tension, precisely as when the forearm is grasped, its tendons are perceived to become tense and resilient when the fingers are moved.

4. It may further be observed in fishes, and the colder blooded animals, such as frogs, serpents, etc., that the heart, when it moves, becomes of a paler color, when quiescent of a deeper blood-red color.

From these particulars it appears evident to me that the motion of the heart consists in a certain universal tension—both contraction in the line of its fibres, and constriction in every sense.

Reading for Meaning

Because *On the Motion of the Heart and Blood in Animals* was written in Latin in the seventeenth century and was translated into English in 1910, the language is very old-fashioned. Rewrite the last paragraph of this passage, paraphrasing it in simple, modern language.

Read Further

In Harvey's time, knowledge about an animal's internal anatomy came from direct observation. Observations of human anatomy and physiology were rare because the observation techniques were injurious and often fatal. What equipment and techniques are used today in modern hospitals to make observations of human anatomy and physiology that are not invasive or harmful to the patient? How are these techniques used in the diagnosis of illness or disease?

SECTION 47-2

BLOOD

Blood is a liquid connective tissue that constitutes the transport medium of the cardiovascular system. The two main functions of the blood are to transport nutrients and oxygen to the cells and to carry carbon dioxide and other waste materials away from the cells. Blood also transfers heat to the body surface and plays a major role in defending the body against disease.

OBJECTIVES

- List the components of blood.
- Distinguish between red blood cells, white blood cells, and platelets in terms of their structure and function.
- Summarize the process of blood clotting.
- Explain what determines the compatibility of blood types for transfusion.

COMPOSITION OF BLOOD

Blood is composed of a liquid medium and blood solids. Blood solids consist of red blood cells, white blood cells, and platelets. The liquid makes up about 55 percent of the blood, and blood solids make up the remaining 45 percent. A healthy adult has about 4 to 5 L of blood in his or her body.

Plasma

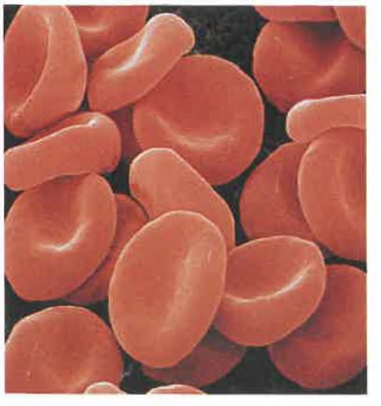
Plasma, the liquid medium, is a sticky, straw-colored fluid that is about 90 percent water. Cells receive nourishment from dissolved substances carried in the plasma. These substances, which may include vitamins, minerals, amino acids, and glucose, are absorbed from the digestive system and transported to the cells. Plasma also carries hormones and brings wastes from the cells to the kidneys or the lungs to be removed from the body.

Proteins are carried in the plasma and have various functions. Some of the proteins in the plasma are essential for the formation of blood clots. Another protein, called albumin, plays an important role in the regulation of osmotic pressure between plasma and blood cells and between plasma and tissues. Other proteins, called antibodies, help the body fight disease.

Red Blood Cells

Red blood cells, or **erythrocytes** (uh-RITH-ruh-siets), shown in Figure 47-11, transport oxygen to cells in all parts of the body. Red blood cells are formed in the red marrow of bones. Red blood cells synthesize large amounts of an iron-containing protein called **hemoglobin.** Hemoglobin is the molecule that actually transports oxygen and, to a lesser degree, carbon dioxide. During the formation of a red blood cell, its cell nucleus and organelles disintegrate. The mature red blood cell becomes little more than a membrane sac containing hemoglobin.

FIGURE 47-11
Notice that a mature red blood cell (RBC) is disk-shaped and is concave on both sides (5,250×). A red blood cell is little more than a cell membrane filled with hemoglobin. How is this structure related to its function?



Because red blood cells lack nuclei, they cannot divide and they have a limited survival period, usually 120 to 130 days. Of the more than 30 trillion red blood cells circulating throughout the body at one time, 2 million disintegrate every second. To replace them, new ones form at the same rate in the red marrow of bones. Some parts of the disintegrated red blood cells are recycled. For example, the iron portion of the hemoglobin molecule is carried in the blood to the marrow, where it is reused in new red blood cells.

White Blood Cells

White blood cells, or **leukocytes** (LOO-kuh-siets), help defend the body against disease. They are formed in the red marrow, the lymph nodes, and the spleen. White blood cells are larger than red blood cells and significantly less plentiful. Each cubic millimeter of blood normally contains about 4 million red blood cells and 7,000 white blood cells. White blood cells can squeeze their way through openings in the walls of blood vessels and into the intercellular fluid. In that way, white blood cells can reach the site of infection and help destroy invading microorganisms.

Notice in Figure 47-12 that a white blood cell has a very different structure from that of a red blood cell. For instance, a white blood cell may be irregularly shaped and may have a rough outer surface. There are other differences between red blood cells and white blood cells as well. In contrast with the short-lived red blood cells, white blood cells may function for years. And while there is only one type of red blood cell, there are several types of white blood cells.

The white blood cell shown in Figure 47-12 is the type of white blood cell known as a **phagocyte** (FA-guh-siets). Phagocytes are cells that engulf invading microorganisms. Locate the microorganisms that are being engulfed by the phagocyte in Figure 47-12. Another type of white blood cell produces **antibodies.** Antibodies are proteins that help destroy substances, such as bacteria and viruses, that enter the body and can cause disease. When a person has an infection, the number of white blood cells can double.

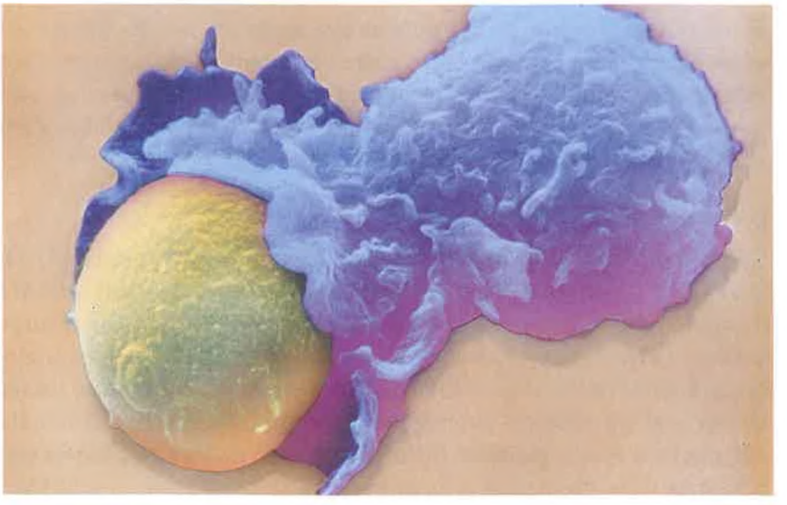


FIGURE 47-12
Some white blood cells, like the phagocyte shown in blue, engulf and destroy invading microorganisms.

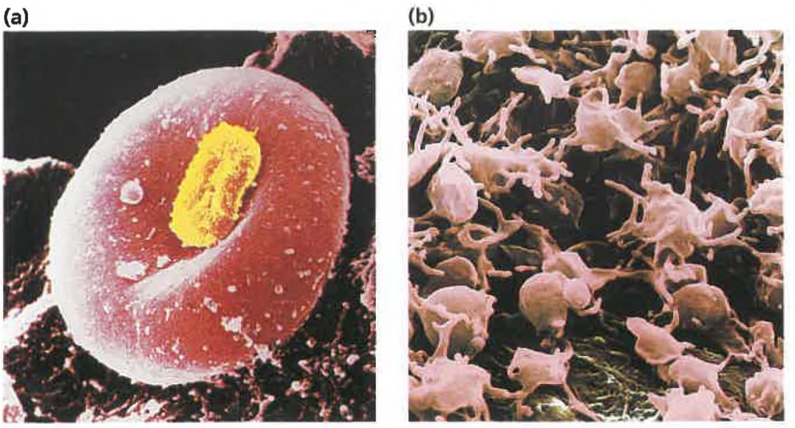


FIGURE 47-13

Inactive platelets, such as the yellow object shown in (a), derive their name from the fact that they look like little plates (7,410×). Platelets are colorless and contain chemicals that are involved in the clotting process. (b) The platelets change shape during the clotting process. When activated, the platelets settle and spread on the substrate (4,900×).

Platelets

Platelets are essential to the formation of a blood clot. A blood clot is a mass of interwoven fibers and blood cells that prevents excess loss of blood from a wound. Platelets are not whole cells. They are fragments of very large cells that were formed in the bone marrow. As you can see in Figure 47-13a, platelets get their name from their platelike structure. Platelets lack a nucleus and have a life span of 7 to 11 days. A cubic micrometer of blood may contain as many as half a million platelets.

When a blood vessel tears or rips, platelets congregate at the damaged site, sticking together and forming a small plug. The vessel constricts, slowing blood flow to the area. Then special clotting factors are released from the platelets. These factors begin a series of chemical reactions that occur at the site of the bleeding. The last step in this series brings about the production of a protein called **fibrin.** Fibrin molecules consist of long, sticky chains. As you can see in Figure 47-14, these chains form a net that traps red blood cells, and the mass of fibrin and red blood cells hardens into a clot, or scab.

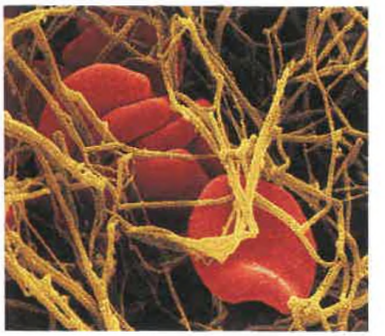


FIGURE 47-14

Long, sticky threads of fibrin trap blood cells and other materials to form a network to stop bleeding. This is comparable to placing a small piece of tissue paper over a cut. The fibers in the tissue paper act like fibrin to form a network to stop the bleeding. (5,000×)

BLOOD TYPES

Blood type is determined by the type of antigen present on the surface of the red blood cells. An **antigen** is a protein or carbohydrate that acts as a signal, enabling the body to recognize foreign substances that enter the body. Antigens that are normally present in a person's body provoke no response. However, when foreign antigens enter the body, cells respond by producing antibodies. In fact, the word *antigen* is an abbreviation for "antibody-generating substance."

Blood from the human population is classified into four groups, based on the antigens on the surface of the red blood cell. Physicians learned of the differences by observing what happened when blood samples from different patients were mixed. In the early 1900s, Karl Landsteiner wanted to find out why some blood transfusions caused no problems, while others led to complications and even death for the recipient. Using blood taken from his laboratory

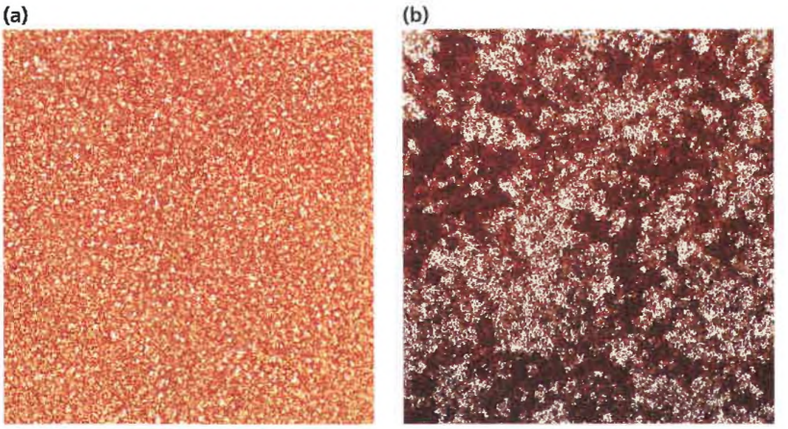


FIGURE 47-15
Notice that there is no agglutination of red blood cells in the slide in (a), where blood samples from two people with the same blood type were mixed (20×). Compare this with the slide in (b), where blood samples from two people with different blood types were mixed (20×).

workers, Landsteiner made observations similar to those you see in Figure 47-15. He noticed that mixing blood samples from two people sometimes resulted in the cells clumping together, or agglutinating. However, at other times no clumping or agglutination occurred when blood samples were mixed. Landsteiner reasoned that clumping occurred when blood samples of two different blood types were mixed.

When samples of two different blood types are mixed together, reactions occur between the antigens on the red blood cells and the antibodies in the plasma, causing the cells to agglutinate. When samples of the same blood type are mixed, no reaction occurs and the blood cells do not agglutinate. Landsteiner's observations led to the classification of human blood by blood types. Blood typing involves identifying the antigens in a sample. Three of the most important human antigens are called A, B, and Rh. The A-B-O system of blood typing, described below, is based on the A and B antigens.

A-B-O System

The A-B-O system is a means of classifying blood by the antigens located on the surface of the red blood cells and the antibodies circulating in the plasma. As shown in Table 47-1, an individual's red blood cells may carry an A antigen, a B antigen, both A and B antigens, or no antigen at all. These antigen patterns are called blood types A, B, AB, and O, respectively.

Notice in Table 47-1 that an individual with type A blood also has anti-B antibodies against type B blood. If type B blood is given to a recipient with type A blood, the recipient's anti-B antibodies will

TABLE 47-1 *Blood Types, Antigens, and Antibodies*

Blood types	Antigen on the red blood cells	Antibodies in the plasma	Can get blood from	Can give blood to
A	A	anti-B	O, A	A, AB
B	B	anti-A	O, B	B, AB
AB	A and B	none	A, B, AB, O	AB
O	none	anti-A, anti-B	O	A, B, AB, O

react with the B antigens on the donated red blood cells and the blood will agglutinate. In addition, the donor's type B blood has anti-A antibodies. Their presence will compound the antigen-antibody reaction in the recipient. The net result will be agglutinated blood that will block the flow of blood through the vessels. For this reason, transfusion recipients must receive blood that is compatible with their own. Based on the information in Table 47-1, why can a person with type AB blood receive blood from any of the four types?

Rh System

An antigen that is sometimes present on the surface of red blood cells is the **Rh factor,** named after the rhesus monkey in which it was first discovered. Eighty-five percent of the United States' population is Rh-positive (Rh^+), meaning that Rh antigens are present. People who do not have Rh antigens are called Rh-negative (Rh^-).

If an Rh^- person receives a transfusion of blood that has Rh^+ antigens, antibodies will react with the antigen and agglutination will occur. The most serious problem with Rh incompatibility occurs during pregnancy. If the mother is Rh^- and the father is Rh^+, the child may inherit the dominant Rh^+ allele from the father. The blood supplies of the mother and the fetus are separated during pregnancy, but during delivery, a small amount of the fetus's Rh^+ blood may reach the mother's bloodstream. If this happens, the mother will develop antibodies to the Rh factor. If a second Rh^+ child is conceived later, the mother's antibodies can cross the placenta and attack the blood of the fetus. This condition is called erythroblastosis fetalis. The fetus may die as a result of this condition, or if the child is born alive, he or she may need an immediate transfusion of Rh^+ blood.

To prevent this condition, an Rh^- mother of an Rh^+ child can be given antibodies to destroy any Rh^+ cells that have entered her bloodstream from the fetus. These antibodies must be administered to the mother within three days after the birth of her first Rh^+ child. By destroying any Rh^+ cells in her bloodstream, any danger to a second child is prevented because the mother will not make any antibodies against the blood cells of the Rh^+ fetus.

Quick Lab

Identifying Offspring

Materials pencil, paper

Procedure Two babies are believed to have been swapped at birth in error. Blood samples were taken from each of the parents and babies. The following results were obtained from the blood samples:

Family 1: mother, type B; father, type O; baby, type A

Family 2: mother, type O; father, type A; baby, type O

Design a chart or data table that correctly pairs the biological parents with their baby.

Analysis Are the babies with the correct biological parents? How do you know?

SECTION 47-2 REVIEW

1. What is plasma? Name at least one major function of plasma.
2. Distinguish between the three solid components of the blood.
3. Identify the stages and structures involved in the clotting process.
4. Explain why a pregnant woman should know her blood type and the blood type of her baby's father.
5. Which blood type, in terms of the A-B-O and Rh antigens, can be donated to all others? Why?
6. **CRITICAL THINKING** Why do you think some people turn pale when they are frightened?

SECTION

47-3

OBJECTIVES

- Trace the passage of air from the environment to the bloodstream.
- Describe how gases are exchanged in the lungs.
- Contrast the ways that oxygen and carbon dioxide are transported in the bloodstream.
- Summarize the skeletal and muscular changes that occur during breathing.
- Describe how the rate of breathing is controlled.

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THE RESPIRATORY SYSTEM

You have read how the blood transports oxygen from the lungs to cells and carries carbon dioxide from the cells to the lungs. It is the function of the respiratory system to transport gases to and from the cardiovascular system. The respiratory system involves both external respiration and internal respiration.

External respiration *is the exchange of gases between the atmosphere and the blood.* ***Internal respiration*** *is the exchange of gases between the blood and the cells of the body. In Chapter 7, you learned how aerobic respiration involves the use of oxygen to break down glucose in the cell. In this section, you will examine the structures and mechanisms that carry oxygen to the cells for use in aerobic respiration and that eliminate the carbon dioxide that is produced by the same process.*

THE LUNGS

The lungs are the site of gas exchange between the atmosphere and the blood. Notice in Figure 47-16 that the right lung has three divisions, or lobes. It is slightly heavier than the two-lobed left lung. The lungs are located inside the thoracic cavity, bounded by the rib cage and the diaphragm. Lining the entire cavity and encasing the lungs are pleura, membranes that secrete a slippery fluid that decreases friction from the movement of the lungs during breathing.

The Passage of Air

Refer to Figure 47-16 to trace the path air follows from the atmosphere to the capillaries in the lungs. External respiration begins at the mouth and at the nose. Air filters through the small hairs of the nose and passes into the nasal cavity, located above the roof of the mouth. In the nasal cavity, mucous membranes warm and moisten the air, which helps prevent damage to the delicate tissues that form the respiratory system. The walls of the nasal cavity are also lined with cilia. These cilia trap particles that are inhaled and are eventually swept into the throat, where they are swallowed.

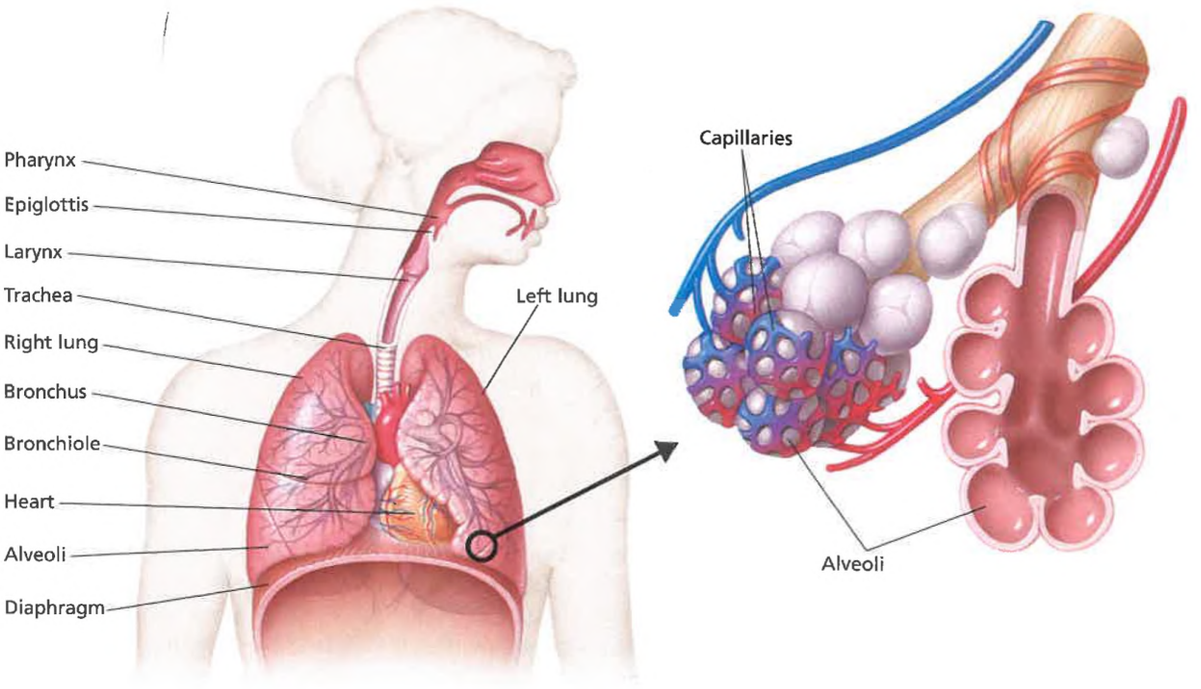


FIGURE 47-16

Trace the passage of air from the atmosphere to the lungs. Oxygen in the air finally reaches the alveoli, the functional units of the respiratory system. All exchange of gases between the respiratory system and the circulatory system occurs in the alveoli.

The moistened, filtered air then moves into the pharynx (FER-inks), a tube at the back of the nasal cavities and the mouth. The pharynx contains passageways for both food and air. When food is swallowed, a flap of cartilage, called the **epiglottis,** presses down and covers the opening to the air passage. When air is being taken in, the epiglottis is in an upright position, allowing air to pass into a cartilaginous tube called the **trachea** (TRAY-kee-uh). The trachea is about 10 to 12 cm long and has walls lined with ciliated cells that trap inhaled particles. The cilia sweep the particles and mucus away from the lungs toward the throat.

At the upper end of the trachea is the **larynx** (LER-inks). Sounds are produced when air is forced past two ligaments—the vocal cords—that stretch across the larynx. The pitch and volume of the sound produced varies with the amount of tension on the vocal cords and on the amount of air being forced past them.

The trachea then branches into two **bronchi** (BRAHN-kie), each of which leads to a lung. The walls of the bronchi consist of smooth muscle and cartilage and are lined with cilia and mucus. Within the lungs, the bronchi branch into smaller and smaller tubes. The smallest of these tubes are known as **bronchioles,** which are also lined with cilia and mucus. Eventually the bronchioles end in clusters of tiny air sacs called **alveoli** (al-VEE-oh-LIE). A network of capillaries surround each alveolus, as you can see in the detailed view shown in Figure 47-16. All exchange of gases in the lungs occurs in the alveoli. To facilitate this exchange, the surface area of the lungs is enormous. Each lung contains nearly 300 million alveoli and has a total surface area of 70 m^2—about 40 times the surface area of the skin.

GAS EXCHANGE AND TRANSPORT

In the lungs, gases are exchanged between the alveoli and the blood in the capillaries. Oxygen to be transported throughout the body moves into the bloodstream, and carbon dioxide to be eliminated from the body moves into the alveoli.

Gas Exchange in the Lungs

Figure 47-17 illustrates the direction in which oxygen and carbon dioxide move in the alveoli. When air moves into the lungs, the oxygen in the air crosses the thin alveolar membranes as well as the capillary walls and enters the blood. Carbon dioxide moves in the opposite direction, crossing the capillary walls and thin alveolar membranes and entering the alveoli.

Air moving into the alveoli is rich in oxygen and contains little carbon dioxide. In contrast, blood in the capillaries surrounding the alveoli is low in oxygen and contains high levels of carbon dioxide. Thus, concentration gradients for both oxygen and carbon dioxide exist. Remember from Chapter 5 that substances diffuse from an area of higher concentration to an area of lower concentration. Consequently, oxygen diffuses from the alveoli into the blood, and carbon dioxide diffuses from the blood into the alveoli. The enormous surface area of the alveoli increases the rate of diffusion of these two gases.

Hemoglobin and Gas Exchange

When oxygen diffuses into the blood, only a small amount dissolves in the plasma. Most of the oxygen—97 percent—moves into the red blood cells, where it combines with hemoglobin. Each hemoglobin molecule contains four iron atoms. Each iron atom can

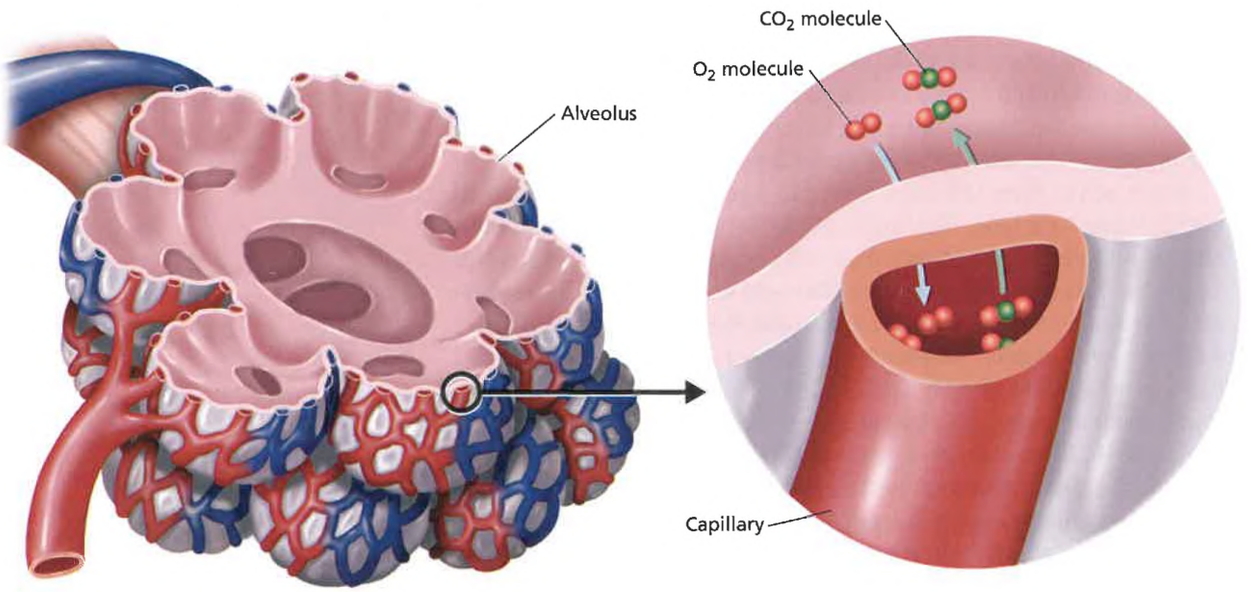


FIGURE 47-17
Because of concentration gradients, oxygen and carbon dioxide diffuse across the alveoli and capillary walls.

bind to one oxygen molecule. Thus, one hemoglobin molecule can carry up to four molecules of oxygen. When oxygenated blood reaches cells, the oxygen concentration is higher in the blood than in the cells. Thus, oxygen is released from the hemoglobin and diffuses out of the capillaries and into the surrounding cells.

Because the concentration of carbon dioxide is higher in the cells, it diffuses out of the cells and into the blood. Only about 8 percent of the carbon dioxide dissolves in the plasma. Approximately 25 percent binds to hemoglobin. The remaining 67 percent reacts with water in the plasma to form carbonic acid. In turn, the carbonic acid disassociates into bicarbonate ions and a proton. Thus, most of the carbon dioxide travels in the blood as bicarbonate ions. When the blood reaches the lungs, the series of reactions is reversed. Bicarbonate ions combine with a proton to form carbonic acid, which in turn forms carbon dioxide and water. The carbon dioxide diffuses out of the capillaries into the alveoli and is exhaled into the atmosphere.

MECHANISM OF BREATHING

Breathing is the process of moving air into and out of the lungs. **Inspiration,** shown in Figure 47-18a, is the process of taking air into the lungs. When you take a deep breath, your chest expands as muscles contract to move the ribs up and outward. At the same time, your diaphragm, a large skeletal muscle, flattens and pushes

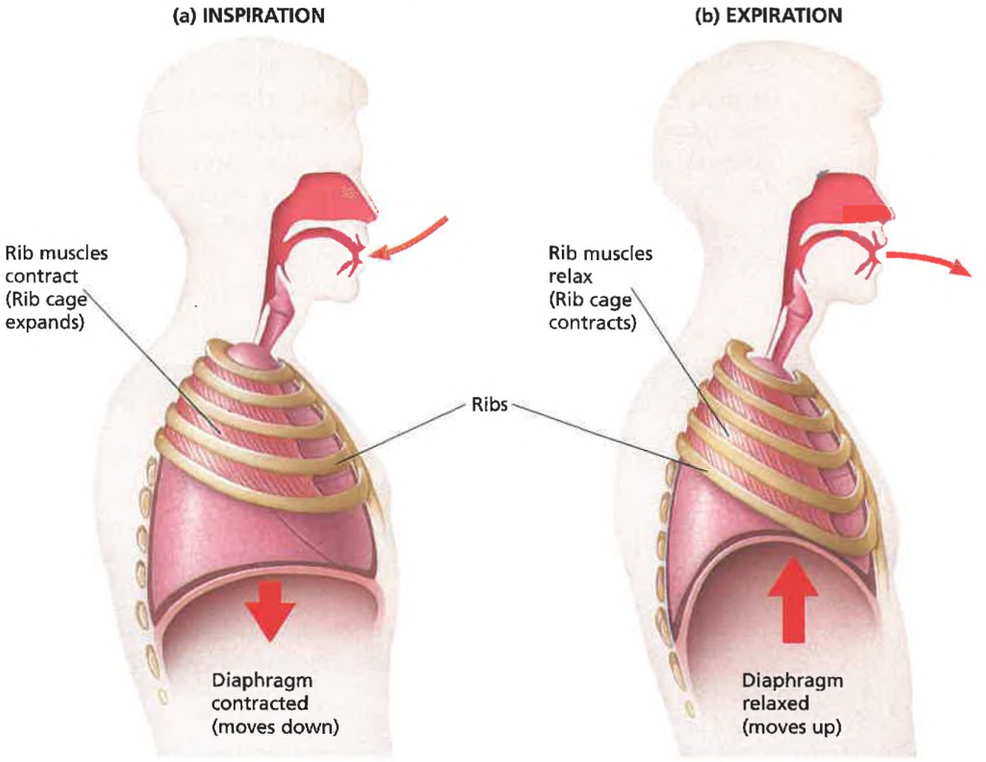


FIGURE 47-18
The diaphragm, a large skeletal muscle that separates the thoracic cavity from the abdominal cavity, and the muscles between the ribs control the movement of the thoracic cavity during breathing. If these muscles were paralyzed, then inspiration and expiration would not occur.

down on the abdomen. Muscles in the abdominal wall in turn relax. This action provides room for the flattened diaphragm.

When the diaphragm flattens and the ribs are lifted up and out, the volume of the thoracic cavity increases. An increased volume reduces the air pressure within the cavity. At this point, the air pressure inside the thoracic cavity is lower than the air pressure outside the body. As a result, air from the atmosphere moves into the lungs.

During **expiration,** the reverse process takes place, as you can see in Figure 47-18b. As the diaphragm and rib muscles relax, the elastic tissues of the lungs recoil, deflating the lungs. The size of the thoracic cavity decreases. Because the volume is smaller, the air pressure inside the cavity becomes greater than the air pressure outside the body. This pressure difference forces air out of the lungs until the pressures are again equal.

Regulation of Breathing

The rate at which oxygen is used depends on the activity of the cells. The greater their activity, the more oxygen they need and the faster the body needs to breathe. The slower their activity, the slower the body needs to breathe.

The rate of breathing is controlled by the brain and brain stem, which monitors the concentration of carbon dioxide in the blood. As activity increases, high levels of carbon dioxide in the blood stimulate nerve cells in the brain. The brain stem in turn stimulates the diaphragm to increase the breathing rate and depth. When the carbon dioxide concentration in the blood returns to lower levels, the sensors in the brain send a message to the respiratory muscles to return to a slower breathing rate. All this is controlled subconsciously by control centers in the brain. However, a person can temporarily override the respiratory control system at any time, holding his or her breath until losing consciousness. Then the brain stem takes control, and normal breathing resumes. This mechanism allows humans to swim underwater for short periods and to sleep without concern for breathing.

SECTION 47-3 REVIEW

1. What structures of the respiratory system prepare air for entry into the lungs?
2. Why does oxygen diffuse from the alveoli into capillaries and then into cells in the body?
3. Describe the main way carbon dioxide is transported in the blood.
4. How does an increased carbon dioxide concentration in the blood affect expiration and inspiration?
5. What is the adaptive value of having the organ of gas exchange—in this case, the alveolus—inside the body?
6. **CRITICAL THINKING** Why does a single-celled organism not need a respiratory system?

CHAPTER 47 REVIEW

SUMMARY/VOCABULARY

47-1

- The circulatory system consists of the cardiovascular system and the lymphatic system.
- The human heart is located in the thoracic cavity and has two atria and two ventricles.
- Heartbeat is initiated by the sinoatrial (SA) node, also known as the pacemaker. A heartbeat has two phases: systole and diastole.
- Blood vessels include arteries, capillaries, and veins. Arteries are thick, muscular vessels that transport blood away from the heart. Arteries branch into smaller vessels known as arterioles and capillaries.
- Capillaries merge to form venules, which then collect into veins. Veins return blood to the heart.
- Pulmonary circulation involves blood flow between the heart and the lungs.
- Systemic circulation includes the heart, the kidneys, the liver, and all other organs, including skin and muscle.
- The lymphatic system returns intercellular fluid to the heart. Fluid in the lymphatic system is called lymph.

Vocabulary

aorta (933)
aortic valve (932)
arteriole (934)
artery (934)
atherosclerosis (936)
atrioventricular (AV) node (933)
atrioventricular valve (932)
atrium (931)
blood pressure (934)
capillary (934)
cardiovascular system (931)
circulatory system (931)
coronary circulation (936)
diastole (933)
diastolic pressure (934)
hepatic portal circulation (936)
hypertension (934)
inferior vena cava (935)
lymph (937)
lymphatic system (931)
lymphocyte (937)
mitral valve (932)
pacemaker (933)
pericardium (931)
pulmonary circulation (935)
pulmonary valve (932)
pulmonary vein (936)
renal circulation (936)
semilunar valve (932)
septum (931)
sinoatrial (SA) node (933)
superior vena cava (935)
systemic circulation (935)
systole (933)
systolic pressure (934)
tricuspid valve (932)
vein (935)
ventricle (931)
venule (935)

47-2

- Blood is composed of plasma, red blood cells, white blood cells, and platelets. Red blood cells transport oxygen. White blood cells help defend the body against disease. Platelets help form blood clots.
- Human blood can be grouped into four types: A, B, AB, and O. In addition, blood is either Rh-positive or Rh-negative.

Vocabulary

antibody (940)
antigen (941)
blood type (941)
erythrocyte (939)
fibrin (941)
hemoglobin (939)
leukocyte (940)
phagocyte (940)
plasma (939)
platelet (941)
Rh factor (943)

47-3

- Oxygen enters the bloodstream through the lungs.
- The epiglottis prevents food from entering the trachea during swallowing. The larynx contains the vocal cords.
- Oxygen and carbon dioxide are exchanged between the alveoli and blood and between blood and the cells.
- Nearly all the oxygen in the body is transported by hemoglobin. The level of carbon dioxide in the blood determines the rate of breathing, which is controlled by the brain.
- During inspiration, the thoracic cavity expands, pulling air into the lungs. During expiration, the thoracic cavity gets smaller, forcing air out of the lungs.

Vocabulary

alveolus (945)
bronchiole (945)
bronchus (945)
epiglottis (945)
expiration (948)
external respiration (944)
inspiration (947)
internal respiration (944)
larynx (945)
trachea (945)

REVIEW

Vocabulary

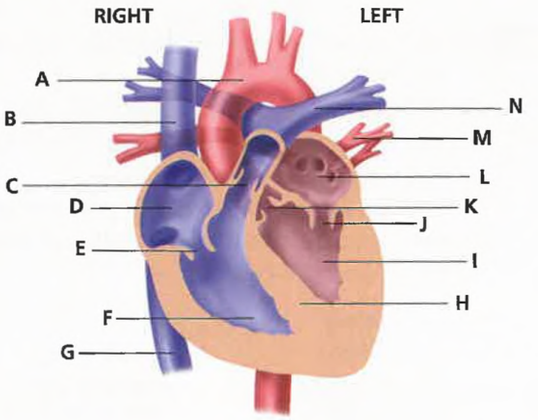
1. Distinguish between systolic pressure and diastolic pressure.
2. What do the pulmonary arteries and the aorta have in common? How are they different?
3. What do the pulmonary veins and the inferior vena cava have in common? How are they different?
4. What do arteries, veins, and capillaries have in common?
5. Identify the solid components of the blood.

Multiple Choice

6. The wall that divides the heart vertically is the (a) ventricle (b) pericardium (c) septum (d) atrium.
7. During systole, blood moves from the (a) ventricles to the atria (b) atria to the veins (c) atria to the ventricles (d) ventricles to the arteries.
8. Pulmonary circulation involves movement of blood between the heart and the (a) lungs (b) brain (c) liver (d) kidneys.
9. One of the functions of the lymphatic system is that it (a) interacts with the respiratory system (b) helps the body fight infection (c) consists of a series of two-way vessels (d) transports intercellular fluid away from the heart.
10. One function of plasma is to (a) carry substances that nourish cells (b) aid in the formation of blood clots (c) carry the majority of the oxygen supply of the blood (d) defend against disease.
11. The function of fibrin is to (a) transport oxygen (b) destroy invading microorganisms (c) stimulate the production of antibodies (d) help form a blood clot.
12. A person who has no antigens present on the red blood cells has blood type (a) AB Rh^+ (b) O Rh^- (c) A Rh^+ (d) O Rh^+.
13. During internal respiration, gases are (a) exchanged between the atmosphere and the blood (b) exchanged between the blood and the cells (c) produced by the heart (d) warmed and moistened.
14. Gases diffuse (a) from an area of high concentration to an area of low concentration (b) from an area of low concentration to an area of high concentration (c) directly from the cells to the air passages (d) from the alveoli to the cells.
15. Cilia (a) move air molecules (b) moisten the air passages (c) sweep foreign particles into the stomach (d) sweep particles out of the air passages.

Short Answer

16. Describe the route of blood through the heart. Include circulation through the lungs, and specify whether the artery or the vein carries oxygenated blood.
17. What are two major roles of the lymphatic system?
18. What structure do red blood cells lack that limits their life span?
19. A child is about to be born to parents who are both Rh^-. Given their Rh status, what concerns might the parents have about the health of their child ? Explain your answer.
20. How are human vocal sounds produced?
21. What is one factor that stimulates the brain stem to increase the breathing rate?
22. Describe three differences between white blood cells and red blood cells.
23. Describe the movement of the diaphragm and the rib muscles during inspiration and expiration.
24. How are the structures of alveoli and capillaries related to their function?
25. List the part of the heart denoted by each letter in the diagram below.



CRITICAL THINKING

1. A person with anemia has too few red blood cells. The most common symptom is a lack of energy. Why would anemia cause this symptom?
2. Polio is a disease that paralyzes muscles by affecting the nerves that make them move. Before the polio vaccine was developed, many people who had polio died because they could not breathe. Some of the survivors had to be placed in an "iron lung" that breathed for them. From what you know about the respiratory system, explain why people stricken with polio could no longer breathe on their own.
3. Even a small increase or decrease in blood volume has an effect on blood pressure. When an accident victim suffers significant blood loss, the person is transfused with plasma rather than whole blood. Why is plasma effective in meeting the immediate threat to life?
4. Explain how the lymphatic system moves lymph through the body without the aid of a pumping organ like that of the cardiovascular system.
5. Calculate the number of times a person's heart will beat if the person lives 75 years. Assume that the average heart beats 70 times per minute. Assuming that the heart of an overweight person beats an additional 10 beats per minute, explain why being overweight can put additional strain on the heart.
6. One function of the cardiovascular system is to help maintain a uniform body temperature. Explain how the constant circulation of blood throughout the body can accomplish this task.
7. Copy the blood-type table below on a sheet of paper. Fill in the missing information for each type.

Blood Types, Antigens, and Antibodies

Blood types	Antigen on the red blood cells	Antibodies in the plasma	Can get blood from	Can give blood to
A		anti-B	O, A	A, AB
B	B		O, B	B, AB
AB	A and B	none	A, B, AB, O	
O	none	anti-A, anti-B		A, B, AB, O

EXTENSION

1. Read "The Beat Goes On" in *Popular Science*, March 2000, on page 62. Describe the port-access mitral valve repair/replacement method of heart surgery. What is the major advantage of this kind of surgery?
2. Using the library or on-line references, research work that has been done about developing and implanting an artificial heart. Write a paper about the operation, the likely candidates for the operation, the number of people who have received an artificial heart, and some of the outcomes of these operations.
3. Carbon monoxide is an odorless gas that is extremely poisonous. Find out how this gas affects the respiratory and circulatory systems. What symptoms would a victim of carbon monoxide inhalation exhibit?
4. Using the library or an on-line data base, research a respiratory ailment, such as cystic fibrosis or emphysema. Write a report that includes information on the people who are most likely to get the disease. What are the causes, and what are the typical outcomes?

CHAPTER 47 INVESTIGATION

Tidal Volume, Expiration Volume, and CO_2 Production

OBJECTIVES

- Use indirect measurement to determine lung capacity.
- Determine the effect of exercise on breathing rate and CO_2 production.

PROCESS SKILLS

- measuring
- hypothesizing
- collecting data
- analyzing data
- experimenting

MATERIALS

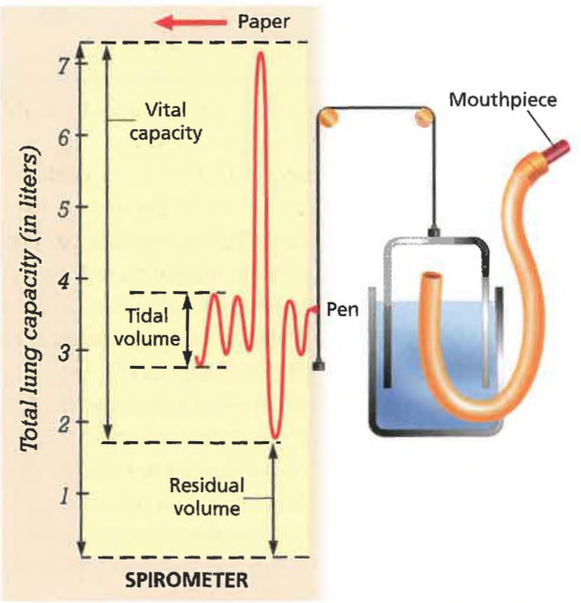
- safety goggles
- 1 L bromothymol indicator solution
- drinking straws
- 100 mL Erlenmeyer flasks, 2 per group
- 100 mL graduated cylinders
- marker
- plastic wrap
- spirometer
- stopwatch or clock with second hand

Background

1. A spirometer is an instrument used to measure the volume of air a person can breathe.
2. Examine the diagram of a spirometer on the right. Compare the diagram with the spirometer you will be using to complete this investigation. Note that the marking pen creates a line that can be compared with the scale on the left side to measure liters of air.
3. Tidal volume is the volume of air you inhale or exhale during a single, normal breath.
4. Lung capacity is the available volume of your lungs. Total lung capacity is 5 to 6 L. What factors might increase or reduce lung capacity?
5. Expiratory reserve volume is the amount of air remaining in the lungs after a normal exhalation.
6. Vital capacity is the maximum amount of air that can possibly be inhaled or exhaled.
7. Carbon dioxide is soluble in water. You can determine the relative amount of CO_2 in your breath at rest and after exercise by using an indicator to react with the CO_2. Higher CO_2 levels will react with the indicator solution faster.

PART A Tidal Volume, Expiratory Volume, and Vital Capacity

1. Make a data table in your notebook like one shown on the next page.
2. Place the tube of the spirometer near your mouth, and inhale a normal breath. Hold your nose, then exhale a normal breath into the spirometer and take a reading. Record your data in the table.
3. Measure your expiratory reserve volume by first breathing a normal breath and exhaling normally. Then put the spirometer tube to your mouth as you forcefully exhale whatever air is left in your lungs. Be sure to force out as much air as possible. Record your data in the table.



PART A *TIDAL VOLUME, EXPIRATORY VOLUME, AND VITAL CAPACITY*

	Average for young adult males	Average for young adult females	Average for athletes	Your readings
Tidal volume	**500 mL**			
Expiratory reserve volume	**100 mL**			
Vital capacity	**4,600 mL**			

4. The table includes values for young adult males. The average volume for young adult females is 20–25 percent lower than that of males. Calculate the average volumes for young adult females. Athletes can have volumes that are 30–40 percent greater than the average for their gender. Calculate the average volume for an athlete.

PART B Breathing Rate and CO_2 Production

5. Discuss the purpose of this part of the investigation with your partners. You will use bromothymol blue as an indicator of the CO_2 you bubble into each flask. Develop a hypothesis that describes a relationship between air volume exhaled during rest or exercise and the volume of CO_2 exhaled.
6.  CAUTION **Wear safety goggles at all times during this procedure. If you get the indicator solution on your skin or clothing, wash it off at the sink while calling to your teacher. If you get the indicator solution in your eyes, immediately flush it out at the eyewash station while calling to your teacher.**
7. Label the two flasks as 1 and 2.
8. Add 100 mL of indicator solution to each flask. Cover the mouth of each flask with plastic wrap.
9. Remove the plastic wrap from flask 1. Blow gently through one straw into flask 1 until the solution turns a yellowish color, exhaling slowly so that the solution does not bubble up. Be careful not to inhale the solution or get it in your mouth.
10. Record on your Part B Data Table the time in seconds that it took to see a color change in flask 1.
11. Exercise by jogging in place or doing jumping jacks for 2 min. Immediately blow gently through a new straw into flask 2 until the solution becomes the same yellowish color as the solution in flask 1.
12. In your Part B Data Table, record the amount of time in seconds that it took to get the same yellow color in flask 2 as you got in flask 1.
13. Calculate the difference in the amount of time it took to see a color change in the two flasks. What can you infer about the amount of CO_2 you exhaled before and after exercise?
14.  Clean up your materials. Pour the solutions down the sink, and rinse the sink thoroughly with water. Wash your hands before leaving the lab.

Analysis and Conclusions

1. How did your tidal volume compare with that of your classmates?
2. What are the independent and dependent variables in Part B of the Investigation? How did you vary the independent variable and measure changes in the dependent variable?
3. Why were the flasks covered with plastic wrap?
4. Do your data support your hypothesis from Part B? Explain your answers.
5. How do you know whether you produced more carbon dioxide before or after you exercised? Support your answer with evidence from this lab.
6. What were some of the possible sources of error in your experiment?

PART B *DATA TABLE*

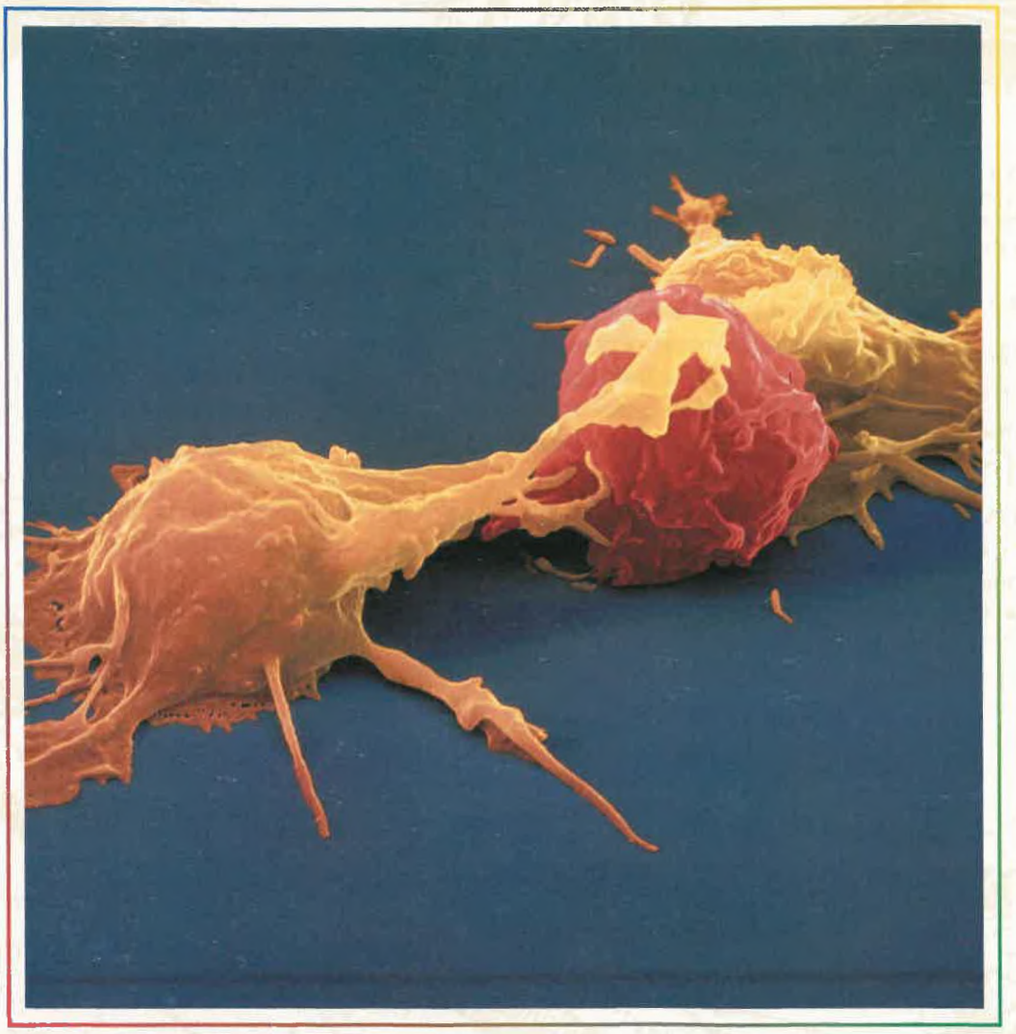
Time for color change in flask 1	
Time for color change in flask 2	
Difference in time between flask 1 and flask 2	

Further Inquiry

Design an experiment to determine whether exercise affects heart rate in the same way it affects breathing rate and tidal volume.

CHAPTER 48

INFECTIOUS DISEASES AND THE IMMUNE SYSTEM



Two natural killer cells, which are defensive cells in the body, are attacking a cancer cell (shown in red). They will kill the cancer cell by puncturing its membrane (SEM 14,900×).

FOCUS CONCEPT: ***Stability and Homeostasis***

As you read, identify ways to prevent, diagnose, treat, and cure diseases.

NONSPECIFIC DEFENSES

The human body is continuously exposed to pathogens, such as viruses and bacteria. When one of these pathogens enters the body and begins to multiply, it causes an ***infectious disease.*** *In this section, you will examine the body's nonspecific defenses, which are the first lines of protection against invading pathogens.*

SECTION 48-1

OBJECTIVES

- Summarize Koch's postulates for identifying a disease-causing agent.
- Describe how the skin and mucous membranes protect the body against pathogens.
- Describe the steps of the inflammatory response.
- Identify the white blood cells involved in a nonspecific response, and describe their functions.
- Explain the functions of interferon and fever.

DISEASE TRANSMISSION

Robert Koch (1843–1910), a German physician, was the first scientist to establish a step-by-step procedure for identifying the particular pathogen responsible for a disease. In the 1870s, Koch was studying anthrax, a disease of cattle that can spread to humans. Koch observed that cattle with anthrax had swarms of bacteria in their blood. He hypothesized that these bacteria caused anthrax.

To test his hypothesis, Koch isolated bacteria from a cow with anthrax and grew the bacteria in a laboratory culture. Then he inoculated a healthy cow with bacteria from the culture. This cow developed anthrax, and Koch found that its blood contained the same kind of bacteria as the blood of the first cow. He concluded that these bacteria caused anthrax. The steps that Koch developed for determining the cause of a given disease, known as **Koch's postulates,** are listed in Figure 48-1.

Scientists have used Koch's postulates to identify thousands of pathogens. Human diseases are caused by bacteria, viruses, protists, fungi, and invertebrates. Each kind of pathogen affects the body differently. Among humans, pathogens can spread in five

Koch's Postulates

1. The suspected pathogen must occur in the body of an animal with the disease and not occur in the body of a healthy animal.
2. The suspected pathogen should be isolated and grown in a laboratory culture.
3. If a healthy animal is inoculated with this culture, the animal should develop the disease.
4. The pathogen from the second animal should be isolated and grown in the laboratory. It should be the same as the pathogen isolated from the first animal.

FIGURE 48-1
The bacterium that causes anthrax, *Bacillus anthracis* (SEM 6,700×), was identified as a pathogen by means of Koch's postulates.

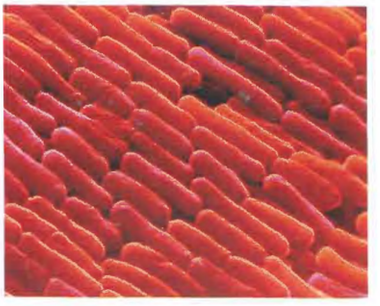


TABLE 48-1 Some Human Diseases and Their Means of Transmission

Disease	Pathogen	Principal means of transmission
AIDS	HIV (human immunodeficiency virus)	sexual intercourse, contaminated syringes
Common cold	any of 100 viruses	air currents, person-to-person contact
Malaria	protozoan parasites of genus *Plasmodium*	mosquitoes
Measles (rubeola)	paramyxovirus	air currents, person-to-person contact
Botulism	*Clostridium botulinum* (bacterium)	contaminated food

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KEYWORD: HM956

main ways—through air, food, water, person-to-person contact, and the bites of animals. Some pathogens are transmitted in only one way, while others may be transmitted in several ways. Table 48-1 lists some human pathogens, the diseases they cause, and their means of transmission.

SKIN AND MUCOUS MEMBRANES

The body's nonspecific defenses protect the body against any pathogen, regardless of its identity. Most pathogens must enter the body to cause disease. The skin, with its tough keratin shield, serves as a physical barrier to pathogens—as long as it remains intact. Any break in the skin may permit pathogens to enter the body. Extensive damage to the skin can be life threatening. A victim of severe burns, for example, is especially vulnerable to infections. Such a person must be thoroughly bandaged and treated with antibiotics until the skin has healed.

The skin continuously releases sweat, oils, and waxes, all of which contain chemicals that are toxic to many bacteria and fungi. Sweat, for example, contains the enzyme lysozyme, which can destroy the cell walls of bacteria. However, if all of the bacteria living on the skin were removed, harmful infections of the skin could occur because some of these bacteria inhibit the growth of pathogens.

Mucous membranes are epithelial tissues that protect the interior surfaces of the body that may be exposed to pathogens. Mucous membranes line the respiratory and digestive systems, the urethra, and the vagina. Mucous membranes serve as a barrier and secrete **mucus,** a sticky fluid that traps pathogens. The mucous membranes of the respiratory tract are covered with many beating cilia, as shown in Figure 48-2. These cilia constantly sweep mucus and pathogens up to the pharynx, where they are swallowed and forced into the stomach. Most swallowed pathogens are destroyed in the stomach by strong acids secreted by the stomach lining.

FIGURE 48-2
The passages of the respiratory system are lined with cells covered with beating cilia. Pathogens that become trapped in mucus secreted by these cells are swept upward, away from the lungs (5,325×).

THE INFLAMMATORY RESPONSE

Any pathogen that penetrates the skin or a mucous membrane will stimulate another nonspecific defense mechanism called the **inflammatory response,** which is summarized in Figure 48-3. Whenever an injury occurs, such as a cut or a splinter, some damaged cells release chemical messengers. One kind of chemical messenger is called histamine (HIS-tuh-MEEN). **Histamine** increases blood flow to the injured area and increases the permeability of the surrounding capillaries. As a result, fluids and white blood cells pass through capillary walls to the injured area. The changes caused by histamine result in redness, swelling, warmth, and pain—the familiar symptoms of inflammation.

If blood vessels have been damaged by the injury, platelets and clotting proteins initiate the blood-clotting process, sealing off the surrounding tissues and preventing pathogens from invading the rest of the body. To combat the pathogens that may have already entered through the wound, the body relies on white blood cells.

The chemical signals released by injured cells attract white blood cells to the site of the injury. Pus, the thick, whitish or yellowish fluid that often accumulates in wounds, contains dead pathogens and white blood cells. The presence of pus is a sign that white blood cells have arrived at the injury and are fighting pathogens.

Among the white blood cells that are involved in an inflammatory response are phagocytes. Phagocytes, as you learned in Chapter 5, are white blood cells that engulf pathogens by phagocytosis. The most common type of phagocyte, constituting 50 to 70 percent of the white blood cells in the body, is the **neutrophil** (NOO-truh-fil). Neutrophils circulate freely through blood vessels, and they

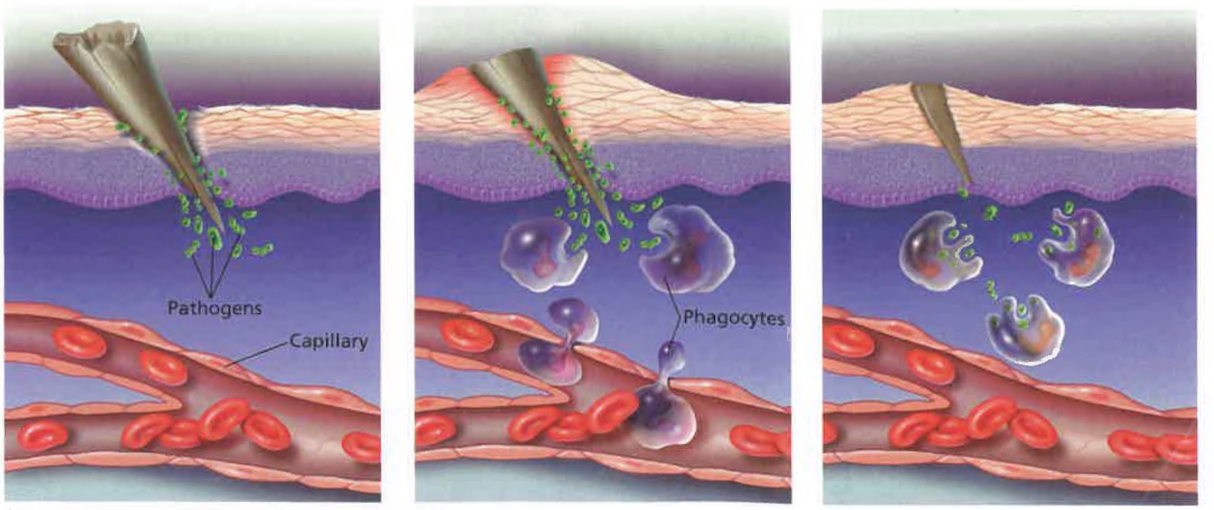
Eco Connection

Agriculture and the Origin of Human Diseases

Although some diseases are as old as our species, others have a more recent origin. One key development that changed the nature of human diseases was the beginning of farming and herding about 10,000 years ago. When humans began to keep large herds of domesticated animals, such as cattle and sheep, they were exposed to the pathogens of these animals. Some of these pathogens apparently began infecting humans. Measles, tuberculosis, smallpox, influenza, and pertussis (whooping cough) are among the diseases that appear to have been transmitted to humans from domesticated animals.

FIGURE 48-3

A small cut in the skin triggers an inflammatory response. (a) Injured cells release chemical alarm signals as pathogens enter through the cut. (b) In response, nearby capillaries swell and become leakier. The area around the wound swells and becomes warm. Phagocytes arrive to attack the pathogens. (c) Phagocytes destroy the pathogens, and the cut begins to heal.



(a) (b) (c)

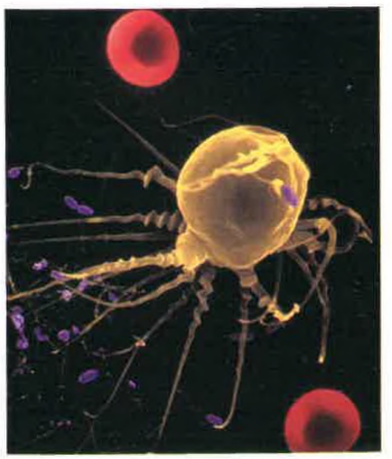


FIGURE 48-4
This macrophage is using cytoplasmic extensions to capture bacteria (shown in purple). (SEM 17,400×)

can squeeze between the cells in the wall of a capillary to reach the site of an infection. Once there, neutrophils engulf and destroy any pathogens they encounter. Another type of phagocyte is the **macrophage** (MA-kroh-FAYJ), shown in Figure 48-4. Macrophages consume and destroy any pathogens they encounter. They also rid the body of worn-out cells and cellular debris. Some macrophages are stationed in the tissues of the body, awaiting pathogens, while others move through the tissues and seek out pathogens.

Natural killer cells are large white blood cells that, unlike phagocytes, attack the cells that have been infected by pathogens, not the pathogens themselves. Natural killer cells are particularly effective in killing cancer cells and cells infected with a virus. A natural killer cell punctures the cell membrane of its target cell, allowing water to rush into the cell, causing the cell to burst.

OTHER NONSPECIFIC DEFENSES

Interferon (in-tuhr-FEER-AHN) is a protein that inhibits the reproduction of viruses. It is produced in small amounts by cells that are infected by a virus. Interferon stimulates neighboring cells to produce an enzyme that inhibits the synthesis of viral proteins. This prevents viruses from reproducing within these cells. Scientists are investigating whether interferon can be used to treat viral diseases and cancer.

Fever is an elevation in body temperature above the normal 37°C (99°F). Fever is not a disease; it is a sign that the body is responding to an infection. Some pathogens trigger fever, as do chemical signals released by macrophages. Research suggests that a moderate fever stimulates the body's defense mechanisms. It suppresses the growth of some bacteria and may promote the action of white blood cells. However, high fevers are harmful. High temperatures can inactivate cellular enzymes in the body. In general, body temperatures greater than 39°C (103°F) are considered dangerous, and those greater than 41°C (105°F) are often fatal.

Word Roots and Origins

macrophage

from the Greek *makros,* meaning "long," and *phagein,* meaning "to eat"

SECTION 48-1 REVIEW

1. How did Koch test his hypothesis about the cause of anthrax?
2. What chemical defenses does the skin use against pathogens?
3. What role does increased permeability of capillaries play in the inflammatory response?
4. How do natural killer cells differ from macrophages?
5. What is the function of interferon?
6. **CRITICAL THINKING** In many cases, not all of Koch's postulates can be applied to determine the cause of a human disease. Explain why.

SECTION 48-2

SPECIFIC DEFENSES: THE IMMUNE SYSTEM

Although the nonspecific defenses usually keep pathogens from entering and becoming established in the body, pathogens occasionally break through these defenses and begin to multiply. In response, the body's specific defenses are called into action. Unlike the nonspecific defenses, the specific defenses act against one particular pathogen.

OBJECTIVES

- Identify and describe the components of the immune system.
- Explain the functions of the three kinds of T cells.
- Describe the actions of B cells in an immune response.
- Explain how a vaccine works.
- Contrast *allergy* with *autoimmune disease.*

THE IMMUNE SYSTEM

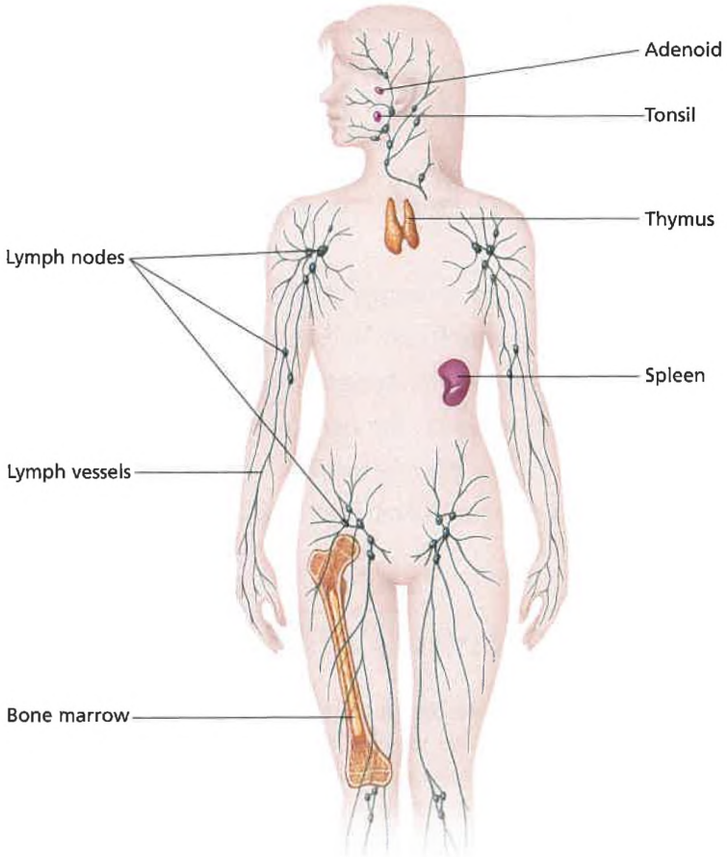
The body's specific defenses are part of the immune system, one of the major organ systems you studied in Chapter 46. The **immune system** has the job of fighting off invading pathogens and preventing the growth and spread of cancers. The immune system consists of several organs and the white blood cells found in these organs, as well as white blood cells in the blood and lymph. The organs of the immune system are scattered throughout the body; they include the bone marrow, thymus, lymph nodes, tonsils, adenoids, and spleen.

Each organ of the immune system plays a different role in defending the body against pathogens. Bone marrow, the soft material found inside long bones, such as the femur, manufactures the billions of new white blood cells needed by the body every day. Some newly produced white blood cells remain in the bone marrow to mature and specialize, while others travel to the **thymus** (THIE-muhs), a gland in the upper part of the chest just above the heart, to mature. Lymph nodes are located throughout the body along the vessels of the lymphatic system and contain large numbers of white blood cells. Lymph nodes filter pathogens from the lymph and expose them to white blood cells. The **spleen,** a fist-sized organ located just behind the stomach, filters pathogens from the blood. It is stocked with white blood cells that respond to the trapped pathogens. Figure 48-5, on the next page, shows the organs of the immune system.

The white blood cells of the immune system are known as lymphocytes (LIM-foh-SIETZ). As their name implies, these white blood cells accumulate in the lymph and lymph nodes, but lymphocytes are also found in the spleen and blood. There are two main types of lymphocytes: B cells and T cells. **B cells** are produced in the bone marrow and complete their development there. **T cells** are also produced in the bone marrow, but they mature after traveling to the thymus.

FIGURE 48-5

The organs of the immune system produce lymphocytes and filter pathogens from the blood and lymph.



RECOGNIZING PATHOGENS

Lymphocytes are the body's specific defenses. When the body is invaded by a pathogen, lymphocytes launch an attack known as an **immune response** to eliminate the pathogen. In order to respond to a pathogen, however, lymphocytes must be able to recognize it as a foreign invader and distinguish it from the cells of the body. Any substance that the immune system recognizes as a potential pathogen and that provokes an immune response is known as an **antigen** (AN-tuh-jin). A wide variety of substances can be antigens, including pathogens or parts of pathogens, bacterial toxins, insect venom, and pollen.

How do lymphocytes identify antigens? Every lymphocyte has receptor proteins scattered over the surface of its cell membrane. These receptor proteins recognize and bind to antigens that match their particular three-dimensional shape, as shown in Figure 48-6. The surface of a bacterial cell, for instance, can be covered with many different kinds of molecules—including proteins and polysaccharides—each of which can function as an antigen and cause lymphocytes to react. All of the receptors on an individual lymphocyte are the same shape and thus bind to the same antigen.

Word Roots and Origins

antigen

From the Greek *anti-*, meaning "against," and *-genes*, meaning "born"

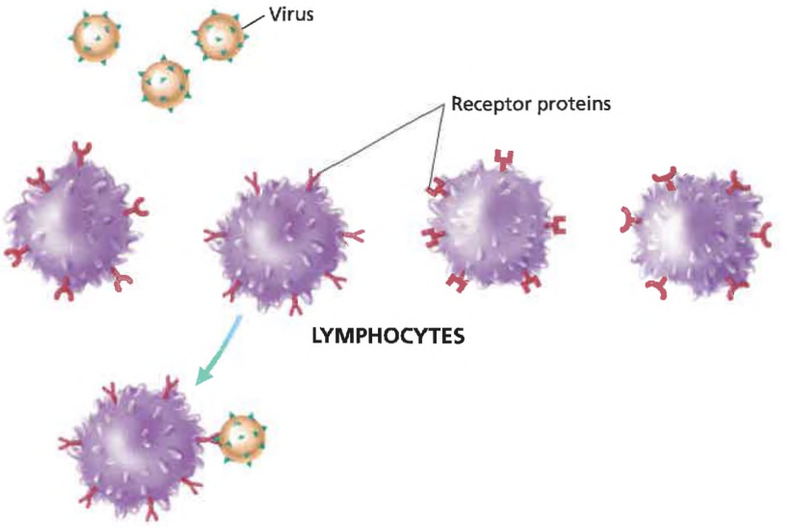


FIGURE 48-6

The receptor proteins on the surface of lymphocytes have a complex, three-dimensional structure. The receptors can fit onto, and thus bind, molecules on pathogens that have a complementary shape.

The body can defend itself against an enormous number of different pathogens because the immune system makes millions of different kinds of lymphocytes, each carrying uniquely shaped receptors. The specificity of the immune system is due to the specificity of the antigen receptors on the lymphocytes. For example, when a cold virus invades the body, lymphocytes whose receptor molecules match the antigens of the cold virus are activated to counterattack. Lymphocytes with different-shaped receptors, such as those that recognize an influenza (flu) virus, do not respond.

IMMUNE RESPONSE

An immune response is a two-pronged assault on a pathogen. One arm of the immune response, the **cell-mediated immune response,** involves T cells. The other arm involves mainly B cells and is called the **humoral** (HYOO-muh-ruhl) **immune response.** Both parts of the immune response are controlled by a type of T cell called a **helper T cell.**

The first step in an immune response occurs when a macrophage engulfs and destroys a pathogen. The macrophage then displays fragments of the pathogen's antigens on the surface of its own cell membrane. When a helper T cell with a receptor matching this antigen encounters the macrophage, the macrophage releases a cytokine called interleukin-1 (IN-tuhr-LOO-kin), which in turn triggers the helper T cell to release a second cytokine, called interleukin-2.

Cell-Mediated Immune Response

Interleukin-2 stimulates the helper T cells and two other types of T cells—cytotoxic T cells and suppressor T cells—to rapidly divide. **Cytotoxic** (SIE-toh-TAHK-sik) **T cells** combat the pathogen by destroying any of the body's cells that have been infected by the

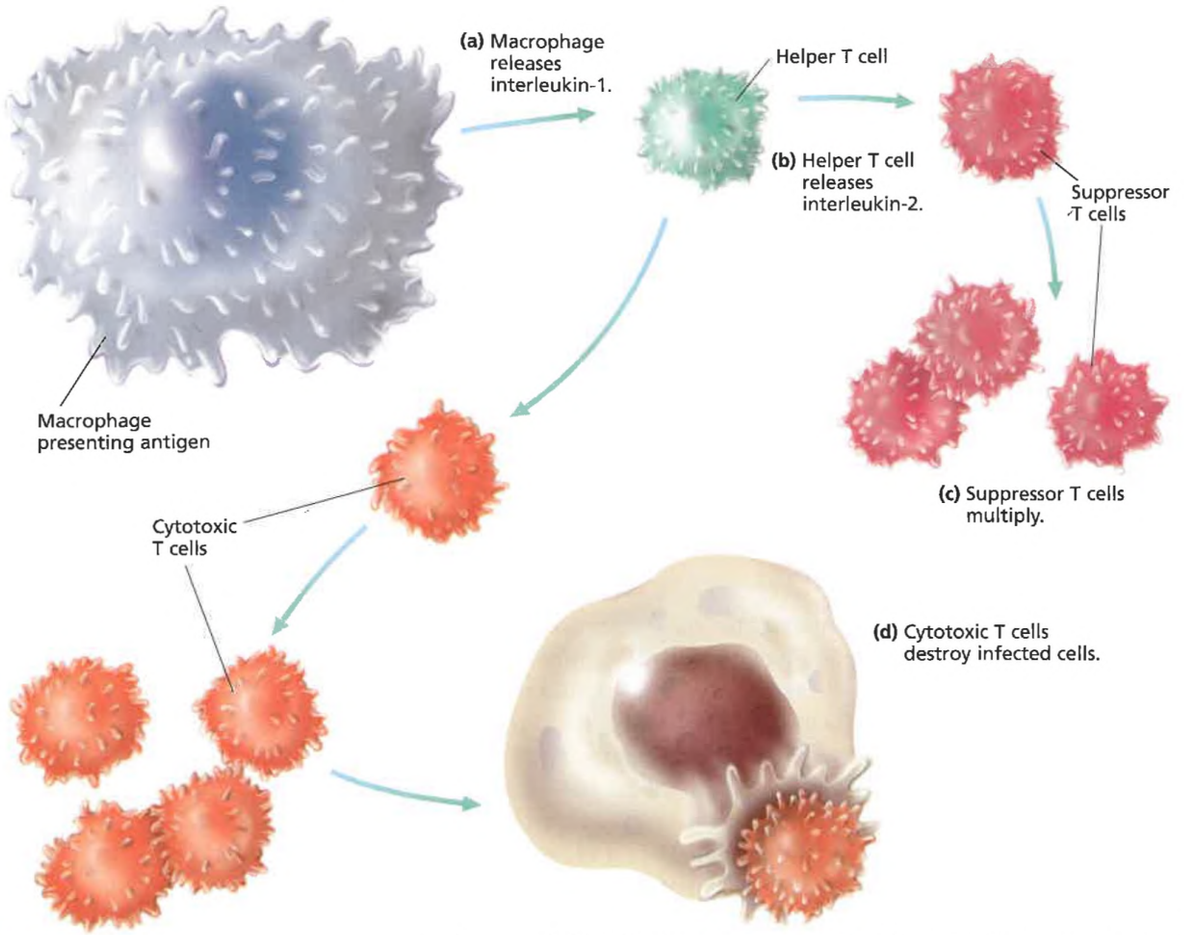


FIGURE 48-7

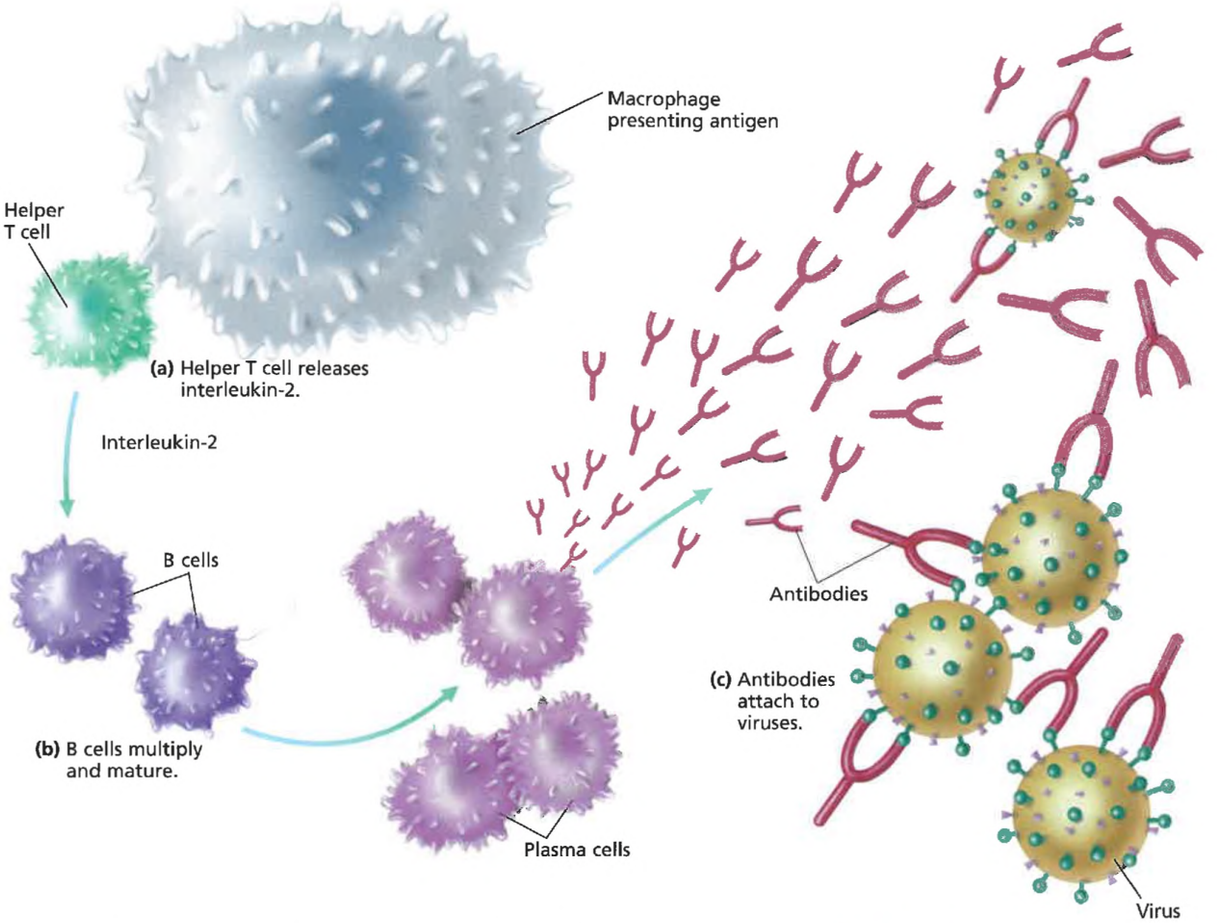
The cell-mediated immune response involves macrophages, helper T cells, cytotoxic T cells, and suppressor T cells. (a) The macrophage releases interleukin-1, which stimulates the helper T cell. (b) The helper T cell then releases interleukin-2. In response, cytotoxic T cells and suppressor T cells begin to divide. (c) Suppressor T cells divide slowly. Their role is to shut down the immune response. (d) Cytotoxic T cells destroy infected cells by puncturing their cell membranes.

pathogen. Cells that have been invaded by a pathogen are recognizable because they usually have some of the pathogen's antigens on their surface. Cytotoxic T cells attach to these antigens. Like natural killer cells, cytotoxic T cells kill by puncturing the cell membrane of their target. Cytotoxic T cells can also kill cancer cells and attack parasites and foreign tissues, such as those received during an organ transplant. **Suppressor T cells** help to shut down the immune response after the pathogen has been cleared from the body. Figure 48-7 illustrates the cell-mediated immune response.

Humoral Immune Response

Interleukin-2 and antigen presentation by a macrophage or T cell stimulate B cells to divide and differentiate into plasma cells. **Plasma cells** are highly specialized cells that produce defensive proteins and secrete them into the blood. These defensive proteins are identical to the plasma cell's antigen receptors and are known as **antibodies.** Antibodies are Y-shaped molecules. The two arms of each Y are identical, and they recognize and attach to the same antigen. One plasma cell can make up to 30,000 antibody molecules per second.

Antibodies bind to specific pathogens but do not destroy them directly. Instead, they either inactivate the pathogen or trigger its destruction by the nonspecific defenses. For example, by attaching



to the surface proteins of a virus, antibodies prevent the virus from entering a cell, thereby blocking its reproduction. Antibodies also cause pathogens to clump together, which facilitates phagocytosis by macrophages. Figure 48-8 summarizes the humoral immune response.

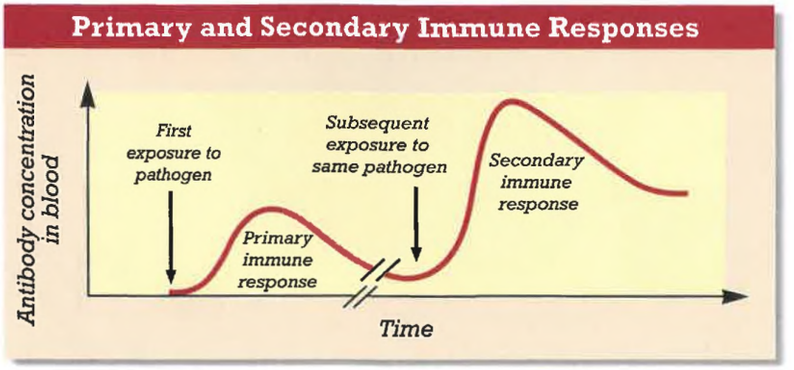
FIGURE 48-8

The humoral immune response involves the activation of B cells and the production of antibodies. (a) After encountering a macrophage, a helper T cell releases interleukin-2. This stimulates rapid division by B cells. (b) After dividing for five days, mature B cells differentiate into antibody-secreting plasma cells. (c) Antibodies bind to free antigen particles and cause antigens such as bacteria and viruses to clump.

Primary and Secondary Immune Responses

After an infection has been overcome, the immune response is shut down and most of the participating cells die. However, some B cells and T cells remain, often throughout the individual's life, as memory cells. **Memory cells** are the body's long-term protection against reinfection by a specific pathogen. Because of memory cells, you cannot get most diseases more than once. If you are exposed to a pathogen a second time, memory cells immediately recognize it and begin to divide rapidly. They eliminate the pathogen before it can produce disease. The first time the body encounters an antigen, the immune response is called a **primary immune response.** The response of memory cells to a subsequent infection by the same pathogen is called a **secondary immune response.** As you can see in Figure 48-9 on the next page, a secondary immune response is much faster and more powerful, producing many more antibodies. Keep in mind that memory cells only protect against a pathogen that the immune system has already encountered.

FIGURE 48-9
Compare the production of antibodies during the primary and secondary immune responses.



IMMUNITY AND VACCINATION

A person who is resistant to a specific pathogen is said to have **immunity** to it. One way to acquire immunity is to be infected by the pathogen and to survive the disease it causes. Another, safer way is through vaccination. Vaccines contain pathogens or toxins that have been modified so that they can no longer cause disease. Vaccines produce immunity because they contain antigens that stimulate an immune response, resulting in the production of memory cells. Thus, a vaccine prepares the immune system to fight off a pathogen should it ever appear in its disease-causing form.

Among the diseases that have been controlled through the use of vaccines are polio, measles, mumps, tetanus, and diphtheria. An intensive worldwide vaccination campaign has eliminated smallpox. Sometimes the protection provided by vaccination wears off over time. That's why doctors recommend periodic booster shots to restore immunity against some diseases, such as tetanus and polio.

Quick Lab

Organizing the Immune Response

Materials paper, pencil

Procedure Create a diagram or a flowchart that outlines the steps involved in a cell-mediated immune response. Label the cells and the steps.

Analysis What are helper T cells? How is a cell-mediated response different from a humoral response?

ALLERGIES

Sometimes the immune system reacts to otherwise harmless antigens in ways that can be harmful. This inappropriate reaction to a harmless substance is called **allergy.** Antigens that can trigger allergic reactions include pollen, animal dander (flakes of skin), dust mites, food, and fungal spores. Allergic reactions are characterized by watery eyes, wheezing, and sneezing. Many of the symptoms of allergy result from the release of histamine by cells that are exposed to the antigen. Drugs called antihistamines help counteract the effects of histamine and can relieve the symptoms of allergies. For most people, allergies are irritating and inconvenient but not life threatening. However, some people experience severe reactions that can be fatal.

TABLE 48-2 *Autoimmune Diseases and Their Target Tissues*

Disease	Tissues affected	Symptoms
Systemic lupus erythematosus	connective tissue throughout the body	facial skin rash, painful joints, fever, fatigue, kidney problems, weight loss
Type 1 diabetes	insulin-producing cells in pancreas	excessive urine production, blurred vision, weight loss, fatigue, irritability
Graves' disease	thyroid	weakness, irritability, heat intolerance, increased sweating, weight loss, insomnia
Rheumatoid arthritis	joints	painful, crippling inflammation of the joints

AUTOIMMUNE DISEASES

Lymphocytes that recognize and react to the body's own cells are usually eliminated during development, before they become functional. This prevents an attack directed at the body's own tissues. However, in rare cases the immune system does respond to the body's own cells, attacking them as if they were pathogens. Such a disorder is called an **autoimmune** (AW-toh-i-MYOON) **disease.** For example, multiple sclerosis is an autoimmune disease of the nervous system that affects mainly young adults. In this disease, T cells attack and slowly destroy the insulating material that covers nerves. Although the severity of multiple sclerosis varies from individual to individual, the damage may progress to a point at which nerve transmission is interrupted. In severe cases, paralysis, blindness, and even death can result. Scientists are still searching for the causes of multiple sclerosis and other autoimmune diseases. Table 48-2 lists several autoimmune diseases and describes their effects on the body.

SECTION 48-2 REVIEW

1. Describe the functions of the spleen and of the bone marrow.
2. Contrast the functions of helper T cells with those of cytotoxic T cells.
3. What is the role of B cells in an immune response? How do B cells depend on T cells?
4. Explain how a vaccine stimulates immunity to a disease.
5. Name one similarity and one difference between autoimmune diseases and allergies.
6. **CRITICAL THINKING** A friend tells you that because he has just recovered from a cold, he now cannot get the flu. Is your friend right? Explain your answer.

SECTION

48-3

OBJECTIVES

- Describe the course of HIV infection.
- Identify four ways HIV is transmitted.
- Describe how HIV's rate of evolution affects the development of vaccines and treatments.

AIDS

The immune system normally provides very effective protection against infectious diseases. Its importance to our health is dramatically illustrated by the diseases in which the immune system malfunctions. The most deadly of these diseases is AIDS, or acquired immunodeficiency syndrome. AIDS was first recognized as a disease in 1981, and since then it has killed more than 300,000 Americans.

HIV AND AIDS

AIDS is a disease in which the immune system loses its ability to fight off pathogens and cancers. As you learned in Chapter 24, AIDS is caused by the human immunodeficiency virus, or HIV, a type of retrovirus. Recall that retroviruses contain RNA, not DNA, as their genetic material. Like other viruses, HIV cannot reproduce outside a cell. HIV can invade several kinds of cells, including macrophages, but its main targets are helper T cells. HIV enters a cell by binding to a receptor called CD4 and one other receptor on the cell's membrane. An infected helper T cell manufactures large numbers of new virus particles, as shown in Figure 48-10.

Course of the Disease

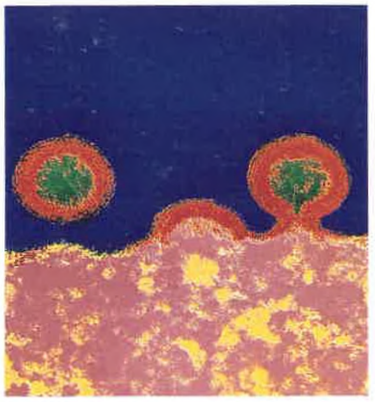
HIV begins to reproduce within the body shortly after infection. The presence of large numbers of viruses stimulates the immune system to launch a vigorous attack. At this point, which usually occurs within a month or so of infection, the individual often experiences a short flulike illness, with fever, fatigue, body aches, and swollen lymph nodes.

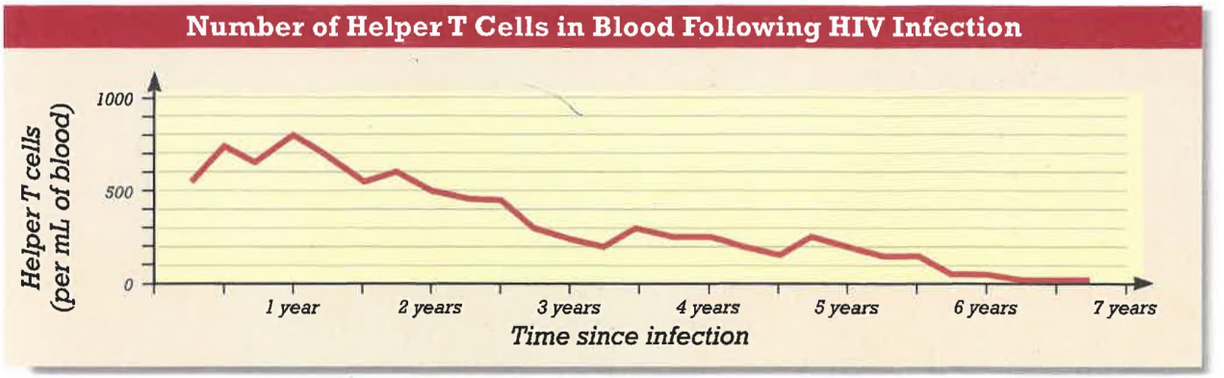
This first battle is the beginning of a long-term struggle between HIV and the immune system. HIV continues to replicate rapidly, but the immune system keeps the virus in check, and the infected person usually feels well and appears healthy. This stage of HIV infection can last for as little as two years, but typically lasts for 10 years or longer.

For reasons that are not well understood, HIV eventually gets the upper hand in its battle with the immune system. The number of helper T cells in the body begins to decline gradually, as shown in Figure 48-11.

The reduction in helper T cells is disastrous for the infected person. Helper T cells play a crucial role as the "commanders" of the

FIGURE 48-10
This image shows particles of HIV escaping through the membrane of an infected T cell. (TEM 117,000×)





immune response, activating both cytotoxic T cells and B cells. As the number of helper T cells falls, the immune system becomes weaker, and the infected individual becomes vulnerable to a variety of cancers and diseases that a healthy immune system would normally defeat. These diseases are called **opportunistic infections,** and they usually strike only people with weakened immune systems. When the number of helper T cells in the blood falls below 200/mL (a normal amount is 600/mL–700/mL), the individual is said to have AIDS. AIDS is the last stage of HIV infection. Few individuals live more than two years after being diagnosed with AIDS, usually dying from opportunistic infections or cancer.

FIGURE 48-11
Once HIV begins to destroy the immune system, the number of helper T cells in the blood falls dramatically.

Transmission

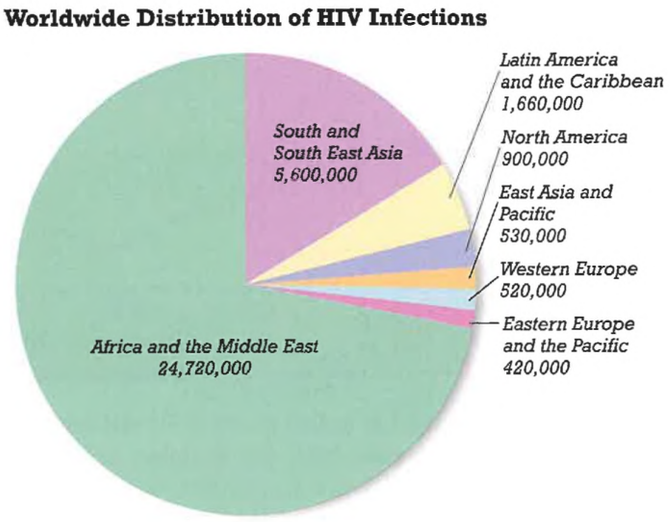
HIV is transmitted by the transfer of body fluids containing HIV or HIV-infected cells. The most common means of infection is sexual intercourse with an infected person. HIV-infected cells are found in semen and vaginal secretions, and infection can occur through vaginal, oral, or anal intercourse. Use of a latex condom during sex greatly reduces the likelihood of transmission but does not eliminate it completely. It is important to remember that people who have been infected with HIV but have not developed AIDS can still transmit the virus.

The second most common means of infection is through the use of syringes and hypodermic needles that have been contaminated with blood containing HIV. People who inject intravenous drugs, such as heroin, and who share syringes or hypodermic needles with others are at very high risk of infection. During the early years of the AIDS epidemic, a number of individuals were infected by receiving HIV-contaminated blood transfusions. Donated blood is now tested for the presence of antibodies to HIV, and people who may have been exposed to the virus are discouraged from donating, so the likelihood of being infected through a transfusion is very low.

You cannot be infected with HIV through casual contact, such as by shaking hands with an infected person or by handling an object used by an infected person. HIV is apparently not transmitted through the air, in water, or on toilet seats. There is no evidence that it can be spread through the bites of arthropods, such as mosquitoes, fleas, and ticks.

FIGURE 48-12

According to the World Health Organization, more than 34.3 million people are infected with HIV. This graph shows estimates of the number of HIV-infected people in each region of the world.



Although most early cases of AIDS were diagnosed in the United States and Western Europe, AIDS is now a worldwide problem. Figure 48-12 shows the estimated numbers of HIV-infected people in different parts of the world.

Treatments and Vaccines

Scientists trying to create vaccines for HIV must contend with its very rapid rate of evolution. The genes that code for the virus's surface proteins mutate frequently. As a result, new variants of the virus with slightly different surface proteins are constantly appearing. To produce effective immunity, a vaccine against HIV must stimulate the immune system to respond to many variants of the virus. Although several vaccines against HIV are under development or being tested, none have yet proven effective.

HIV quickly becomes resistant to drugs used against it. To avoid this problem, scientists have begun treating patients with three antiviral drugs. Even if the virus evolves resistance to one drug, it is unlikely to become simultaneously resistant to three drugs. Scientists have already observed some encouraging results from this treatment. However, it is important to note that there is currently no cure for HIV infection.

SECTION 48-3 REVIEW

1. Name two kinds of cells that HIV can infect.
2. How does the immune system respond to the first appearance of HIV in the body?
3. Why is the risk of becoming infected with HIV through a blood transfusion extremely low?
4. Name two ways that HIV apparently cannot be transmitted.
5. How does HIV's rapid rate of evolution affect the development of a vaccine?
6. **CRITICAL THINKING** Explain the difference between HIV infection and AIDS.

CHAPTER 48 REVIEW

SUMMARY/VOCABULARY

48-1

- Robert Koch developed four basic steps, known as Koch's postulates, for identifying the particular pathogen responsible for a disease.
- The skin is a nonspecific defense that helps keep pathogens out of the body. Mucous membranes line vulnerable interior surfaces of the body and serve as a barrier to pathogens.
- A break in the skin will trigger another nonspecific defense, called the inflammatory response, characterized by swelling, redness, raised temperature, and pain.
- Neutrophils and macrophages are phagocytes that engulf and destroy pathogens and cellular debris. Natural killer cells destroy infected cells.

Vocabulary

fever (958)
histamine (957)
infectious disease (955)
inflammatory response (957)
interferon (958)
Koch's postulates (955)
macrophage (958)
mucous membrane (956)
mucus (956)
natural killer cell (958)
neutrophil (957)

48-2

- The immune system consists of the spleen, tonsils, adenoids, lymph nodes, thymus, bone marrow, and white blood cells called lymphocytes.
- An antigen is any substance that can stimulate a response from the immune system. Lymphocytes have receptor proteins on their cell membrane that allow them to recognize antigens.
- The immune system's reaction to a pathogen is called an immune response. The immune response is controlled by helper T cells.
- Helper T cells activate the division of B cells to give rise to plasma cells, which produce and secrete defensive proteins called antibodies.
- An allergy is an extreme reaction by the immune system to a harmless antigen. An autoimmune disease is an attack on the cells of the body by the immune system.

Vocabulary

allergy (964)
antibody (962)
antigen (960)
autoimmune disease (965)
B cell (959)
cell-mediated immune response (961)
cytotoxic T cell (961)
helper T cell (961)
humoral immune response (961)
immune response (960)
immune system (959)
immunity (964)
memory cell (963)
plasma cell (962)
primary immune response (963)
secondary immune response (963)
spleen (959)
suppressor T cell (962)
T cell (959)
thymus (959)

48-3

- Acquired immunodeficiency syndrome (AIDS) is caused by the human immunodeficiency virus (HIV). HIV enters and reproduces inside helper T cells.
- HIV and the immune system fight a long battle, which the immune system eventually loses.
- Most AIDS patients die of opportunistic diseases or cancers.
- HIV is transmitted mainly through sexual intercourse and the use of HIV-contaminated hypodermic needles or syringes.

Vocabulary

opportunistic infection (969)

REVIEW

Vocabulary

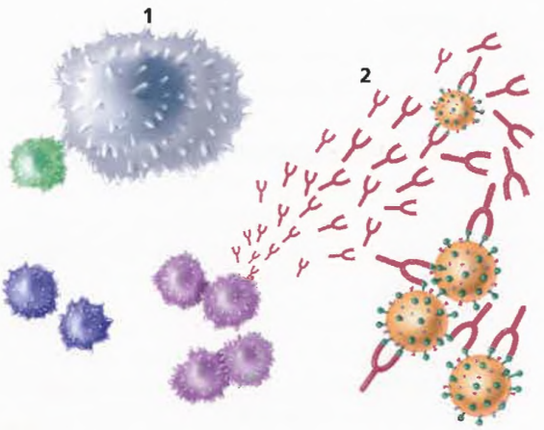
1. Distinguish between a primary immune response and a secondary immune response.
2. Describe the function of interferon.
3. Contrast a neutrophil with a B cell.
4. Using a dictionary, find the meaning of the word *opportunistic*. Relate the meaning of this word to the action of opportunistic infections.
5. Explain the relationship between T cells and B cells.

Multiple Choice

6. Robert Koch (a) established procedures for identifying the cause of disease (b) identified specific neurotoxins (c) discovered interferon (d) pioneered the process of vaccination.
7. Pathogens can be (a) bacteria (b) viruses (c) invertebrates (d) any of the above.
8. Nonspecific defenses include the (a) primary immune response (b) secondary immune response (c) inflammatory response (d) T cells.
9. The skin acts as a defense against infection by (a) forming a physical barrier to pathogens (b) engulfing and digesting pathogens (c) forming blood clots (d) producing antibodies.
10. The primary immune response involves (a) the recognition of antigens (b) release of antibodies by macrophages (c) a general reaction to all pathogens (d) the action of cilia lining the air passages.
11. Antibodies are produced by (a) helper T cells (b) plasma cells (c) suppressor T cells (d) macrophages.
12. Cytotoxic T cells (a) are directly stimulated by macrophages (b) attack infected cells (c) mature in the bone marrow (d) help shut down the immune response.
13. Which of the following is *not* true of autoimmune diseases?
    (a) An example is Type 1 diabetes.
    (b) They are a type of cancer.
    (c) They target the body's cells.
    (d) They can be fatal.
14. HIV is transmitted through (a) infected food or water (b) sexual contact that involves the exchange of body fluids (c) intravenous injections with contaminated syringes (d) both b and c.
15. HIV (a) infects only macrophages (b) has DNA as its genetic material (c) can be eliminated with antibiotics (d) replicates in helper T cells.

Short Answer

16. What steps must be followed to prove that a particular pathogen is responsible for a disease?
17. Look at the diagram shown below.
    a. Identify the cell labeled *1*.
    b. What is the function of the structure labeled *2*?
    c. What process is illustrated by this diagram?

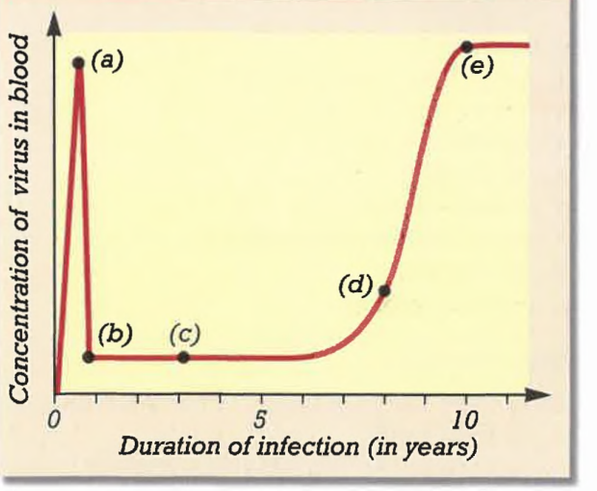


18. How does the function of the mucous membranes compare with that of the skin?
19. Describe the steps of an inflammatory response.
20. What is the function of the thymus?
21. Describe the primary immune response.
22. What functions do antibodies serve?
23. What are memory cells, and what is their role in providing immunity against disease?
24. What white blood cells are involved in the inflammatory response?
25. What problem have scientists encountered in trying to develop a vaccine against HIV?

CRITICAL THINKING

1. Many people take fever-reducing drugs as soon as their temperature exceeds 37°C (99°F). Why might it not be a good idea to immediately reduce a fever with drugs? What are the benefits of taking fever-reducing drugs?
2. Scientists created an effective vaccine for smallpox but have not been able to do so for AIDS. What does this suggest about the rate of evolution of the smallpox virus?
3. Cytotoxic T cells attack and destroy some kinds of cancer cells. What can you conclude about the surface proteins of these cancer cells?
4. A government agency is reviewing two proposals for HIV research, but it can fund only one. Suppose you are asked to provide input. Which proposal would you recommend that the agency fund? You should consider not only the likely effectiveness of the treatment but also the likely side effects. Explain how you made your choice. **Proposal 1**: Develop a drug that interferes with protein synthesis. **Proposal 2:** Develop a substance that binds to CD4 receptors on helper T cells.
5. Look at the graph shown below. It shows the amount of HIV in the blood of an infected person. Answer the following questions about the graph:
   a. What caused the peak in viral concentration at point *a*?
   b. Why did the level of virus drop between points *a* and *b*?
   c. Describe what is happening to both the virus and the immune system at points *c* and *d*.

Virus Concentration in HIV Infection



EXTENSION

1. Read "Granting Immunity" in *Scientific American*, March 2000, on page 15. Why are some parents becoming uncooperative about obtaining vaccines for their children? At what age should a person have the chicken pox vaccine?
2. Use the *Physicians' Desk Reference* (PDR) at your local library to research the large numbers of specialized antibiotics made by drug companies. To summarize what you have learned, make a large chart on poster board using the following headings: brand name of the drug, generic name of the drug, uses of the drug, company that manufactures the drug, and disease the drug controls. Select five or six antibiotics, and fill in the appropriate information on the chart.
3. During the early stages of the AIDS epidemic, many hemophiliacs became infected with HIV after using infected clotting factor. Using library resources or an on-line database, research this aspect of the AIDS epidemic. Why do hemophiliacs need clotting factor? How was it produced, and how did this lead to contamination with HIV? What changes have been made in the production of clotting factor to reduce the risk of infection?

CHAPTER 48 INVESTIGATION

Simulating Disease Transmission

OBJECTIVES

- Simulate the transmission of a disease.
- Determine the original carrier of the disease.

PROCESS SKILLS

- organizing data
- analyzing data
- identifying
- modeling

MATERIALS

- lab apron
- safety goggles
- disposable gloves
- dropper bottle of unknown solution
- large test tube
- indophenol indicator

Background

1. What are the five main ways that human diseases can be transmitted?
2. How does a cold or flu spread from person to person?
3. How does the body fight invading viruses?
4. Why has the transmission of HIV become a great concern worldwide?
5. Why is a person with AIDS less able to combat infections than a person who does not have AIDS?

PART A Simulating the Transmission of a Disease

1. This investigation will involve the class in a simulation of disease transmission. After the simulation, you will try to identify the original infected person in the closed class population.
2. In your lab report, construct a data table similar to Table A.
3.  CAUTION **Put on a lab apron, goggles, and disposable gloves.**
4.  CAUTION **If you get any solution used in this investigation on your skin or clothing, wash it off at the sink while calling to your teacher. If you get any solution used in this investigation in your eyes, immediately flush your eyes with water at the eyewash station while calling to your teacher.** You have been given a dropper bottle of unknown solution and a clean test tube. The solution in the dropper bottle represents the pathogens that you carry. Handle the unknown solution with care because it is not simply water.
5. When your teacher says to begin, transfer three dropperfuls of your solution to your clean test tube. Then replace the lid on the dropper bottle and do not reopen it until Part B of this investigation.
6. Select one person to be your partner. Let one partner pour the contents of his or her test tube into the other partner's test tube. Then pour half the solution back into the first test tube. You and your partner now share pathogens of any possible transmittable disease that either of you might have had. Record the name of your first partner (Round 1) in your data table in your lab report.
7. For Round 2, wait for your teacher's signal, and then find a different partner and exchange solutions in the same manner as you did in step 6. Record the name of your second partner (Round 2) in your lab report. Do not exchange solutions with the same person more than once. Repeat this procedure again for Round 3.
8. After all rounds are finished, your instructor will ask you to add one dropperful of indophenol indicator to your test tube to see if the fluids in your test tube have become infected. Infected solutions will be colorless or light pink. All uninfected solutions will appear blue. Record the outcome of your tests in your lab report.

TABLE A *LIST OF PARTNERS' NAMES*

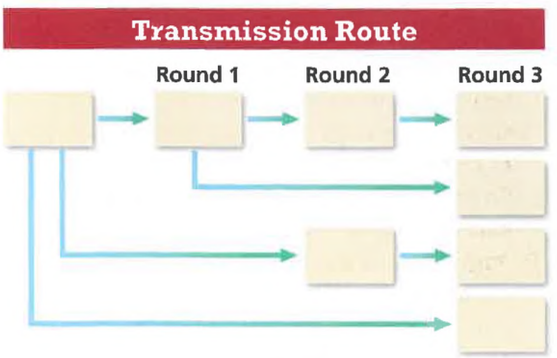
Round number	Partner's name
1	
2	
3	

TABLE B *PATH OF DISEASE TRANSMISSION*

Name of infected person	Names of infected person's partners		
	Round 1	Round 2	Round 3

PART B Tracing the Source of the Disease

9. If you are an infected person, give your name to your teacher. As names of infected people are written on the chalkboard or on the overhead projector, record them in your lab report in a table similar to Table B shown above.
10. Try to trace the original source of the infection, then determine the transmission route of the disease. In your table, cross out the names of all the uninfected partners in Rounds 1, 2, and 3. There should be only two people in Round 1 who were infected. One of these people was the original carrier.
11. Draw a diagram that shows the transmission route of the disease through all three rounds. Your diagram may look something like the chart below. Include your diagram in your lab report.



12. In your diagram, insert the names of the two people in Round 1 who were infected and the names of their partners in Rounds 2 and 3.
13. To test whether a person was the original disease carrier, pour a sample from his or her dropper bottle into a clean test tube and add indophenol indicator.
14. Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

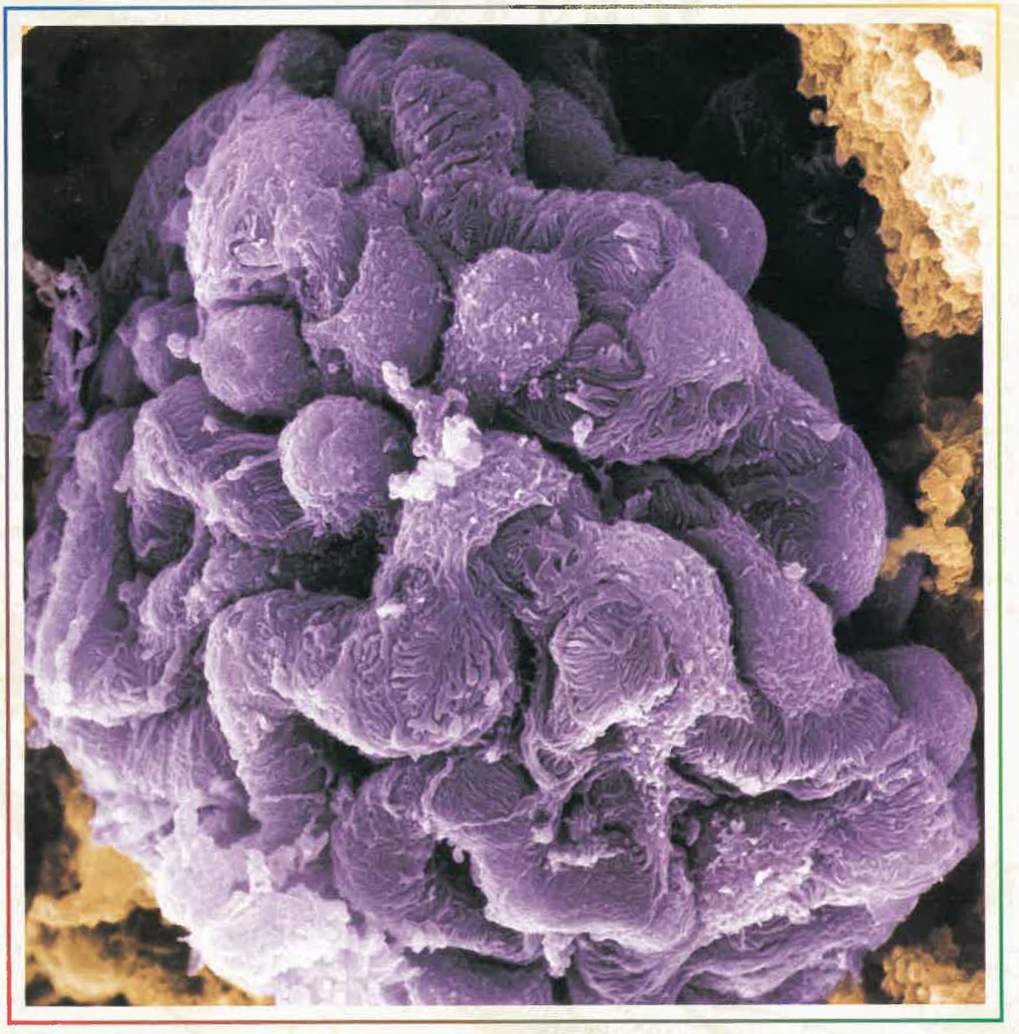
1. What might the clear fluid in each student's dropper bottle represent?
2. Does the simulated disease have any apparent symptoms?
3. What chemical is added to the test tubes when the rounds are completed?
4. What color indicates a positive result?
5. What color indicates a negative result?
6. Who was the original disease carrier?
7. After the three rounds, how many students were infected? Express this as a percentage of the number of students in the class.
8. If an epidemic occurred in your community, how might public-health officials work to stop the spread of the disease?

Further Inquiry

A public-health official is sent to investigate an outbreak of a new disease. Devise an experiment to allow the official to determine whether the disease has been caused by the passing of pathogens from person to person or by environmental conditions.

CHAPTER 49

DIGESTIVE AND EXCRETORY SYSTEMS



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

FOCUS CONCEPT: *Structure and Function*

As you read, notice how the structure of each digestive and excretory organ relates to its function.

NUTRIENTS

Carrots, fish, eggs, hamburgers, blackberries, cow's milk—the human body is able to convert each of these foods into nutrients that body cells need to function, grow, and replicate. In this section you will learn what nutrients the human body needs and how it uses those nutrients to carry out life processes.

SECTION 49-1

OBJECTIVES

- List the four organic nutrients needed by the human body.
- Identify foods containing each of the organic nutrients.
- Explain the importance of inorganic mineral nutrients.
- Summarize the functions that the six nutrients perform in the body.
- Explain why water is a vital nutrient.

SIX BASIC FOOD INGREDIENTS

All of the different foods in the world contain at least one of six basic ingredients: carbohydrates, proteins, lipids, vitamins, minerals, and water. These ingredients, called **nutrients,** are the chemical substances necessary for organisms to grow and function properly. Four of these nutrients—carbohydrates, proteins, fats, and vitamins—are organic compounds because they contain the elements carbon, hydrogen, and oxygen. The two remaining nutrients—minerals and water—are inorganic compounds.

Few foods contain all six nutrients. In fact, most foods contain a concentration of just one or two. Nutritionists classify foods into four groups—meat, milk, fruits and vegetables, and breads and cereals—based on nutrient similarity.

Carbohydrates

Carbohydrates are organic compounds composed of carbon, hydrogen, and oxygen in a ratio of about two hydrogen atoms to one oxygen atom and one carbon atom. Carbohydrates are broken down in aerobic respiration to provide most of the body's energy. Although proteins and fats also supply energy, the body most easily uses the energy provided by carbohydrates. Carbohydrates contain sugars that are quickly converted into the usable energy ATP, while proteins and fats must go through many chemical processes before the body can obtain energy from them.

The fructose and glucose (also known as dextrose) in fruit and honey are simple sugars, or monosaccharides. These sugars can be absorbed directly into the bloodstream and made available to cells for use in aerobic respiration. Sucrose (cane sugar), maltose, and lactose (milk sugar) are disaccharides. Disaccharides are sugars that consist of two chemically linked monosaccharides. These disaccharides must be converted into monosaccharides before they can be used by the body for energy. Disaccharides are split into two

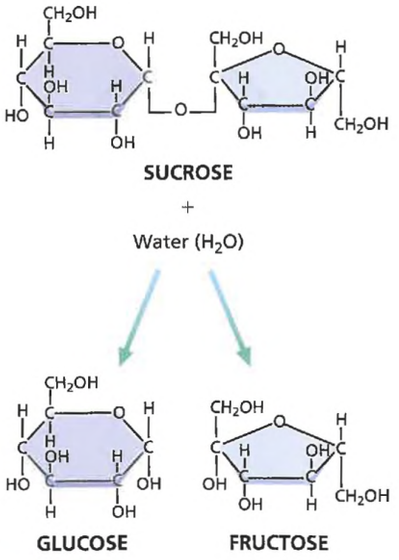


FIGURE 49-1

The hydrolysis, or digestion, of a disaccharide, such as sucrose, requires water and an enzyme. When sucrose is digested, two monosaccharides are formed—glucose and fructose. These monosaccharides are then transported through cell membranes to be used by cells.

monosaccharides in a process called hydrolysis. Figure 49-1 shows how sucrose is hydrolyzed to produce glucose and fructose.

The carbohydrates that require the longest digestion time are polysaccharides. Polysaccharides are complex molecules that consist of many monosaccharides bonded together. The starch found in rice, corn, and many other grains and vegetables is a polysaccharide made up of long chains of glucose molecules. During digestion, the body chemically breaks down these long chains into individual glucose units, which then can be absorbed by the blood and carried to the tissues.

Many foods we get from plants contain cellulose, a polysaccharide that the body cannot break down into individual component sugars. Cellulose, the substance that forms the walls of plant cells, is nevertheless an extremely important part of the human diet. Although indigestible, it provides fiber that aids in human digestion. Cellulose stimulates contractions of the smooth muscles that line the organs of the digestive system. These contractions help move the food along.

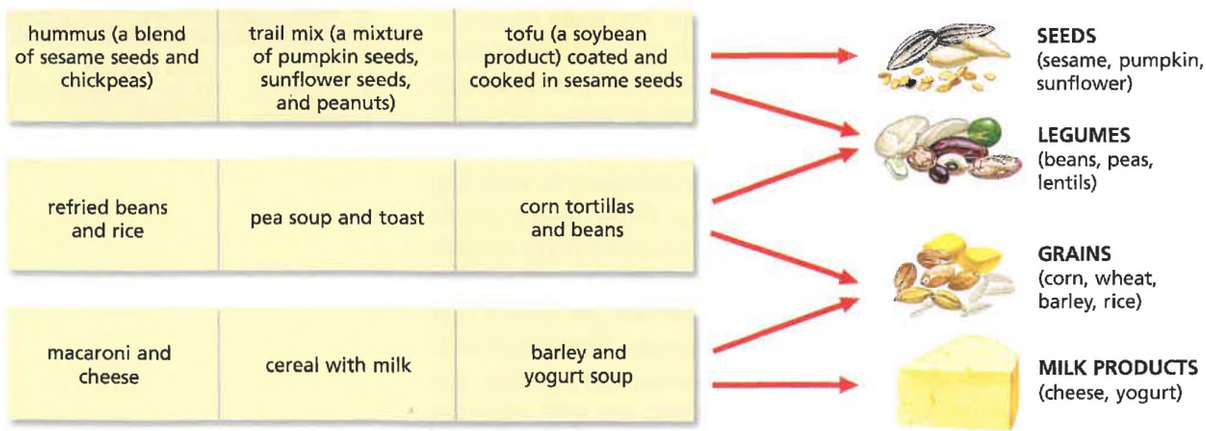
Proteins

Proteins are the major structural and functional material of body cells. Proteins from food help the body to grow and to repair tissues. Proteins consist of long chains of amino acids. The human body uses about 20 kinds of amino acids to construct the proteins it needs. The body manufactures many of these amino acids, but it cannot produce all of them in the quantities that it needs. Amino acids that the body produces are called nonessential amino acids because you do not have to get them from your food. Amino acids that must be obtained from food are called essential amino acids. Ten amino acids are essential to children and teenagers, while only eight are essential to adults. The two additional amino acids needed by children are involved in growth.

Most of the foods we get from plants do not contain all the essential amino acids. Eating certain combinations of two or more plant products, such as those shown in Figure 49-2, can supply all the essential amino acids. Vegetarians who do not eat animal

FIGURE 49-2

The combination of legumes with seeds or grains and the combination of grains with milk products furnish all the essential amino acids.



products get their proteins by eating combinations of two or more plant products or by combining seeds or grains with legumes. Most animal products, such as eggs, milk, fish, poultry, and beef, contain all the essential amino acids.

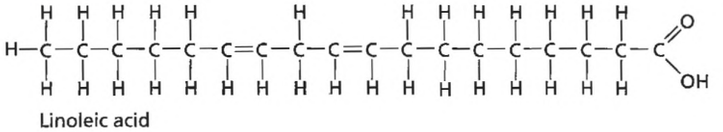
Lipids

Lipids are organic compounds that contain more carbon and hydrogen atoms than oxygen atoms. Lipids include triglycerides, commonly known as fats. Fats are organic molecules that the body uses to obtain energy and to build cell membranes and other cell parts. The body stores excess fat from the diet in special tissues under the skin and around the kidneys and liver. Excess carbohydrates may be converted to fat for storage.

Why does the human body store fat? The answer is that stored fats are beneficial unless they are excessive. A light layer of body fat beneath the skin provides insulation in cold weather. Fat surrounding vulnerable organs, such as the kidneys and liver, acts as protective padding. And most important, fat reserves are a source of energy. While you cannot live off just your body fat, the body can use its fat for energy, especially when carbohydrates are unavailable.

To use fats, the body must first break down each fat molecule into glycerol and fatty acids. The glycerol molecule is the same in all fats, but the fatty acids differ in both structure and composition. The body converts some fatty acids to other fatty acids, depending on which one the body needs at the time.

Scientists classify fats as saturated or unsaturated, based on structural differences in their fatty acids. A saturated fatty acid has all its carbon atoms connected by single bonds and thus contains as many hydrogen atoms as possible. An unsaturated fatty acid has at least one double bond between carbon atoms. If there are two or more double bonds, the fatty acid is called polyunsaturated. How many double bonds are shown in the structure of a fatty acid in Figure 49-3? In general, animal fats are saturated and plant oils are unsaturated. However, some vegetable oils, such as palm oil and coconut oil, are composed primarily of saturated fats.



Linoleic acid

FIGURE 49-3

The structure of linoleic acid, a fatty acid in margarine, is shown in this figure. Is this fatty acid saturated, unsaturated, or polyunsaturated?

TABLE 49-1 *Food Sources of Vitamins*

Vitamins	Best sources	Essential for	Deficiency diseases and symptoms
Vitamin A (carotene; fat soluble)	fish-liver oils, liver and kidney, green and yellow vegetables, yellow fruit, tomatoes, butter, egg yolk	growth, health of the eyes, and functioning of the cells of the skin and mucous membranes	retarded growth, night blindness, susceptibility to infections, changes in skin, defective tooth formation
Vitamin B_1 (thiamin; water soluble)	meat, soybeans, milk, whole grains, legumes	growth; carbohydrate metabolism; functioning of the heart, nerves, muscles	beriberi—loss of appetite and weight, nerve disorders, and faulty digestion
Vitamin B_2 (riboflavin; water soluble)	meat, fowl, soybeans, milk, green vegetables, eggs, yeast	growth, health of the skin and mouth, carbohydrate metabolism, functioning of the eyes, red blood cell formation	retarded growth, dimness of vision, inflammation of the tongue, premature aging, intolerance to light
Vitamin B_3 (niacin; water soluble)	meat, fowl, fish, peanut butter, potatoes, whole grains, tomatoes, leafy vegetables	growth; carbohydrate metabolism; functioning of the stomach, intestines, and nervous system	pellagra—smoothness of the tongue, skin eruptions, digestive disturbances, and mental disorders
Vitamin B_6 (pyridoxine; water soluble)	whole grains, liver, fish	coenzymes for metabolic reactions	dermatitis, nervous disorders
Vitamin B_{12} (cyanocobalamin; water soluble)	green vegetables, liver	preventing pernicious anemia	a reduction in number of red blood cells
Vitamin C (ascorbic acid; water soluble)	fruit (especially citrus), tomatoes, leafy vegetables	growth, strength of the blood vessels, development of teeth, health of gums	scurvy—sore gums, hemorrhages around the bones, and tendency to bruise easily
Vitamin D (calciferol; fat soluble)	fish-liver oil, liver, fortified milk, eggs, irradiated foods	growth, calcium and phosphorus metabolism, bones and teeth	rickets—soft bones, poor development of teeth, and dental decay
Vitamin E (tocopherol; fat soluble)	wheat-germ oil, leafy vegetables, milk, butter	normal reproduction	anemia in newborns
Vitamin K (naphthoquinone; fat soluble)	green vegetables, soybean oil, tomatoes	normal clotting of the blood, liver functions	hemorrhages

Vitamins

Vitamins are complex organic molecules that serve as coenzymes. Vitamins activate the enzymes and help them function. For example, vitamin B_1, or thiamin, is essential to the functioning of two enzymes that catalyze the first step in aerobic respiration. Because vitamins generally cannot be synthesized by the body, a diet should include the proper daily amounts of all vitamins. Like enzymes, coenzymes can be reused many times. Thus only small quantities of vitamins are needed in the diet. Table 49-1 summarizes the sources of the vitamins and their functions.

Vitamins dissolve in either water or fat. The fat-soluble vitamins include vitamins A, D, E, and K. The water-soluble vitamins are vitamins C and the B vitamins. Fat-soluble vitamins are absorbed and stored like fats. As with fats, the body can amass a reserve of fat-soluble vitamins. Unpleasant physical symptoms and even death can result from storing too much or having too little of a particular vitamin. Continual large doses of vitamin A, for example, can result in severe nausea and a yellow skin color. Because the body cannot store water-soluble vitamins, it excretes surplus amounts in urine.

The only vitamin that the body can synthesize in large quantities is vitamin D. This synthesis involves the conversion of cholesterol to vitamin D by intestinal enzymes and sunlight. People who do not spend a lot of time in the sun can get their vitamin D from food. With the exception of vitamin D, human beings must obtain the vitamins they need from food sources and vitamin supplements.

Minerals

Minerals are inorganic substances required for the normal functioning of the body. Some minerals, such as calcium, magnesium, and iron, are drawn from the soil and become part of plants. Animals that feed on plants extract the minerals and incorporate them into their bodies. Table 49-2 lists the primary sources and functions of a few of the minerals considered most essential to human beings. Iron, for example, is necessary for the formation of red blood cells, while potassium maintains the body's acid-base balance and aids in growth. Both are found in certain fruits and vegetables; iron is also found in meats. Iodine—found in seafood, water, and iodized salt—is needed for hormone production by the thyroid gland. Minerals are excreted through the skin in perspiration and through the kidneys in urine.

TABLE 49-2 *Food Sources of Minerals*

Minerals	Source	Essential for
Calcium salts	milk, whole-grain cereals, vegetables, meats	deposition in bones and teeth; functioning of heart, muscles, and nerves
Iodine	seafoods, water, iodized salt	thyroid gland secretion
Iron salts	leafy vegetables, liver, meats, raisins, prunes	formation of red blood cells
Magnesium salts	vegetables	muscle and nerve action
Phosphorus salts	milk, whole-grain cereals, vegetables, meats	deposition in bones and teeth; formation of ATP and nucleic acid
Potassium salts	vegetables, citrus fruits, bananas, apricots	maintaining acid-base balance; growth; nerve action
Sodium salts	table salt, vegetables	blood and other body tissues; nerve action

TABLE 49-3 Sources of Water Balance in Humans

Source of water	Water gain (mL/day)	Water loss (mL/day)
Ingested in liquid	1,500 (60%)	
Ingested in food	750 (30%)	
Derived from metabolism	250 (10%)	
Evaporation		900 (36%)
Urine		1,500 (60%)
Feces		100 (4%)
Total gain	2,500 (100%)	
Total loss		2,500 (100%)

Water

Water accounts for over half of your body weight. Most of the reactions that maintain life can take place only in water. Water makes up over 90 percent of the fluid part of the blood, which carries essential nutrients to all parts of the body. It is also the medium in which waste products are dissolved and carried away from body tissues.

Water also helps regulate body temperature. It absorbs the heat released in cellular reactions and distributes the heat throughout the body. When the body needs to cool, perspiration—a water-based substance—evaporates from the skin, and heat is drawn away from the body.

Usually the water lost through your skin and kidneys is easily replaced by drinking water or consuming moist foods. If excess water is lost and not replenished, water moves from intercellular spaces to the blood by osmosis. Eventually, water will be drawn from the cells themselves. As a cell loses water, the cytoplasm becomes more concentrated until, finally, the cell can no longer function. This condition is referred to as **dehydration.** Humans can die if they lose as much as 12 percent of their body water. Table 49-3 summarizes sources of water gain and loss for the average person in the United States. The statistics vary according to the person's location and level of activity.

SECTION 49-1 REVIEW

1. Differentiate between organic nutrients and inorganic nutrients.
2. What are the primary functions performed by proteins?
3. Describe three benefits of a normal distribution of body fat.
4. Explain why water is a vital nutrient.
5. Explain the function of indigestible cellulose in digestion.
6. **CRITICAL THINKING** What do you think the consequences might be of a diet of only water, brown rice, and fruits?

SECTION 49-2

DIGESTIVE SYSTEM

Before your body can use the nutrients in the food you consume, the nutrients must be broken down physically and chemically. This process of breaking down food into molecules the body can use is called ***digestion.***

OBJECTIVES

- List the major organs of the digestive system.
- Distinguish between mechanical digestion and chemical digestion.
- Relate the structure of each digestive organ to its function in mechanical digestion.
- Identify the source of each major digestive enzyme, and describe the function of the enzyme.
- Summarize the process of absorption in both the small and large intestine.

THE GASTROINTESTINAL TRACT

Digestion occurs in the **gastrointestinal tract,** or digestive tract, which begins at the mouth and winds through the body to the anus. The gastrointestinal tract, shown in Figure 49-4, is a long, winding tube that is divided into several distinct organs. These organs, such as the stomach and small intestine, carry out the digestive process. Located along the gastrointestinal tract are other organs that aid in digestion. These organs, such as the liver and pancreas, are not part of the gastrointestinal tract, but they deliver secretions into the tract through ducts. As you read, locate each of the structures of the digestive system in Figure 49-4.

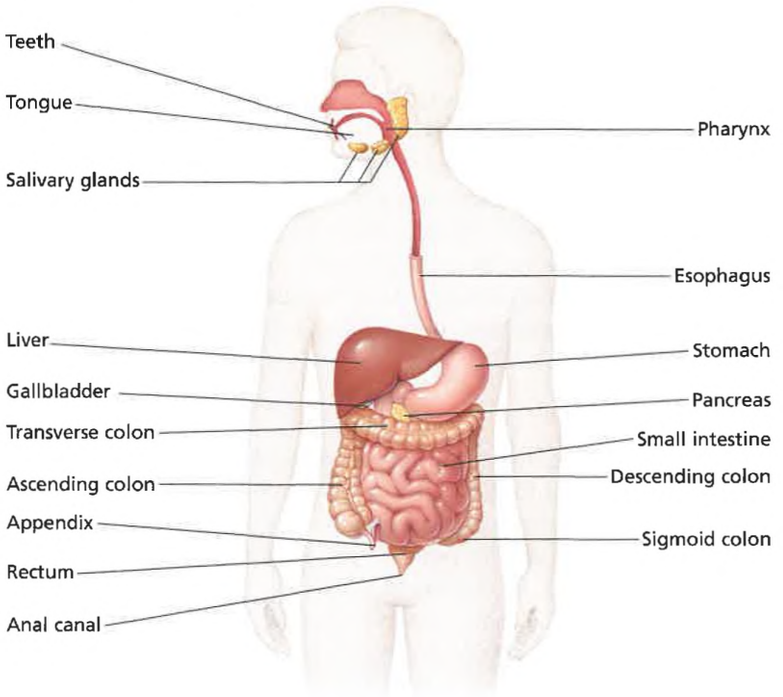
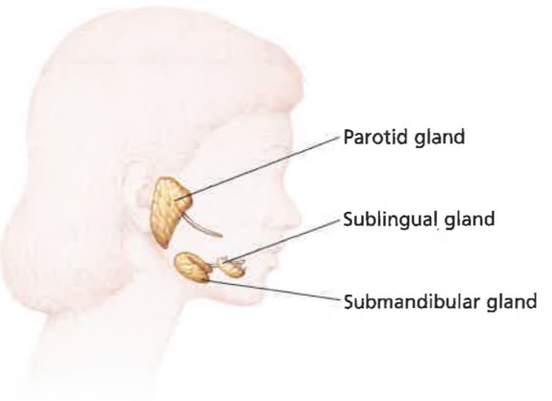


FIGURE 49-4
Notice that the gastrointestinal tract is basically a long tube with an opening at each end. Although food never passes through the liver and pancreas, these two organs are part of the digestive system because they secrete enzymes that break down food.

FIGURE 49-5
Saliva is produced by three sets of glands located near the mouth. The set closest to the ear is the target of the virus that causes mumps.



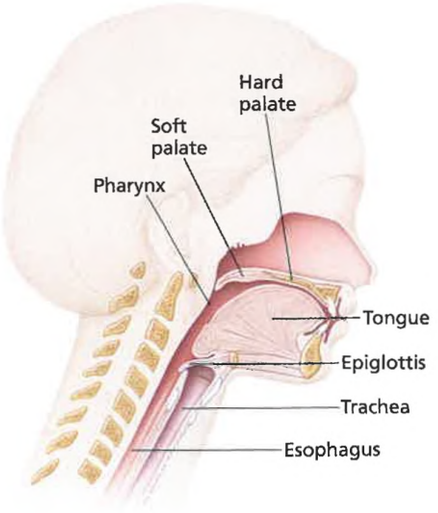
Mouth

When you take a bite of food, you begin the mechanical phase of digestion. In the mechanical phase, the body physically breaks down chunks of food into small particles. Mechanical digestion increases the surface area of food on which digestive enzymes can act. **Incisors**—sharp, flat front teeth—cut the food. Then the broad, flat surfaces of **molars,** or back teeth, grind it up. The tongue helps keep the food between the chewing surfaces of the upper and lower teeth by manipulating it against the **hard palate,** the bony, membrane-covered roof of the mouth. This structure is different from the **soft palate,** an area located just behind the hard palate. The soft palate is made of folded membranes and separates the mouth cavity from the nasal cavity.

While the mechanical phase of digestion is occurring, the chemical phase of digestion also takes place. Chemical digestion involves a change in the chemical nature of the nutrients. Preparations for chemical digestion begin even before the first bite of food is taken. The mouth starts to water—that is, the salivary glands increase their production of **saliva** (suh-LIE-vuh), a mixture of water, mucus, and a digestive enzyme called salivary amylase. Besides the many tiny salivary glands located in the lining of the mouth, there are three more pairs of larger salivary glands. Locate the three sets of salivary glands in Figure 49-5.

The mucus in the saliva softens and lubricates food and helps hold the food together. The salivary amylase begins the chemical digestion of carbohydrates by breaking down some starch into the disaccharide maltose.

FIGURE 49-6
The pharynx is the only passage shared by the digestive and respiratory systems. Notice how the epiglottis can close off the trachea so that food can pass only down the esophagus.



Esophagus

After food has been thoroughly chewed, moistened, and rolled into a **bolus,** or ball, it is forced into the pharynx by swallowing action. The pharynx, an open area that begins at the back of the mouth, serves as a passageway for both air and food. As Figure 49-6 shows, during swallowing, a flap of tissue called the **epiglottis** (ep-uh-GLAHT-is) prevents food from entering the trachea, or windpipe. Instead, the bolus passes into the esophagus, a muscular tube approximately 25 cm long that connects the pharynx with the stomach. The esophagus has two muscle layers: a circular layer that wraps

around the esophagus and a longitudinal layer that runs the length of the tube. As you can see in Figure 49-7, alternating contractions of these muscle layers push the bolus through the esophagus and into the stomach. This series of rhythmic muscular contractions and relaxations is called **peristalsis.**

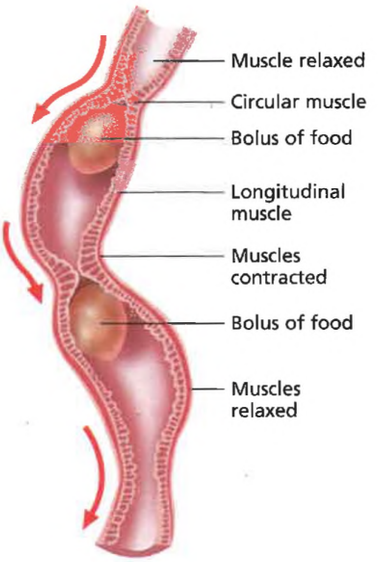


FIGURE 49-7
Peristalsis is so efficient at moving materials down the esophagus that you can drink while standing on your head. The smooth muscles move the water "up" the esophagus, against the force of gravity.

Stomach

The **stomach,** an organ involved in both mechanical and chemical digestion, is located in the upper left side of the abdominal cavity, just below the diaphragm. It is an elastic bag that is J-shaped when full and that lies in folds when empty. You have probably heard your stomach "growl" when it has been empty for some time. These sounds are made by the contraction of smooth muscles that line the stomach.

The walls of the stomach have several layers of smooth muscle. As you can see in Figure 49-8, there are three layers of muscle—a circular layer, a longitudinal layer, and a diagonal layer. Together, these muscles twist and turn the stomach. When nothing is present in the stomach, the growling sound is the result. When food is present, the muscles churn the contents of the stomach. This churning helps the stomach carry out mechanical digestion.

The inner lining of the stomach is a thick, wrinkled mucous membrane composed of epithelial cells. This membrane is dotted with small openings called gastric pits. **Gastric pits,** which are shown in Figure 49-9, are the open ends of gastric glands that release secretions into the stomach. Some of these glands secrete mucus, some secrete digestive enzymes, and still others secrete hydrochloric acid. The mixture of these secretions forms the acidic digestive fluid.

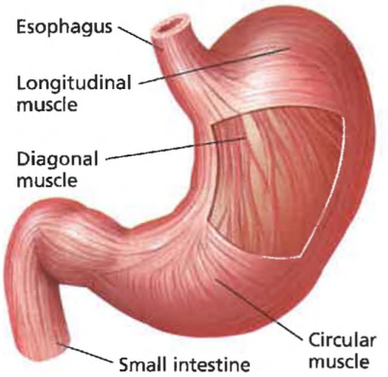


FIGURE 49-8
Each of the muscle layers of the stomach is oriented in a different direction. This allows the stomach to twist and turn in a variety of ways to thoroughly mix food.

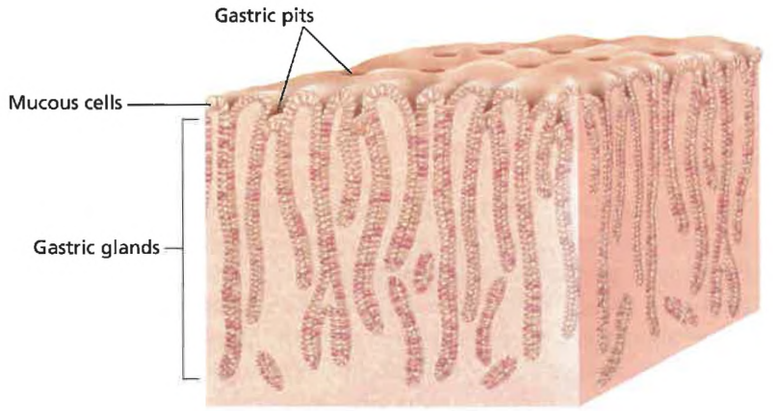


FIGURE 49-9
Because of the hydrochloric acid that the gastric glands secrete, the pH of the stomach is normally between 1.5 and 2.5, making it by far the most acidic environment in the body. Mucous cells lining the stomach wall protect the organ from damage.

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CHEMICAL DIGESTION

Gastric fluid carries out chemical digestion in the stomach. An inactive stomach secretion called pepsinogen is converted into a digestive enzyme called **pepsin** at a low pH. Chemical digestion starts in the stomach when pepsin splits complex protein molecules into shorter chains of amino acids called peptides. The presence of hydrochloric acid in the stomach not only ensures the low pH needed for the pepsinogen to transform into pepsin, but also dissolves minerals and kills bacteria that enter the stomach along with food.

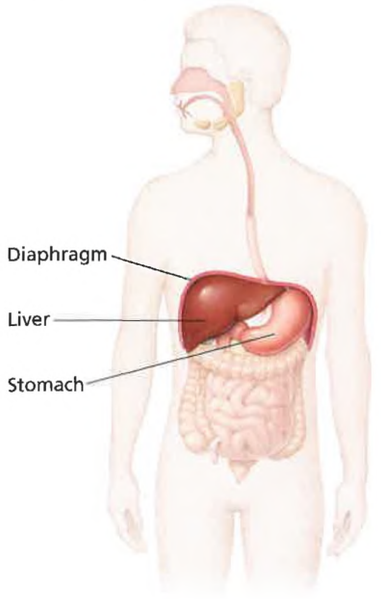
The mucus secreted in the stomach is vital to the survival of this organ. Mucus forms a coating that protects the lining from hydrochloric acid and prevents pepsin from digesting the proteins that make up the stomach tissue. In some people, the mucous coating of the stomach tissue breaks down, allowing digestive enzymes to eat through part of the stomach lining. The lesion, or sore, that results is called an **ulcer.** Scientists have recently discovered that the breakdown of the mucous layer is often caused by bacteria. These bacteria secrete toxins that destroy the epithelial cells that form the mucous layer.

Formation of Chyme

The **cardiac sphincter** (SFINK-tuhr) is a circular muscle located between the esophagus and the stomach. Food enters the stomach when the cardiac sphincter opens. After the food enters the stomach, the cardiac sphincter closes to prevent the food from reentering the esophagus. Food usually remains in the stomach for three to four hours. During this time, muscle contractions in the stomach churn the contents, breaking up food particles and mixing them with gastric fluid. This process forms a mixture called **chyme** (KIEM), a pastelike substance containing various nutrients. Chyme usually contains fats, sugars, starches, vitamins, minerals, peptides, and proteins that were not broken down by the pepsin.

Peristalsis forces chyme out of the stomach and into the small intestine. The **pyloric** (pie-LOR-ik) **sphincter,** a circular muscle between the stomach and the small intestine, regulates the flow of chyme. Each time the pyloric sphincter opens, about 5 to 15 mL (about 0.2 to 0.5 oz) of chyme moves into the small intestine, where it mixes with secretions from the liver and pancreas.

FIGURE 49-10
The liver is the body's largest internal organ, weighing about 1.5 kg (3 lb). If a small portion is surgically removed because of disease or injury, the liver regenerates the missing section.



Liver

The **liver** is a large organ located to the right of the stomach and in the upper right area of the abdominal cavity, just below the diaphragm, as shown in Figure 49-10. The liver performs numerous functions in the body, including storing glycogen and breaking down toxic substances, such as alcohol. The liver also secretes bile, which is vital in the digestion of fats. Though it is not a digestive enzyme, bile breaks fat globules into small droplets, forming a

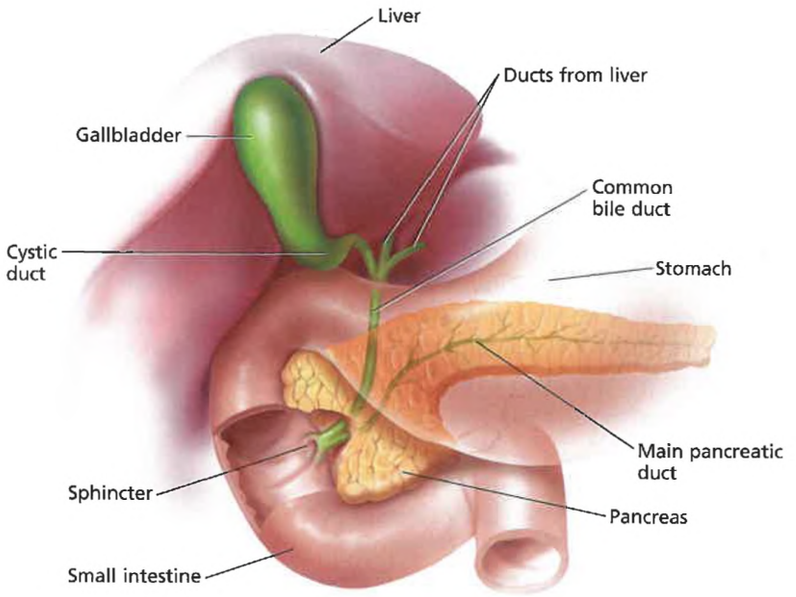


FIGURE 49-11
Cholesterol deposits known as gallstones can form in the ducts leading from the liver and gallbladder to the small intestine. If the gallstones interfere with the flow of bile, they must be removed, along with the gallbladder in most cases.

milky fluid in which fats are suspended. This process exposes a greater surface area of fats to the action of digestive enzymes and prevents small fat droplets from rejoining into large globules.

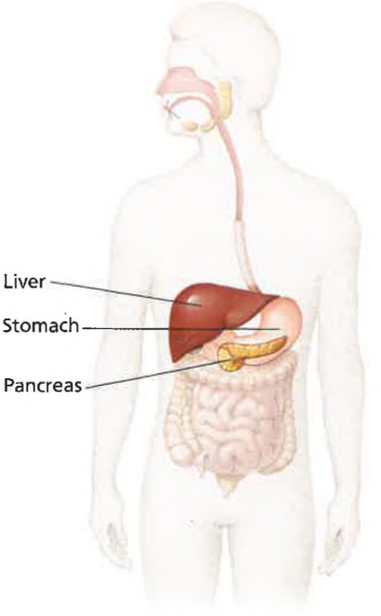
The bile secreted by the liver passes through a Y-shaped duct, as shown in Figure 49-11. The bile travels down one branch of the Y, the hepatic duct, and then up the other branch, the cystic duct, to the **gallbladder,** a saclike organ that stores and concentrates bile. When chyme is present in the small intestine, the gallbladder releases bile through the common bile duct into the small intestine.

Pancreas

As you can see in Figure 49-12, the pancreas is an organ that lies behind the stomach, against the back wall of the abdominal cavity. As part of the digestive system, the pancreas secretes pancreatic fluid, which contains digestive enzymes that help complete the breakdown of nutrients in the chyme. This pancreatic fluid enters the small intestine through the pancreatic duct, which joins the common bile duct just before it enters the intestine.

Pancreatic fluid contains sodium bicarbonate, which changes the pH of the chyme from an acid to a base. Many enzymes in the pancreatic fluid are activated by the higher pH. These enzymes hydrolyze disaccharides into monosaccharides, fats into fatty acids and glycerol, and proteins into amino acids.

FIGURE 49-12
Most of the pancreas looks like the salivary glands of the mouth region. Like the salivary glands, the pancreas secretes amylases to digest carbohydrates. Other digestive enzymes are secreted by the pancreas to break down nutrients in the chyme.



Small Intestine

If you could stretch the small intestine to its full length, you would find that it is nearly 7 m (about 21 ft) long. The duodenum, the first section of this coiled tube, makes up only the first 25 cm (about

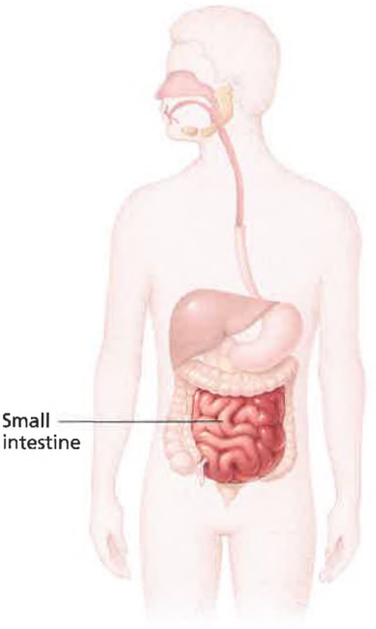


FIGURE 49-13
Although the small intestine is nearly 7 m long, only the first 25 cm is involved in digesting food. The rest is involved in the absorption of the digested products, including monosaccharides, amino acids, glycerol, and fatty acids.

10 in.) of that length. The **jejunum** (jee-JOO-nuhm), the middle section, is about 2.5 m (about 8 ft) long. The ileum, which makes up the remaining portion of the small intestine, is approximately 4 m (about 13 ft) in length. As you can see in Figure 49-13, the entire length of the small intestine lies coiled in the abdominal cavity.

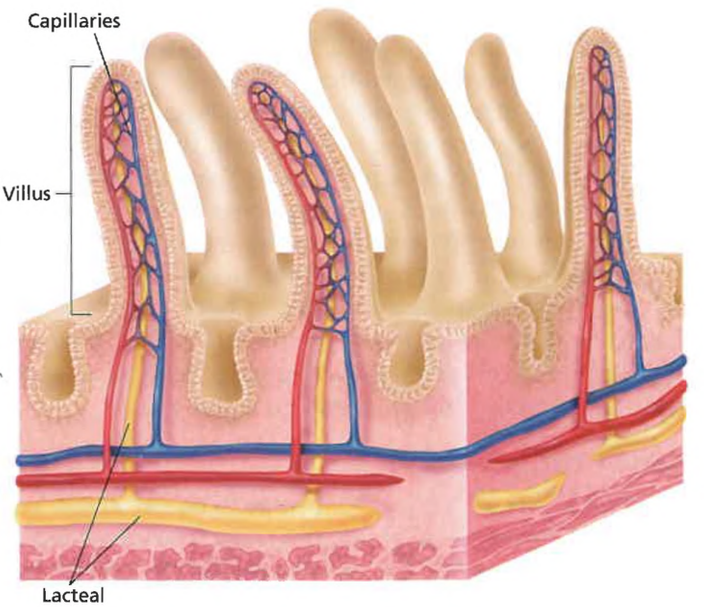
The secretions from the liver and pancreas enter the duodenum, where they continue the chemical digestion of chyme. When the secretions from the liver and pancreas, along with the chyme, enter the duodenum, they trigger intestinal mucous glands to release large quantities of mucus. This mucus protects the intestinal wall from protein-digesting enzymes and the acidic chyme. Glands in the mucous lining of the small intestine release enzymes that complete digestion by breaking down peptides into amino acids, disaccharides into monosaccharides, and fats into glycerol and fatty acids.

Absorption

The end products of digestion—amino acids, monosaccharides, glycerol, and fatty acids—are absorbed into the circulatory system through blood and lymph vessels in the lining of the small intestine. The structure of this lining provides a huge surface area for absorption to take place. In **absorption,** the end products of digestion are transferred into the circulatory system. The highly folded lining of the small intestine is covered with millions of fingerlike projections called **villi,** which are shown in Figure 49-14. The cells covering the villi, in turn, have extensions on their cell membranes called **microvilli.** The folds, villi, and microvilli give the small intestine a surface area of about 250 m^2 (about 2,685 ft^2), or roughly the area of a tennis court. Nutrients are absorbed through this surface by means of diffusion and active transport.

Inside each of the villi are capillaries and tiny lymph vessels called **lacteals** (lak-TEE-uhls). Locate the lacteals in Figure 49-14.

FIGURE 49-14
Villi, as shown in the SEM (137×) and the diagram, expand the surface area of the small intestine to allow greater absorption of nutrients.



Glycerol and fatty acids enter the lacteals, which carry them through the lymph vessels and eventually to the bloodstream through lymphatic vessels near the heart. Amino acids and monosaccharides enter the capillaries and are carried to the liver. The liver neutralizes many toxic substances in the blood and removes excess glucose, converting it to glycogen for storage. The filtered blood then carries the nutrients to all parts of the body.

LARGE INTESTINE

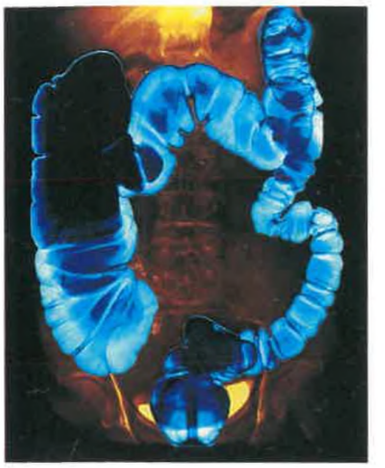
After absorption in the small intestine is complete, peristalsis moves the remaining material on to the large intestine. The **large intestine,** or **colon,** is the final organ of digestion. Study Figure 49-15 to identify the four major parts of the colon: ascending colon, transverse colon, descending colon, and sigmoid colon. The sigmoid colon leads into the very short, final portions of the large intestine called the rectum and the anal canal.

Most of the absorption of nutrients and water is completed in the small intestine. About 9 L (about 9.5 qt) of water enters the small intestine daily, but only 0.5 L (about 0.53 qt) of water is present in the material that enters the large intestine. In the large intestine, only minerals and vitamins produced by bacteria that live in the colon, as well as most of the remainder of the water, are absorbed. Slow contractions move the material in the large intestine toward the rectum. Distension of the colon initiates reflex contractions which move the material out of the body. As this matter moves through the intestine, the absorption of water solidifies the mass. The solidified material is called **feces.**

As the fecal matter solidifies, cells lining the large intestine secrete mucus to lubricate the intestinal wall. This lubrication makes the passing of the feces less abrasive. Mucus also binds together the fecal matter, which is then eliminated through the anus.

FIGURE 49-15

This X ray shows the large intestine, or colon. Identify the four major regions of the colon in the X ray.



SECTION 49-2 REVIEW

1. Describe the gastrointestinal tract.
2. Name one structure involved in the mechanical phase of digestion, and explain its function in mechanical digestion.
3. Trace the route of bile, noting where it is produced, where it is stored, and how it functions in digestion.
4. Explain how the structure of the small intestine is related to the function of absorption.
5. Compare the process of chemical digestion with the process of mechanical digestion, and list the organs involved in each.
6. **CRITICAL THINKING** Which of the six basic nutrients might a person need to restrict after an operation to remove the gallbladder? Explain your answer.

Literature & Life

Food Poisoning

The following excerpt is from "Family Reunion," a chapter in *Eleven Blue Men and Other Narratives of Medical Detection,* by Berton Roueché, published in 1954.

Botulism is a true but atypical form of food poisoning. Its methodical approach, its excessive lethality, and the predominantly neural cast of its clinical features all are unpleasantly peculiar. Even its history is unusual. Ordinary food poisoning, in common with many other ailments, is probably as old as mankind. Its beginnings go back to the first butcher with an infected finger, the first cook with a streptococcic cough, the first imprudent assumption of the first man rash enough to eat mushrooms.

Botulism is of far less fundamental origin. It is, in fact, one of the very few diseases for whose existence man has nobody to blame but himself. Like carbon-monoxide poisoning, and alcoholism, and the bends, botulism is essentially, if inadvertently, a product of human ingenuity. *Clostridium botulinum,* though plethorically abundant throughout the world, is not among man's natural antagonists. The organism is incapable of establishing itself in any living plant or animal. Its home is soil and earthy dust, its food is inanimate matter, and although it is able to exist in a dormant, sporal state almost indefinitely in almost any environment, it can mature and multiply and manufacture its vigorous venom only in the total absence of oxygen. Because of these physiological quirks, the toxin of *Clostridium botulinum,* under normal conditions, is safely out of human reach. It is dissipated deep in the earth.

Exactly when botulism seized its first victim is unknown, but it could hardly have been more than eight or ten thousand years ago, when man ceased to subsist exclusively on fresh food. Freshly gathered food, along with everything else on the face of the earth, is exposed to the intrusion of dust-borne botulinus spores, but it is also exposed to the spore-stunting sweep of air. Botulism came into being when man made the otherwise triumphant discovery that prompt deoxidation would make numerous foods more or less permanently resistant to decay.

Reading for Meaning

How is botulism a result of human ingenuity?

Interpret the writer's meaning when he says that *Clostridium botulinum* is "plethorically abundant."

In the last paragraph, this excerpt explains how the botulism toxin first came into contact with humans. Explain what the writer means by "prompt deoxidation" of food.

Read Further

In an article more recent than this one, what new information might be included about how current methods of food handling help prevent food poisoning?

Use your school library or an online database to investigate infant botulism. How does infant botulism relate to sudden infant death syndrome (SIDS)?

SECTION 49-3

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

- Define the term *excretion,* and list the functions of each of the major excretory organs.
- Identify the major parts of the kidney.
- Relate the structure of a nephron to its function.
- Explain how the processes of filtration, reabsorption, and tubular secretion help maintain homeostasis.
- Name the main parts of the urinary system.

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 kidneys, bean-shaped excretory organs each about the size of a clenched fist. The kidneys are located in the small of the back, one behind the stomach and the other behind the liver. Together they regulate the chemical composition of the blood.

Structure

Figure 49-16 shows the three main parts of the kidney. The **cortex,** the outermost portion of the kidney, makes up about a third of the

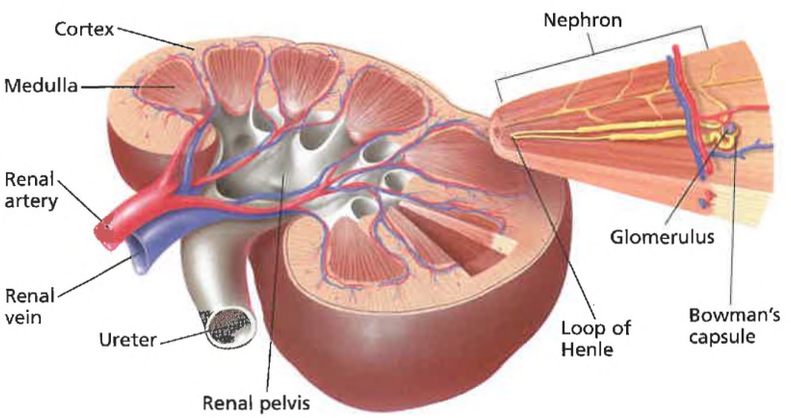


FIGURE 49-16
The outer region of the kidney, the cortex, contains structures that filter blood brought by the renal artery. The inner region, or medulla, consists of structures that carry urine, which empties into the funnel-shaped renal pelvis. The renal vein transports the filtered blood back to the heart.

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kidney's tissue mass. The **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 49-16 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.

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-rahns), the functional units of the kidney.

Take a close look at the structure of the nephron, shown in Figure 49-17. 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 49-17.

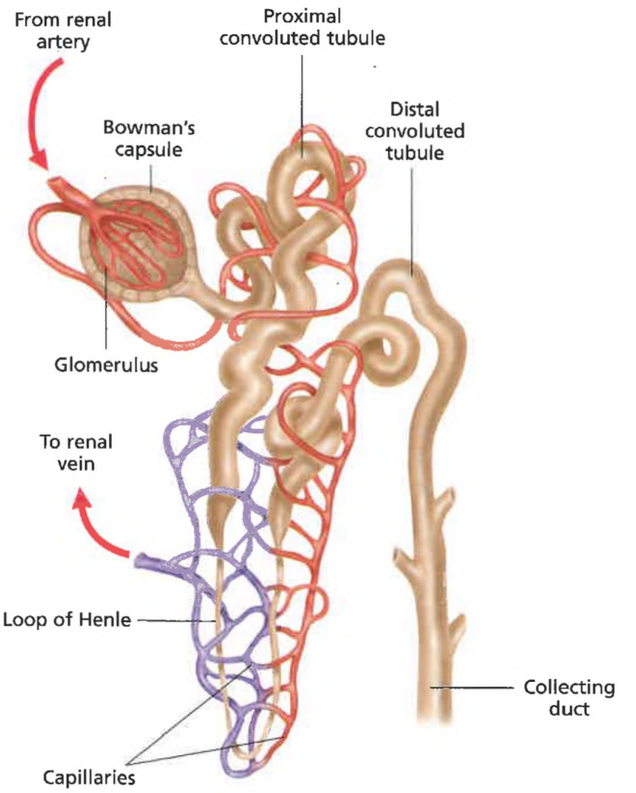


FIGURE 49-17
Notice the close association between a nephron of the kidney and capillaries of the circulatory system. Initially, fluid passes from the glomerulus, which is made of a capillary network, into a Bowman's capsule of the nephron. As the fluid travels through the nephron, nutrients that passed into the Bowman's capsule are removed and returned to the bloodstream. All that normally remains in the nephron are waste products, which form the urine that passes out of the kidney.

Each nephron has a cup-shaped structure, called a **Bowman's capsule,** that encloses a bed of capillaries. This capillary bed, called a **glomerulus** (glo-MER-yoo-luhs), receives blood from the renal artery. High pressure forces fluids 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,** a long tube with permeable walls. The renal tubule 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 that wraps around these three parts of the renal tubule. 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 49-18 shows the site of each of these processes in the nephron.

Word Roots and Origins

glomerulus

from the French *glomérule,* meaning "a compact cluster"

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.

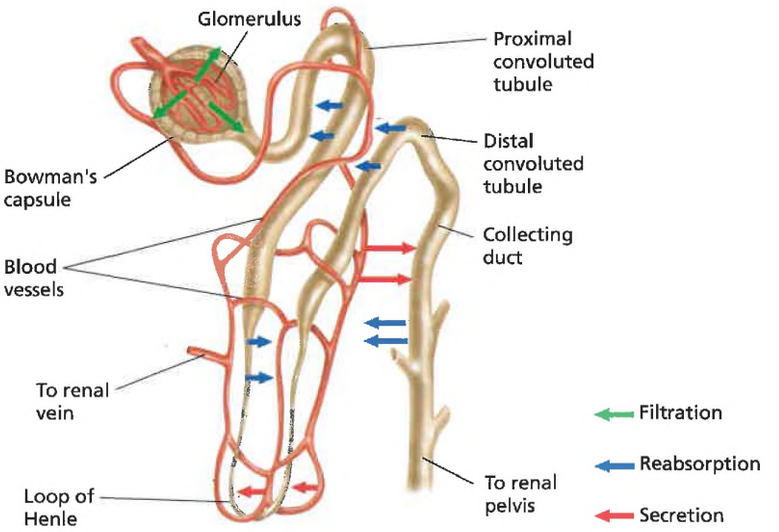


FIGURE 49-18
Color-coded arrows indicate where in the nephron filtration, reabsorption, and secretion occur.

Eco Connection

Kidneys and Pollution

According to 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 eliminate 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.

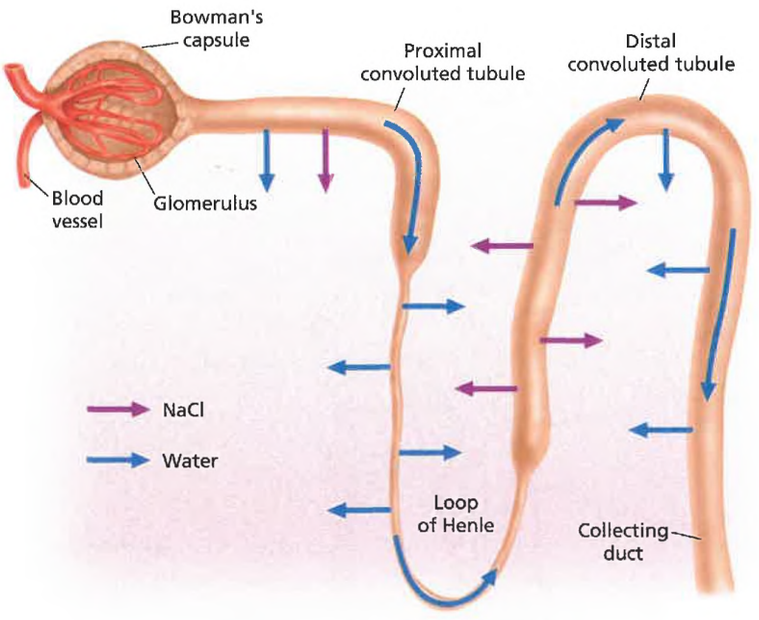
Reabsorption and Secretion

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 entering 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 49-19 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.



FORMATION OF URINE

FIGURE 49-19
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. Notice in Figure 49-19 that cells in the wall of the loop actively transport negatively charged 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 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 49-20.

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.

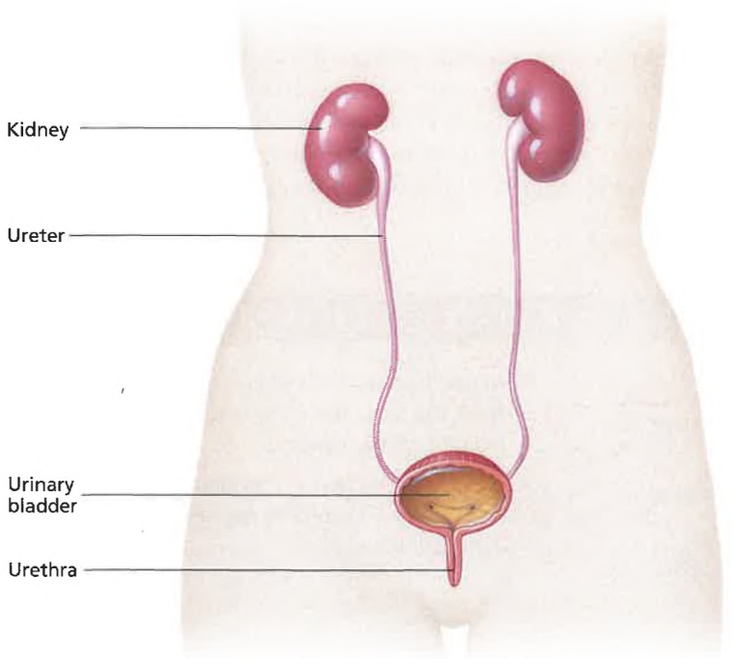


FIGURE 49-20
Urine trickles from each kidney through a ureter to the urinary bladder, where it is stored until it is eliminated from the body through the urethra.

Quick Lab

Analyzing Kidney Filtration

Materials disposable gloves, lab apron, and 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?

TABLE 49-4 *Waste Substances and Excretion Sites*

Substance excreted	Excreting organ(s)
Nitrogenous waste	kidneys, skin (a small amount in sweat)
Water	kidneys, skin, lungs
Salts	kidneys, skin (in sweat)
Carbon dioxide	lungs
Spices	lungs, kidneys

The Excretory System

The kidneys are the primary organs of the excretory system. They play a vital role in maintaining the homeostasis of body fluids. While kidney failure is an immediate, life-threatening situation, there are other organs that are involved in the excretion of metabolic waste.

As you know, 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 strong spices. These strong spices are frequently detectable on a person's breath.

While the kidneys control the salt composition of the blood, some salt is excreted through perspiration. A person working in extreme heat may lose water through perspiration at the rate of 1 L per hour. This loss of water represents a loss of about 10 to 30 g of salt per day.

Table 49-4 summarizes some waste substances and the organ(s) that excrete them. Notice that undigested food is not in the table of substances excreted by the body. 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* is correctly used only to indicate those substances that must pass through a membrane to leave the body.

SECTION 49-3 REVIEW

1. Define and describe *excretion.*
2. Explain the function of an organ other than the kidney that is involved in excretion.
3. Name and describe each structure of the renal tubule.
4. Contrast the function of filtration with the function of reabsorption.
5. Given the definition of excretion, why do you think the large intestine is not classified as a major excretory organ?
6. **CRITICAL THINKING** Explain why a high concentration of protein in the urine may indicate damaged kidneys.

CHAPTER 49 REVIEW

SUMMARY/VOCABULARY

49-1

- The human body needs six nutrients—carbohydrates, proteins, lipids, vitamins, minerals, and water—to grow and function.
- Carbohydrates provide most of the body's energy. Monosaccharides are quickly processed by the body. Cellulose cannot be digested but is needed for fiber.
- Proteins help the body grow and repair tissues. Amino acids must be obtained from foods.
- Lipids are used to build cell membranes.
- Vitamins act as coenzymes. The body can synthesize vitamin D.
- Minerals are inorganic substances that are needed in small amounts.
- Water helps regulate body temperature and transports nutrients and wastes.

Vocabulary

dehydration (982) mineral (981) nutrient (977) vitamin (980)

49-2

- 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 carry out mechanical digestion. Chemical digestion of carbohydrates occurs in the mouth.
- The esophagus is a passageway through which food passes 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

absorption (988)
bolus (984)
cardiac sphincter (986)
chyme (986)
colon (989)
digestion (983)
epiglottis (984)
feces (989)
gallbladder (987)
gastric fluid (986)
gastric pit (985)
gastrointestinal tract (983)
hard palate (984)
incisor (984)
jejunum (988)
lacteal (988)
large intestine (989)
liver (986)
microvillus (988)
molar (984)
pepsin (986)
peristalsis (985)
pyloric sphincter (986)
saliva (984)
soft palate (984)
stomach (985)
ulcer (986)
villus (988)

49-3

- The kidneys are the main organs of the urinary system. Reabsorption and secretion occur in the proximal and distal convoluted tubules and the loop of Henle. Nutrients are removed from the nephron and returned to the blood. The filtrate is called urine.
- The urine passes through a ureter and is stored in the urinary bladder until it is eliminated through the urethra.

Vocabulary

ammonia (992)
Bowman's capsule (993)
cortex (991)
excretion (991)
filtration (993)
glomerulus (993)
loop of Henle (995)
medulla (992)
nephron (992)
reabsorption (994)
renal pelvis (992)
renal tubule (993)
secretion (994)
urea (992)
ureter (995)
urethra (995)
urinary bladder (995)
urine (992)

REVIEW

Vocabulary

For each set of terms below, choose the one that does not belong, and explain why it does not belong.

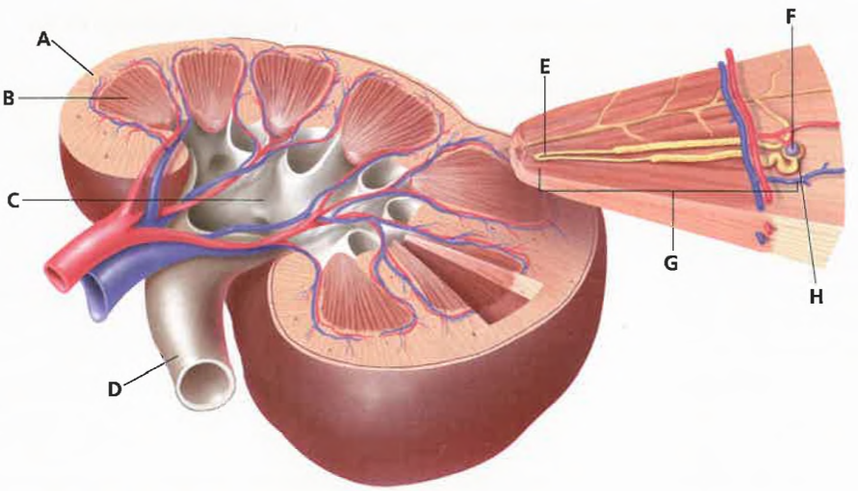
1. carbohydrate, protein, fat, mineral
2. pharynx, epiglottis, bolus, esophagus
3. cardiac sphincter, gastric pits, medulla, pyloric sphincter
4. absorption, filtration, secretion, reabsorption
5. nephron, ileum, glomerulus, renal tubule

Multiple Choice

6. The primary function of carbohydrates is to (a) break down molecules (b) aid in digestion (c) supply the body with energy (d) regulate the flow of chyme.
7. Cellulose (a) builds body tissue (b) is a monosaccharide (c) is used for energy (d) aids in digestion.
8. Proteins consist of (a) catalysts (b) enzymes (c) amino acids (d) polysaccharides.
9. The body needs vitamins because they (a) supply it with energy (b) serve as coenzymes (c) function as enzymes (d) act as hormones.
10. Dehydration is best prevented by (a) inhaling air (b) drinking water (c) not drinking water (d) perspiring.
11. The epiglottis is important because it (a) prevents food from going down the trachea (b) separates the pharynx from the nasal cavity (c) is the passage through which food travels to the stomach (d) regulates the flow of chyme.
12. The gallbladder (a) creates bile (b) stores urine (c) stores, concentrates, and secretes bile (d) is made up of nephrons.
13. During absorption, the lacteals absorb (a) glycogen (b) glycerol and fatty acids (c) amino acids and monosaccharides (d) lactose.
14. Organs involved in the excretion process include the (a) kidneys and stomach (b) liver and pancreas (c) nephron and glomerulus (d) kidneys and lungs.
15. During secretion in the kidney, substances move from (a) filtrate to blood (b) blood to blood (c) blood to filtrate (d) filtrate to filtrate.

Short Answer

16. Why can consuming a great deal of saturated fat be harmful?
17. Briefly explain the synthesis of vitamin D in the body.
18. What role does bile play in digestion?
19. In what two ways do the liver and pancreas differ from other digestive organs?
20. How is mechanical digestion carried out by the stomach?
21. Why does the body convert ammonia into urea?
22. Explain the difference between water-soluble and fat-soluble vitamins.
23. What processes occur in the nephron that maintain homeostasis?
24. List the structures of a nephron.
25. Examine the diagram of the kidney. Name each of the indicated structures.



CRITICAL THINKING

1. 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?
2. Some people cannot drink milk because they are unable to digest lactose, the sugar in milk. Doctors think this inability involves specific areas of the digestive system. What do you think these areas are?
3. Why is it important that the large intestine reabsorb water and not eliminate it?
4. When the kidneys stop functioning, urea builds up in the blood and poisons the body. A person with kidney failure will eventually die if the urea is not somehow removed. For the urea to be removed, the patient must be attached to an artificial kidney, also called a dialysis machine. Using your understanding of how a normal kidney functions, suggest a design for the major components of a dialysis machine.
5. A person has a small intestine that has villi but lacks microvilli. Would you expect this person to be underweight or overweight? Explain your answer.
6. The loop of Henle functions to conserve water by reabsorbing it. Its length varies among mammal species. Would you expect the loop of Henle of an animal like the beaver, which lives in a watery environment, to be longer or shorter than that found in humans? Explain your answer.
7. 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 the other animals shown here?

EXTENSION

1. Bring the label from a cereal box to class. Compare the "percent daily value" of vitamins and minerals on your label with those on labels brought in by other students.
2. Use the library and on-line sources for information about diets that claim to reduce the chances of a heart attack and cancer. Write a brief report summarizing a few of these articles.
3. Read "Fire in the Belly" in *Time*, April 26, 1999, on page 108. What is heartburn? What does heartburn have to do with the heart? What are the most common foods that cause heartburn?
4. Use library references to research kidney diseases and disorders. Write and illustrate a report focusing on the causes of these illnesses, their symptoms, and their treatment.
5. Look at your library's reference books that describe the cultures and customs of other nations. Find information relating to eating habits for at least five different countries. How do these customs differ from those in America? Investigate at least one nation or area where food is scarce. What are some of the causes and consequences of widespread food shortages?

CHAPTER 49 INVESTIGATION

Modeling Human Digestion

OBJECTIVES

- Test a model of digestion in the human stomach.

PROCESS SKILLS

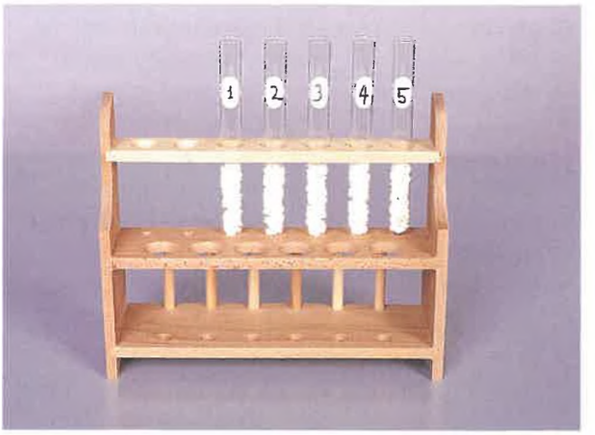
- modeling
- observing
- predicting
- inferring

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. Fill in the first column with the test-tube numbers. Under the heading "Contents," fill in a description of the contents of each test tube, as shown.
7. Predict 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

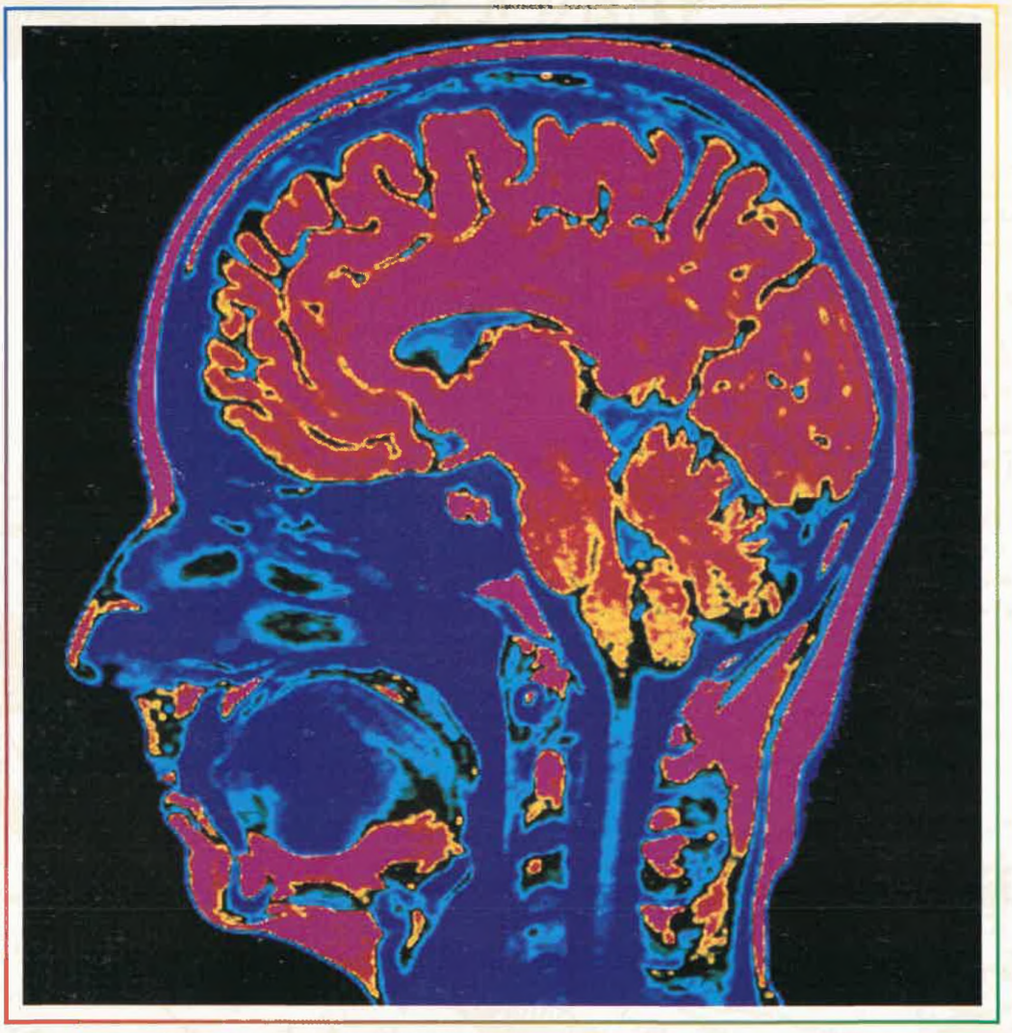
1. What conditions caused the greatest digestion of cooked egg white?
2. Which test tube best modeled the chemical composition in the human stomach?
3. What information do test tubes 1, 2, and 3 give you? What do they control?
4. Compare test tubes 4 and 5. What can you conclude about the effects of 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.

CHAPTER 50

NERVOUS SYSTEM AND SENSE ORGANS



This color-enhanced magnetic-resonance imaging (MRI) of the head shows a living brain and spinal cord in cross section.

FOCUS CONCEPT: ***Stability and Homeostasis***

As you read, notice how the nervous system functions to ensure that other body systems work together in an efficient and coordinated manner.

SECTION

50-1

CENTRAL NERVOUS SYSTEM

Mental and physical activity and many aspects of homeostasis are controlled by the ***nervous system,*** *a complex network of cells that communicate with one another. Within this communications network, a carefully organized division of labor exists so that each component of the nervous system operates effectively. As a result, a football player can weave through opposing tacklers, an architect can create an original design, and you can read and understand the words on this page.*

OBJECTIVES

- Identify the two main organs of the central nervous system.
- Summarize the functions of the cerebrum, brain stem, and cerebellum.
- Describe how the central nervous system is protected from injury.
- Describe the structure of the spinal cord.
- Distinguish between sensory receptors, motor neurons, and interneurons.

ORGANIZATION

The nervous system is composed of neurons, specialized cells that transmit information throughout the body. A neuron, such as the one shown in Figure 50-1, demonstrates the relationship between structure and function in living systems. The **axon,** a threadlike projection of the cell body, enables the neuron to transmit signals rapidly over relatively long distances in the body. Other structures projecting from the cell body allow the neuron to receive signals from other neurons. You will examine the structure and function of neurons more closely later in this chapter.

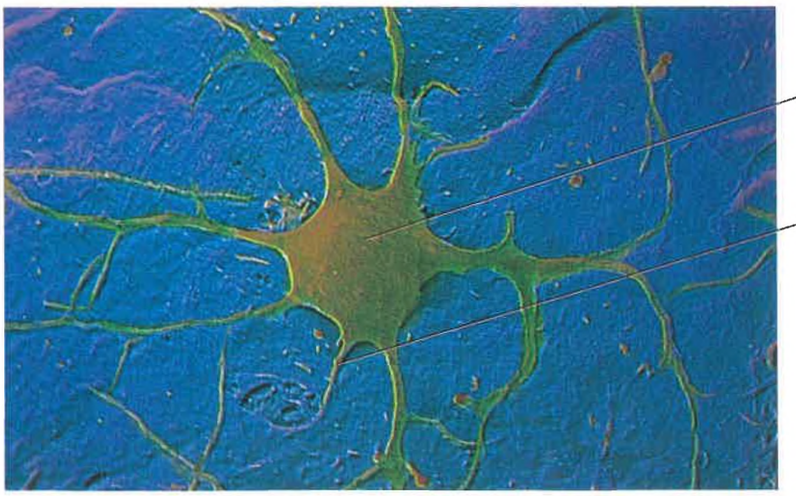


FIGURE 50-1
Neurons transmit information throughout the body in a combination of chemical and electrical signals. This stellate neuron is named for its starlike shape (SEM, 26,000×).

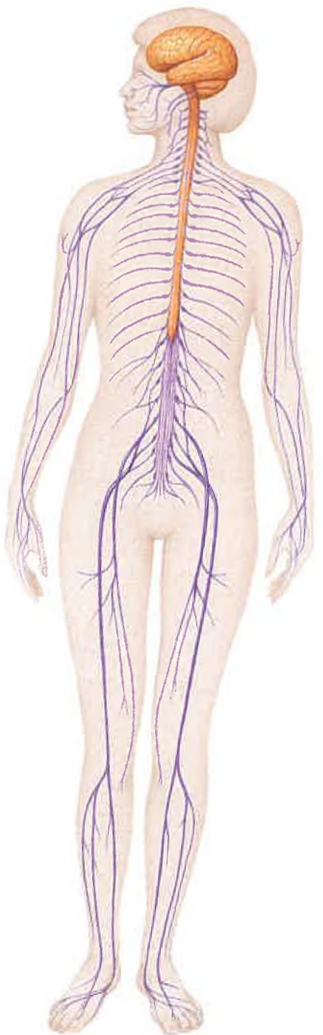


FIGURE 50-2

The central nervous system includes the brain and spinal cord, shown in orange. The peripheral nervous system, shown in violet, includes all other nervous tissue in the body.

The nervous system includes two major divisions: the central nervous system and the peripheral nervous system. The brain and spinal cord make up the **central nervous system,** shown in orange in Figure 50-2. The spinal cord carries messages from the body to the brain, where they are analyzed and interpreted. Response messages are then passed from the brain through the spinal cord and to the rest of the body.

The **peripheral nervous system,** shown in violet in Figure 50-2, consists of the neurons that are not included in the brain and spinal cord. Some peripheral neurons collect information from the body and transmit it *toward* the central nervous system. These are called **afferent neurons.** Other peripheral neurons transmit information *away* from the central nervous system. These are called **efferent neurons.**

BRAIN

The human brain is responsible for overseeing the daily operations of the human body and for interpreting the vast amount of information it receives. The adult human brain weighs an average of 1.4 kg, or about 2 percent of total body weight. Despite its relatively small mass, the brain contains approximately 100 billion neurons. Functioning as a unit, these neurons make up the most complex and highly organized structure on Earth. Because of the brain's complex nature, much remains to be learned about how it functions, but scientists have uncovered a good deal of information about the brain's many functions.

You may realize that the brain is responsible for many of the qualities that make each individual unique—thoughts, feelings, emotions, talents, memories, and the ability to process information. It is important to understand, however, that much of the brain is dedicated to running the body. For example, the brain is responsible for maintaining homeostasis by controlling and integrating the various systems that make up the body. Through painstaking trial-and-error study of the brain, scientists have established how and where various functions are localized in the brain.

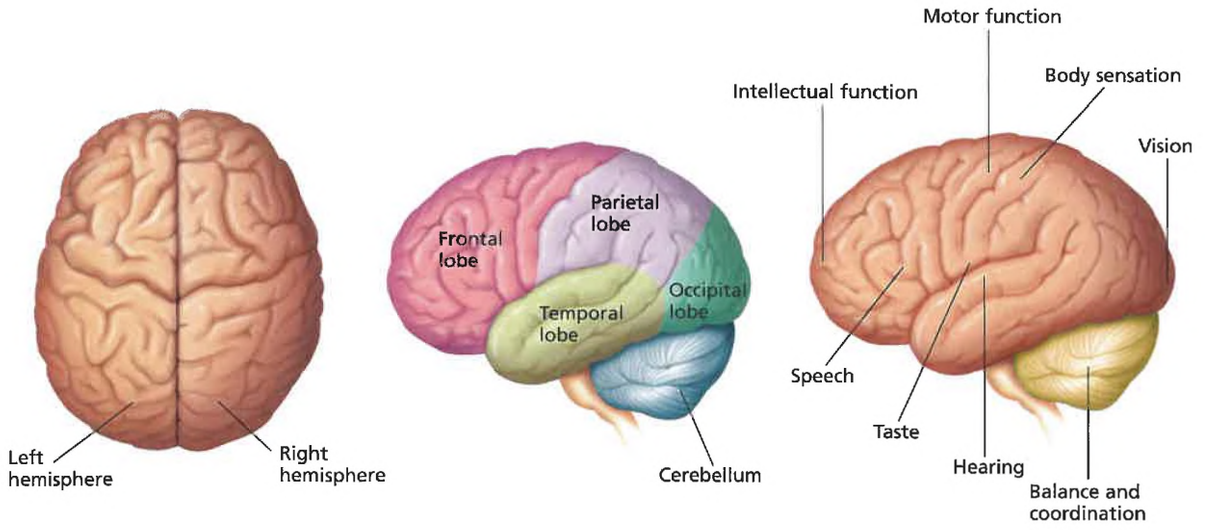
Cerebrum

The largest portion of the human brain consists of the cerebrum (SER-uh-bruhm). The **cerebrum,** which is easily identified by its highly folded outer layer, is composed of two **cerebral hemispheres,** as shown in Figure 50-3a. The cerebral hemispheres are connected by the **corpus callosum** (KOR-puhs kuh-LOH-suhm), a heavy band of the axons of many neurons. The corpus callosum lies deep in the central groove that separates the right hemisphere from the left hemisphere. Other deep grooves separate each hemisphere into four lobes: the frontal, parietal (puh-RIE-uh-tuhl), temporal, and occipital (ahk-SIP-i-tuhl) lobes, as shown in Figure 50-3b.

Word Roots and Origins

corpus callosum

from the Latin *corpus,* meaning "body," and *callosus,* meaning "thick and hard"



(a) TOP OF BRAIN

(b) LOBES OF THE LEFT HEMISPHERE

(c) LEFT HEMISPHERE FUNCTIONAL AREAS

FIGURE 50-3

(a) A view of the top of the brain shows the left and right cerebral hemispheres. (b) Each cerebral hemisphere of the brain has four lobes. (c) Control centers for various functions are located in different areas of the brain.

The folded outer layer of the cerebral hemispheres is called the **cerebral cortex.** In humans, the cerebral cortex is a sheet of neurons about 2 to 4 mm (0.75 to 1.5 in.) thick. Scientists estimate that it contains nearly 10 percent, or about 10 billion, of the brain's total number of neurons. The surface area of the cerebral cortex is too large to lie smoothly over the lower structure of the brain. The folds, or convolutions, accommodate the surface area of the cortex within the limits of the interior of the skull.

The cerebral cortex is very important in sensory processing and in motor responses. As shown in Figure 50-3c, separate areas of the cerebral cortex control auditory, visual, body sensation, and motor processing. For example, an area of the cortex in the occipital lobe, at the rear of the brain, is essential for processing visual information. The area of the cortex that interprets touch information from all parts of the body lies in a band across the top of the brain, in the parietal lobe. Some functions are not localized in a symmetrical way in the brain. In right-handed individuals, cortical areas and other brain centers involved in speech and language production are located primarily in the left hemisphere. Brain centers involved in processing spatial information and in certain kinds of reasoning are located primarily in the right hemisphere. In left-handers, there is some variation in the location of functions.

Below the wrinkled surface of the cerebral cortex lies the **white matter,** which is composed of the axons of cortical neurons. These axons link specific regions of the cortex with each other and with other neural centers. There is a great degree of crossover of axons in the spinal cord and brain. That is, many impulses originating in the right half of the body are processed in the left half of the brain, and vice versa.

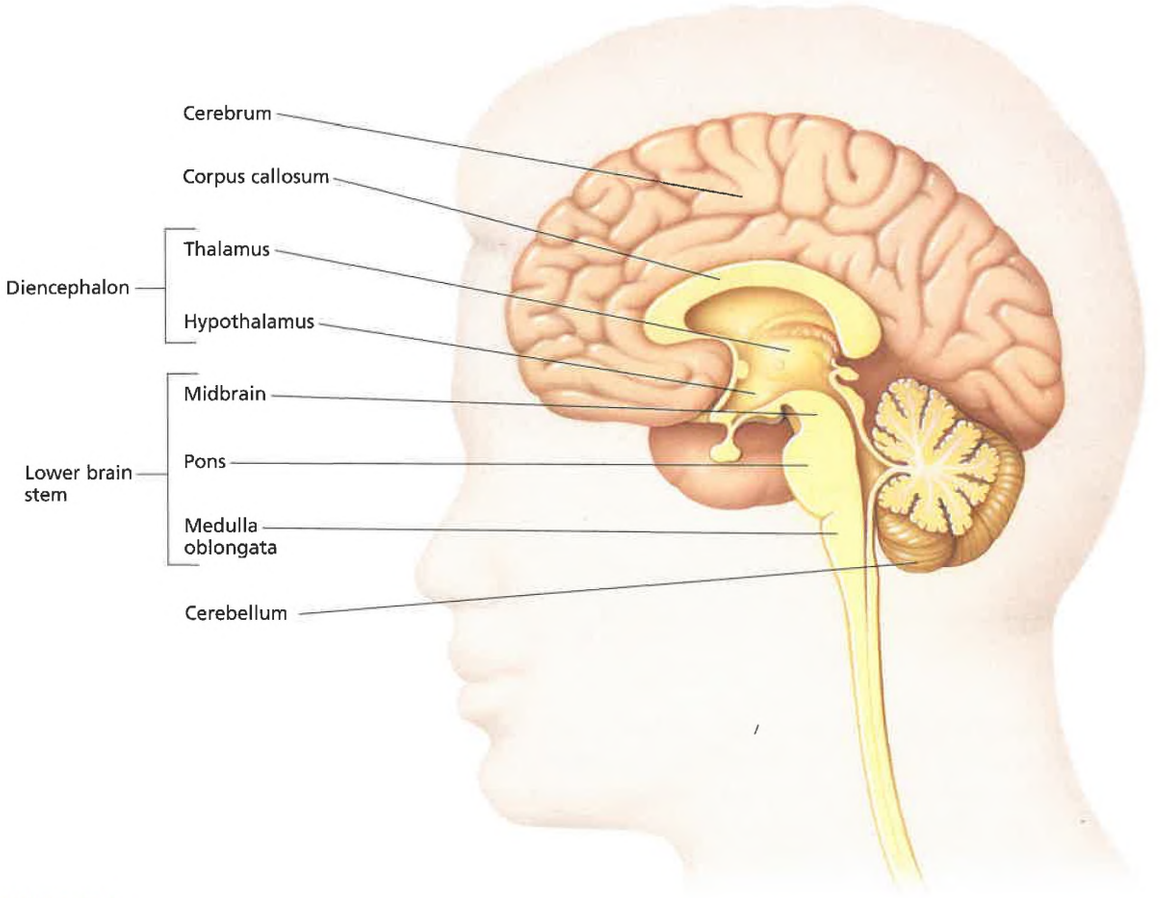


FIGURE 50-4

A side view through the center of the brain shows the right hemisphere. The wrinkled cerebral cortex is visible along the front, rear, and top of the brain, where it rolls into the deep groove separating the two hemispheres. The structures lying below the cerebrum are shown in cross section.

Upper Brain Stem—Diencephalon

Below the cerebrum, the **brain stem** links the cerebrum with the spinal cord. The upper part of the brain stem, the **diencephalon** (DIE-uhn-SEF-uh-lahn), contains important relay centers for information entering and exiting the brain. The upper relay center, the **thalamus** (THAL-uh-muhs), shown in Figure 50-4, directs most incoming sensory signals to the proper region of the cerebral cortex. The hypothalamus, located just below the thalamus, is linked to several other parts of the brain. The hypothalamus is very important in maintaining homeostasis, and it both directly and indirectly controls much of the body's hormone production.

Parts of the diencephalon and the cerebrum are included in an important group of connected brain centers called the **limbic system.** The limbic system includes the thalamus, the hypothalamus, some deeper parts of the cerebral cortex, and centers in the temporal lobes. The limbic system plays an important role in emotion, memory, and motivation, among other things. Scientists have tried to determine the functions of the different parts of the limbic system by observing problems associated with damage to its various regions. For example, people with damage to certain limbic areas may display inappropriate emotional responses, such as rage in response to a trivial, irritating stimulus.

Lower Brain Stem

Below the diencephalon, the brain stem narrows. This region of the brain stem has three main divisions: the midbrain, the pons, and the medulla oblongata.

The **midbrain** is an important relay center for visual and auditory information. The **pons** serves as a relay center between the neurons of the cerebral hemispheres and those of the cerebellum. The **medulla oblongata** (mi-DUHL-uh AHB-lahn-GAHT-uh) contains neurons that serve as both a relay center and a control center. Also within the medulla oblongata are centers that control various homeostatic activities, including heart rate and respiration rate.

Lying throughout the brain stem is a diffuse network of neurons called the **reticular formation.** The reticular formation helps to control respiration and circulation and serves as a filtering system for incoming sensory signals. The reticular formation separates signals that demand attention from those that are unimportant. Some of this function of the reticular formation is modified by learning. For example, a person can learn to sleep through the noise of a radio or television but awaken at the sound of a doorbell.

Cerebellum

Just below the occipital lobes of the cerebral hemispheres lies the **cerebellum** (SER-uh-BEL-uhm), a region of the brain that plays a vital role in the coordination of muscle action, particularly the timing of muscle contractions. As Figure 50-4 shows, the surface of the cerebellum is very highly folded, giving it a striated appearance. The cerebellum receives sensory impulses from muscles, tendons, joints, eyes, and ears, as well as input from other brain centers. It processes information about body position and controls posture by keeping skeletal muscles in a constant state of partial contraction. The cerebellum coordinates rapid and ongoing movements. It acts together with brain stem motor centers and with the section of cerebral cortex that is responsible for motor responses. Nerve impulses are sent down through the spinal cord and stimulate or inhibit the contraction of skeletal muscles.

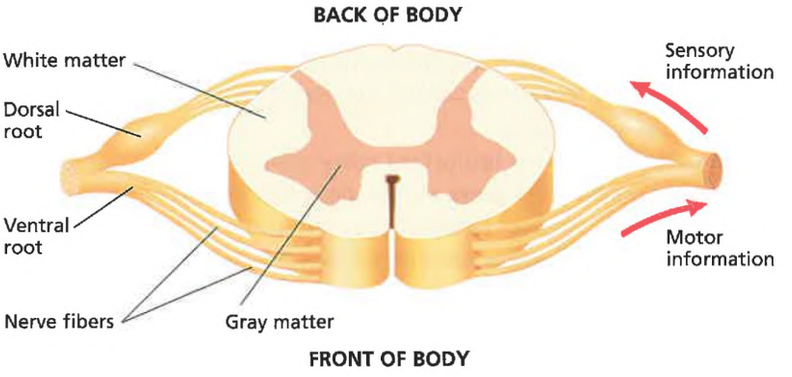
Protection

The delicate neurons of the brain and spinal cord are surrounded by three protective layers called the **meninges** (muh-NIN-JEEZ). The outer layer, the **dura mater** (DU-ruh MAYT-uhr), consists of connective tissue, blood vessels, and neurons. The middle layer, the **arachnoid** (uh-RAK-NOYD) **layer,** is elastic and weblike. The thin inner layer, the **pia mater** (PIE-uh MAYT-uhr), adheres to the brain and spinal cord and contains many blood vessels and neurons.

A clear liquid called **cerebrospinal** (SER-uh-BROH-SPIE-NUHL) **fluid** provides a cushion that protects the brain and spinal cord from injury. Cerebrospinal fluid separates the middle and inner meninges and fills four interconnected **ventricles,** or cavities, in the brain. Within the ventricles, cerebrospinal fluid acts as a transport medium for substances that are important to brain function.

FIGURE 50-5

The spinal cord, shown in cross section, carries information toward and away from the brain. Sensory information from the body enters the spinal cord through the dorsal roots. Instructions to the body's many motor neurons exit the spinal cord through the ventral roots.



Spinal Cord

The **spinal cord** is a column of nerve tissue that starts in the medulla oblongata and runs down through the vertebral column. The spinal cord is composed of an outer sheath of white matter. As it does in the brain, the white matter contains primarily the axons of neurons. The white matter surrounds a rigid inner core of gray matter, which is composed of the cell bodies of neurons.

Thirty-one pairs of spinal nerves, part of the peripheral nervous system, originate in the spinal cord and branch out to both sides of the body. Recall that neurons have long axons that enable them to transmit signals rapidly. When bundled together, these axons form a **nerve.** Each spinal nerve consists of a dorsal root and a ventral root. The dorsal roots, shown in Figure 50-5, contain neurons that carry signals to the central nervous system from various kinds of sensory receptor neurons. A **sensory receptor** is a neuron that is specialized to detect a stimulus, such as pressure or heat.

The ventral roots, also shown in Figure 50-5, contain the axons of **motor neurons,** which are neurons that contact and carry information to muscles and glands. Within the spinal cord and elsewhere in the body are **interneurons,** which are neurons that connect other neurons to each other.

SECTION 50-1 REVIEW

1. Name the two organs that make up the central nervous system.
2. How do the functions of the cerebral hemispheres, cerebellum, and brain stem differ?
3. Explain the difference between sensory receptors and motor neurons.
4. How are the brain and spinal cord protected from injury?
5. What are the gray matter and white matter in the spinal cord composed of?
6. **CRITICAL THINKING** Strokes result in the death of neurons in the brain. How can a doctor tell what areas of the brain have been affected in a person who has had a stroke?

SECTION 50-2

PERIPHERAL NERVOUS SYSTEM

The workings of your brain may be largely a mystery to you. You are undoubtedly more familiar with the workings of your peripheral nervous system. In the peripheral nervous system, 12 pairs of cranial nerves connect the brain with the head and neck and 31 pairs of spinal nerves connect the central nervous system with the rest of the body.

OBJECTIVES

- Name the two divisions of the peripheral nervous system and describe their function.
- Distinguish between the somatic nervous system and the autonomic nervous system.
- Distinguish between the sympathetic division and the parasympathetic division.
- Describe a spinal reflex.

SENSORY DIVISION

The **sensory division** of the peripheral nervous system is composed of sensory receptors and the interneurons that connect them to the central nervous system. Sensory receptors acquire information from the external and internal environments of the body. Spinal and cranial nerves enable the flow of sensory information to the central nervous system. You will learn more about the processing of sensory information in Section 50-4.

MOTOR DIVISION

The **motor division** of the peripheral nervous system allows the body to react to the sensory information. The motor division is composed of two independent systems—the somatic nervous system and the autonomic nervous system.

Somatic Nervous System

The **somatic nervous system** of the motor division consists of motor neurons that control the movement of skeletal muscles. The somatic system is said to be voluntary—that is, skeletal muscles can be moved at will. The somatic system can also operate automatically, as it does when you maintain your balance.

One important function of the peripheral nervous system is the relay of signals in **reflexes,** which are involuntary and often self-protective movements. The patellar reflex, which depends on one of the simplest neural circuits in the human body, is shown in Figure 50-6.

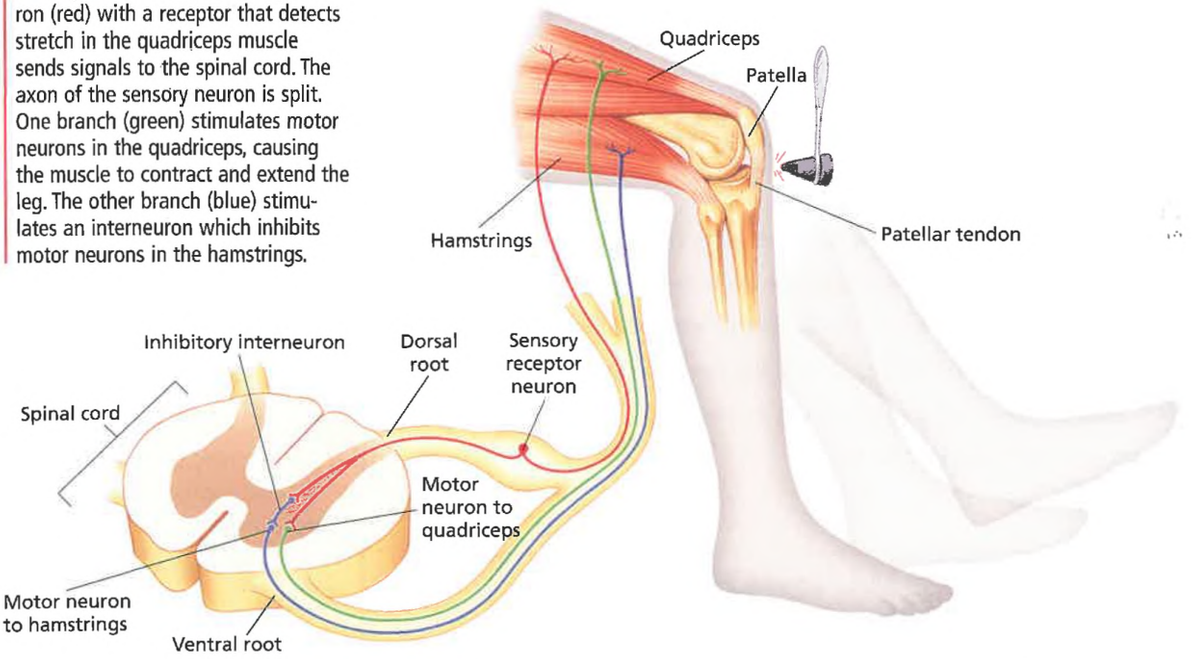
Word Roots and Origins

somatic

from the Greek *somatikos,* meaning "of the body"

FIGURE 50-6

In the patellar reflex, a sensory neuron (red) with a receptor that detects stretch in the quadriceps muscle sends signals to the spinal cord. The axon of the sensory neuron is split. One branch (green) stimulates motor neurons in the quadriceps, causing the muscle to contract and extend the leg. The other branch (blue) stimulates an interneuron which inhibits motor neurons in the hamstrings.



When the tendon below the patella is tapped sharply, a sensory receptor, shown in red, in the attached quadriceps muscle sends an impulse to the spinal cord. This impulse activates a motor neuron, shown in green, that leads back to the quadriceps muscle, causing the muscle to contract. The impulse also activates an interneuron, shown in blue, that has an inhibitory, or calming, effect on the motor neurons of the hamstrings in the lower thigh. The contraction of the quadriceps coupled with the relaxation of the hamstrings extends the lower leg. This type of reflex is a true **spinal reflex;** that is, it involves only neurons in the body and spinal cord, and completely bypasses the brain. Many of the body's involuntary actions, however, originate in a second subdivision of the motor division of the peripheral nervous system—the autonomic nervous system.

Autonomic Nervous System

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The **autonomic nervous system** of the motor division consists of nerves that control the body's internal conditions by affecting smooth muscles, both in blood vessels and in organs. The main function of the autonomic nervous system is the control of respiration, heartbeat, and other functions involved in homeostasis. Stimulation and inhibition of body systems are the responsibility of two different subdivisions of the autonomic system—the sympathetic division and the parasympathetic division—as shown in Figure 50-7.

A major function of the **sympathetic division** is the shunting of blood from one part of the body to another. The sympathetic division of the autonomic nervous system is activated by conditions

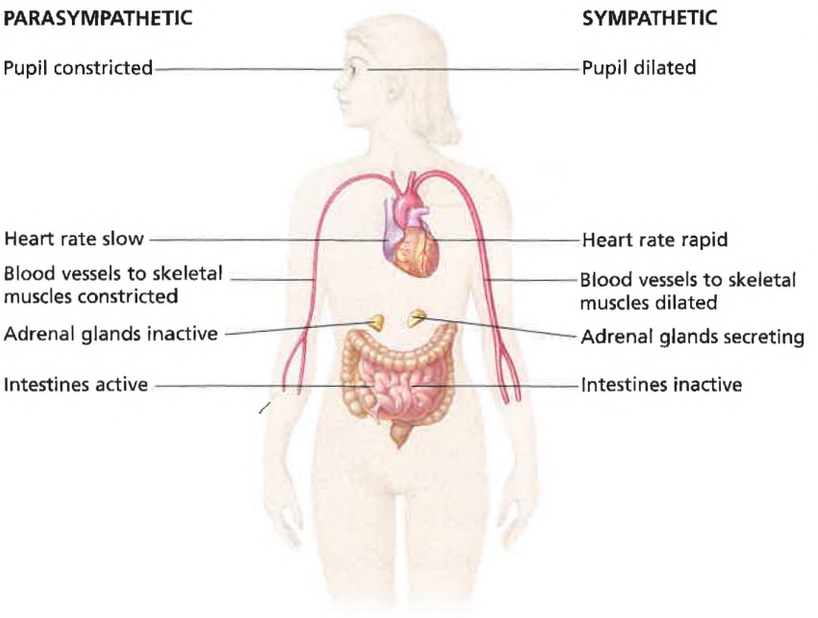


FIGURE 50-7

In the autonomic nervous system, the sympathetic division readies the body to respond to stress or danger. Activation of the parasympathetic division conserves energy and restores homeostasis.

of physical or emotional stress. For example, the threat of a physical attack would cause your sympathetic division to redirect the flow of blood away from your digestive organs and toward your heart and skeletal muscles. This is often called the "fight-or-flight" response. As Figure 50-7 shows, the sympathetic division stimulates activities that consume large amounts of energy.

The **parasympathetic division** of the autonomic nervous system controls the internal environment during routine conditions. After a threat of danger has passed, nerves from the parasympathetic division signal organs to revert to normal levels of activity. Blood flow to the heart and skeletal muscles is decreased and their function slows. The action of the parasympathetic division induces the body to conserve energy. Under normal conditions, both systems usually are activated to some degree. The balance of actions of the sympathetic division and the parasympathetic division of the autonomic nervous system help the body maintain homeostasis.

SECTION 50-2 REVIEW

1. **Name the two main divisions of the peripheral nervous system.**
2. **Name two types of neurons in the peripheral nervous system.**
3. **Name the parts of the nervous system that are involved in a spinal reflex.**
4. **How do the somatic nervous system and the autonomic nervous system differ?**
5. **Which division of the autonomic nervous system is involved in "fight-or-flight" reactions in response to danger?**
6. **CRITICAL THINKING Most organs in the body are stimulated by both the sympathetic division and the parasympathetic division of the autonomic nervous system. Explain how this helps maintain homeostasis.**

SECTION

50-3

OBJECTIVES

- Describe the structure of a neuron.
- Summarize the electrical and chemical conditions of resting potential.
- Describe the electrical and chemical changes that occur during an action potential.
- Describe the role of neurotransmitters in transmitting a signal across a synapse.

TRANSMISSION OF NERVE IMPULSES

The ability of the nervous system to monitor and respond to the environment, both external and internal, depends on the transmission of signals within a neuron and from one neuron to another. The transmission of a signal along the axon of a neuron is known as an ***action potential.*** *The transmission of action potentials depends on electrochemical energy—electrical energy that is generated as charged chemical substances move into and out of neurons.*

NEURON STRUCTURE

Figure 50-8 shows the morphology of a typical neuron. The nucleus of a neuron, along with most of its organelles, is located in the cell body. Extending out from the cell body in different directions are membrane-covered extensions called dendrites. **Dendrites** receive action potentials from other neurons. The axon is a long, membrane-bound projection that transmits the action potentials away from the cell body. A neuron may have a single axon or branching axons that contact several other neurons. The end of the axon is called the **axon terminal.** It may lie near a muscle, a gland, or the dendrite or cell body of another neuron.

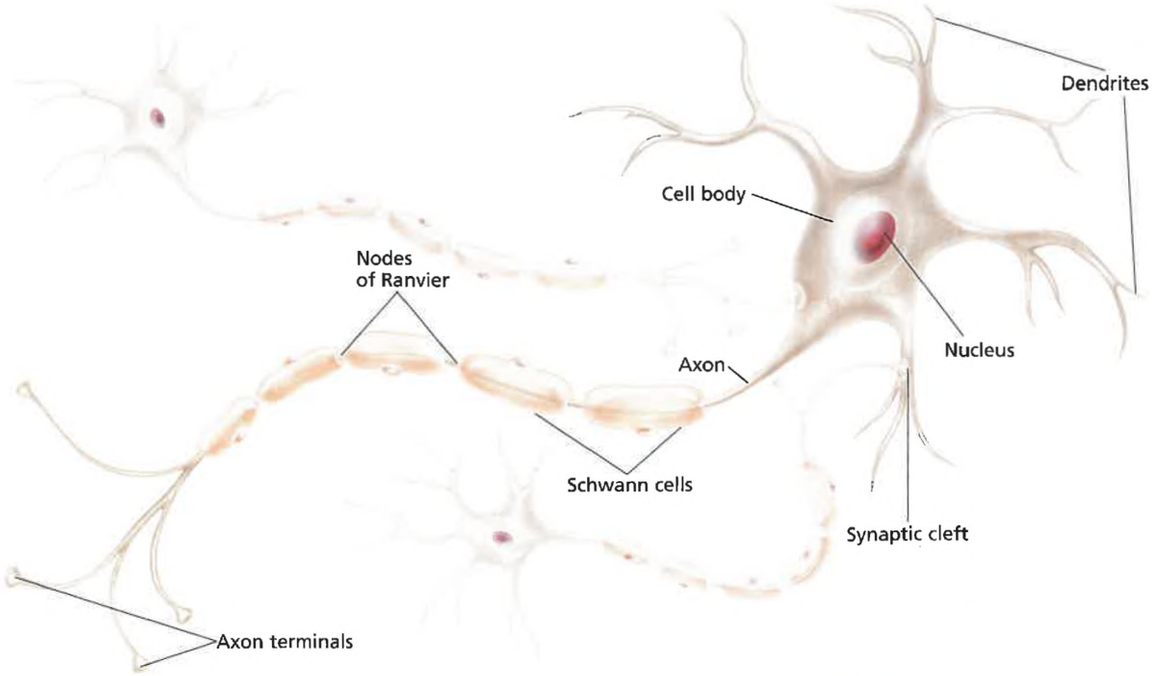
The axons of most neurons are covered with a lipid layer known as the **myelin** (MIE-uh-lin) **sheath.** The myelin sheath both insulates the axon much like the rubber coating of an electrical cord and speeds up transmission of action potentials through the axon. In the peripheral nervous system, myelin is produced by cells called **Schwann cells,** which surround the axon. Gaps in the myelin sheath along the length of the axon are known as the **nodes of Ranvier** (RAHN-vee-ay).

As Figure 50-8 shows, neurons do not touch each other. Instead a small gap, called a **synaptic cleft,** is present between the end of the axon of one neuron and the dendrite or cell body of another neuron. In most neurons, electrical activity in the neuron causes the release of chemicals into the synaptic cleft. These chemicals, called **neurotransmitters,** in turn elicit electrical activity in a second neuron. Thus, the signalling activity of the nervous system is composed of electrical activity *within* neurons and chemical flow

Word Roots and Origins

synapse

from the Greek *synaptein,* meaning "to fasten together"



between neurons. Neurons form numerous interconnections that in turn form circuits in the same way that telephone lines interconnect to form circuits. These neural circuits form complex networks throughout the body, just as telephone circuits form networks that extend throughout the world.

FIGURE 50-8

Neurons are separated from other neurons by small gaps. Some neurons have many other neurons contacting their multiple dendrites. A long axon, which carries action potentials, extends from the cell body of the neuron. Most axons are covered by a fatty insulating layer called the myelin sheath.

NEURON FUNCTION

Nearly 200 years ago, scientists discovered that when an electrical current is passed through a muscle removed from a dead animal, the muscle will contract just as it did in life. Scientists have learned that electricity stimulates neurons that affect muscle cells. Neuron function is dependent on electrical activity.

Neurons have an electrical charge different from the extracellular fluid that surrounds them. A difference in the electrical charge between two locations is called a **potential.** In neurons, potentials are produced by a complex interplay of several different ions. The movement of these ions is affected by their ability to pass through the cell membrane, their concentrations inside and outside of the cell, and their charge.

Resting Potential

A neuron is at rest when it is not receiving or transmitting a signal. In a neuron at rest, the concentration of large, negatively-charged proteins and potassium, K^+, ions is greater inside the cell than outside. In contrast, the concentration of sodium, Na^+, ions is greater outside the cell than inside. This imbalance of Na^+ and K^+ ions is, in

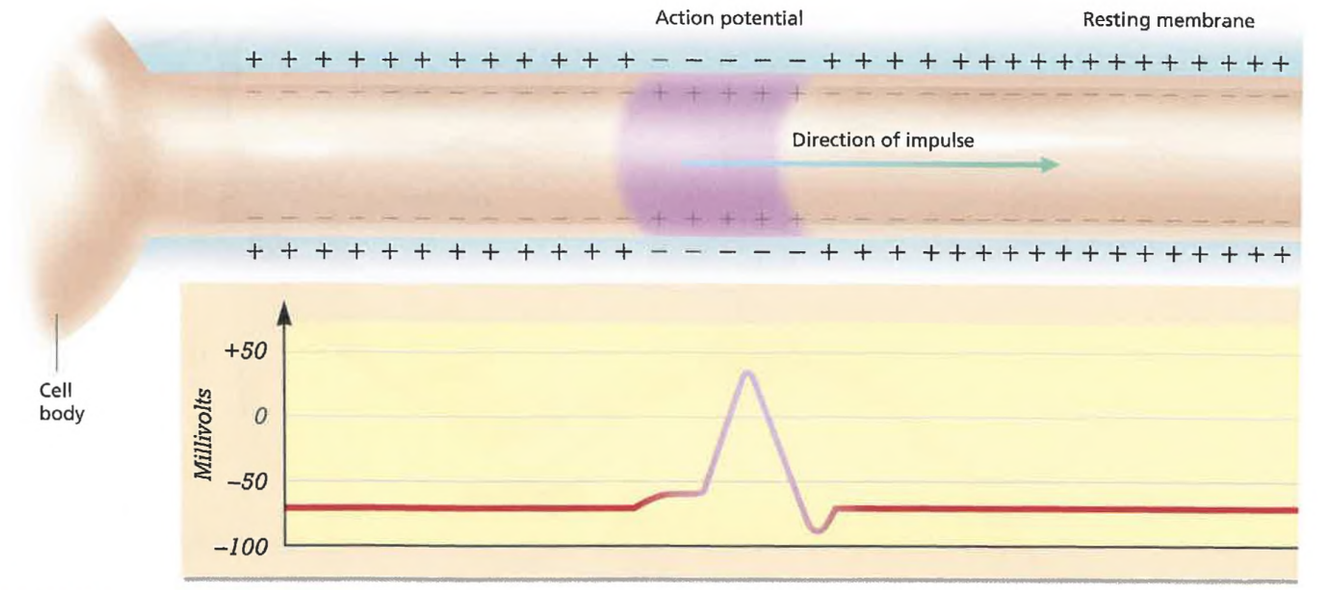


FIGURE 50-9

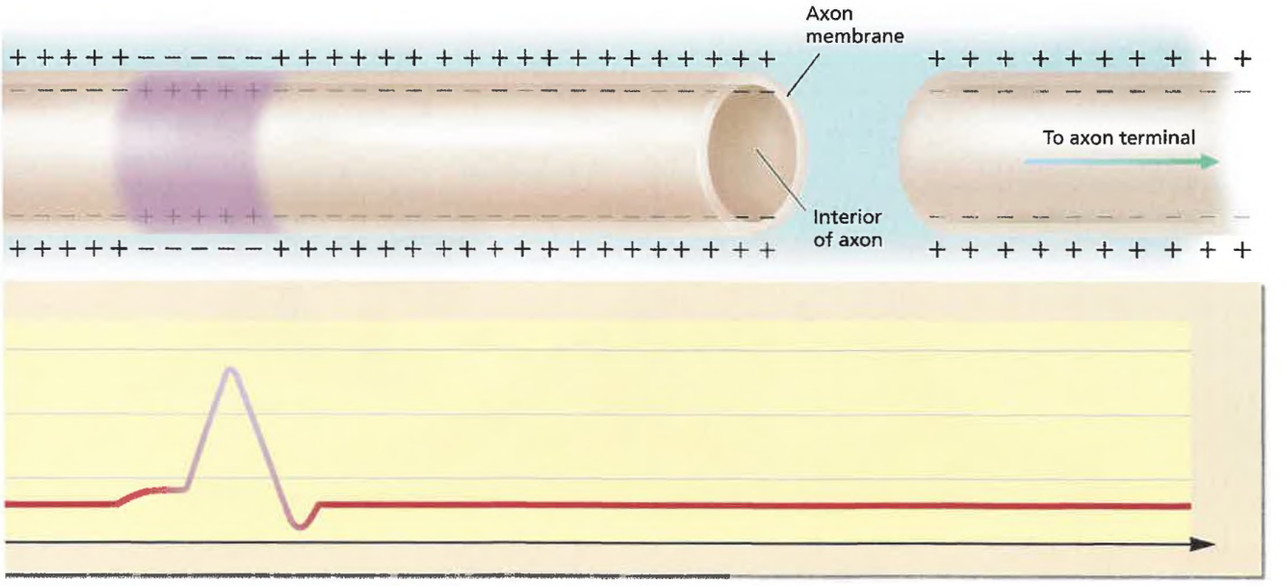
In the resting state, the interior of a neuron is negatively charged with respect to the extracellular fluid. The passage of an action potential over the membrane of the axon reverses this polarity, making the interior of the axon positively charged for a brief time. A graph shows the change in voltage during an action potential. The charge of the interior of the neuron rapidly switches from negative to positive, and then immediately reverses, the interior regaining its negative charge.

part, due to the action of the sodium-potassium pump. Recall from Chapter 5 that the sodium-potassium pump actively moves Na^+ out of cells while moving K^+ in.

The cell membrane is permeable to some ions but not to others. Na^+ ions do not readily diffuse through the membrane, and they accumulate outside the cell. The negatively charged proteins remain inside because they are too large to exit. K^+ ions, however, pass freely through the membrane and tend to diffuse out of the cell, down their concentration gradient. This exit of positively charged potassium ions, coupled with the retention of negatively charged protein ions, eventually causes the interior of the neuron to become negatively charged with respect to the exterior. This charge difference is called the **resting potential** of the membrane. In animal neurons, the resting potential is about –70 millivolts.

Action Potential

When a dendrite or the cell body of a neuron is stimulated, a sudden change occurs in the permeability of its cell membrane. At the point where it is stimulated, the cell membrane becomes permeable to Na^+ ions. The rush of Na^+ ions into the cell opens voltage gated channels in the membrane that allow even more Na^+ ions to diffuse rapidly from the outside of the membrane to the inside of the neuron. Remember from Chapter 5 that gated channels control the passage of ions through a cell membrane. As a result of the inward diffusion of Na^+ ions, the interior of the neuron's cell body becomes more positively charged than the outer surface. The interior, once negatively charged, is now positively charged. The exterior, once positively charged, is now negatively charged with respect to the interior. This reversal of polarity across the membrane begins an action potential. The action potential starts at the point where the cell body of the neuron joins the axon.



Voltage gated channels exist along the entire length of the axon. As the first small segment of the axon becomes positively charged, the rise in voltage opens channels in the adjacent segment of axon membrane. As before, Na^+ ions enter, driving the voltage in a positive direction and opening channels in the next segment of the axon. In this way, a wave of positive charge passes down the membrane of the axon like a flame burning down a length of rope. Axon potentials travel in one direction only—away from the cell body, where they begin, and toward the axon terminal.

Shortly after they open, the gated channels for Na^+ ions close. Then voltage gated channels for K^+ ions open. The result is an abrupt outward flow of K^+ ions. The outer surface again becomes positively charged, and the inner surface regains its negative charge. This signals the end of the action potential. The neuron cannot generate another action potential until the resting membrane potential is restored. This period, during which the neuron cannot fire, is called the **refractory period.**

After the action potential, the concentration of Na^+ inside the cell is abnormally high, and the concentration of K^+ inside the cell is abnormally low. The sodium-potassium pump reestablishes the original concentrations of Na^+ ions and K^+ ions on both sides of the membrane. Na^+ ions are actively pumped out across the cell membrane, while K^+ ions are actively pumped in across the membrane. Thus, the original ion concentrations are restored, and the neuron is ready for the next action potential. This restoration of resting potential comes at a price. Recall from Chapter 5 that the sodium-potassium pump requires energy in order to function. Neurons need a continuous supply of ATP to keep the sodium-potassium pump operating. In fact, neurons consume a great deal of energy in the body.

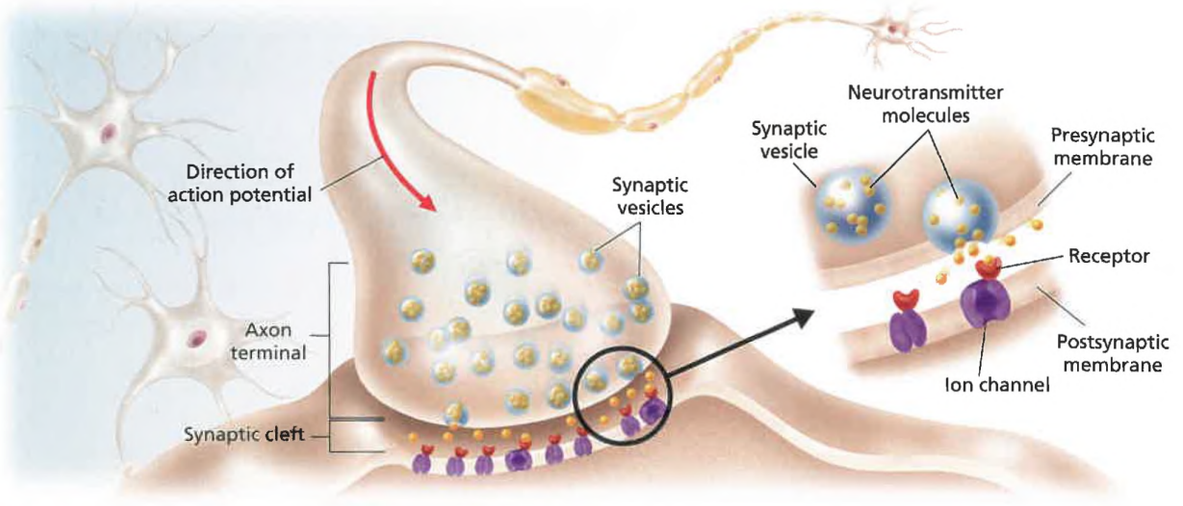


FIGURE 50-10

Neurotransmitter molecules are released into the synaptic cleft by the presynaptic neuron. These molecules bind at receptors in the postsynaptic membrane, opening ion channels. Positive ions entering through these channels cause the resting membrane potential of the postsynaptic neuron to rise. If it rises sufficiently, the postsynaptic neuron will generate an action potential, continuing the signal.

Neurotransmitter Function

When an action potential reaches the axon terminal, vesicles that are stored in the axon terminal and that contain neurotransmitters fuse with the presynaptic membrane. As Figure 50-10 shows, the fusion releases neurotransmitter molecules into the synaptic cleft. These molecules diffuse across the short distance of the synaptic cleft and bind to receptor molecules embedded in the postsynaptic membrane.

The interaction of neurotransmitter molecules and receptor molecules changes the permeability of the postsynaptic membrane by affecting chemically-gated ion channels. The opening of Na^+ channels in the postsynaptic membrane causes the neuron to become more positive in charge. If this positive change of the membrane potential is great enough, a new action potential is generated in the receiving neuron, effectively continuing the electrical signal.

On the other hand, if a sufficient number of Na^+ channels in the postsynaptic membrane fail to open, or if other channels open, allowing the rush of negatively charged ions in, the membrane potential of the receiving neuron will not rise appreciably or will become more negative. No new action potential will be generated in the receiving neuron, and the nervous signal will terminate.

SECTION 50-3 REVIEW

1. **Describe the structure of a neuron.**
2. **What is the resting potential of the membrane?**
3. **How is a signal in the nervous system transmitted between adjacent neurons?**
4. **Why does the nervous system consume a large amount of energy?**
5. **Describe two possible effects that neurotransmitters may have at a synapse.**
6. **CRITICAL THINKING What functional advantage does a neuron with several dendrites have over a neuron with only one dendrite?**

SECTION

50-4

SENSORY SYSTEMS

Human experience is affected by both internal and external stimuli. Humans are able to distinguish among many different types of stimuli by means of a highly developed system of sense organs. Sensory systems represent an integration of the functions of the peripheral nervous system and the central nervous system. The sensory division of the peripheral nervous system gathers information about the body's internal conditions and the external environment. Sensory systems translate light, sound, temperature, and other aspects of the environment to electrical signals and transmit these signals, in the form of action potentials, to the central nervous system, where they are interpreted.

OBJECTIVES

- List five types of sensory receptors.
- Describe the structure of the eye and the roles of rods and cones in vision.
- Identify the parts of the ear responsible for hearing and for maintaining balance.
- Explain how taste and smell are detected.

RECEPTORS AND SENSE ORGANS

A sensory receptor is a neuron that is specialized to detect a stimulus. There are many kinds of sensory receptors, and they can be categorized on the basis of the types of stimuli they respond to.

- *Mechanoreceptors* respond to movement, pressure, and tension.
- *Photoreceptors* respond to variations in light.
- *Chemoreceptors* respond to chemicals.
- *Thermoreceptors* respond to changes in temperature.
- *Pain receptors* respond to tissue damage.

Sensory receptors are found in high concentrations in the **sense organs**—the eyes, ears, nose, mouth, and skin—and in fewer numbers, throughout the rest of the body. When a particular sense organ receives appropriate stimulation, its sensory receptors convert the stimulus into electrical signals that are sent to specific regions of the brain. The action potentials generated by the different sense organs are electrically similar, but the regions of the brain where they are interpreted vary according to the type of stimulus.

As you learned in Section 50-1, the brain has a specific region for each sense. Thus, signals received by the auditory region of the temporal lobe may be interpreted as sounds regardless of whether a sound wave was the original stimulus.

Word Roots and Origins

tympanic

from the Greek *tympanon*, meaning "drum"

HEARING AND BALANCE

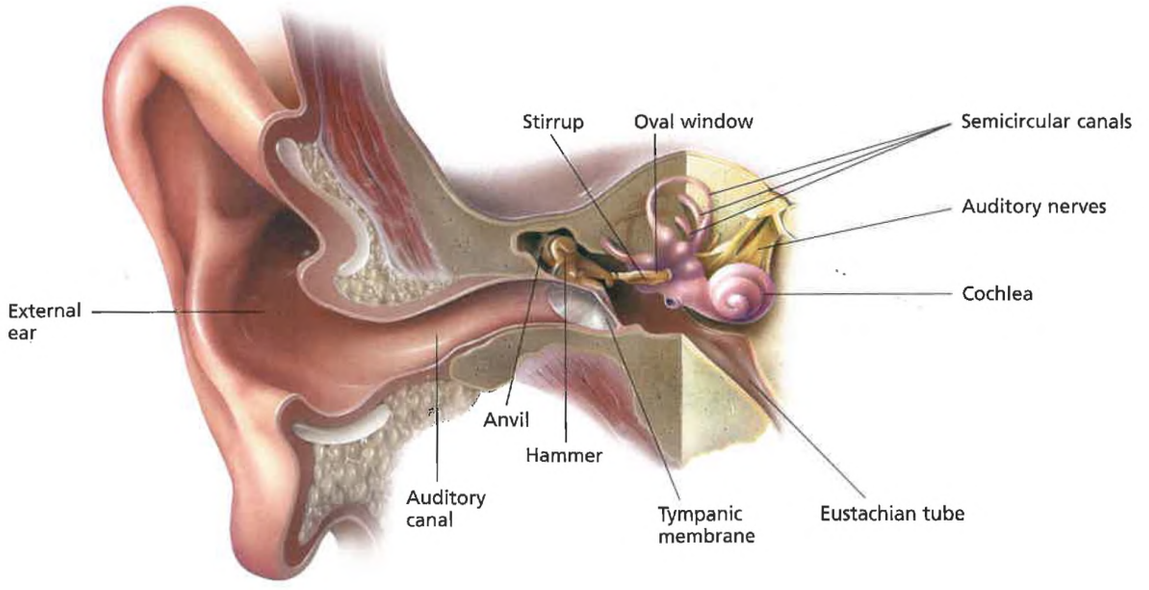
The ear is specialized for two functions: detecting sound and maintaining balance. Sound is transmitted as vibrations of a substance; for humans, usually the substance is air. Sound is directed by the fleshy structure of the external ear into the ear itself, where the vibrations are translated into action potentials.

As shown in Figure 50-11, the **auditory canal** connects the external ear with the **tympanic** (tim-PAN-ik) **membrane,** also called the eardrum. Vibrations in the air passing through the auditory canal cause the tympanic membrane to vibrate. Air pressure in the chamber beyond the tympanic membrane, the middle ear, can be regulated and balanced by the amount of air allowed to enter the middle ear through the Eustachian tube. The **Eustachian** (yoo-STAY-kee-uhn) **tube** is an opening to the throat that enables you to equalize the pressure on both sides of your tympanic membrane whenever you experience a sudden change in atmospheric pressure, such as when you take off in an airplane. By swallowing, you allow air to enter the middle ear through the Eustachian tube. This air is under the same pressure as the air pressing against the tympanic membrane on the exterior side. Thus, the air pressure is equalized and you no longer feel pressure on the tympanic membranes in your ears.

Vibrations of the tympanic membrane are transmitted to three small bones of the middle ear: the hammer, the anvil, and the stirrup. The stirrup transfers the vibrations to a membrane called the **oval window,** which separates the middle ear from the inner ear. The inner ear contains the **cochlea** (KAHK-lee-uh), a coiled tube consisting of three fluid-filled chambers that are separated by membranes. The middle chamber contains the **organ of Corti,** which is the organ of

FIGURE 50-11

Sound waves, which are vibrations in the air, cause the tympanic membrane to move back and forth. This motion causes the small bones of the middle ear to move as well, transferring vibrations to the oval window. Mechanoreceptors in the inner ear translate these vibrations to action potentials, which travel through the auditory nerve to auditory processing centers in the brain.



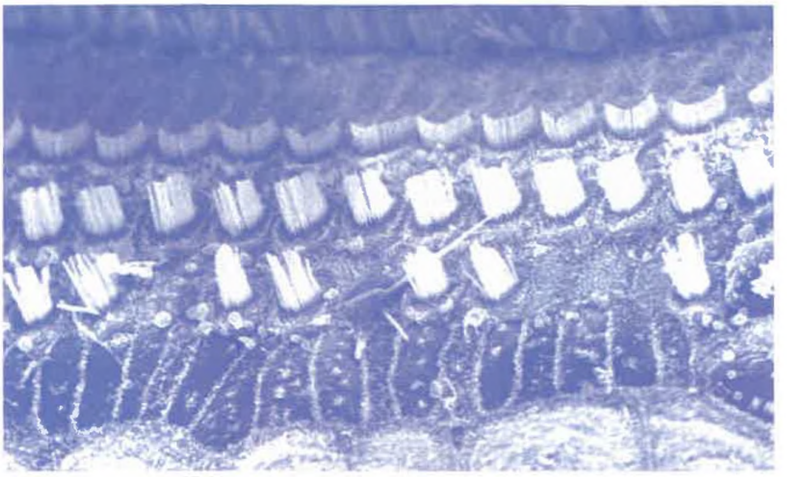


FIGURE 50-12

Hair cells are arranged in orderly rows in the organ of Corti in the cochlea. In this damaged section, the hair cells in the top and center rows are relatively intact. Many of the hair cells of the bottom row, however, are frayed and bent. Four clusters of hair cells (the third, sixth, ninth, and tenth from the left) have been completely destroyed.

hearing. The organ of Corti rests on the bottom membrane in the cochlea and contains sensory receptors known as hair cells. Vibrations of fluid in the cochlea move the bottom membrane and cause these hair cells to bend against a second membrane, which covers them like a roof. This movement stimulates the hair cells to produce action potentials. These action potentials travel along the auditory nerve to the auditory region of the brain stem, then to the thalamus, and finally to the auditory cortex, where they are interpreted as sound.

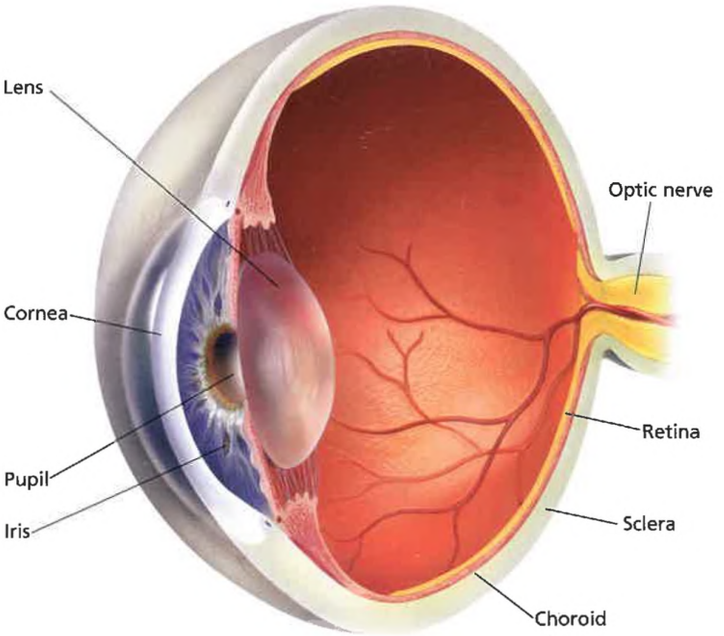
Different pitches stimulate different parts of the cochlea. Normally, the human ear can detect sounds ranging from 16 to 20,000 cycles per second. If the human ear could hear sounds lower than 16 cycles per second, it would pick up sounds generated by the flow of blood through the vessels and the movement of food through the digestive system.

The hair cells that line the cochlea are a delicate and vulnerable part of the ear. Repeated or sustained exposure to loud noise destroys the neurons of the organ of Corti. Once destroyed, the hair cells are not replaced, and the sound frequencies interpreted by them are no longer heard. Figure 50-12 shows rows of hair cells in a damaged section of the organ of Corti. Damage is most apparent in the bottom row of hair cells. Hair cells that respond to high frequency sound are very vulnerable to destruction, and loss of these neurons typically produces difficulty understanding human voices. Much of this type of permanent hearing loss is avoidable by reducing exposure to loud noises in the environment, such as industrial and machinery noise, gunfire, and loud music.

Balance is maintained with the help of mechanoreceptors in the three **semicircular canals** of the inner ear, shown in Figure 50-11. These canals are filled with fluid, and their interiors are lined with hair cells that have tiny particles of calcium carbonate on top of them. When the head moves, the hair cells are bent by the action of gravity on the calcium carbonate particles. The brain decodes the degree and direction of bend of the hair cells, interpreting the motion and the orientation of the head in space.

FIGURE 50-13

Light entering the eye travels through the cornea, pupil, and the clear lens to the retina, which contains millions of photoreceptors. Activation of these specialized sensory receptors sends a signal through the optic nerve to the optic centers of the brain—first to the thalamus and eventually to the visual cortex in the occipital lobe.



Quick Lab

Observing a Lens

Materials beaker, water, piece of newspaper, 4 drops cooking oil

Procedure

1. Observe the newspaper through the sides of an empty beaker. Fill the beaker with water, and observe the newspaper through the water. Note any difference in print size.
2. Add four drops of oil to the top of the water. Place the newspaper under the glass, and observe the print size through the oil drops and the water.

Analysis Infer why the print size changes when the newspaper is viewed through water. What structure of the eye does the oil on the water represent?

VISION

The eyes are specialized organs that function by receiving light and transmitting signals to visual processing areas of the brain. The eye is basically a hollow sphere filled with a clear fluid. The structures of the eye, shown in Figure 50-13, act together to focus light on the **retina,** the light-sensitive inner layer of the eye.

Light passes first through a clear, protective layer called the **cornea.** Light then passes through the **pupil,** the opening to the interior of the eye. The pupil becomes larger when light is dim and smaller when light is bright. These involuntary responses are controlled by muscles in the pigmented **iris** that surrounds the pupil.

After light passes through the pupil, it travels through a convex crystalline structure called the **lens.** Attached to the lens are muscles that adjust the lens's shape to bend the rays of the incoming light. This bending focuses the complete image formed by the light onto the retina.

Lying deep within the retina are rods and cones, photoreceptors that translate light energy into electrical signals that can be interpreted by the brain. There are nearly 125 million **rods** in a single retina. Rods contain rhodopsin, a light-sensitive pigment that allows the rods to respond to dim light. The 7 million **cones** in the retina are stimulated by bright light. The cones initiate the production of sharp images and respond to different colors. Humans have three kinds of cones. Each type of cone contains a pigment that absorbs different wavelengths of light. When the signals from these three kinds of cones are integrated, a person is able to see all the colors in the visible spectrum. Colorblindness, which is the inability to distinguish certain colors, is caused by a chemical disorder in the cones.

Each photoreceptor responds to light from a single location in the visual field. Signals from the stimulated photoreceptors in the deepest layer of the retina travel to neurons on the surface of the retina. From these neurons, millions of axons, which form the optic nerve, exit the eye. The **optic nerve** carries visual information in the form of action potentials from the retina to the thalamus. Visual information is ultimately processed in the cortex of the occipital lobe.

TASTE AND SMELL

Specialized chemoreceptors allow humans to perceive variations in tastes and odors. The chemoreceptors for taste are clustered in the **taste buds.** Most of the 10,000 taste buds are embedded between bumps called **papillae** (puh-PIL-ee) on the tongue; additional taste buds are found on the roof of the mouth and in the throat.

Chemicals from food dissolved in saliva enter a taste bud through a small opening and stimulate a signal in the neurons that line the inner surface of the taste buds. As Figure 50-14 shows, taste signals travel through a relay in the brain stem, then to the thalamus and finally to the cortex, where they are interpreted.

Other chemicals in the environment are perceived by receptors in the nasal passages. Specialized chemoreceptors called **olfactory** (ahl-FAK-tuh-ree) **receptors** are located in the olfactory epithelium of the nasal passage, as shown in Figure 50-14. These cells lie within the mucous lining of the epithelium. The binding of molecules in the air to specific receptor molecules in the olfactory receptors

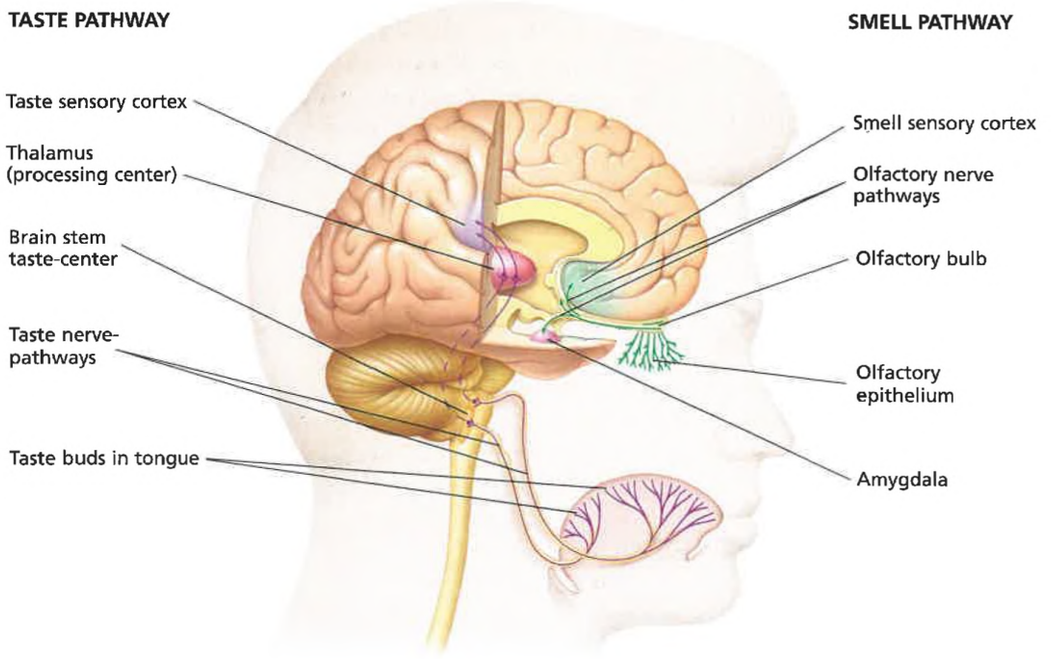


FIGURE 50-14
Taste and smell are chemical senses. Sensory receptors in the mouth and nasal passage bind molecules from the environment, initiating neural signals that travel to the brain.

stimulates the receptors. Signals from olfactory receptors travel to the olfactory bulb, a structure of the limbic system, then to olfactory areas of the cortex and to the **amygdala,** another limbic structure important in emotion, memory, and eating behavior.

OTHER SENSES

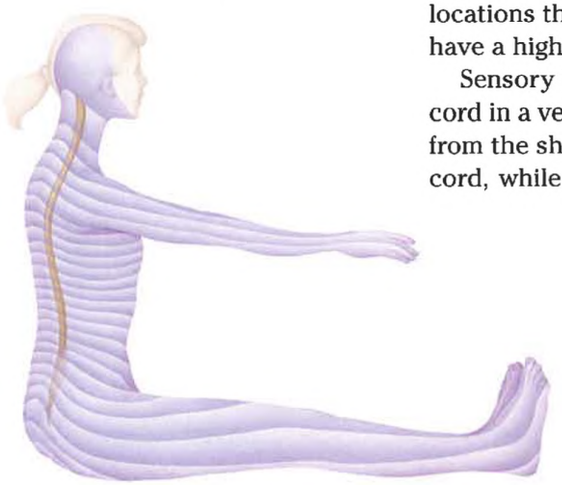
Mechanoreceptors located throughout the skin make it possible to sense touch, pressure, and tension. In humans, the receptors for touch are concentrated in the face, tongue, and fingertips. Body hair also plays an important role in the ability to sense touch. Large numbers of mechanoreceptors are found in the skin at the base of the hair follicles.

Two types of specialized thermoreceptors monitor temperature. Cold receptors are most sensitive to temperatures below 20°C. Heat receptors respond to temperatures between about 30°C and 45°C.

Pain receptors are sensory neurons located in the base of the epidermis and throughout the interior of the body. Pain receptors are stimulated by mechanical, thermal, electrical, or chemical energy. The type and number of pain receptors vary at different locations throughout the body. For example, the hands and mouth have a high concentration of pain receptors.

Sensory input from the surface of the body goes to the spinal cord in a very orderly way, as shown in Figure 50-15. Sensory input from the shoulders enters upper dorsal root sections of the spinal cord, while sensory input from the lower body enters the dorsal roots of the lower spinal cord. Damage to a specific section of the spinal cord results in sensory problems limited to a well-defined area of the body. This is an example of how function is mapped throughout the nervous system. In the brain, specific areas of the sensory cortex and motor cortex likewise correspond to specific body parts, and damage to specific areas of the cortex results in isolated problems, such as the loss of sensation in part of a hand.

FIGURE 50-15
Specific dorsal roots of the spinal cord carry sensory information from certain parts of the skin and body.



SECTION 50-4 REVIEW

1. Distinguish between chemoreceptors and mechanoreceptors.
2. How are sound vibrations transmitted through the ear?
3. Explain the role of rods and cones in the perception of images by humans.
4. What mechanisms do the senses of taste and smell have in common?
5. What is the importance of the high concentration of pain receptors in the hands?
6. **CRITICAL THINKING** Why might an injury to the lower spinal cord cause a loss of sensation in the legs?

CHAPTER 50 REVIEW

SUMMARY/VOCABULARY

50-1

- The central nervous system (CNS) includes the brain and spinal cord.
- Main divisions of the brain include the cerebrum and the brain stem—including the diencephalon—and the cerebellum. The cerebral cortex forms the outer layer of the cerebrum.
- The cerebellum coordinates muscle action and helps the body maintain its balance.
- The lower brain stem has three main sections—the midbrain, the pons, and the medulla oblongata.
- Thirty-one pairs of spinal nerves each consist of a dorsal root containing sensory neurons and a ventral root containing motor neurons.

Vocabulary

afferent neuron (1004)
arachnoid layer (1007)
axon (1003)
brain stem (1006)
central nervous system (1004)
cerebellum (1007)
cerebral cortex (1005)
cerebral hemispheres (1004)
cerebrospinal fluid (1007)
cerebrum (1004)
corpus callosum (1004)
diencephalon (1006)
dura mater (1007)
efferent neuron (1004)
interneuron (1008)
limbic system (1006)
medulla oblongata (1007)
meninges (1007)
midbrain (1007)
motor neuron (1008)
nerve (1008)
peripheral nervous system (1004)
pia mater (1007)
pons (1007)
reticular formation (1007)
sensory receptor (1008)
spinal cord (1008)
thalamus (1006)
ventricle (1007)
white matter (1005)

50-2

- The peripheral nervous system (PNS) links the central nervous system and the rest of the body. The PNS is composed of a sensory division and a motor division.
- The motor division of the PNS is divided into the somatic nervous system and the autonomic nervous system.
- The somatic nervous system controls skeletal muscles and is under voluntary control.
- In a reflex, a signal is routed from sensory neurons, through the spinal cord and out through motor neurons.
- In autonomic control of internal conditions, the sympathetic division and the parasympathetic division have largely opposite effects.

Vocabulary

autonomic nervous system (1010)
motor division (1009)
parasympathetic division (1011)
reflex (1009)
sensory division (1009)
somatic nervous system (1009)
spinal reflex (1010)
sympathetic division (1010)

50-3

- A neuron consists of a cell body, dendrites, and an axon. The transmission of a signal through a neuron is called an action potential.
- In a neuron at rest, K^+ ions are concentrated inside the membrane while Na^+ ions are concentrated outside the cell membrane. The inside of the cell membrane has a negative charge relative to the outside.
- During an action potential, the polarity of the membrane is reversed briefly as Na^+ ions diffuse into the neuron and K^+ ions diffuse out of the neuron through gated channels.
- When an action potential reaches the presynaptic membrane of the next neuron, neurotransmitter molecules diffuse across the synapse, where they can either stimulate or inhibit the start of an action potential in the postsynaptic neuron.

Vocabulary

action potential (1012)
axon terminal (1012)
dendrite (1012)
myelin sheath (1012)
neurotransmitter (1012)
node of Ranvier (1012)
potential (1013)
refractory period (1015)
resting potential (1014)
Schwann cell (1012)
synaptic cleft (1012)

50-4

- Sensory receptors include mechanoreceptors, photoreceptors, chemoreceptors, thermoreceptors, and pain receptors.
- The eye receives light through the pupil. The lens focuses this light on the retina, which is composed of photoreceptors. The optic nerve that exits at the back of the retina carries a signal to the brain.
- In the ear, vibrations pass through the auditory canal, the tympanic membrane, the bones of the middle ear, the oval window, and the cochlea of the inner ear. Hair cells in the organ of Corti produce signals that travel through the auditory nerve to the brain.
- Hair cells in the semicircular canals of the inner ear monitor the body's position in space.
- Stimulation of neurons that line the inner surface of a taste bud initiates signals that travel to the brain, where they are interpreted as taste. Likewise, olfactory receptors in the nasal passage transmit signals to the brain, where they are interpreted as odor.

Vocabulary

amygdala (1022)
auditory canal (1018)
cochlea (1018)
cone (1020)
cornea (1020)
Eustachian tube (1018)
iris (1020)
lens (1020)
olfactory receptor (1021)
optic nerve (1021)
organ of Corti (1019)
oval window (1018)
papilla (1021)
pupil (1020)
retina (1020)
rod (1020)
semicircular canal (1019)
sense organ (1017)
taste bud (1021)
tympanic membrane (1018)

REVIEW

Vocabulary

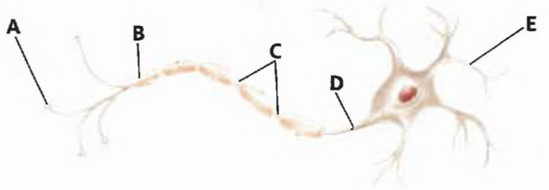
1. Explain the relationship between the autonomic nervous system, the sympathetic division, and the parasympathetic division.
2. Where is the hypothalamus located with respect to the thalamus?
3. Explain the relationship between the resting potential of the membrane and the action potential.
4. The word *pons* means "bridge." How is this related to the function of the pons in the brain?
5. What do the terms *afferent* and *efferent* mean with respect to neurons?

Multiple Choice

6. The central nervous system consists of (a) the brain and spinal cord (b) 31 pairs of spinal nerves (c) the cranial nerves (d) the peripheral nervous system.
7. The cerebral cortex (a) is located deep in the brain (b) is the folded outer covering of the brain (c) is the lobed, highly folded structure located at the back of the brain (d) contains the reticular formation.
8. The thalamus (a) lies below the medulla oblongata in the brain stem (b) controls homeostasis (c) directs sensory information to the proper regions of the cerebral cortex (d) is important in maintaining balance.
9. The cerebellum is important in (a) coordinating motor responses and maintaining posture (b) controlling hormone levels and maintaining homeostasis (c) protecting the brain and spine (d) processing olfactory and taste information.
10. In a spinal reflex, the signal travels (a) immediately to the brain (b) to the spinal cord and then to the brain (c) to the spinal cord and out to a muscle (d) directly to a sense organ.
11. When a neuron is at resting potential, (a) the outside is negatively charged (b) the inside is negatively charged (c) both sides are equally charged (d) the polarity across the membrane reverses.
12. Neurotransmitters (a) diffuse across the membrane, carrying charge with them (b) diffuse across the synaptic cleft and open channels on the postsynaptic neuron (c) are transported across the synaptic cleft and close channels in the postsynaptic neuron (d) do not work at the synaptic cleft.
13. Sensory receptors (a) link interneurons with motor neurons (b) are found only in the spine (c) are found only in the brain (d) respond to stimuli.

14. Photoreceptors are stimulated by (a) heat (b) pressure (c) chemicals (d) light.
15. Mechanoreceptors are stimulated by (a) heat (b) pressure (c) chemicals (d) light.

Short Answer



16. List the part of the neuron denoted by each letter in the diagram above.
17. What are two functions of cerebrospinal fluid?
18. What is the relationship between afferent neurons, interneurons, and efferent neurons?
19. How does the autonomic nervous system work to maintain homeostasis?
20. What are the roles of the three sections of the lower brain stem?
21. At resting potential, what ions do not readily cross the cell membrane of the neuron?
22. What role does the sodium-potassium pump play in the restoration of the membrane potential?
23. What event triggers release of neurotransmitter molecules?
24. What are dendrites and what function do they play in signaling in neurons?
25. What is the role of the ear in maintaining balance?
26. What are rods and cones, and how do their functions differ?

CRITICAL THINKING

1. Epilepsy affects one of every 200 Americans. Brain neurons normally produce small bursts of action potentials in varying patterns. During an epileptic seizure, large numbers of brain neurons send rapid bursts of action potentials simultaneously. The body of an individual having a seizure may grow rigid and jerk or convulse. From what you know about the brain's control of muscles and posture, how might you explain these symptoms?
2. Synesthesia is a puzzling phenomenon in which one type of sensory input is interpreted by the brain as another type. For example, a person hearing music might associate certain notes with certain colors. What may be happening in the central nervous system to produce this effect?
3. An imbalance of electrolytes, the ion-containing fluids of the body, can impair transmission of nerve signals. Why might this be so?
4. Look at the diagram below of the brain of a fish. How does the cerebrum differ from that of a human? The fish's brain has large olfactory bulbs. What does this tell you about the relative importance of the sense of smell to the fish?

EXTENSION

1. Read "Why We Cry" in *Current Science,* February 11, 2000, on page 8. Describe the three kinds of tears that humans produce. Do any other animals cry tears? Explain the following comment by the writer: "Contrary to common belief, recent studies show that people don't weep while they're feeling a strong emotion."
2. Research the way general anesthetics work. Then write a short report in which you discuss a specific anesthetic, the effect of the anesthetic on the brain, and the effect of body weight and the passage of time on the action of an anesthetic.

CHAPTER 50 INVESTIGATION

Sheep's Eye Dissection

OBJECTIVES

- Describe the main external and internal structures of a sheep's eye.
- Name the various structures associated with sight.

PROCESS SKILLS

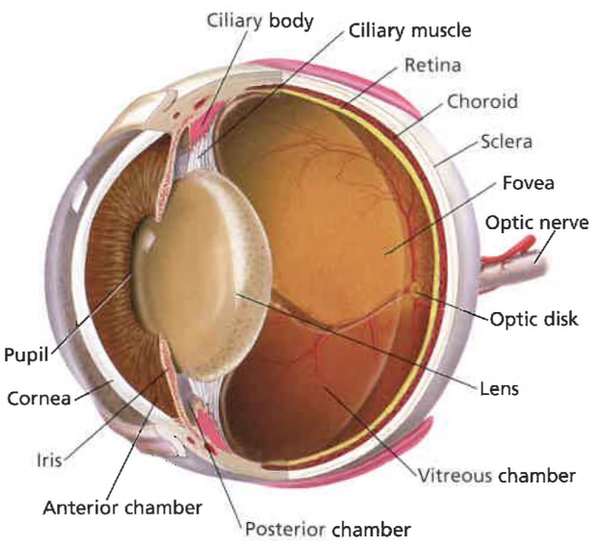
- observing
- identifying
- comparing and contrasting

MATERIALS

- safety goggles
- disposable gloves
- lab apron
- preserved sheep's eye
- dissection tray
- scalpel
- tweezers
- fine scissors
- blunt probe

Background

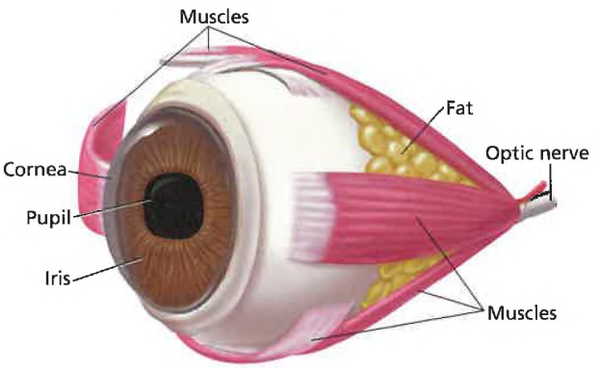
1. The sheep's eye is very similar to the human eye, as shown in the diagram below. The wall of the eyeball is made up of three layers. The outer layer, the sclera, is a tough tissue that forms the white of the eye. At the front of the eye, the sclera becomes thin and transparent to form the cornea.



2. The middle layer, the choroid, is dark and rich with blood vessels. At the front of the eye behind the cornea, the choroid is modified into the iris and the ciliary body. The pigment in the doughnut-shaped iris determines the color of the eye. The opening in the center of the iris is the pupil. What is the function of the pupil?
3. The inner layer, the retina, is sensitive to light. What are the sensory receptor neurons in the retina called?
4. Directly behind the iris is the elastic, transparent lens. The suspensory ligament attaches the ciliary muscle, the main part of the ciliary body, to the lens. This ring of muscle changes the shape of the lens to focus on near and far objects.
5. The lens and its suspensory ligament divide the eye into two chambers. The large vitreous chamber extends from the retina to the lens and ligaments. It is filled with a gelatinous mass, the vitreous humor. This vitreous humor helps to maintain the shape of the eye and hold the retina in place. The second chamber, which extends from the iris to the cornea, is subdivided into two parts, the anterior and posterior chambers. The anterior chamber extends from the cornea to the iris; the posterior chamber from the iris to the suspensory ligament. Both chambers contain aqueous humor, a watery substance that bathes the front part of the eye.
6. In the retina, the nerves from the rods and cones bundle together at the optic nerve. The region of the retina where its nerve fibers and blood vessels enter the optic nerve is the small optic disk, which contains no rods or cones. Why is the optic disk also called the blind spot?
7. A very short distance away is a yellowish spot, the fovea. It is the site of sharpest vision because it has a high concentration of photoreceptors.

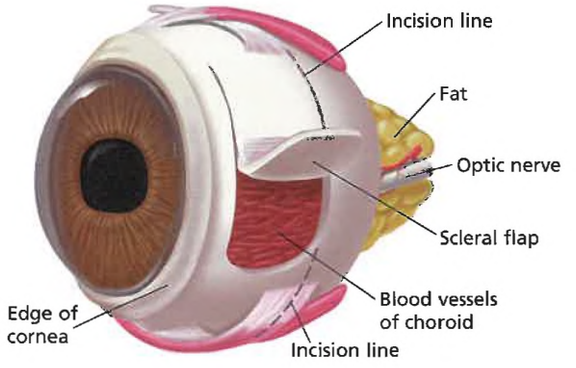
Procedure

1. Put on safety goggles, gloves, and a lab apron.
2. Locate the six main muscles on the outside of the eye, as shown in the diagram below. These



muscles move the eye in various directions. Use a scalpel to carefully cut the muscles near the eye. This will expose the sclera.

3. Observe the fatty tissue that cushions the eye in its socket, especially around the optic nerve. This fatty tissue helps to prevent shock. With a tweezer and scalpel, remove the fatty tissue. This will expose the optic nerve more fully.
4. Using a scalpel, carefully cut the sclera about 1 cm behind the cornea. Using fine scissors, extend the cut to make a flap that you can lift, as shown in the diagram below.



5. With forceps, carefully remove the sclera in this area and observe the dark choroid layer immediately below the sclera.
6. Next, use a scalpel to make an incision through the eye. Following along the incision you made in step 4, cut almost completely around the eye. You have separated the eye into an anterior and a posterior portion.
7. In the posterior section, observe the whitish retina. It is probably shriveled and may have fallen into the vitreous chamber.
8. In the anterior section, use a blunt probe to expose the lens. In a preserved eye, the lens is no longer clear.
9. In the anterior section, also locate the ciliary muscle and as many other structures as possible.
10. When you have finished your dissection, remove the specimen from the dissecting tray. Dispose of your materials according to the directions from your teacher.
11. Clean up your work area and wash your hands before leaving the lab.

Analysis and Conclusions

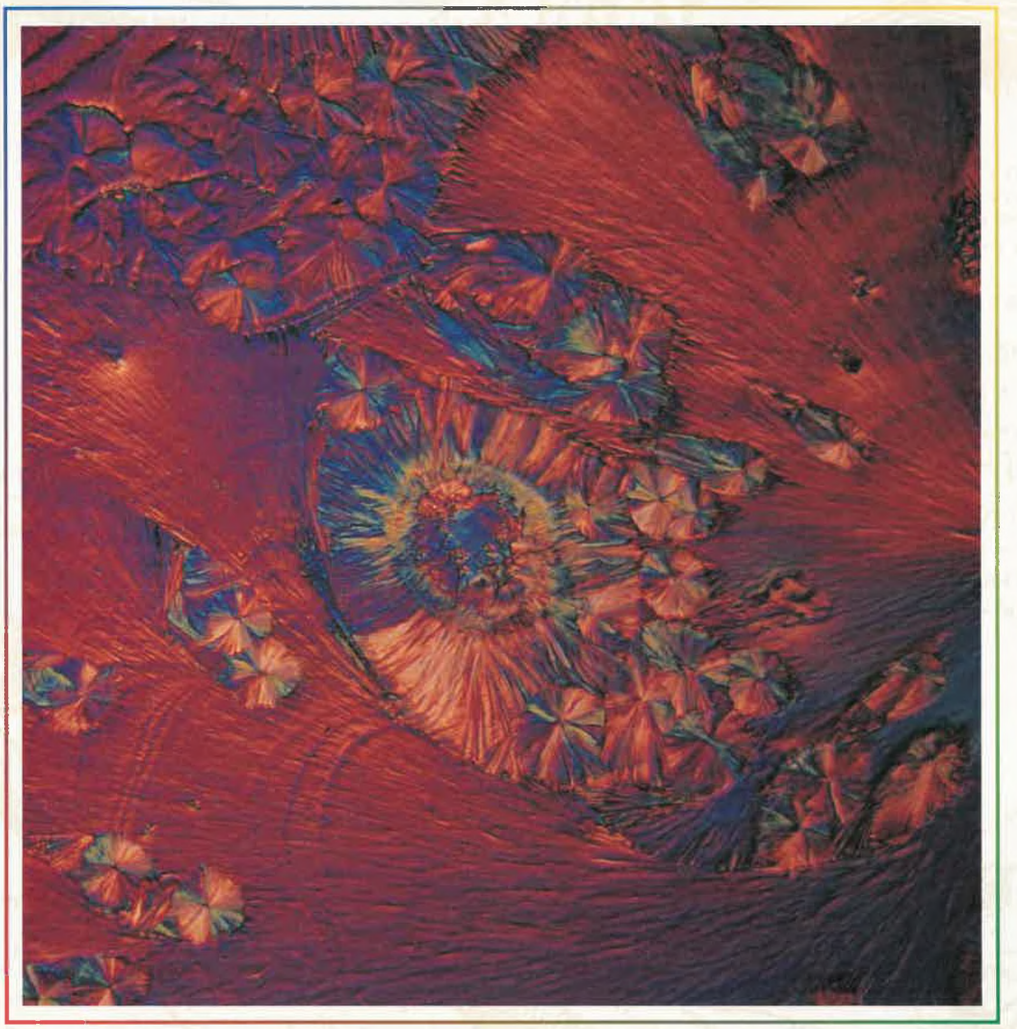
1. How is the lens different from the other structures of the eye?
2. How do the nature of the sclera and choroid change as they reach the front part of the eye?
3. How does the vitreous chamber differ from the anterior and posterior chambers?
4. What would be the result of the cornea becoming cloudy during an animal's lifetime?
5. Sometimes the retina of the eye becomes detached. Why is it important that the retina be reattached, if possible?

Further Inquiry

You see light if the vision center of your cerebrum is stimulated electrically. Scientists are trying to find out which brain cells are involved in forming images in our brains. How might scientists someday use this knowledge to help blind people see?

CHAPTER 51

ENDOCRINE SYSTEM



The neurotransmitter dopamine is one of many amino acid–based compounds that act as chemical messengers in the body.

FOCUS CONCEPT: ***Stability and Homeostasis***

As you read, examine the various ways that the endocrine system helps the body maintain homeostasis and stability.

SECTION 51-1

HORMONES

*The **endocrine** (EN-duh-KRIN) **system** consists of glands that transmit chemical messengers throughout the body. These chemical messengers, called **hormones** (HOHR-MOHNZ), circulate in the bloodstream and affect many types of body cells. In this section, you will learn about hormones and mechanisms of their action.*

OBJECTIVES

- Compare exocrine glands with endocrine glands.
- Contrast amino acid–based hormones with steroid hormones.
- Describe two ways that hormones affect their target cells.
- Distinguish hormones from prostaglandins.

TYPES OF GLANDS

A gland is an organ that consists of cells that secrete materials into other regions of the body. The body contains two types of glands: exocrine glands and endocrine glands. **Exocrine** (EK-suh-KRIN) **glands** secrete nonhormonal chemicals into ducts, which transport the chemicals to specific locations inside and outside the body. Sweat glands, mucous glands, salivary glands, and other digestive glands are examples of exocrine glands. **Endocrine glands** are ductless glands that are located throughout the body. Endocrine glands secrete hormones into the bloodstream through the fluid that surrounds their cells. You will learn more about endocrine glands in Section 51-2.

TYPES OF HORMONES

Hormones are compounds that are secreted in small amounts into the bloodstream and that influence the activity of distant cells. Hormones diffuse into the blood, which is their vehicle for transportation to various cells throughout the body. Hormones can be grouped into two general categories based on their structure: amino acid–based hormones and steroid, or lipid, hormones. **Amino acid–based hormones,** such as epinephrine (adrenaline), include proteins, peptides, amino acids, and other forms that are derived from amino acids. **Steroid** (STER-OYD) **hormones,** such as estrogen and testosterone, are lipids that the body synthesizes from cholesterol.

These two general classes of hormones differ significantly in their physical, and therefore chemical, properties. Thus, their mechanisms of action on body cells are also different. As you will see, mechanisms of hormone action depend on the way that hormones interact with cells that they affect.

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Word Roots and Origins

hormone

from the Greek *hormon,* meaning "to excite"

HORMONE ACTION

The body produces many hormones, and each hormone affects only specific cells, called **target cells.** Target cells have receptors that recognize and bind to specific hormones. **Receptors** are proteins that are located both inside the cytoplasm and on the surface of a target cell. When a hormone binds to a receptor on its target cell, it triggers events that lead to changes within the cell.

Amino Acid–Based Hormones

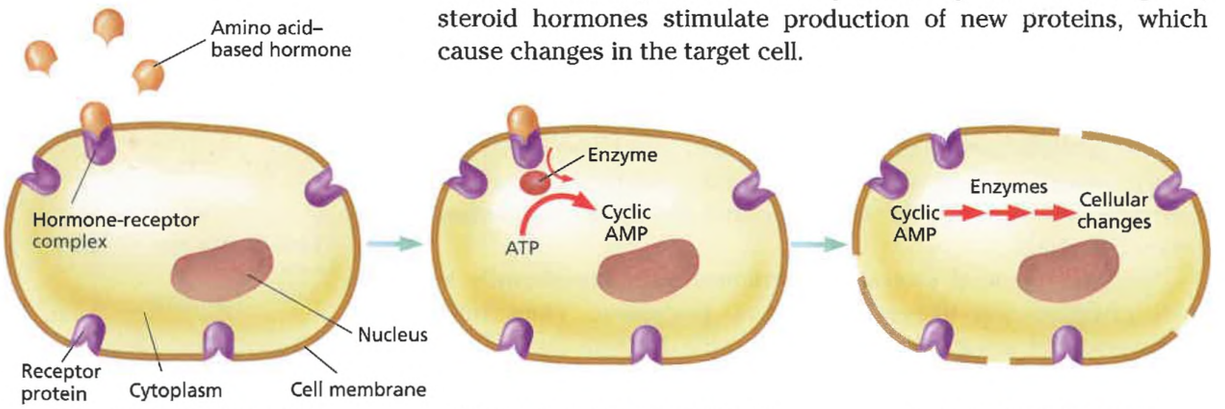
Because most amino acid–based hormones cannot diffuse passively across the membranes of their target cells, a two-messenger system is commonly required for the action of most of these hormones. Amino acid–based hormones identify their target cells by their attraction to receptor proteins that are embedded in the target cell membrane. The hormone acts as a **first messenger** by binding to a specific receptor on the surface of its target cell. This forms a **hormone-receptor complex,** which activates a second messenger located inside the target cell. A **second messenger** relays and amplifies the hormone signal. Figure 51-1 shows how, in many cases, the hormone-receptor complex indirectly activates an enzyme that converts molecules of ATP to cyclic AMP (c-AMP) inside the cell. Cyclic AMP acts as a second messenger by indirectly activating other enzymes and proteins in the target cell. Thus, c-AMP initiates a chain of biochemical events that leads to functional changes within the target cell.

FIGURE 51-1

(a) An amino acid–based hormone acts as a first messenger by binding to receptor proteins located on the target cell membrane. (b) The hormone-receptor complex indirectly activates an enzyme that converts ATP to cyclic AMP. (c) Cyclic AMP indirectly activates other enzymes that cause changes in the target cell.

Steroid Hormones

Steroid hormones do not act through cell surface receptors. Instead, they diffuse through the membranes of their target cells and bind to receptors in the cytoplasm. The newly formed hormone-receptor complexes cause the cells to activate existing enzymes or to initiate synthesis of new enzymes or proteins. Figure 51-2 illustrates how a hormone-receptor complex binds to DNA inside the nucleus of a target cell. Once bound to DNA, the hormone-receptor complex activates transcription of mRNA. By activating mRNA transcription, steroid hormones stimulate production of new proteins, which cause changes in the target cell.



(a) FIRST-MESSENGER ACTION (b) SECOND-MESSENGER ACTION (c) CELLULAR RESPONSES

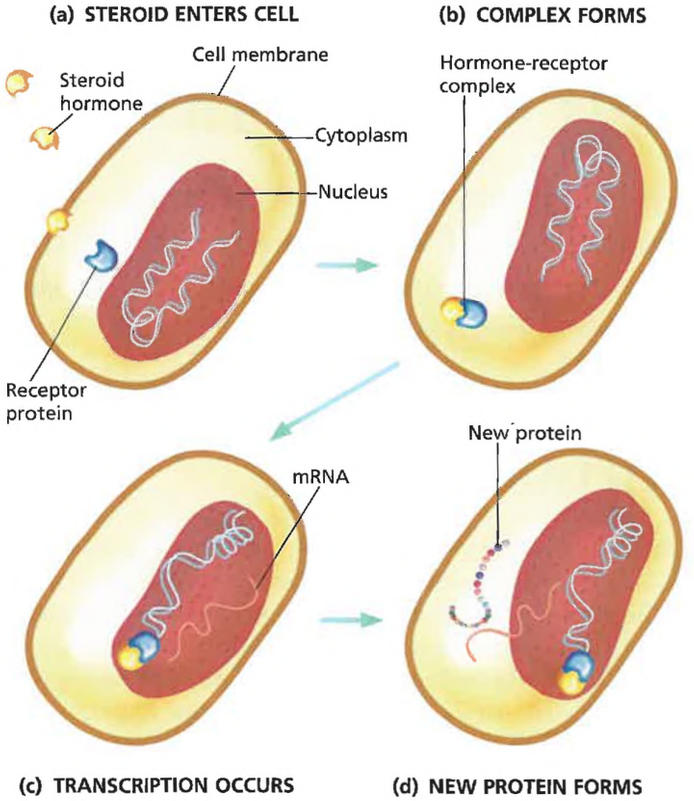


FIGURE 51-2

(a) Steroid hormones diffuse through the target cell membrane. (b) Once inside the target cell, the hormone binds to a receptor protein. (c) The newly formed hormone-receptor complex enters the nucleus of the target cell and binds to DNA, activating mRNA transcription. (d) Genes are activated, mRNA is transcribed, and new proteins are synthesized.

PROSTAGLANDINS

Prostaglandins (PRAHS-tuh-GLAN-dinz), a group of hormonelike lipids, also regulate cell activities. Unlike hormones, prostaglandins are not produced by specific endocrine glands. Instead, these chemicals are produced in small quantities by many cells throughout the body. Rather than being transported through the blood to distant regions of the body, prostaglandins act locally. Their effects include relaxation of smooth muscles that line air passageways and blood vessels, regulation of blood pressure, contraction of the intestinal walls and the uterus, and stimulation of the body's inflammatory response to infection.

SECTION 51-1 REVIEW

1. Compare exocrine glands with endocrine glands.
2. What are hormones, and what do they do?
3. Explain the differences in the way amino acid–based hormones and steroid hormones affect their target cells.
4. How are hormones transported throughout the body?
5. Compare prostaglandins with hormones.
6. **CRITICAL THINKING** Why are nonendocrine messengers not considered to be hormones?

SECTION

51-2

OBJECTIVES

- List the major endocrine glands and hormones found in the body.
- Discuss the relationship between the hypothalamus and the pituitary gland.
- Describe the function of each endocrine gland.

ENDOCRINE GLANDS

Endocrine glands, shown in Figure 51-3, are located throughout the body and regulate many of its vital processes. This section discusses the hormones that each endocrine gland produces and their effects on the body.

PITUITARY GLAND

The **pituitary** (puh-TOO-uh-TER-ee) **gland,** shown in Figure 51-4, secretes hormones that affect other glands and organs. The two lobes of the pituitary gland are regulated by the hypothalamus, a structure of the nervous system, also shown in Figure 51-4. The hypothalamus links the nervous system to the endocrine system. **Neurosecretory** (NOO-roh-SEE-kret-ohr-ee) **cells** of the hypothalamus produce hormones that either are stored in the pituitary gland or regulate the pituitary's activity. The hypothalamus and the pituitary gland are the primary regulators of the endocrine system.

Posterior Pituitary

Two amino acid–based hormones—oxytocin and antidiuretic hormone—are produced by neurosecretory cells whose axons extend into the posterior pituitary lobe, as shown in Figure 51-4. These hormones are transported down these axons into the posterior pituitary, where they are stored for eventual release into the bloodstream. Signaling through these neurons, the hypothalamus also regulates the secretion of these hormones from the posterior pituitary.

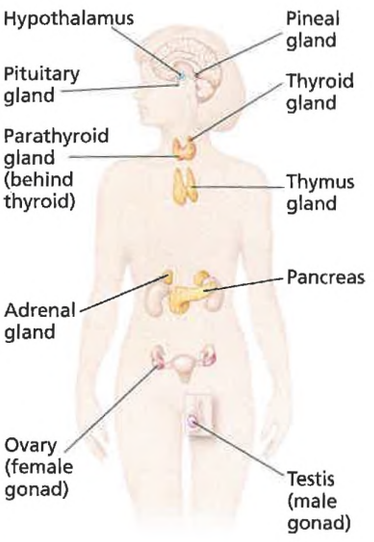
Oxytocin (AHK-see-TOH-sin) stimulates contraction of the uterus—a structure of the female reproductive system—during childbirth and flow of breast milk from the mammary glands during nursing. **Antidiuretic** (AN-tie-die-yoo-RET-tik) **hormone (ADH)** helps regulate the concentration of solutes in the blood by controlling the amount of water excreted by the kidneys. When the concentration of solutes in the blood increases, the hypothalamus signals the posterior pituitary to secrete ADH. ADH causes tubules in the kidneys to reabsorb water into the blood. Thus, the kidneys produce urine with a high solute concentration. Hypothalamic receptors detect the subsequent decrease in the concentration of solutes in the blood and stop signaling the posterior pituitary to release ADH.

Anterior Pituitary

Neurosecretory cells also produce and secrete **releasing hormones,** which stimulate endocrine cells of the anterior pituitary

FIGURE 51-3

Endocrine glands are located throughout the body. All of these glands contain cells that secrete hormones. The hypothalamus is a part of the nervous system that regulates the pituitary gland.



lobe to produce and secrete hormones. Other hypothalamic neurosecretory cells produce **release-inhibiting hormones,** which inhibit production and secretion of anterior-pituitary hormones. Releasing hormones and release-inhibiting hormones are produced in response to various stimuli that are processed by the nervous system. There is at least one releasing hormone for each anterior-pituitary hormone. As shown in Figure 51-4, a specialized system of blood vessels connects the hypothalamus with the anterior pituitary. Neurosecretory cells release hormones into the anterior pituitary through blood vessels.

Some anterior pituitary hormones, such as prolactin and growth hormone, are regulated by the hypothalamus through both a releasing hormone and a release-inhibiting hormone. **Growth hormone (GH)** controls skeletal and muscular growth. **Prolactin** (proh-LAK-tin) **(PRL)** stimulates and sustains production of breast milk during lactation. PRL-releasing hormone stimulates PRL production and secretion, whereas PRL release-inhibiting hormone stops PRL secretion. Releasing hormones also regulate production and secretion of other hormones—luteinizing hormone, follicle-stimulating hormone, adrenocorticotropic hormone, and thyroid-stimulating hormone—in the anterior pituitary that stimulate other endocrine glands. Table 51-1 lists eight hormones that are secreted by the pituitary gland.

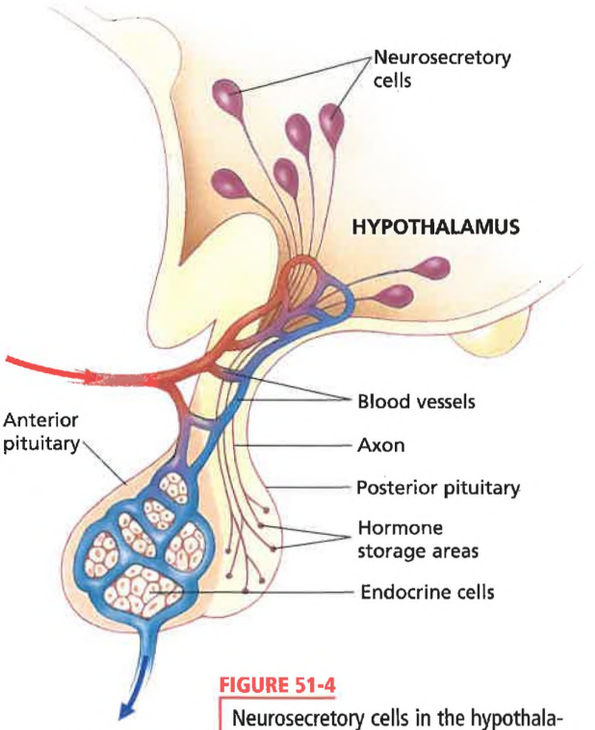


FIGURE 51-4
Neurosecretory cells in the hypothalamus produce hormones that affect the pituitary gland. The hypothalamus regulates the posterior pituitary through axons and the anterior pituitary through blood vessels. (Blood vessels in the posterior pituitary have been omitted to show axon projections.)

TABLE 51-1 *Hormones Secreted by the Pituitary Gland*

Hormone	Target	Function
Adrenocorticotropic hormone (ACTH)	adrenal cortex	stimulates secretion of cortisol and aldosterone by the adrenal cortex
Antidiuretic hormone (ADH)	kidney tubules	stimulates reabsorption of water by kidneys, reducing the concentration of solutes in the blood
Follicle-stimulating hormone (FSH)	ovaries in females; testes in males	stimulates egg production in females; stimulates sperm production in males
Growth hormone (GH)	muscle and bone	regulates development of muscles and bones
Luteinizing hormone (LH)	ovaries in females; testes in males	stimulates progesterone and estrogen production; initiates ovulation in females; stimulates testosterone production
Oxytocin	mammary glands and uterine muscles	initiates uterine contractions during childbirth; stimulates flow of milk from breasts during lactation
Prolactin (PRL)	mammary glands	stimulates milk production in breasts during lactation
Thyroid-stimulating hormone (TSH)	thyroid gland	regulates secretion of the thyroid hormones—thyroxine and triiodothyronine

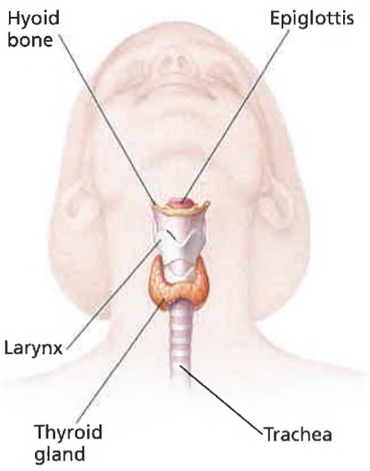


FIGURE 51-5

The thyroid gland is located under the larynx and on the trachea.

Quick Lab

Observing Solubilities

Materials 100 mL beakers (4), water, gelatin, cooking oil, vitamin A or E capsules, dissecting pin, measuring spoon

Procedure

1. Put 75 mL of water into a beaker. Place 2.5 g of gelatin (protein) into the beaker, and swirl the solution. Does the gelatin dissolve? Record your observations.
2. Put 75 mL of oil into a clean beaker. Repeat the procedure in step 2 using oil instead of water.
3. Repeat steps 1 and 2 using the contents of a vitamin capsule (fat) instead of gelatin.

Analysis Which substance is fat soluble? Which substance is water soluble? What type of substance can diffuse through a cell membrane? Relate the solubilities of hormones to whether or not they enter their target cells or work outside them.

THYROID GLAND

The two lobes of the **thyroid** (THIE-ROYD) **gland** are located near the lower part of the larynx, as shown in Figure 51-5. **Thyroid-stimulating hormone (TSH)** regulates the thyroid gland. Release of TSH from the anterior pituitary is regulated by both a releasing hormone and a release-inhibiting hormone. When stimulated by TSH, the thyroid gland produces and secretes the hormones **thyroxine** (thie-RAHK-sin) and **triiodothyronine** (TRIE-ie-oh-DOH-THIE-roh-NEEN). Both of these hormones are derived from the same amino acid and are synthesized with iodine atoms. The thyroid hormones help maintain normal heart rate, blood pressure, and body temperature. They stimulate enzymes that are associated with glucose oxidation and oxygen consumption, generating heat and increasing cellular metabolic rates. They also promote carbohydrate usage over fat usage for energy.

The thyroid gland is important to human development. It also produces **calcitonin** (KAL-sih-TOH-nin), a hormone that stimulates the transfer of calcium ions from blood to bone, where they can be used to generate bone tissue.

Abnormal thyroid activity can be detrimental to the body's metabolism. Overproduction of the thyroid hormones is called **hyperthyroidism** (HIE-puhr-THIE-royd-izm). Symptoms of hyperthyroidism include overactivity; weight loss; and high blood pressure, heart rate, and body temperature. Hyperthyroidism can be treated with medication or by surgical removal of part of the thyroid gland. Thyroid-hormone deficiency is known as **hypothyroidism** (HIE-poh-THIE-royd-izm). Symptoms of hypothyroidism include growth retardation, lethargy, weight gain, and low heart rate and body temperature. It can also cause **cretinism** (KREET-uhn-IZ-uhm), a form of mental retardation, during fetal and childhood development. If hypothyroidism is caused by iodine deficiency, then **goiter** (GOY-tuhr), or swelling of the thyroid gland, results. Hypothyroidism can be treated with supplementary thyroxine.

ADRENAL GLANDS

One **adrenal** (uh-DREE-nuhl) **gland** is located above each kidney, as shown in Figure 51-6. Each adrenal gland has an inner core, the medulla, and an outer layer, the cortex. The medulla and cortex function as separate endocrine glands. Medullary hormone secretion is controlled by the nervous system, whereas the anterior pituitary regulates cortical hormone secretion.

Adrenal Medulla

The adrenal medulla produces two amino acid–based hormones: **epinephrine** (EP-i-NEF-rin) and **norepinephrine** (NOHR-ep-i-NEF-rin) **(NE),**

also known as adrenaline (uh-DREN-uh-lin) and noradrenaline (NOR-uh-DREN-uh-lin), respectively. These hormones orchestrate the nervous system's reaction to stress and its "fight-or-flight" response to danger. When a person is stressed, the medulla secretes epinephrine and NE into the bloodstream. These hormones cause the liver to break down glycogen into glucose, raising the level of glucose, which is oxidized for additional energy, in the blood. The results include enlargement of the bronchial tubes, dilation of the pupils, and an increase in heart rate. As the heart beats faster, surface blood vessels constrict, blood pressure rises, and more blood circulates to the muscles, brain, and heart.

Adrenal Cortex

The adrenal cortex responds to **adrenocorticotropic** (uh-DRE-noh-KOHR-ti-koh-TROH-pik) **hormone (ACTH),** which is secreted by the anterior pituitary. Stress causes the hypothalamus to secrete ACTH-releasing hormone. ACTH then stimulates the adrenal cortex to produce the steroid hormones **cortisol** (KOHRT-uh-SAWL), which regulates metabolism of carbohydrates and proteins, and **aldosterone** (al-DAHS-tuh-ROHN), which helps maintain the salt-and-water balance in the body by affecting the kidneys.

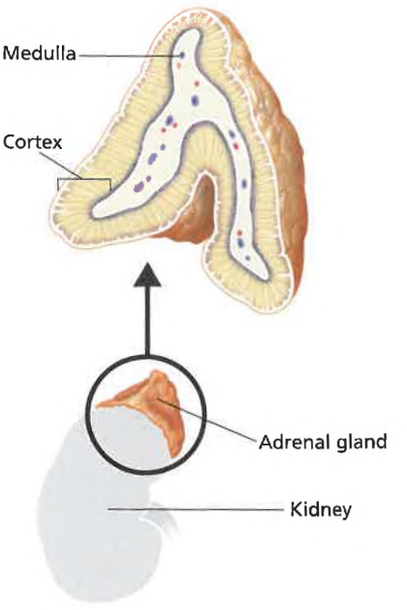


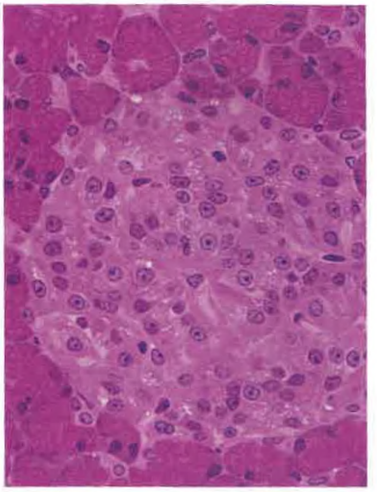
FIGURE 51-6
The adrenal glands, located above each kidney, consist of an inner medulla and an outer cortex. Epinephrine and norepinephrine are produced in the medulla, while cortisol and aldosterone are produced in the cortex.

GONADS

Gonads—the ovaries in females and the testes in males—are gamete-producing organs that also produce a group of steroid sex hormones. **Sex hormones** regulate body changes that begin at puberty. **Puberty** (PYOO-buhr-tee) is the adolescent stage during which the sex organs mature and secondary sex characteristics, such as facial hair, appear. During puberty in males, sperm production begins, the voice deepens, the chest broadens, and hair grows on the body and face. In females, the menstrual cycle begins, the breasts grow, and the hips widen. When secreted by the anterior pituitary, **luteinizing** (LOO-tee-in-IZE-ing) **hormone (LH)** and **follicle-stimulating** (FOL-uh-kuhl) **hormone (FSH)** stimulate secretion of sex hormones from the gonads.

In females, LH and FSH stimulate secretion of **estrogen** (ES-truh-jen) and **progesterone** (proh-JES-tuh-ROHN) from the ovaries. In preparation for a possible pregnancy, these sex hormones cause the monthly release of an egg by an ovary and buildup of the uterine lining. Estrogen also regulates female secondary sex characteristics. In males, LH stimulates the testes to secrete a group of sex hormones called **androgens** (AN-druh-jenz). **Testosterone** (tes-TAHS-tuh-ROHN) is an androgen that regulates male secondary sex characteristics. Along with FSH, testosterone also stimulates sperm production. You will learn more about the gonads and the sex hormones in Chapter 52.

FIGURE 51-7
A cross section of pancreatic tissue shows the islets of Langerhans (lightly colored region). These endocrine cells are surrounded by exocrine cells that produce digestive fluids. (LM 315×)



PANCREAS

The pancreas mostly contains exocrine cells, but specialized cells in the pancreas called the **islets of Langerhans** (LANG-uhr-HANZ) function together as an endocrine gland. Shown in Figure 51-7, these endocrine cells secrete two amino acid–based hormones that regulate the level of sugar in the blood. **Insulin** (IN-suh-lin) lowers the blood sugar level by stimulating body cells, especially muscles, to absorb glucose. In contrast, **glucagon** (GLOO-kuh-gahn) stimulates release of glucose into the bloodstream by liver cells.

Insulin deficiency causes **diabetes mellitus** (die-uh-BEET-eez muh-LIET-uhs), a condition of abnormally high blood glucose concentration. Type I diabetes is a severe childhood disorder in which insulin-producing islet cells die. Type I generally is treated with daily injections of insulin into the blood, and sometimes is treated with islet cell transplant. Type II diabetes usually occurs after age 40, and it is more common and less severe than type I. Type II is caused by insufficient insulin or unresponsive target cell receptors. Although type II is hereditary, its onset correlates with obesity, and type II often can be controlled through exercise and diet. In people with diabetes, excess glucose inhibits water reabsorption by the kidneys, producing large amounts of urine. Thus, dehydration and kidney damage can result. Lack of insulin can also cause nausea and rapid breathing, possibly leading to oxygen deficiency, circulatory and nervous system failure, diabetic coma, or even death.

TABLE 51-2 *Summary of Endocrine Glands and Their Functions*

Glands	Hormone	Function
Adrenal glands		
Cortex	aldosterone	maintains salt-and-water balance
	cortisol	regulates carbohydrate and protein metabolism
Medulla	epinephrine, norepinephrine	initiate body's response to stress and the "fight-or-flight" response to danger
Ovaries	estrogen	regulates female secondary sex characteristics
	progesterone	maintains growth of uterine lining
Pancreas (islets of Langerhans)	glucagon	stimulates release of glucose
	insulin	stimulates absorption of glucose
Parathyroid glands	parathyroid hormone	increases blood calcium concentration
Pineal gland	melatonin	regulates sleep patterns
Pituitary gland	see Table 51-1	see Table 51-1
Testes	androgens (testosterone)	regulate male secondary sex characteristics
Thymus gland	thymosin	stimulates T-cell formation
Thyroid gland	thyroxine, triiodothyronine	increase cellular metabolic rates

Excessive insulin causes **hypoglycemia** (HIE-poh-glie-SEE-mee-uh), a disorder in which glucose is stored, rather than being properly delivered to body cells. This leads to a lowered blood glucose concentration and subsequent release of glucagon and epinephrine. Symptoms of hypoglycemia include lethargy, dizziness, nervousness, overactivity, and in extreme cases, unconsciousness and death.

OTHER ENDOCRINE GLANDS

There are several other glands in the endocrine system, including the thymus gland, the pineal gland, and the parathyroid glands. There are also specialized digestive endocrine cells. The endocrine glands and their functions are listed in Table 51-2.

The **thymus** (THIE-muhs) **gland,** located beneath the sternum and between the lungs, consists mostly of T-cells and plays a role in the development of the immune system. The thymus gland secretes **thymosin** (THIE-moh-sin), an amino acid–based hormone that stimulates formation of T-cells, which help defend the body from pathogens.

The **pineal** (PIEN-ee-uhl) **gland** is located near the base of the brain, as shown in Figure 51-8. It secretes the hormone melatonin. **Melatonin** (mel-uh-TOH-nin) concentrations increase sharply at night and decrease dramatically during the day. This cyclic release of melatonin indicates that it helps regulate sleep patterns.

As Figure 51-9 shows, the four **parathyroid glands** are embedded in the back of the thyroid gland, two in each lobe. These glands secrete **parathyroid hormone,** which increases the concentration of calcium ions in the blood. A proper balance of calcium ions is necessary for normal bone growth, muscle tone, and neural activity.

Endocrine cells within the walls of some digestive organs also secrete a variety of hormones that help digest food. When food is eaten, endocrine cells in the stomach lining secrete **gastrin** (GAS-trin), a hormone that stimulates other stomach cells to release digestive enzymes and hydrochloric acid. Endocrine cells of the small intestine release **secretin** (si-KREE-tin), a hormone that stimulates the release of various digestive fluids from the pancreas and bile from the liver.

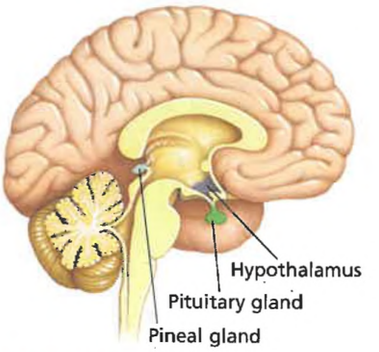
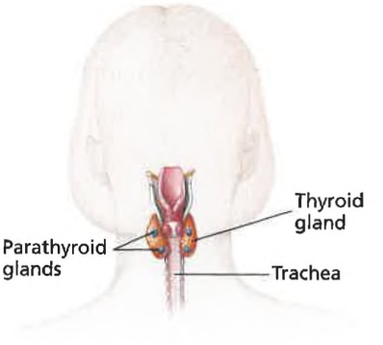


FIGURE 51-8
The pineal gland, located near the base of the brain, secretes the hormone melatonin at night.

FIGURE 51-9
The four parathyroid glands are embedded in the dorsal side of the thyroid gland. They secrete a hormone that regulates the concentration of calcium ions in the blood.



SECTION 51-2 REVIEW

1. List six endocrine glands and their functions.
2. What is a releasing hormone?
3. Describe the effects of two releasing hormones on the pituitary gland.
4. Explain why the pineal gland is considered the "biological clock" of the body and why the pituitary gland is considered the "master gland" of the body.
5. Describe the malfunctions that cause Type I and Type II diabetes.
6. **CRITICAL THINKING** Why might overactive parathyroid glands cause bone problems?

SECTION

51-3

OBJECTIVES

- Define the terms *feedback mechanism* and *antagonistic hormones.*
- Distinguish positive feedback from negative feedback.
- Explain the role of negative feedback mechanisms in maintaining homeostasis.
- Give examples of negative feedback in the endocrine system.

FEEDBACK MECHANISMS

The endocrine system uses feedback mechanisms to respond and adjust to changes that occur in and outside the body. In a ***feedback mechanism,*** *the last step in a series of events controls the first step.*

HOMEOSTASIS

Recall that homeostasis is defined as a stable internal environment. The endocrine system plays an important role in the maintenance of homeostasis because it affects the activities of cells, tissues, and organs throughout the body. For example, glucagon and insulin together maintain a balanced blood glucose concentration. These hormones are considered **antagonistic hormones** because their actions have opposite effects. Figure 51-10 illustrates how an increase in glucose concentration following glucagon secretion is counteracted by insulin secretion.

To maintain homeostasis, hormone secretion must be tightly regulated. One example of hormone regulation was discussed in Section 51-2: ADH secretion is controlled by hypothalamic receptors that detect the concentration of solutes in the blood. More-common types of endocrine control are **feedback mechanisms,** which are illustrated in Figure 51-11. Most hormone systems use **negative feedback,** in which release of an initial hormone stimulates release or production of other hormones or substances that subsequently inhibit further release of the initial hormone. In **positive feedback,** release of an initial hormone stimulates release or production of other hormones or substances, which stimulate further release of the initial hormone. For example, although LH regulates estrogen production by the ovaries, increased estrogen concentrations stimulate a surge in LH secretion prior to ovulation.

internetconnect

SCILINKS NSTA

TOPIC: Homeostasis
GO TO: www.scilinks.org
KEYWORD: HM1038

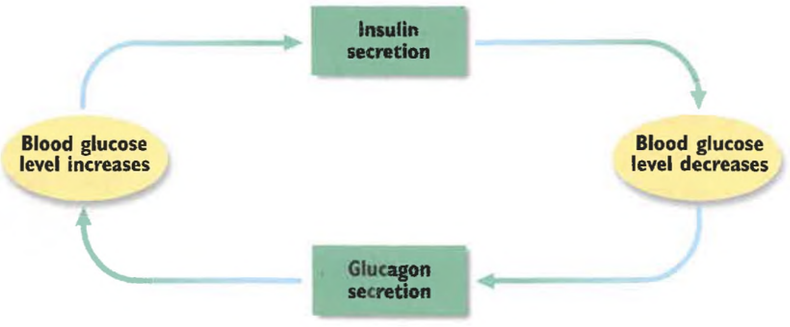


FIGURE 51-10
Working in opposition, glucagon and insulin maintain a balanced blood glucose concentration. These antagonistic hormones oppositely affect the amount of glucose in the blood.

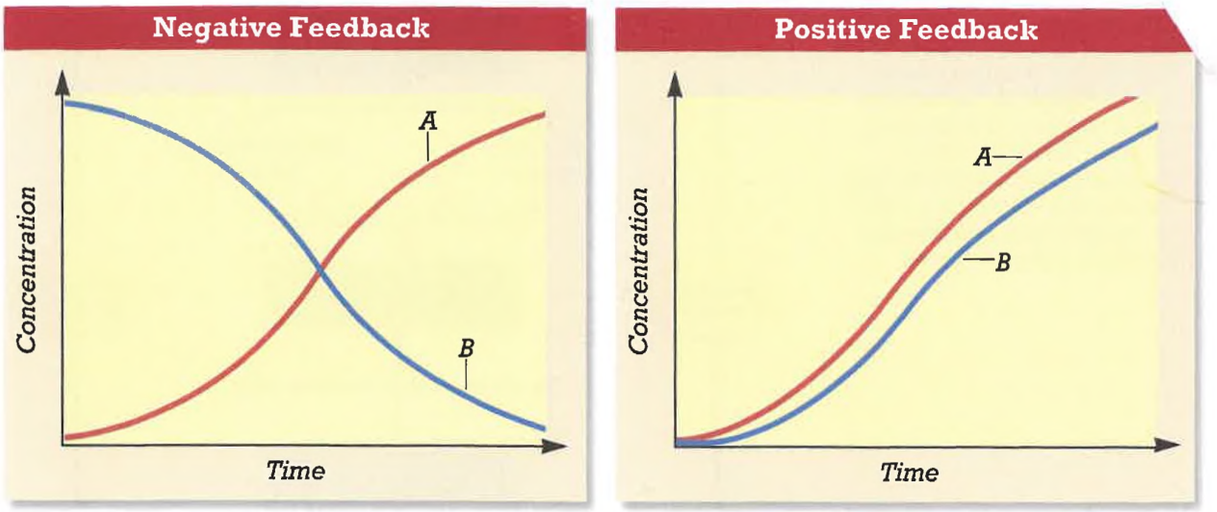


FIGURE 51-11
In negative feedback, a secondary substance (A) inhibits production of its initial stimulating substance (B). In positive feedback, a secondary substance (A) stimulates production of its initial stimulating substance (B).

NEGATIVE FEEDBACK MECHANISMS

Negative feedback mechanisms in the body involve interactions of the nervous, endocrine, and circulatory systems. In negative feedback, the final step in a series of events inhibits the initial signal in the series. To understand negative feedback, consider a home heating system that is controlled by a thermostat, as illustrated in Figure 51-12. When the room temperature drops below a set point, the thermostat activates the heater to produce heat. When room temperature returns to the set point, the thermostat shuts off the heater.

Negative feedback mechanisms help maintain hormone concentrations at a certain range. A good example of negative feedback in the endocrine system is the hypothalamus–anterior-pituitary–testis system discussed in Section 51-2. The hypothalamus secretes LH-releasing hormone, which stimulates secretion of LH from the anterior pituitary. LH is released into the bloodstream and is transported throughout the body. LH binds to its target cells in the testes, forming hormone-receptor complexes that stimulate c-AMP production, which leads to testosterone secretion into the bloodstream. Testosterone binds to its target cells, some of which are the hypothalamic neurosecretory cells that produce LH-releasing hormone. If the testosterone concentration is higher than normal, then secretion of LH-releasing hormone will be inhibited.

Another example of negative feedback in the endocrine system is the regulation of the concentration of the thyroid hormones in the blood. When the hypothalamus detects low concentrations of thyroxine and triiodothyronine, it secretes TSH-releasing hormone into the anterior

FIGURE 51-12
Negative feedback mechanisms inhibit the original signal as its products build up.

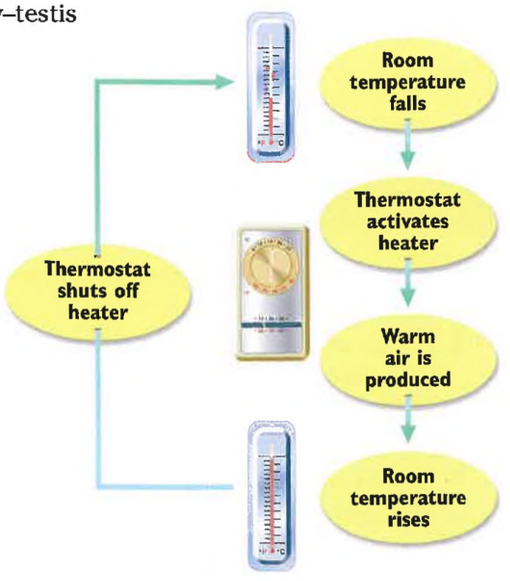
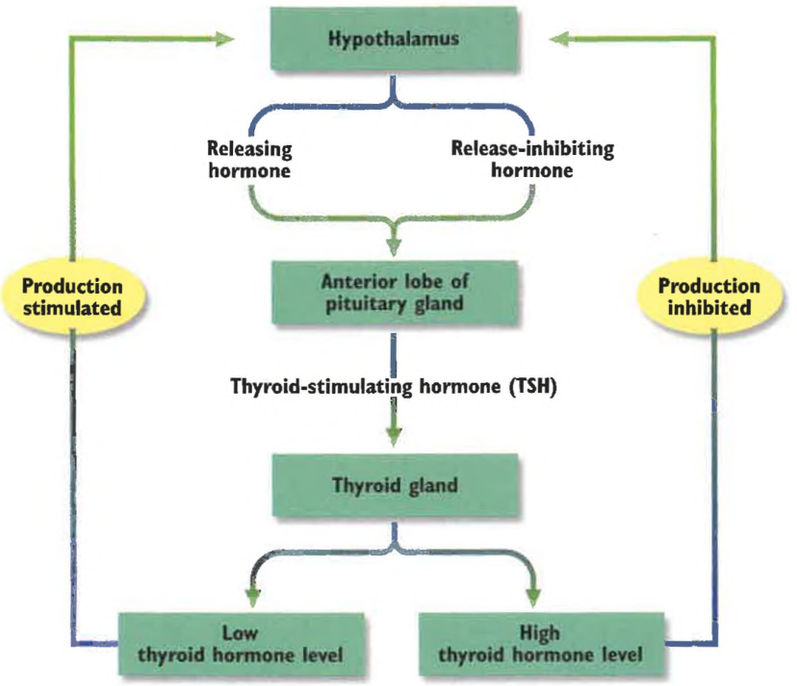


FIGURE 51-13

The thyroid hormones regulate cellular metabolic rates through a negative feedback mechanism. Low concentrations of the thyroid hormones stimulate production and secretion of TSH-releasing hormone from the hypothalamus; high concentrations inhibit TSH-releasing hormone but stimulate TSH release-inhibiting hormone.



pituitary, as Figure 51-13 illustrates. The anterior pituitary then secretes TSH into the bloodstream. TSH stimulates the thyroid gland to secrete thyroxine and triiodothyronine, whose target cells include hypothalamic neurosecretory cells that produce TSH-releasing hormone and TSH release-inhibiting hormone. When the hypothalamus detects increasing concentrations of the thyroid hormones in the blood, it stops secreting TSH-releasing hormone and begins to secrete TSH release-inhibiting hormone into the anterior pituitary. Thus, the anterior pituitary no longer secretes TSH, and the thyroid gland no longer secretes thyroxine and triiodothyronine. As a result, the concentration of the thyroid hormones in the blood decreases. When the concentration again drops to a certain point, the cycle is repeated.

SECTION 51-3 REVIEW

1. Explain why glucagon and insulin are antagonistic hormones.
2. Explain what might happen to the level of glucose circulating in the blood if the production of insulin were controlled by a positive, rather than a negative, feedback mechanism.
3. How do feedback mechanisms help maintain homeostasis?
4. What would happen if a thermostat operated under a positive feedback mechanism?
5. How would lack of dietary iodine affect the negative feedback mechanism that controls the level of the thyroid hormones?
6. **CRITICAL THINKING** Why is it important to carefully control the dose of thyroxine administered to a person with hypothyroidism?

CHAPTER 51 REVIEW

SUMMARY/VOCABULARY

51-1

- Endocrine glands produce and secrete hormones that affect distant target cells.
- Amino acid–based hormones bind to receptors on their target cells, activating a second messenger.
- Steroid hormones diffuse through the membranes of their target cells and bind to cytoplasmic receptors.
- Prostaglandins are hormonelike lipids that affect nearby cells.

Vocabulary

amino acid–based hormone (1029)
endocrine gland (1029)
endocrine system (1029)
exocrine gland (1029)
first messenger (1030)
hormone-receptor complex (1030)
hormone (1029)
prostaglandin (1031)
receptor (1030)
second messenger (1030)
steroid hormone (1029)
target cell (1030)

51-2

- The hypothalamus links the nervous system to the endocrine system by regulating the pituitary gland.
- Releasing hormones and release-inhibiting hormones secreted by the hypothalamus regulate the anterior-pituitary hormones.
- The thyroid gland secretes hormones that regulate metabolism.
- The adrenal glands help regulate metabolism and the body's responses to stress and danger.
- The gonads secrete sex hormones that are responsible for body changes that begin at puberty.
- The islets of Langerhans of the pancreas secrete hormones that regulate the blood glucose level.
- Other endocrine glands include the thymus gland, the pineal gland, the parathyroid glands, and endocrine cells of the digestive system.

Vocabulary

adrenal gland (1034)
adrenocorticotropic hormone (1035)
aldosterone (1035)
androgens (1035)
antidiuretic hormone (1032)
calcitonin (1034)
cortisol (1035)
cretinism (1034)
diabetes mellitus (1036)
epinephrine (1034)
estrogen (1035)
follicle-stimulating hormone (1035)
gastrin (1037)
glucagon (1036)
goiter (1034)
gonads (1035)
growth hormone (1033)
hyperthyroidism (1034)
hypoglycemia (1037)
hypothyroidism (1034)
insulin (1036)
islets of Langerhans (1036)
luteinizing hormone (1035)
melatonin (1037)
neurosecretory cell (1032)
norepinephrine (1034)
oxytocin (1032)
parathyroid gland (1037)
parathyroid hormone (1037)
pineal gland (1037)
pituitary gland (1032)
progesterone (1035)
prolactin (1033)
puberty (1035)
release-inhibiting hormone (1033)
releasing hormone (1032)
secretin (1037)
sex hormones (1035)
testosterone (1035)
thymosin (1037)
thymus gland (1037)
thyroid gland (1034)
thyroid-stimulating hormone (1034)
thyroxine (1034)
triiodothyronine (1034)

51-3

- Feedback mechanisms help maintain homeostasis.
- In negative feedback, the final step in a series inhibits the first step.
- In positive feedback, the final step in a series stimulates the first step.

Vocabulary

antagonistic hormone (1038)
feedback mechanism (1038)
negative feedback (1038)
positive feedback (1038)

REVIEW

Vocabulary

For each set of terms below, choose the one that does not belong and then explain why it does not belong.

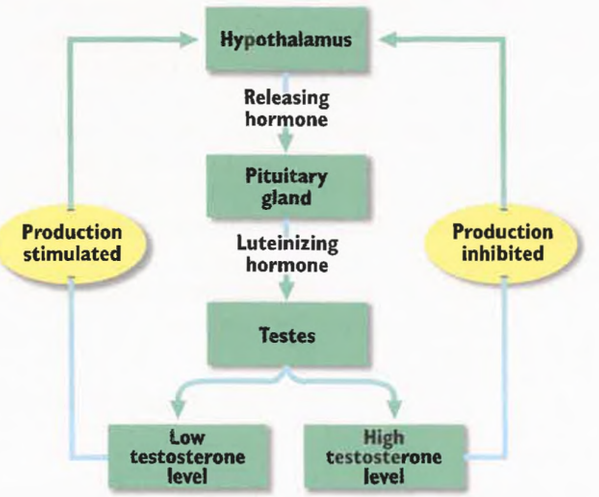
1. insulin, prostaglandin, thyroxine, GH
2. oxytocin, prolactin, epinephrine, ADH
3. cortisol, parathyroid hormone, epinephrine, aldosterone
4. aldosterone, estrogen, progesterone, testosterone
5. thyroid gland, liver, adrenal glands, pineal gland

Multiple Choice

6. The endocrine system (a) affects only the nervous system (b) helps maintain homeostasis (c) affects only the reproductive system (d) primarily uses positive feedback.
7. In a negative feedback system, the end product (a) inhibits the first step (b) inhibits the last step (c) stimulates the first step (d) stimulates the last step.
8. Steroid hormones (a) bind to receptors on a target cell (b) convert ATP to cyclic AMP (c) diffuse through the target cell membrane (d) activate a second messenger.
9. Cyclic AMP is produced by a cell in response to (a) estrogen (b) amino acid–based hormones (c) testosterone (d) steroid hormones.
10. Which of the following organs does not contain endocrine cells? (a) stomach (b) pancreas (c) small intestine (d) liver
11. Diabetes mellitus can be caused by (a) insufficient insulin (b) lack of insulin receptors (c) obesity (d) all of the above.
12. The interaction of the hypothalamus and the pituitary gland demonstrates (a) the relationship between the nervous system and the endocrine system (b) the relationship between the endocrine system and the digestive system (c) that energy from the hypothalamus transports glucose (d) the involvement of the pituitary gland in prostaglandin production.
13. Prostaglandins are (a) lipids (b) hormones (c) endocrine glands (d) proteins.
14. Oxytocin (a) is secreted by the posterior pituitary (b) controls the amount of water excreted in the urine (c) increases the calcium ion concentration in the blood (d) regulates secondary sex characteristics.
15. Which of the following is both an exocrine gland and an endocrine gland? (a) the thyroid gland (b) the pancreas (c) the thymus gland (d) the pituitary gland

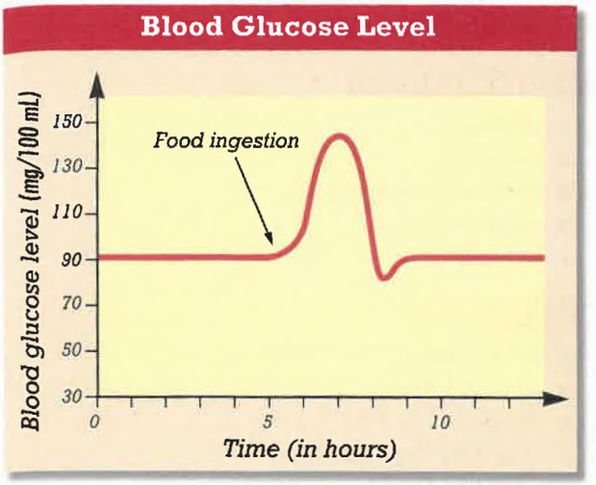
Short Answer

16. Describe the interaction of a steroid hormone and its target cell.
17. Why is positive feedback not an efficient way to control hormone levels?
18. What would be the consequence if the pituitary gland secreted too little ADH?
19. Explain why frequent urination is a symptom of diabetes.
20. How does gastrin help digestion?
21. Describe two ways in which the endocrine system and the nervous system are similar.
22. How does the endocrine system help the immune system?
23. Name two antagonistic hormones besides insulin and glucagon.
24. How do LH and FSH help regulate secondary sex characteristics in males and females?
25. Identify and describe the type of feedback mechanism operating in the diagram shown below.



CRITICAL THINKING

1. Why might damage to the pituitary gland be considered far more serious than damage to one of the other endocrine glands?
2. A number of different hormones secreted by various endocrine glands help regulate the blood glucose concentration. Based on your knowledge of the importance of glucose, hypothesize why glucose should be controlled by several hormones rather than just one hormone.
3. Severe structural abnormalities result from gigantism, a condition of extremely rapid growth, and from pituitary dwarfism, a condition of slowed growth. Based on your knowledge of the endocrine system, suggest what causes these disorders.
4. Suppose that a friend tells you that he or she has recently experienced some of the warning signs of diabetes mellitus. What other conditions could cause symptoms that are similar to those of diabetes?
5. The graph shown at right illustrates the change in the blood glucose level before and after eating. According to the graph, what happens after food is eaten?
6. Which hormones are primarily responsible for the changes in blood glucose level shown in the graph?
7. Referring to the graph, identify and explain the type of feedback mechanism that enables the body to adjust the blood glucose level after eating.



EXTENSION

1. The connection between melatonin and sleep patterns has kindled interest in this hormone. Check the library and on-line references for information about other uses that have been proposed for melatonin.
2. Read "Hormone Helps Ring Internal Alarm Clock" in *Science News*, January 9, 1999, on page 22. Describe the hormones that control waking from sleep. What did the researchers conclude was the primary factor that set the neurological timer to prepare the body to awaken?
3. Read "Is Leptin a 'Thrifty' Hormone in Muscle and Fat?" in *Science*, March 10, 2000, on page 1739. Explain the "thrifty genotype" proposition as an evolutionary mechanism that prepares a body for times of famine. How does this hypothesis explain why many people who live in developed countries struggle with obesity?
4. Check the library and on-line references for information about disorders of the endocrine system, such as Addison's disease, diabetes mellitus, Cushing's syndrome, and pituitary gigantism and dwarfism. Describe the symptoms and treatments for these and other disorders of the endocrine system.
5. Read "Hormone Recall" in *New Scientist*, September 18, 1999, on page 12. Investigate evidence presented in the article that estrogen is involved in memory and cognitive circuits in the brain. Also investigate the evidence that hormone replacement therapy protects the brains of postmenopausal women against diseases such as Alzheimer's.

CHAPTER 51 INVESTIGATION

Observing the Effects of Thyroxine on Frog Metamorphosis

OBJECTIVES

- Observe the effects of the hormone thyroxine on the development of tadpoles.

PROCESS SKILLS

- observing
- measuring
- comparing and contrasting
- organizing data
- inferring

MATERIALS

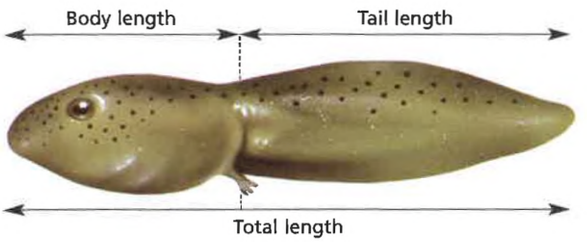
- safety goggles
- protective gloves
- lab apron
- glass-marking pencil
- six 600 mL beakers
- pond water
- 10 mL graduated cylinder
- 0.01% thyroxine solution
- strained spinach
- graph paper marked in 1 mm squares
- Petri dish
- small fish net
- 9 tadpoles with budding hind legs
- 3 pencils in different colors

Background

1. What is a hormone?
2. What is metamorphosis?
3. Describe the stages of frog development.
4. What are the effects of thyroxine in humans?
5. What effects do you predict the hormone thyroxine will have on tadpole growth and development?

PART A Setting Up the Experiment

1. In your lab report, make a data table similar to the one shown on the facing page.
2. Use a glass-marking pen to label three beakers A, B, and C. Also write your initials on the beakers.
3. Add 500 mL of pond water to each beaker.
4. CAUTION **Put on a lab apron and safety goggles. If you get thyroxine on your skin or clothing, rinse with water while calling to your teacher. If you get thyroxine in your eyes, immediately flush them with water at the eyewash station while calling to your teacher.**
5. Use a graduated cylinder to measure 10 mL of thyroxine solution. Add the 10 mL of solution to beaker A. Measure and add 5 mL of thyroxine solution to beaker B.
6. Add equal amounts (about 1 mL) of strained spinach to beakers A, B, and C.
7. Place a sheet of graph paper, ruled side up, under a Petri dish.
8. CAUTION **You will be working with live animals. Handle them with care and follow directions carefully.** Catch a tadpole with a fish net and place the tadpole in the Petri dish. Measure the tadpole's total length, tail length, and body length in millimeters by counting the number of squares that it covers on the graph paper. Then place the tadpole in beaker A.



9. Repeat step 8 with two more tadpoles. Average the total length, tail length, and body length of the three tadpoles that you placed in beaker A. In your data table, record the average measurements under the column labeled "Beaker A."

10. Repeat step 8 with three more tadpoles, this time placing the tadpoles in beaker B. Average the total length, tail length, and body length of the three tadpoles. Record your average measurements in your data table under "Beaker B."
11. Repeat step 8 with three more tadpoles. Place these three tadpoles in beaker C. Average the total length, tail length, and body length of the three tadpoles. Record your average measurements in your data table under "Beaker C." You should have measured a total of nine tadpoles and placed three in each beaker.
12.  Clean up your materials and wash your hands before leaving the lab.

Part B Observing the Effects of Thyroxine on Tadpoles

13. Feed the tadpoles 1 mL of spinach every other day. Be careful not to overfeed the tadpoles. Change the water in the beakers every 4 days, adding thyroxine solution in the original amounts to beakers A and B. Label the beakers, and do not mix up the tadpoles during the water changes.
14. Measure the tadpoles once a week for 3 weeks and average the length of the tadpoles in each beaker. Record the average lengths in your data table.
15. Calculate the average growth-per-week for each set of three tadpoles. For example, the average growth in total length during the second week is equal to the average total length at the end of week 2 minus the average total length at the end of week 1. Record your values in the appropriate spaces of your data table.
16. Graph your data using a different colored pencil for the tadpoles in each beaker. Label the horizontal axis "Time in weeks," and label the vertical axis "Length in centimeters." You should have three graphs. Each graph should include the changes in average total length, average tail length, and average body length for one group of tadpoles.
17.  Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

1. Did this investigation include a control group? If so, describe it. If not, suggest a possible control that you could have used.
2. Why are three tadpoles used for each beaker rather than just one?
3. According to the data that you collected in this investigation, what is the effect of thyroxine on tadpole metamorphosis?
4. Which concentration of thyroxine solution caused the greatest visible change in the tadpoles?
5. How do average body length and tail length change during metamorphosis?

Further Inquiry

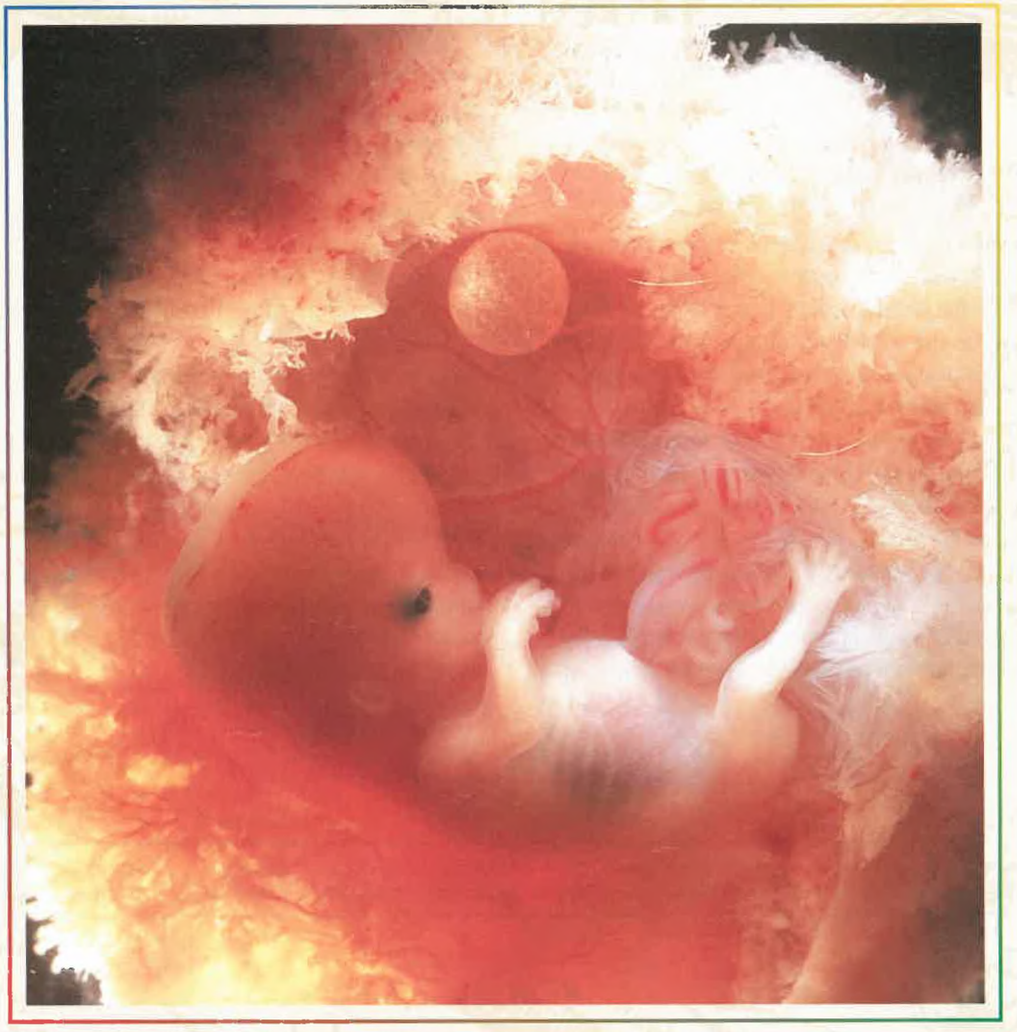
Iodine is needed to produce thyroxine. Design—but do not conduct—an experiment that shows the effect of adding iodine to water that contains tadpoles. NOTE: Iodine is a highly poisonous substance.

MEASUREMENT OF TADPOLE GROWTH

	Beaker A			Beaker B			Beaker C		
	Average total length	Average tail length	Average body length	Average total length	Average tail length	Average body length	Average total length	Average tail length	Average body length
Initial									
End of week 1									
End of week 2									
End of week 3									

CHAPTER 52

REPRODUCTIVE SYSTEM



This is a photograph of a fetus. Notice the umbilical cord and the placenta, through which oxygen and nutrients are passed from the mother to the fetus.

FOCUS CONCEPT: *Structure and Function*

As you read this chapter, notice how the structures of the male and female reproductive systems are adapted for fertilization and development.

MALE REPRODUCTIVE SYSTEM

Recall from Chapter 51 that the gonads—testes and ovaries—are endocrine glands that secrete sex hormones. However, the primary function of the gonads is not to produce hormones but to produce and store gametes—sperm and eggs. Other organs in the male reproductive system prepare sperm for the possible fertilization of an egg.

SECTION 52-1

OBJECTIVES

- Describe the structure of a human sperm.
- Identify the major parts of the male reproductive system.
- Describe the function of each part of the male reproductive system.
- Trace the path that sperm follow in leaving the body.

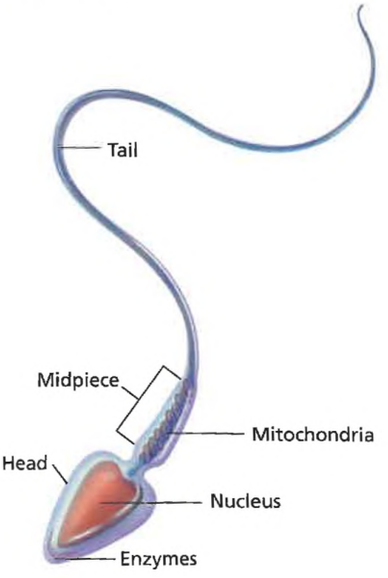
FORMATION OF SPERM

Males begin to produce sperm during puberty, the adolescent stage of development when changes in the body make reproduction possible. At this time, the concentration of the hormone testosterone is high enough to stimulate sperm production. Recall from Chapter 51 that testosterone is the main androgen (male sex hormone) produced by the testes. The **testes** (TES-teez) are the gamete-producing organs of the male reproductive system. A male will continue to produce sperm as long as his testosterone level is high enough—usually for most of his life.

In Chapter 8, you learned that the formation of gametes in humans involves the process of meiosis. Recall that meiosis results in a reduction of the number of chromosomes from the diploid ($2n$) number to the haploid ($1n$) number. As cells that produce sperm within the testes undergo meiosis, their chromosome number drops from 46 to 23. Four sperm cells result from each cell that begins meiosis. The immature sperm that result from meiosis then undergo significant changes. These changes prepare the sperm for passage through the female reproductive system.

The structure of a mature sperm is shown in Figure 52-1. Notice that a mature sperm consists of three regions—a head, a midpiece, and a tail. The tip of the head region contains enzymes. During fertilization, these enzymes help the sperm penetrate the protective layers that surround an egg cell. Also located in the head region are the 23 chromosomes that will be delivered to the egg. The midpiece is packed with mitochondria. Remember from Chapter 6 that mitochondria are the sites of aerobic respiration and ATP production. These mitochondria supply the energy that is required for sperm to reach an egg. The tail consists of a single, powerful flagellum that propels the sperm.

FIGURE 52-1
A mature sperm is an elongated cell with three distinct parts, all of which are enclosed by a cell membrane.



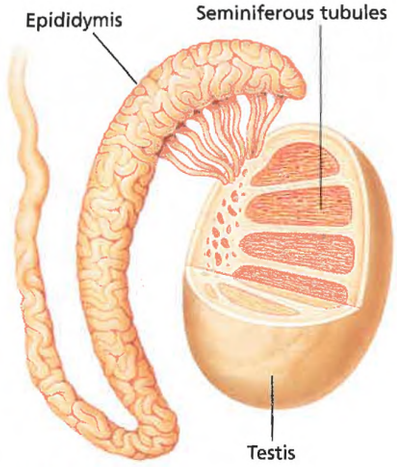


FIGURE 52-2

Sperm are formed continuously within the seminiferous tubules, which make up the bulk of each testis. Cells in the tissue that surrounds the seminiferous tubules secrete testosterone, which stimulates the production of sperm. Before leaving the body, sperm mature and are stored in each epididymis.

MALE REPRODUCTIVE STRUCTURES

The male reproductive system contains two egg-shaped testes. Each testis, which is about 4 cm (1.5 in.) long and 2.5 cm (1 in.) in diameter, has about 250 compartments. As shown in Figure 52-2, these compartments contain many tightly coiled tubules, called **seminiferous** (SEM-uh-NIF-uhr-uhs) **tubules.** Each seminiferous tubule is approximately 80 cm (32 in.) long. If all of the tubules in both testes were stretched out end to end, they would extend about 500 m (1,640 ft). Sperm form through meiosis in the specialized lining of this extensive network of tubules.

The testes develop within the abdominal cavity. Before a male is born, the testes leave this cavity and descend into an external sac called the **scrotum** (SKROHT-uhm). The temperature within the scrotum is about 3°C cooler than the temperature inside the abdomen. The slightly cooler temperature of the scrotum is necessary for the development of normal sperm.

Path of Sperm Through the Male Body

Mature sperm move through and past several other male reproductive structures, some of which further prepare the sperm for a possible journey through the female reproductive system. Figure 52-3 shows the path taken by sperm as they exit the body.

Sperm move from the seminiferous tubules to the **epididymis** (EP-uh-DID-i-mis), a long, coiled tubule that is closely attached to each testis. Within each epididymis, a sperm matures and gains the ability to swim as its flagellum completes development. Although most sperm remain stored in each epididymis, some leave the epididymis and pass through the **vas deferens** (vas DEF-uh-RENZ), a duct that extends from the epididymis. Smooth muscles that line each vas deferens contract to help move sperm along as they exit the body. Each vas deferens enters the abdominal cavity, where it loops around the urinary bladder and merges with the urethra. Recall from Chapter 49 that the urethra is the duct through which urine exits the urinary bladder. Thus, in a male, both urine and sperm exit the body through the urethra.

In the urethra, sperm mix with fluids that are secreted by three exocrine glands—the seminal vesicles, bulbourethral glands, and the prostate gland. Recall from Chapter 51 that exocrine glands deliver their products through ducts. Ducts that extend from the seminal vesicles, bulbourethral glands, and the prostate gland connect with the urethra. These glands secrete fluids that nourish and protect the sperm. Together, sperm and these secretions form a fluid called **semen** (SEE-muhn). Semen has a high concentration of fructose. Sperm break down fructose by aerobic respiration to obtain energy that they need for movement. To increase sperm survival, semen also contains alkaline fluids that help neutralize the acidic environment of the female's vagina. To help sperm move

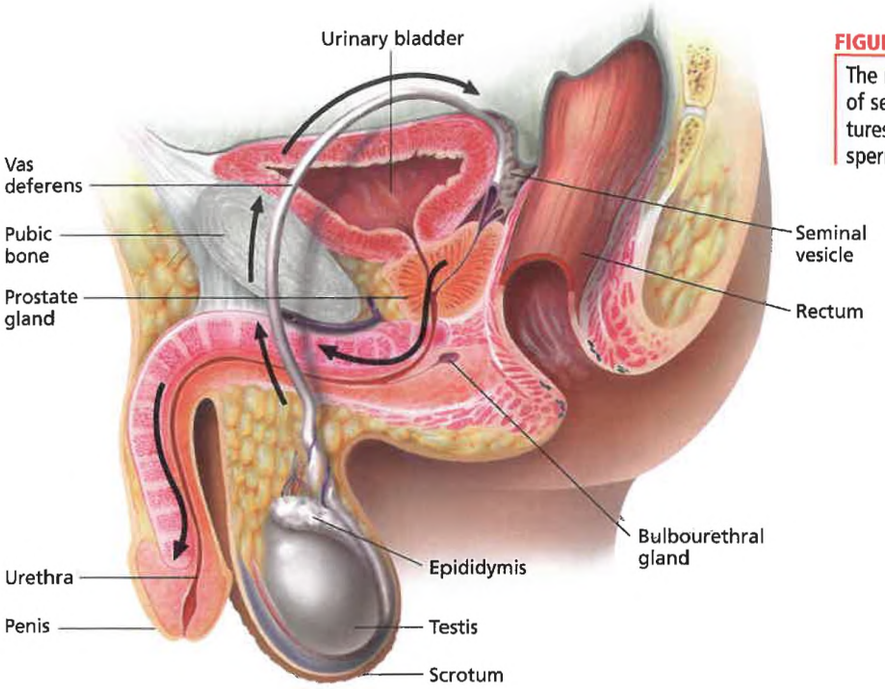


FIGURE 52-3
The male reproductive system consists of several internal and external structures. Arrows indicate the path taken by sperm as they leave the body.

through the female reproductive system, semen also contains prostaglandins that stimulate contractions of smooth muscles that line the female reproductive tract.

Delivery of Sperm

The urethra passes through the **penis,** the organ that deposits sperm in the female reproductive system. When a male becomes sexually aroused, spongy tissue in the penis fills with blood. This causes the penis to become erect, enabling it to deposit sperm. Semen is forcefully expelled from the penis by contractions of the smooth muscles that line the urethra. This process is called **ejaculation** (ee-JAK-yoo-LAY-shun). Each ejaculation expels 3–4 mL (0.10–0.14 fl oz) of semen. Sperm make up only 10 percent of this volume. Fluids that are secreted by the seminal vesicles, bulbourethral glands, and the prostate gland make up the other 90 percent. Even so, 300–400 million sperm leave the male body during a single ejaculation. Still, only a few sperm reach the site of fertilization. Most sperm are killed by the acidic environment of the female reproductive tract.

SECTION 52-1 REVIEW

1. What parts make up a mature sperm? What does each part contain?
2. Which structures in a male produce fluids that mix with sperm to form semen?
3. What is the function of the testes? the epididymis?
4. Describe the composition of semen.
5. Trace the path that sperm take in exiting the body.
6. **CRITICAL THINKING** Why are so many sperm produced by the male reproductive system?

SECTION

52-2

OBJECTIVES

- Compare eggs with sperm.
- Identify the major parts of the female reproductive system.
- Describe the function of each part of the female reproductive system.
- Describe the menstrual cycle and explain how it is regulated.

FEMALE REPRODUCTIVE SYSTEM

Like the testes, the female gonads—ovaries—are endocrine glands that produce gametes. The female reproductive system prepares the female gametes—eggs—for possible fertilization. It also contains structures that enable fertilization to occur and that house and nourish a developing baby.

FORMATION OF EGGS

A female is born with more than 400,000 eggs in her **ovaries** (OH-vuh-reez), the gamete-producing organs of the female reproductive system. When a female is born, her eggs are immature and cannot be fertilized. Typically, a female will release 300–400 mature eggs during her lifetime, averaging one egg about every 28 days from the time she reaches puberty to about age 50. Thus, fewer than 1 percent of a female's eggs reach maturity.

Like sperm formation, the formation of eggs involves meiosis. Unlike in sperm production—in which four sperm result from each cell that begins meiosis—only one egg results from each cell that undergoes meiosis. All immature eggs begin meiosis, but the process is stalled in prophase I until the female reaches puberty, when levels of the sex hormones become high enough to complete the maturation of the eggs. Regulated by these hormones, 10–20 immature eggs resume meiosis every 28 days. However, typically only one mature egg is released each time. A mature egg, or **ovum** (OH-vuhm), shown in Figure 52-4, is about 75,000 times larger than a sperm and is visible to the unaided eye. Meiosis II is not completed unless a sperm fuses with the egg. If the ovum is fertilized, it completes the final meiotic division. Only one cell retains most of the cytoplasm, which provides nutrients that are needed for the egg's survival through the early stages of development. Deprived of cytoplasm, the other three meiotic cells die.

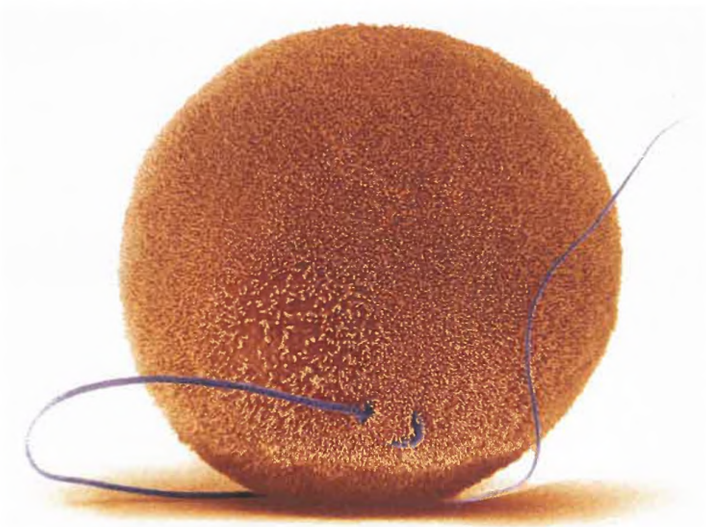


FIGURE 52-4
This ovum is being approached by a single sperm. Notice the tremendous size difference between the egg and the sperm. (SEM 1225×)

FEMALE REPRODUCTIVE STRUCTURES

The female reproductive system contains two almond-shaped ovaries that are located in the lower abdomen. Eggs mature near the surface of the ovaries, which are about 3.5 cm (1.4 in.) long and 2 cm (0.8 in.) in diameter. An ovum is released into the abdominal cavity, where it is swept by cilia into the opening of a nearby **fallopian** (fuh-LOH-pee-uhn) **tube,** or uterine tube. This narrow passageway leads to the uterus, as shown in Figure 52-5. The **uterus** (YOOT-uhr-uhs) is a hollow, muscular organ about the size of a fist. If an egg is fertilized, it will develop in the uterus. The lower entrance to the uterus is called the **cervix** (SUHR-viks). A sphincter muscle in the cervix controls the opening to the uterus. Leading from the cervix to the outside of the body is a muscular tube called the **vagina** (vuh-JIE-nuh). The vagina receives sperm from the penis; it is also the channel through which a baby passes during childbirth. The external structures of the female reproductive system are collectively called the **vulva** (VUHL-vuh). The vulva includes the **labia** (LAY-bee-uh), folds of skin and mucous membranes that cover and protect the opening to the female reproductive system.

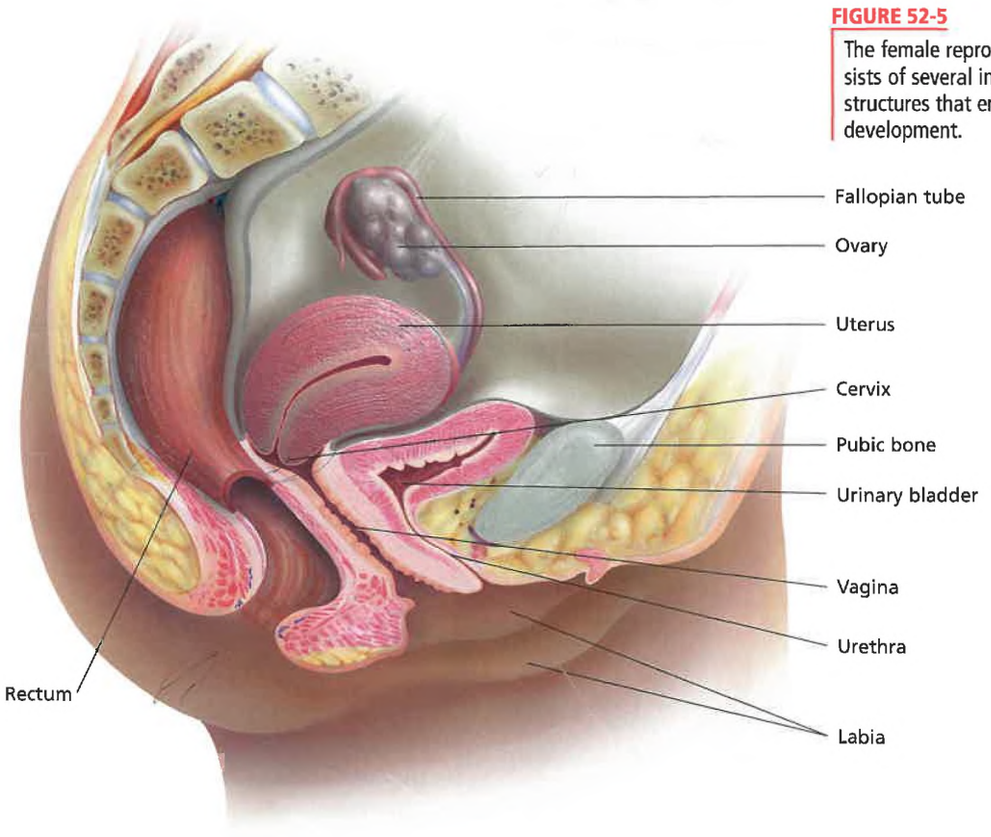


FIGURE 52-5
The female reproductive system consists of several internal and external structures that enable fertilization and development.

Word Roots and Origins

menstrual

from the Latin *mensis,* meaning "month"

PREPARATION FOR PREGNANCY

Each month, the female reproductive system prepares for a possible pregnancy by undergoing a series of changes called the **menstrual** (MEN-struhl) **cycle.** For most women, the menstrual cycle lasts about 28 days. During this time, an egg matures and enters a fallopian tube, where it is able to fuse with a sperm. If the egg does not fuse with a sperm, the egg degenerates. The menstrual cycle has four stages: the follicular phase, ovulation, the luteal phase, and menstruation. These stages are regulated by hormones secreted by the endocrine system. Figure 52-6 summarizes the stages of the menstrual cycle.

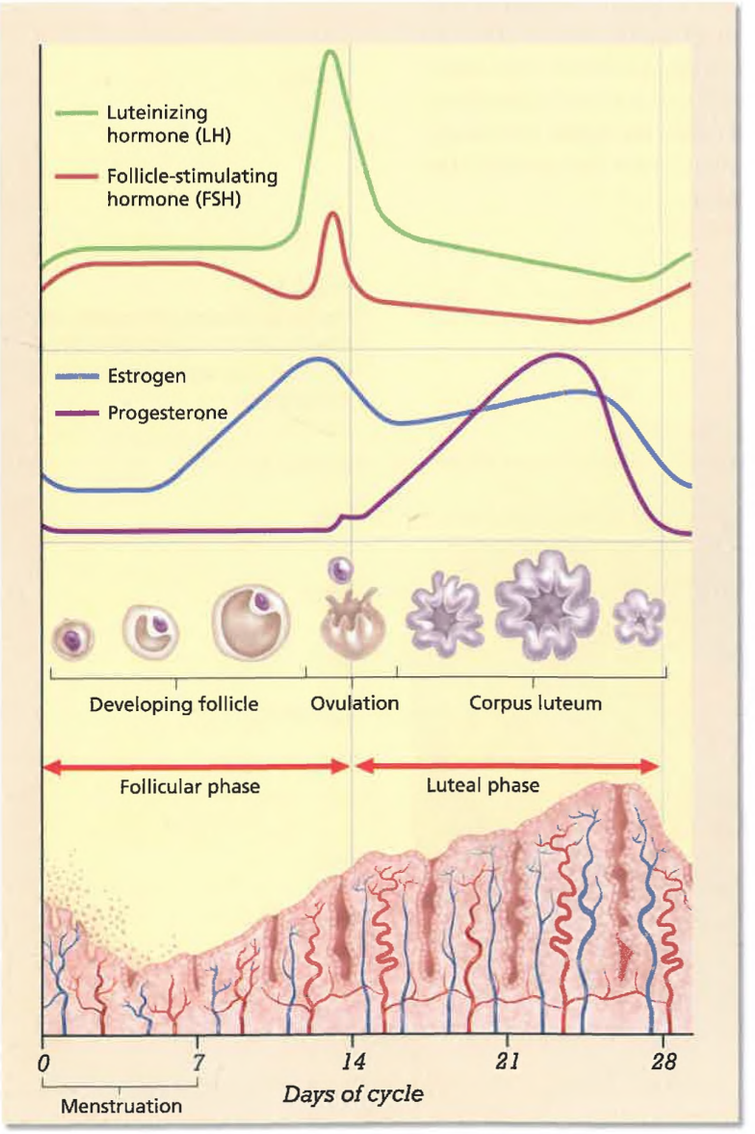


FIGURE 52-6

During the 28-day menstrual cycle, an egg matures and is released by an ovary, and the uterus prepares for a possible pregnancy. The events of the menstrual cycle are regulated by hormones that are produced by the anterior pituitary and the ovaries.

Follicular Phase

An immature egg cell completes its first meiotic division during the **follicular** (fuh-LIK-yoo-luhr) **phase.** This phase begins when the hypothalamus secretes a releasing hormone that stimulates the anterior lobe of the pituitary gland to secrete follicle-stimulating hormone (FSH). FSH stimulates cell division in a **follicle,** a layer of cells that surrounds an immature egg. Follicle cells supply nutrients to the egg. They also secrete estrogen, which stimulates mitotic divisions of cells in the lining of the uterus, causing the lining to thicken. The follicular phase lasts approximately 14 days. During this time, the estrogen level in the blood continues to rise until it reaches a peak and the egg moves to the surface of the ovary. The elevated estrogen level stimulates the anterior pituitary to secrete luteinizing hormone (LH), which initiates the next stage of the menstrual cycle (a positive feedback mechanism).

Ovulation

The sharp rise in the level of LH that occurs midway through the menstrual cycle causes the follicle to rupture and release its egg at that time. The release of an egg from a ruptured follicle is called **ovulation** (AHV-yoo-LAY-

shuhn). Following ovulation, an egg is swept into a fallopian tube, where it travels toward the uterus awaiting fertilization. The egg has enough stored nutrients to survive about 48 hours.

Luteal Phase

The cells of the ruptured follicle grow larger and fill the cavity, forming a new structure called a **corpus luteum** (KOHR-puhs LOOT-ee-uhm). Thus, this stage of the menstrual cycle is called the **luteal** (LOOT-ee-uhl) **phase.** The corpus luteum begins to secrete large amounts of progesterone and estrogen. Progesterone stimulates growth of blood vessels and storage of fluids and nutrients in the lining of the uterus. This causes the uterine lining to become even thicker. In addition, increased levels of estrogen and progesterone cause the pituitary gland to stop secreting LH and FSH (a negative feedback mechanism). The luteal phase lasts about 14 days. During this time, estrogen and progesterone levels in the blood rise, while the FSH and LH levels drop.

Menstruation

If an egg is fertilized, the resulting zygote attaches to the lining of the uterus, where it will develop for the next nine months. A hormone that is produced early in pregnancy stimulates the corpus luteum to continue producing estrogen and progesterone, and the thickened lining of the uterus is maintained. If the egg is not fertilized, the corpus luteum stops producing sex hormones. Without estrogen and progesterone to maintain the thickened uterine lining, the lining begins to slough off. In the last stage of the menstrual cycle, called **menstruation** (men-STRAY-shuhn), the lining of the uterus and blood from ruptured blood vessels are discharged through the vagina. Menstruation lasts about five days at the beginning of the follicular phase.

Menstruation continues in most women until about age 50. By then, most of a woman's follicles have either matured and ruptured or degenerated. Without follicles, the ovaries cannot secrete enough estrogen and progesterone to continue the menstrual cycle, and menstruation ceases. This stage is called **menopause** (MEN-uh-PAHZ).

SECTION 52-2 REVIEW

1. What are the main female reproductive organs?
2. How are eggs and sperm similar? How are they different?
3. Where does fertilization occur?
4. What is ovulation? When does it occur?
5. How do high levels of estrogen and progesterone during the luteal phase of the menstrual cycle affect the uterus?
6. **CRITICAL THINKING** What might happen if more than one egg were simultaneously released from the ovaries?

SECTION

52-3

OBJECTIVES

- Describe the processes of fertilization, cleavage, and implantation.
- Summarize the changes that take place during the development of an embryo.
- List the three stages of pregnancy, and describe each stage.

GESTATION

A new individual is produced when a sperm fertilizes an egg, resulting in the formation of a zygote. During the nine-month period of ***gestation*** *(jes-TAY-shuhn), a series of changes transforms a single cell into a complex organism made of trillions of cells—a human.*

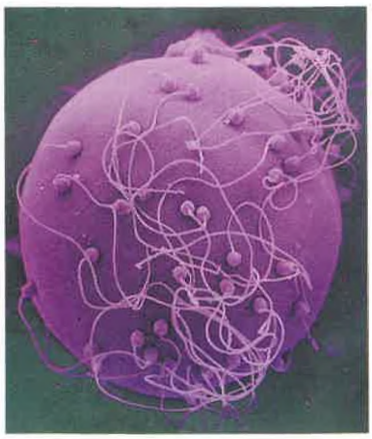
FERTILIZATION

Recall that with one ejaculation, a male releases hundreds of millions of sperm into the vagina of a female. Once sperm are released, they swim through the vagina, cervix, and uterus, and, finally, up the fallopian tubes. If ovulation occurs anytime from 72 hours before to 48 hours after ejaculation, sperm may encounter an egg in one of the fallopian tubes. Fertilization occurs when a sperm and an egg fuse and form a zygote.

An egg in a fallopian tube is encased in a jellylike substance and surrounded by a layer of cells from the follicle of the ovary. As shown in Figure 52-7, several sperm may attach to an egg and attempt to penetrate its outer layers. Recall from Section 52-1 that the head of a sperm contains digestive enzymes. These enzymes break down an egg's outer layers and enable the cell membrane that surrounds the head of the sperm to fuse with the egg's cell membrane. The sperm's nucleus and midpiece then enter the cytoplasm of the egg. The tail of the sperm remains outside the egg. Usually only one sperm is successful in penetrating an egg. Changes that occur in an egg's cell membrane after a sperm enters the egg help keep other sperm from penetrating the egg.

After a sperm enters an egg, its nucleus fuses with the egg's nucleus. The diploid cell that results from this fusion is called a zygote. Recall that each gamete contains 23 chromosomes, the haploid ($1n$) number. Thus, fusion of a sperm nucleus and an egg nucleus causes a zygote to have 46 chromosomes, the diploid ($2n$) number.

FIGURE 52-7
Several sperm surround this ovum, but only one will be able to fertilize it. (SEM 1165×)



Cleavage and Implantation

Immediately following fertilization and while still in the fallopian tube, the zygote begins a series of mitotic divisions known as cleavage. The resulting cells do not increase in size during these cell divisions. Cleavage produces a ball of cells called a **morula** (MOHR-yoo-luh), which is not much larger than the zygote. Cells of the morula divide and release a fluid, resulting in a blastocyst. A **blastocyst** (BLAS-toh-SIST) is a ball of cells with a large, fluid-filled cavity.

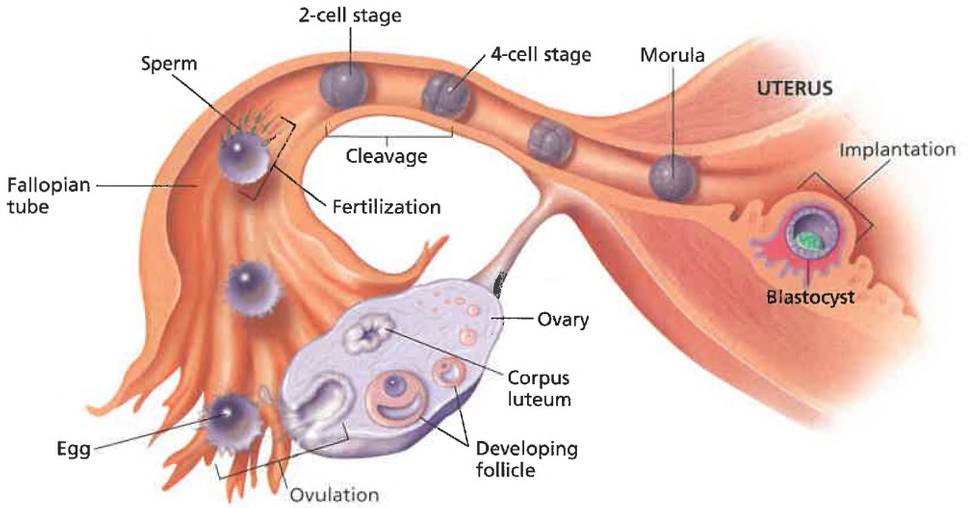


FIGURE 52-8
The earliest stages of development occur within a fallopian tube as a zygote travels toward the uterus.

As shown in Figure 52-8, the morula has become a blastocyst by the time it reaches the uterus. In the uterus, the blastocyst attaches to the thickened uterine lining. The blastocyst then releases an enzyme that breaks down the epithelial tissue that lines the uterus and burrows into the thickened lining. The process in which the blastocyst burrows and embeds itself into the lining of the uterus is called **implantation** (IM-plan-TAY-shun). Pregnancy begins at implantation, which occurs about six days after fertilization.

PREGNANCY

After implantation, the blastocyst slowly takes on the recognizable features of a human infant. This nine-month period of development is called gestation, or **pregnancy.** Pregnancy is divided into three equal periods, or **trimesters.** Significant changes occur during each trimester.

First Trimester

The most dramatic changes in human development take place during the first trimester. Throughout the first two to three weeks following fertilization, a developing human embryo resembles the embryos of other animals. The embryo develops from the mass of cells on the inner surface of the blastocyst. At first, all of the cells in the mass look alike. But the cells soon reorganize, first into two and then into three distinct types of cells, forming the primary germ layers: the ectoderm, mesoderm, and endoderm. Different parts of the body develop from each of the primary germ layers. The nervous system and the epidermis of the skin develop from the ectoderm. Muscle tissue, connective tissue, and organs develop from the mesoderm. The linings of the digestive, respiratory, and urinary tracts develop from endoderm, as do glands, such as the liver, pancreas, thyroid, and thymus.

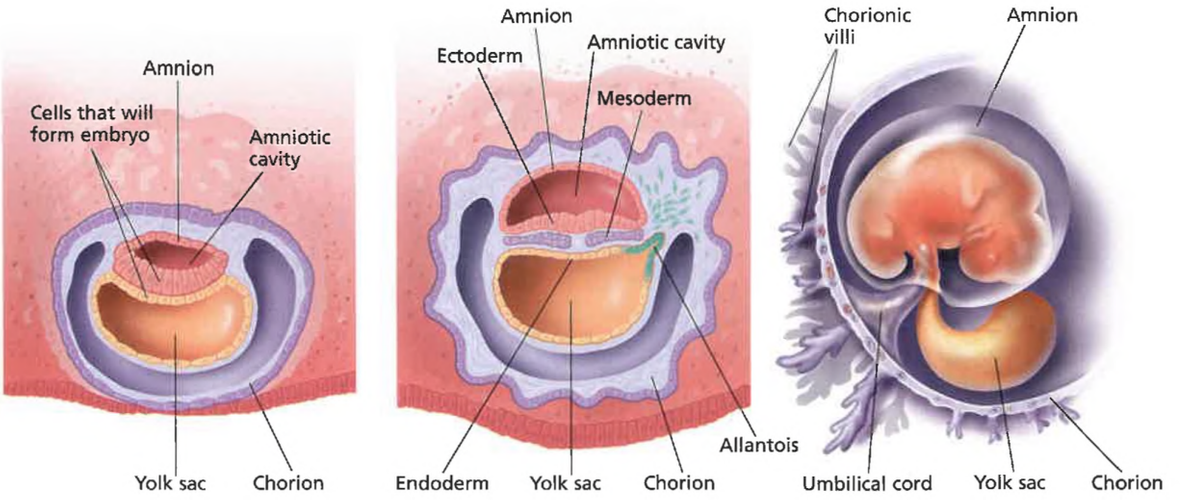
Quick Lab

Summarizing Vocabulary

Materials pencil, paper, dictionary

Procedure Write and define the following list of words: *ovary, ovum, follicle, gestation, morula, blastocyst, amnion, chorion, umbilical, uterus, corpus,* and *luteum.*

Analysis Do any of the meanings of the words surprise you? Explain. How does knowing the roots and meanings of the words help you remember them?



(a) 9-DAY BLASTOCYST (b) 16-DAY EMBRYO (c) 4-WEEK EMBRYO

FIGURE 52-9

(a) An embryo develops from the mass of cells on one side of a blastocyst. (b) The primary germ layers develop by the third week of pregnancy, and the four embryonic membranes form. (c) By the end of the first month of pregnancy, all of the embryonic membranes are formed.

Four membranes that aid the development of the embryo also form during the first trimester. One of these membranes, called the amnion (AM-nee-uhn), forms the fluid-filled **amniotic** (AM-nee-AHT-ik) **sac,** which surrounds the developing embryo. The fluid in the amniotic sac cushions the embryo from injury and keeps it moist. A second membrane forms the yolk sac. Although it does not contain yolk, the yolk sac is an important structure because it is where the first blood cells and reproductive cells originate. A third membrane, called the allantois (uh-LAN-toh-is), forms near the yolk sac. The fourth membrane, called the chorion (KOHR-ee-AHN), surrounds all of the other membranes. As shown in Figure 52-9, one side of the chorion forms many small, fingerlike projections called **chorionic villi** (KOHR-ee-AHN-ik VIL-IE), which extend into the uterine lining. Blood vessels that form within the chorionic villi originate in the allantois.

Together, chorionic villi and the portion of the uterine lining that they invade form a close-knit structure called the placenta. A human placenta is about 15–20 cm (6–8 in.) in diameter and about 2.5 cm (1 in.) thick. Nutrients, gases, pathogens, drugs, and other substances pass from the mother to the fetus through the placenta. The developing fetus is attached to the placenta by the **umbilical** (uhm-BIL-i-kuhl) **cord,** which contains arteries and veins that carry blood between the fetus and the placenta. As Figure 52-10 shows, blood from the mother and fetus never mixes. Instead, materials are exchanged by diffusion.

By this time, had the egg not been fertilized, the corpus luteum would have stopped producing sex hormones, and menstruation would have followed. A developing placenta begins to secrete a hormone called **human chorionic gonadotropin (HCG)** early in the second week after fertilization. In the early stages of pregnancy, HCG stimulates the corpus luteum to continue producing sex hormones, and thus the uterine lining and the embryo are retained. As

the placenta grows, it begins to secrete large amounts of progesterone and estrogen, which take over maintenance of the uterine lining from hormones that were produced by the corpus luteum. Continued production of estrogen and progesterone throughout pregnancy prevents the release of FSH and LH, and eggs are not ovulated.

The brain, the spinal cord, and the rest of the nervous system begin to form in the third week. The heart begins to beat at 21 days, and it develops a smooth, rhythmic beat at 28 days. By the fifth week, human features, including arms, legs, eyes, ears, and the digestive system have begun to develop. At six weeks, the fingers and toes form, and the brain shows signs of activity. The embryo also begins to move, although it is so small that the mother cannot feel it. From eight weeks until birth, the developing child is called a **fetus** (FEET-uhs). The fetus is only about 5 cm (2 in.) long when the first trimester ends, but all of its organ systems have begun to form.

Second Trimester

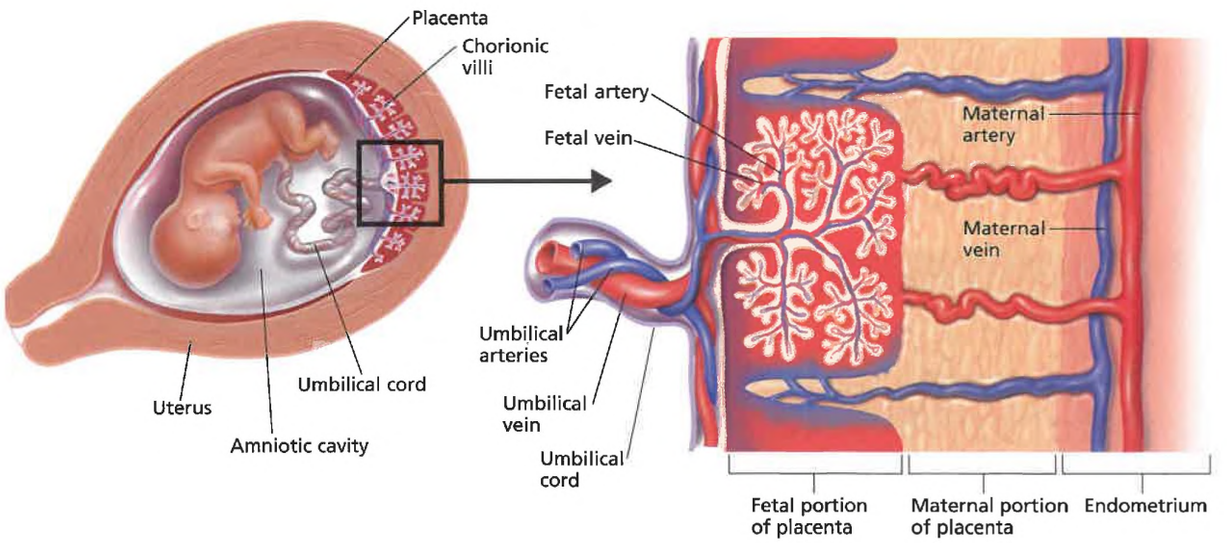
During the second trimester, the mother's abdomen begins to swell as her uterus enlarges. The fetus's heartbeat can be heard, its skeleton begins to form, and a layer of soft hair grows over its skin. At this time, the fetus also begins to wake and sleep. The mother may feel the fetus move about. The fetus swallows, hiccups, sucks its thumb, and makes a fist. It also kicks its feet and curls its toes. By the end of the second trimester, the fetus is about 32 cm (12.6 in.) long, and its eyes are open.

Third Trimester

In the third trimester, the fetus grows quickly and undergoes changes that will enable it to survive outside the mother. The fetus can see light and darkness through the mother's abdominal wall,

FIGURE 52-10

About two weeks after fertilization, chorionic villi form and the placenta begins to develop. The placenta and umbilical cord function as the lifeline between an embryo and its mother.



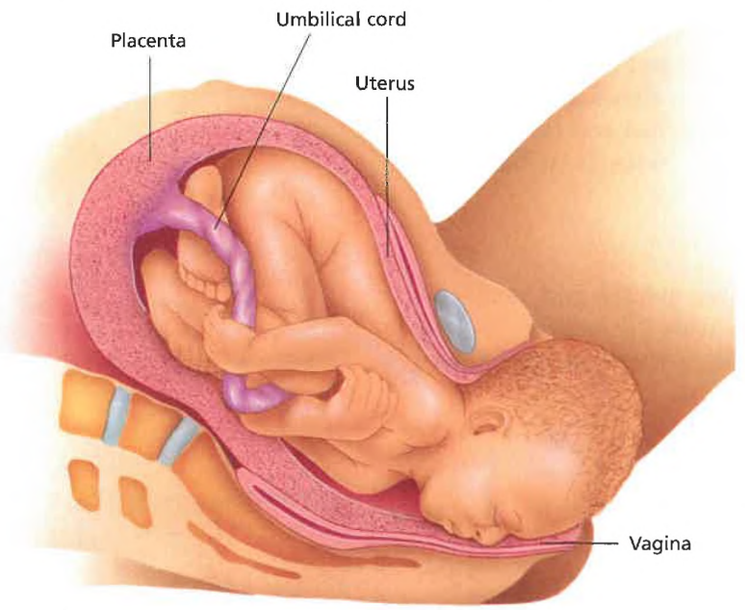
and it can react to music and loud sounds. During the last half of this trimester, the fetus develops fat deposits under its skin. These fat deposits, which make the fetus look rounded and less wrinkled, insulate the body so that it can maintain a steady body temperature.

Birth

Birth occurs about 270 days after fertilization. Prostaglandins that are produced by the fetal membranes, along with hormones that are produced by the fetus and the mother, initiate childbirth. High levels of estrogen, prostaglandins, and oxytocin, a hormone that is secreted by the pituitary gland, cause the smooth muscles that line the uterus to contract. The amniotic sac breaks, and its fluid flows out through the vagina. This is called "breaking water." Muscles in the cervix and the vagina relax, enabling the cervix and vagina to enlarge and allowing the fetus to pass through them. The muscular contractions and other events that lead up to childbirth are called **labor.**

During childbirth, strong contractions of the uterus push a fetus out through the cervix, through the vagina, and from the body, as shown in Figure 52-11. The placenta, the amnion, and the uterine lining, collectively called **afterbirth,** are expelled from the mother's body about 10 minutes after the baby is born. Following birth, the newborn baby's lungs expand for the first time as the baby cries and begins to breathe on its own. At this time, the umbilical cord is tied and cut. The umbilical arteries and veins close off within 30 minutes after birth. This and other changes in the baby's blood vessels lead to completion of cardiopulmonary and renal circulation, allowing the baby to function independent of the mother. The newborn baby's respiratory and excretory systems soon become fully functional.

FIGURE 52-11
During childbirth, the fetus passes through the greatly enlarged cervix and vagina.



SECTION 52-3 REVIEW

1. What is the process of implantation?
2. What is a blastocyst?
3. How is a fetus nourished during development?
4. Summarize the events of human development that occur during the first trimester of pregnancy.
5. What changes occur in a fetus during the third trimester of pregnancy?
6. **CRITICAL THINKING** Why is it important for a pregnant woman to eat healthy foods, to avoid unhealthy substances, and to follow her doctor's advice?

CHAPTER 52 REVIEW

SUMMARY/VOCABULARY

52-1

- Sperm form in the seminiferous tubules of the testes. Meiosis reduces the number of chromosomes in sperm to 23.
- A mature sperm consists of a head, which contains the nucleus and chromosomes; a midpiece that contains mitochondria; and a tail, which consists of a flagellum.
- The testes are contained in the scrotum, where the cooler temperature allows normal sperm development.
- Sperm take the following path to exit the body: seminiferous tubules of the testes → epididymis → vas deferens → urethra.
- Fluids that are secreted by various exocrine glands are mixed with sperm to produce semen.

Vocabulary

ejaculation (1049)
epididymis (1048)
penis (1049)
scrotum (1048)
semen (1048)
seminiferous tubules (1048)
testes (1047)
vas deferens (1048)

52-2

- Eggs form in the ovaries. Meiosis reduces the chromosome number in eggs to 23.
- A female is born with all of the eggs that she will ever produce.
- Starting at puberty, one egg matures (completes meiosis) approximately every 28 days during the menstrual cycle.
- The menstrual cycle consists of four phases: follicular phase, ovulation, luteal phase, and menstruation.
- In the follicular phase, FSH causes a follicle to grow in an ovary. Estrogen produced by the follicle causes an egg to mature and stimulates the buildup of the uterine lining.
- Ovulation occurs midway through the menstrual cycle, when LH causes the follicle to rupture and release its egg.
- In the luteal phase, the follicle becomes a corpus luteum. The corpus luteum secretes progesterone, which stimulates further buildup of the uterine lining.
- Menstruation, the discharge of the uterine lining, occurs when a corpus luteum stops secreting progesterone and estrogen.

Vocabulary

cervix (1051)
corpus luteum (1053)
fallopian tube (1051)
follicle (1052)
follicular phase (1052)
labia (1051)
luteal phase (1053)
menopause (1053)
menstrual cycle (1052)
menstruation (1053)
ovary (1050)
ovulation (1052)
ovum (1050)
uterus (1051)
vagina (1051)
vulva (1051)

52-3

- Fertilization occurs in a fallopian tube.
- Pregnancy begins when a blastocyst implants itself in the lining of the uterus.
- The three primary germ layers—the ectoderm, mesoderm, and endoderm—form early in embryonic development.
- Four membranes—the amnion, yolk sac, allantois, and chorion—also form early in embryonic development.
- Part of the chorion and part of the lining of the uterus form the placenta, through which nutrients, gases, and other substances pass by diffusion to the fetus from the mother.
- From the eighth week until birth, a developing human is known as a fetus.
- During childbirth, contractions of the uterus initiated by prostaglandins and oxytocin push the baby from the mother's body through the vagina.

Vocabulary

afterbirth (1058)
amniotic sac (1056)
blastocyst (1054)
chorionic villi (1056)
fetus (1057)
gestation (1054)
human chorionic gonadotropin (1056)
implantation (1055)
labor (1058)
morula (1054)
pregnancy (1055)
trimester (1055)
umbilical cord (1056)

REVIEW

Vocabulary

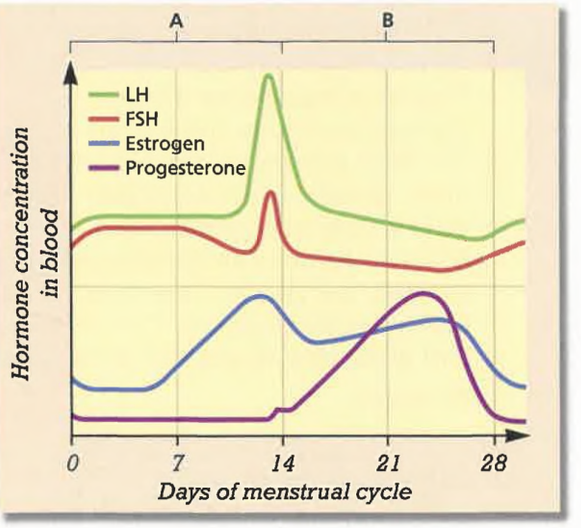
1. Name the male and female gamete-producing organs.
2. What is the difference between sperm and semen?
3. Explain the relationships between the following: the menstrual cycle, menstruation, and menopause.
4. Which two structures form the placenta?
5. What is the difference between an embryo and a fetus?

Multiple Choice

6. The correct pathway for sperm is from the (a) testes to the vas deferens to the epididymis (b) epididymis to the urethra to the vas deferens (c) urethra to the vas deferens to the testes (d) testes to the epididymis to the vas deferens.
7. One similarity between a sperm and an egg is their (a) chromosome number (b) size (c) ability to move quickly (d) role in producing hormones.
8. Which of the following is not a function of the uterus? (a) house the developing fetus (b) help produce eggs (c) provide protection for an embryo (d) aid the birth of the baby.
9. Follicle-stimulating hormone (a) promotes contractions of the uterine muscles (b) is secreted by the follicle (c) is secreted by the pituitary gland (d) stimulates the development of the placenta.
10. During menstruation (a) the egg moves into the fallopian tube (b) the corpus luteum develops (c) the uterine lining is discharged (d) the egg matures.
11. Fertilization takes place in the (a) vagina (b) cervix (c) uterus (d) fallopian tube.
12. The embryonic membranes that help form the placenta and umbilical cord are (a) the amnion and yolk sac (b) the chorion and allantois (c) the chorion and yolk sac (d) the amnion and chorion.
13. Which of the following organs develops from ectoderm? (a) brain (b) liver (c) heart (d) lungs
14. The placenta is the (a) site of yolk development (b) site of nutrient and gas exchange between the mother and the fetus (c) structure that protects the fetus from injury (d) tip of the uterus.
15. By the end of the first trimester (a) the fetus can suck its thumb (b) the brain of the fetus is fully developed (c) the fetus uses its lungs to breathe (d) all of the organs of the fetus have begun to form.

Short Answer

16. Describe the structure of a mature human sperm cell.
17. How is semen formed?
18. How are sperm formation and egg formation similar?
19. Use the graph shown below to answer the following questions:
    (a) What phase of the menstrual cycle is occurring during the period labeled *A*?
    (b) What phase of the menstrual cycle is occurring at the period labeled *B*?
    (c) When during the menstrual cycle does ovulation usually occur?
    (d) When during the menstrual cycle is fertilization most likely to occur?
    (e) When during the menstrual cycle is the estrogen level highest?
    (f) When during the menstrual cycle does the progesterone level start to fall?



20. Where are eggs produced?
21. Which part of the menstrual cycle does not occur if implantation occurs? Why is this important?
22. How does a sperm penetrate an egg during fertilization?
23. How does the developing fetus receive nourishment?
24. What role does the amnion play in human development?
25. What changes does the cervix undergo during childbirth?

CRITICAL THINKING

1. Why are sperm able to survive as long as they do in the female, even though they have very little cytoplasm to provide nutrients?
2. What do you think might happen if more than one sperm were able to penetrate the cell membrane of an egg?
3. A human female produces on average only one mature egg every 28 days. In contrast, a female salmon lays 50 million eggs at each spawning. Hypothesize why there is such a great difference in egg production between the two species.
4. Women who smoke tobacco, drink alcoholic beverages, or consume other drugs or harmful substances during pregnancy give birth to infants who are often addicted to drugs, have severe birth defects, or develop learning disabilities and behavioral disorders. Why is this so?
5. About 20 years ago, a large number of women who took a tranquilizer called thalidomide early in pregnancy gave birth to babies with serious limb defects. Other mothers who took the drug later on in pregnancy had normal children. What does this tell you about the sequence of development in a fetus?
6. What is the fetus doing in the photograph below? Suggest an adaptive advantage for this activity.

EXTENSION

1. Concerned about the rapid increase in the world's population, several countries are attempting to reach zero population growth (ZPG). These countries have encouraged women to have fewer children or have instituted laws that limit the number of children that each woman may have. Check on-line references to identify one such country, and prepare a report summarizing what measures the country has taken to attain ZPG.
2. Read "Why We Don't Lay Eggs" in *New Scientist,* June 12, 1999, on page 12. Prepare a report on the origin of ERVs in the human placenta. Include in your report how ERVs are involved in protecting the fetus.
3. Research some of the physical and hormonal causes of infertility. Write a report describing the conditions, and explain how medical science is helping couples overcome infertility.

CHAPTER 52 INVESTIGATION

Observing Embryonic Development

OBJECTIVES

- Identify the stages of early animal development.
- Describe the changes that occur during early development.
- Compare the stages of human embryonic development with those of echinoderm embryonic development.

PROCESS SKILLS

- observing
- comparing and contrasting
- making drawings
- drawing conclusions

MATERIALS

- prepared slides of sea-star development, including
  - unfertilized egg
  - zygote
  - 2-cell stage
  - 4-cell stage
  - 8-cell stage
  - 16-cell stage
  - 32-cell stage
  - 64-cell stage
  - blastula
  - early gastrula
  - middle gastrula
  - late gastrula
  - young sea-star larva
- compound light microscope
- paper and pencil

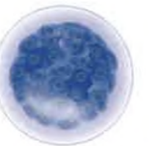
Background

1. Most members of the animal kingdom (including sea stars and humans) begin life as a single cell—the fertilized egg, or zygote. How does a fertilized egg become a completely developed organism?
2. The early stages of development are quite similar in different species. Cleavage follows fertilization. During cleavage, the zygote divides many times without growing. The new cells migrate and form a hollow ball of cells called a blastula. The cells then begin to organize into the three primary germ layers: endoderm, mesoderm, and ectoderm. During this process, the developing organism is called a gastrula.
3. The early stages of mammalian development are difficult to study because mammalian eggs are tiny and are not produced in great numbers. In addition, mammalian embryos develop within the mother's body. In the laboratory, it is difficult to replicate the internal conditions of the mother's body. Because the early stages of echinoderm development are similar to those of human development, and because echinoderm development is easier to study in the laboratory than human development, you will observe the early developmental stages of an echinoderm—the sea star—in this investigation.

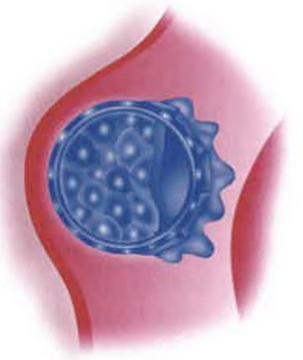
2-cell stage

4-cell stage

8-cell stage



64-cell stage



Blastocyst

4. As development continues, the cells continue to specialize as they become part of specific tissues and complex structures. Ectoderm forms the epidermis and nerve tissue. Mesoderm forms muscle, connective tissue, and vascular organs. Endoderm forms the lining of the digestive, urinary, and respiratory tracts.
5. Similarities and differences in early stages of development reflect evolutionary relationships between species.

Procedure

1. Obtain a set of prepared slides that show sea-star eggs at different stages of development. Choose slides labeled unfertilized egg, zygote, 2-cell stage, 4-cell stage, 8-cell stage, 16-cell stage, 32-cell stage, 64-cell stage, blastula, early gastrula, middle gastrula, late gastrula, and young sea-star larva. (Note: *Blastula* is the general term for the embryonic stage that results from cleavage. In mammals, a blastocyst is a modified form of the blastula.)
2. Examine each slide using a compound light microscope. Using the microscope's low-power objective first, focus on one good example of the developmental stage listed on the slide's label. Then switch to the high-power objective, and focus on the image with the fine adjustment.
3. In your lab report, draw a diagram of each developmental stage that you examine (in chronological order). Label each diagram with the name of the stage it represents and the magnification used. Record your observations as soon as they are made. Do not redraw your diagrams. Draw only what you see; lab drawings do not need to be artistic or elaborate. They should be well organized and include specific details.
4. Compare your diagrams with the diagrams of human embryonic stages shown at left.
5.  Clean up your materials and wash your hands before leaving the lab.

Analysis and Conclusions

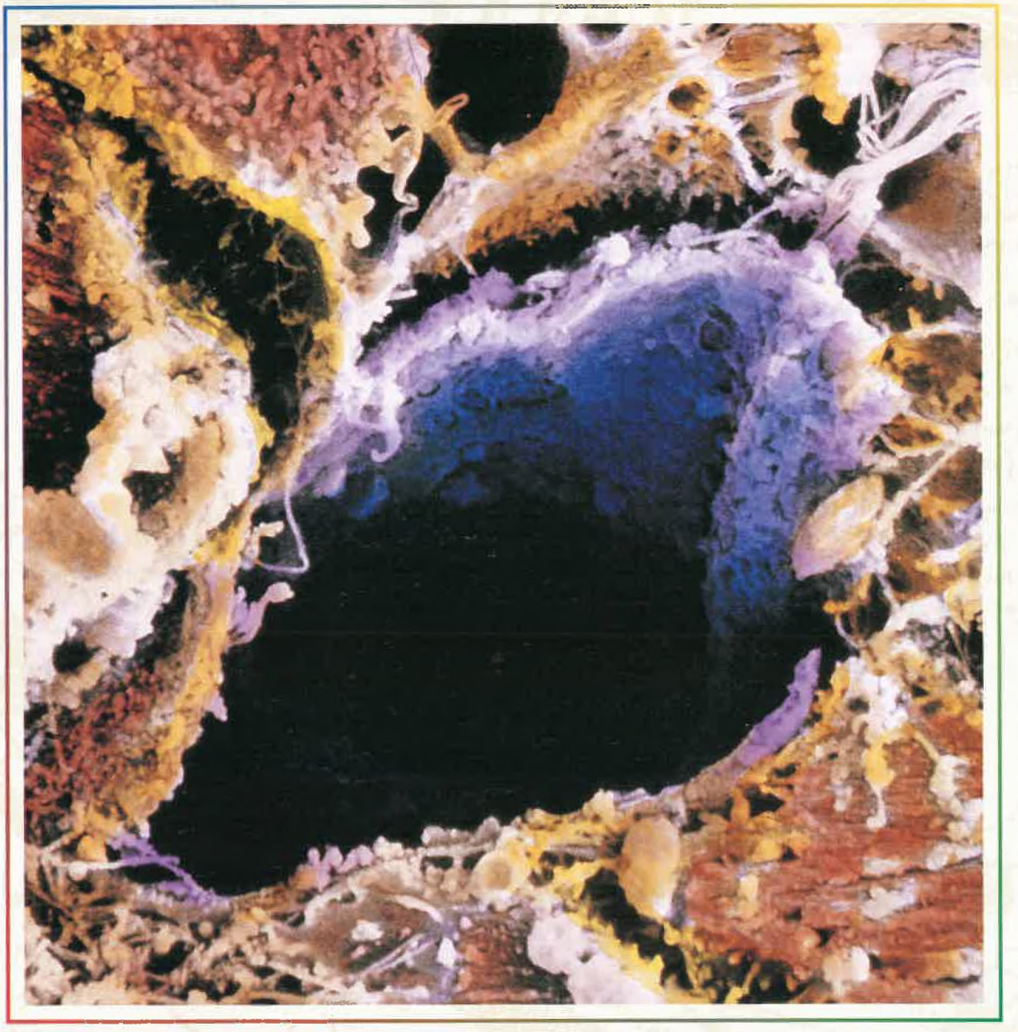
1. Compare the size of the sea-star zygote with that of the blastula. At what stage does the embryo become larger than the zygote?
2. At what stage do all of the cells in the embryo not look exactly like each other?
3. How do cell shape and size change during successive stages of development?
4. Do the cell nuclei stay the same size, get larger, or get smaller as the stages progress?
5. Compare the number of chromosomes in a fertilized sea-star egg with the number of chromosomes in one cell of each of the following phases: 2-cell stage, blastula, gastrula, and adult stage.
6. From your observations of changes in cellular organization, why do you think the blastocoel (the space in the center of the hollow sphere of cells of a blastula) is important during embryonic development?
7. Label the endoderm and ectoderm in your drawing of the late gastrula stage. What do these two tissue types eventually develop into?
8. How are the symmetries of a sea-star embryo and a sea-star larva different from the symmetry of an adult sea star? Would you expect to see a similar change in human development?
9. What must happen to the sea-star gastrula before it becomes a mature sea star?
10. How do your drawings of sea-star embryonic development compare with those of human embryonic development? Based on your observations, in what ways do you think sea-star embryos could be used to study early human development?
11. Describe one way that the cleavage of echinoderms and mammals is alike.
12. Describe two ways that the cleavage of echinoderms and mammals is different.
13. Why are sea-star eggs a good choice for the study of embryonic development in humans?

Further Inquiry

Using the procedure that you followed in this investigation, compare embryonic development in other organisms with embryonic development in sea stars. Which types of organisms would you expect to develop similarly to sea stars? Which types of organisms would you expect to develop differently from sea stars?

CHAPTER 53

DRUGS



This color-enhanced micrograph (SEM, 6000×) shows a liver affected by the disease cirrhosis. The deep blue central cavity is a blood vessel. Fibers and clumps of scar tissue surrounding the blood vessel have replaced much of the liver's normal cellular architecture.

FOCUS CONCEPT: ***Stability and Homeostasis***

As you read, note how certain drugs affect the body's ability to maintain homeostasis.

ROLE OF DRUGS

As biologists explore the structure and function of the various systems that make up the human body, they discover the complex series of chemical reactions that form the basis of each life process. Understanding the chemistry of the body has enabled scientists to alter it by administering naturally occurring or laboratory-synthesized chemicals called drugs. *The wise use of drugs can alleviate suffering by curing or controlling many kinds of diseases. But the unwise use of drugs can cause great harm because many drugs taken for nonmedical purposes have the potential to destroy human lives.*

SECTION 53-1

OBJECTIVES

- Define the term *drug.*
- Name four ways that a drug can be administered.
- List five common types of prescription and nonprescription drugs.
- Describe the potential consequences of a drug interaction.
- Describe the consequences of the overuse of a drug.

DRUG USE AND ADMINISTRATION

A **drug** is a chemical compound that affects the structure of a body part or the functioning of a biological process. There are thousands of different drugs, and they affect many different parts of the body. Some drugs are synthesized in laboratories, while other drugs are derived from natural sources. Many drugs are refined from plant or animal tissue. For example, *Rauwolfia serpentina* is a plant native to India and neighboring countries. Ancient Hindu writings describe use of the plant's roots as a remedy for snakebites, insomnia, and psychotic behavior. The modern drug reserpine, which is used to control blood pressure, is extracted from the roots of *Rauwolfia serpentina.*

A drug can be introduced into the body in a variety of ways. Drugs taken orally, in pill or liquid form, are absorbed by the small intestine and then enter the bloodstream. Drugs can also be injected directly into the bloodstream or muscle tissue or under the skin. Other methods of administering drugs include inhaling the drug, placing the drug under the tongue, inserting it in the rectum in the form of a suppository, or applying the drug to the skin.

The method of administering a drug depends on its chemical nature and the organ to be treated. For example, because insulin is a protein, if it were taken orally, it would be digested in the stomach and would therefore be useless. Thus, insulin is injected under the skin, where it can diffuse into the bloodstream for transport throughout the body. In contrast, drugs used to treat respiratory problems are often administered by inhalation so that they can reach their destination quickly.

MEDICAL USE

Drugs classified as **prescription drugs** cannot be obtained unless they are prescribed by a physician or dentist. The physician or dentist specifies the **dose,** that is, the amount of the drug to be taken and the number of times per day that the drug should be taken. Thousands of prescription drugs are currently available to treat a variety of diseases and disorders.

Nonprescription drugs, also called over-the-counter (OTC) drugs, can be purchased without a prescription and are available at pharmacies and supermarkets. A quick look at the shelves in a supermarket will show the variety of nonprescription drugs that are available. Such drugs are used to relieve pain, treat minor skin infections, reduce stomach acidity, and alleviate symptoms of a cold or flu.

The labels on nonprescription drugs contain information regarding correct usage. These drugs are safe for most people when taken in the recommended dose but can be dangerous if too much is taken. More than 100 children in the United States die each year from accidental overdoses of aspirin, and even children's vitamins are harmful in large doses. Certain precautions may be stated on the drug's label. For example, aspirin labels caution against giving aspirin to children or teenagers who have flulike symptoms or chickenpox because of the possibility of their developing Reye's syndrome, an often fatal condition. Pregnant women and nursing mothers should consult their physician before using any drug, even nonprescription drugs, because many drugs can cross the placenta or enter a mother's milk and can affect a fetus or a young child.

TABLE 53-1 *Common Types of Prescription and Nonprescription Drugs*

Drug type	Medical use	Mode of action
Antacids, acid reducers	heartburn, indigestion, ulcer	neutralize excess stomach acid or slow its production
Antibiotics	bacterial infection	kill or prevent growth of infectious bacteria
Antidepressants	mental depression	increase activity in some neurons in the brain
Anti-inflammatory and non-narcotic pain medications	arthritis; headache; injury to bone, joint, or muscle	reduce inflammatory response (swelling, redness, pain) to injury; relieve pain
Antihistamines	allergy, cold, influenza	reduce allergic response (excess fluid in tissue, contraction of bronchi, dilation of capillaries)
Blood pressure medications	hypertension	dilate blood vessels or cause excretion of water, which reduces blood volume
Decongestants	asthma, cold, influenza	dilate nasal passages and bronchi
Hormone replacements	diabetes mellitus, hypothyroidism, post-menopausal hormone loss	restore normal levels of hormones

Drug Interactions

Table 53-1 lists several common types of drugs. You may have taken one or more of these kinds of drugs. Have you ever taken more than one drug at the same time? Many people do, particularly the elderly and those with chronic diseases. For example, a person with a heart ailment might take a drug to reduce blood clotting, a drug to reduce high cholesterol levels, and a drug to regulate heart function. Although simultaneous use of more than one drug is common, some combinations of drugs are inappropriate because of the chemical interactions between them. In such cases, one drug might add to the effect of the other drug, resulting in symptoms of overdose, or one drug might cancel the effectiveness of the other drug. For example, the commonly prescribed antibiotic tetracycline is rendered inactive in the presence of calcium. Therefore, taking tetracycline within an hour of taking a chewable antacid containing calcium will impair the drug's effectiveness. Similarly, some antibiotics interfere with the action of birth-control pills.

In some cases, drug interactions can lead to more-serious problems and can even cause death. A commonly used antihistamine combined with an often-prescribed antifungal drug can cause an irregular heartbeat and even a heart attack. A physician or pharmacist must closely monitor anyone who is taking more than one drug simultaneously. And a prescribing physician must be informed of the name and dose of *any* drugs—prescription or nonprescription—that a patient is taking or has taken in the past few weeks.

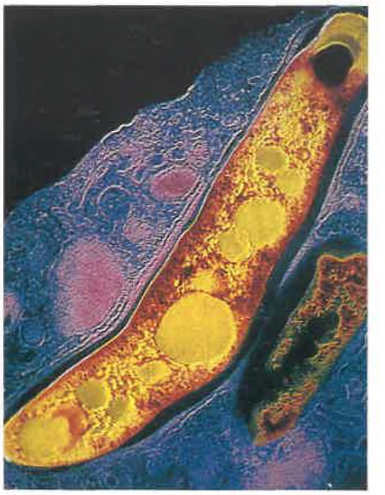


FIGURE 53-1
Some strains of the common pathogen *Mycobacterium tuberculosis* are resistant to antibiotics.

Drug Overuse

Overuse of both prescription drugs and nonprescription drugs can lead to serious problems. Continual use of acetaminophen, a common nonprescription pain medication, can damage the liver. Large doses of magnesium-containing antacids can interfere with the functioning of the heart and kidneys. Anyone who is taking any drug for an extended period of time should consult a doctor.

The problems of drug overuse are not confined to damage to the body. The overuse and misuse of antibiotics have resulted in strains of bacteria that are resistant to these drugs. For example, some strains of the organism, shown in Figure 53-1, that causes the lung disease tuberculosis, are resistant to all antibiotics currently in use.

SECTION 53-1 REVIEW

1. What is a drug?
2. Describe four ways that a drug can be administered.
3. Explain why doctors ask patients to list all the medications they are taking.
4. Name five commonly used types of drugs.
5. What problem has the overuse of antibiotics produced?
6. **CRITICAL THINKING** Colds, flu, and 90 percent of sore throats are caused by viruses. Why would taking an antibiotic be useless in these cases?

SECTION

53-2

OBJECTIVES

- Describe the effects of nicotine on the body.
- List three diseases that can result from smoking or chewing tobacco.
- Explain what can happen to the fetus of a pregnant woman who smokes.
- Distinguish between a stimulant and a depressant.
- Define *blood alcohol concentration,* and name three factors that affect it.
- Explain what can happen as a result of excessive alcohol consumption.

SOCIAL DRUGS

Two drugs that are often used by people in a social context are nicotine, found in all tobacco products, and alcohol. The leaves of the tobacco plant, Nicotiana tabacum, *are dried and crushed, then smoked in cigarettes, cigars, and pipes. Tobacco is also chewed and snuffed. Ethanol—the alcohol found in beer, wine, liquor, and certain other beverages—comes from the anaerobic respiration of sugars in fruits and grains. Both tobacco and alcohol have gained wide social acceptance, but that acceptance has come at a great price.*

TOBACCO

Nicotine, the major drug found in tobacco, is a stimulant. A **stimulant** is a drug that increases the activity of the central nervous system. When tobacco is inhaled, nicotine is absorbed into the bloodstream through the lining of the mouth and through the lungs. Nicotine is quickly transported throughout the body, penetrating the brain, all other organs, and, in pregnant women, the fetus.

Effects of Tobacco

Nicotine increases blood pressure and heart rate while decreasing the oxygen supply to body tissues and the blood supply to the hands and feet. Nicotine is an addictive drug. In **addiction,** the user of a drug becomes dependent on the drug and cannot function comfortably without it. Nicotine is a poison—60 mg of nicotine is a lethal dose for an adult. But nicotine is not the only poison found in tobacco. There are more than 2,000 potentially toxic chemical compounds produced when tobacco is burned. Collectively, these are called tars.

Tars are complex mixtures of chemicals and smoke particles produced by burning tobacco. Tars paralyze the cilia that line the air passages. Remember from Chapter 47 that these cilia move particles out of the air passages and protect the passages from disease-causing microorganisms. Tars irritate the nose, throat, trachea, and bronchial tubes, causing sore throat and coughing. Eventually, tars settle in the lungs. The result is a reduction in breathing capacity and increased susceptibility to infections. The lungs of a smoker look much different from those of a nonsmoker due to the accumulation of tars, as shown in Figure 53-2.

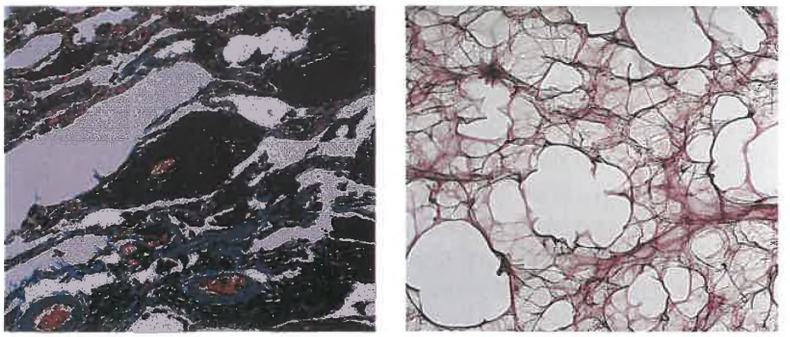


FIGURE 53-2
The blackened appearance of a smoker's lung is the result of years of tar accumulation. Contrast the smoker's lung (left) with the healthy lung (right).

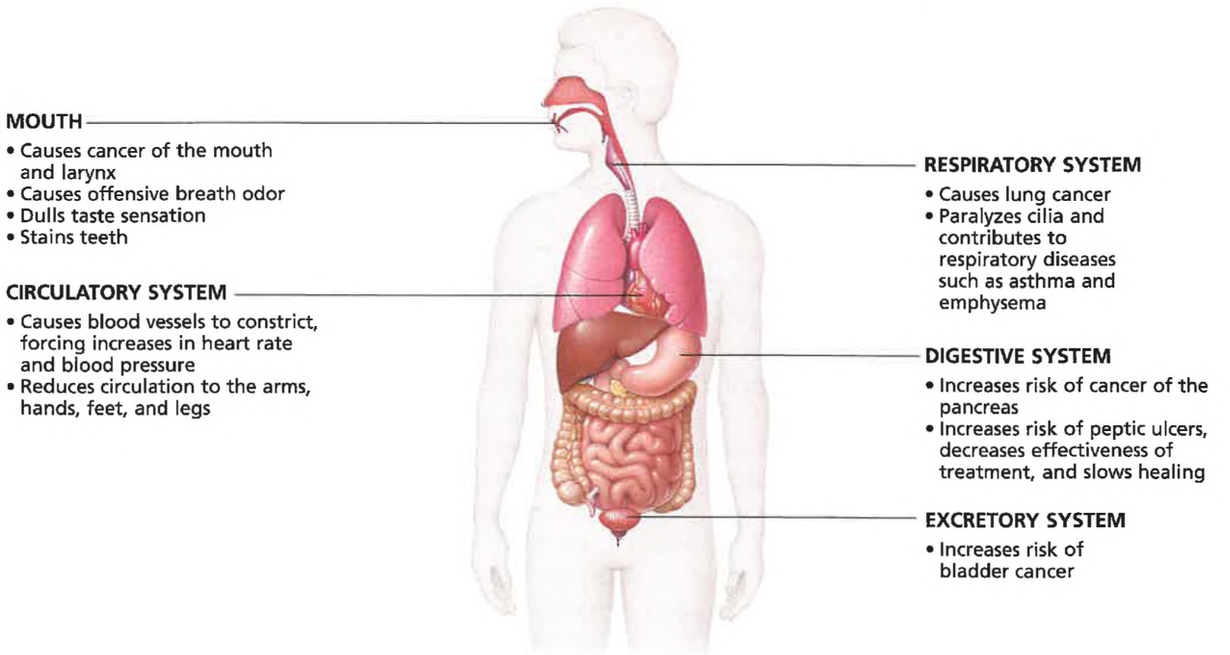
Hazards of Long-Term Tobacco Use

Figure 53-3 illustrates the hazards of tobacco use. Notice how many parts of the body can be affected by tobacco. As it circulates in the bloodstream, nicotine can affect the performance of nearly every system in the body. The system that is most affected is the cardiovascular system. Approximately 25 percent of all heart attacks are associated with the use of tobacco.

The causal relationship between smoking and lung cancer is well established. As you read in Chapter 11, lung cancer is one of the deadliest forms of cancer. More than 90 percent of all lung cancer deaths can be attributed to smoking. Many smokers contract **chronic bronchitis** (brahn-KIET-is), an inflammation of the bronchi and bronchioles, or **emphysema** (EM-fuh-SEE-muh), a degenerative lung disease. In emphysema, the alveoli lose their elasticity and eventually rupture, reducing the surface area available for gas exchange in the lungs.

Users of smokeless tobacco, such as chewing tobacco and snuff, have a higher rate of lip, gum, and mouth cancer than people who

FIGURE 53-3
The health risks associated with smoking extend to many parts of the body.



do not use smokeless tobacco. Tobacco-induced cancers can also occur far from the respiratory system. Smoking is associated with cancers of the bladder and pancreas and may be associated with other types of cancer as well. Cancers associated with smoking likely result from the effects of tars on body tissues.

The consequences of smoking during pregnancy are serious. Pregnant women who smoke are twice as likely as nonsmoking mothers to suffer miscarriages. Their babies tend to have lower birth weights than babies of nonsmokers and are twice as likely to die in the first few months of life. The infants of nursing mothers who smoke may have concentrations of nicotine in their blood as high as those of their mothers.

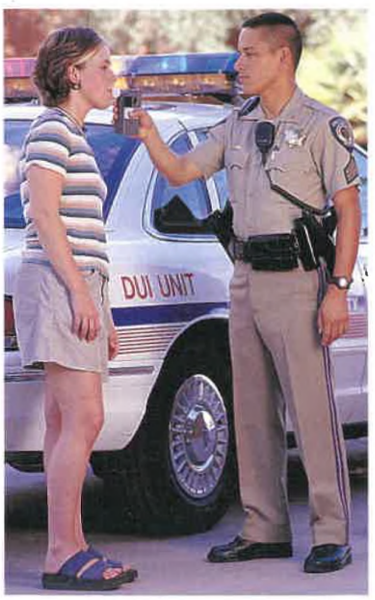
Tobacco even affects nonsmokers. Tobacco smoke released by cigarettes or exhaled by a smoker is called **secondhand smoke.** Laboratory studies have shown that people exposed to secondhand smoke are at risk for the same diseases as people who smoke. Researchers have recently found that exposure to secondhand smoke increases the risk of sudden infant death syndrome in infants up to the age of 12 months.

ALCOHOL

Ethanol is the alcohol found in beer, wine, and mixed drinks. Alcohol is generally a **depressant,** a drug that decreases the activity of the central nervous system. Following consumption, alcohol is immediately absorbed by the stomach and intestines, where it enters the bloodstream and is transported to the brain and other organs.

FIGURE 53-4

A Breathalyzer is an instrument that estimates blood alcohol concentration from alcohol vapors released by the lungs.



Effects of Alcohol

Alcohol increases circulation to the skin, resulting in decreased blood flow to internal organs and a net drop in body temperature. Alcohol increases excretion of water by the kidneys and can result in dehydration if the fluid is not replaced. The greatest and most immediate effects of alcohol, however, occur in the brain.

Alcohol affects different classes of neurons in the brain at different times as a person drinks. This accounts for the wide spectrum of behaviors associated with alcohol consumption. Behavioral excitability and an increased respiration rate are often seen immediately after a person begins to drink. As drinking continues, judgment and coordination are significantly impaired, speech becomes slurred, and reaction time lengthens. Respiration rate slows after the initial increase, and high doses of alcohol can cause death by respiratory failure.

The severity of all of these effects depends largely on **blood alcohol concentration (BAC),** a measurement of the amount of alcohol in the blood. As shown in Figure 53-4, BAC can be determined by a breath test, which measures alcohol vapors given off by the lungs. Table 53-2 illustrates the relationship between body

TABLE 53-2 *Blood Alcohol Concentration (in mg of alcohol per mL of blood) and Its Effects*

Drinks per hour	Body weight in pounds 100	120	140	160	180	200	220	240	Result
1	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	impairment
2	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03	impairment
3	0.11	0.09	0.08	0.07	0.06	0.06	0.05	0.05	intoxication
4	0.15	0.12	0.11	0.09	0.08	0.08	0.07	0.06	intoxication
5	0.19	0.16	0.13	0.12	0.11	0.09	0.09	0.08	intoxication
6	0.23	0.19	0.16	0.14	0.13	0.11	0.10	0.09	intoxication
7	0.26	0.22	0.19	0.16	0.15	0.13	0.12	0.11	severe intoxication
8	0.30	0.25	0.21	0.19	0.17	0.15	0.14	0.13	severe intoxication

One drink is 1 oz of 80 proof (40%) liquor, 12 oz of 4.5% beer, or 4 oz of 12% wine.

weight, rate of alcohol consumption, and BAC values. A BAC level of 0.30 or greater produces unconsciousness, and a BAC of 0.50 can be fatal. The BAC can be affected by factors other than body weight, such as gender—BAC rises more rapidly in female drinkers—and the ratio of lean body mass to fat. Food in the stomach slows the absorption of alcohol, so a person who drinks on an empty stomach will have a higher BAC than a person of similar weight who drinks the same amount but has recently eaten.

Drivers who have consumed alcohol are much more likely to be involved in motor-vehicle accidents than are sober drivers. In fact, alcohol is a factor in nearly 50 percent of all fatal crashes involving young people, and alcohol-related motor-vehicle accidents are the leading cause of death among people 15 to 24 years of age. You can see in Table 53-3 that many tragedies stem from the impaired judgment that invariably results from drinking.

Like other drugs, alcohol can contribute to serious and even fatal drug interactions. For example, when alcohol is combined with another depressant, such as a tranquilizer or a narcotic analgesic, the cumulative effects of the two drugs can slow the cardiac and respiratory systems to the point of causing death.

TABLE 53-3 *Alcohol-Related Tragedies*

Alcohol is a factor in the following:
• 70 percent of all murders
• more than 50 percent of all suicides
• more than 50 percent of all drownings
• more than 50 percent of all fire-related deaths
• 50 percent of all arrests
• nearly 50 percent of all fatal car accidents involving young people

Quick Lab

Graphing Tobacco Use

Materials graph paper, poster board, pencil, colored markers or pencils, ruler

Procedure

1. Examine the following table, which lists the percentage of students who said on national surveys that they smoked.

Grade	1991	1994	1998
8th	14.3%	18.4%	19.1%
10th	20.9%	25.4%	27.6%
12th	28.3%	31.2%	35.1%

2. Using a different color for each grade, graph each grade on the same set of axes. Put the year along the *x*-axis and the percentage along the *y*-axis.
3. Using the data in the graph and the table, design a poster to help prevent a teenager from smoking.

Analysis Analyze the resulting graph. What trends do you notice?

FIGURE 53-5

This child shows some of the abnormalities associated with fetal alcohol syndrome. The forehead is narrow, the wide-set eyes have a shallow crease in the upper eyelid, the upper lip is thin, and the span from the upper lip to the nose is long and lacks a central groove.

Hazards of Long-Term Alcohol Use

People who consume alcohol in large amounts over long periods of time are more likely than nonusers to suffer from high blood pressure and some forms of heart disease. Excessive alcohol use can irritate the lining of the stomach. The most serious result of long-term or inappropriate use of alcohol is **alcoholism,** the addiction to alcohol.

In alcoholics, alcohol takes the place of nutritious foods, causing metabolic disorders. Long-term use of alcohol is associated with the degeneration of neurons in the peripheral nervous system as well as irreversible damage to the brain. Chronic alcohol use forces the liver to use alcohol as an energy source. Eventually, liver cells become unable to function properly, and they accumulate fat deposits. As a result, the liver enlarges. This **fatty liver** is a condition that occurs in 75 percent of all alcoholics. If the drinker abstains from alcohol, the liver can return to normal functioning. If drinking continues, however, the drinker may develop **alcoholic hepatitis** (HEP-uh-TIET-is), an inflammation of the liver, or even **cirrhosis** (suh-ROH-sis), a condition in which normal liver tissue is replaced by scar tissue. Locate the scar tissue in the liver shown in the first illustration in this chapter, on page 1064. Cirrhosis causes severe impairment of liver function and is often fatal.

Like many other drugs, alcohol passes through the placenta and thus can affect a fetus. Children born to women who drink during pregnancy, such as the child shown in Figure 53-5, may suffer from fetal alcohol syndrome. **Fetal alcohol syndrome (FAS)** is a cluster of physical and mental disabilities associated with exposure of the developing fetus to alcohol. Babies that exhibit FAS are small and have an abnormally formed head. They lack normal motor coordination, grow slowly, and may be mentally retarded. Mild degrees of FAS in children often go undiagnosed and may exhibit themselves as behavioral, intellectual, or motor problems.

The severity of FAS seems to be related to the amount of alcohol a pregnant woman drinks and when, during her pregnancy, drinking occurs. There is no established safe level of alcohol intake during pregnancy; researchers think that fetal brain damage occurs at very low levels of alcohol exposure. Moreover, the fetus may be vulnerable to serious damage very early in development, even before a woman realizes that she is pregnant.

Word Roots and Origins

cirrhosis

from the Greek *kirrhos,* meaning "tawny-colored"

SECTION 53-2 REVIEW

1. In what ways does nicotine affect the body?
2. How do tars contribute to a smoker's increased susceptibility to colds and infections?
3. What factors influence blood alcohol concentration in a drinker?
4. How does a stimulant drug differ from a depressant drug?
5. What are some of the effects of fetal alcohol syndrome?
6. **CRITICAL THINKING** Why does alcohol, a single drug, have a wide range of effects on a user?

ABUSE OF DRUGS

When used correctly, both prescription and nonprescription drugs can be beneficial. However, many drugs are abused, that is, taken for nonmedical reasons. Drug abuse includes taking a drug in doses greater than prescribed or for a longer time than recommended, as well as taking a drug that is obtained illegally or without a doctor's prescription.

SECTION 53-3

OBJECTIVES

- Define the term *tolerance.*
- Explain the physical basis of drug addiction.
- Describe the process of withdrawal.
- Identify five types of psychoactive drugs.
- List one example of each type of drug, and describe how each affects the body.

DRUG ADDICTION

Addiction to a drug involves physiological changes in neurons, especially those in the brain. Studies have shown that physical addiction results in changes in body and brain chemistry that in turn create a demand for a steady or increasingly large supply of the drug. The drive to consume greater and greater amounts of a drug is all too familiar to alcoholics and abusers of many other drugs.

Tolerance

As a person becomes addicted to a drug, his or her body may become less responsive to the drug. The addict has developed **tolerance,** which means that increasingly large amounts of the drug are needed to attain the sensation previously achieved with a smaller dose. This rise in the **effective dose,** the dose that results in the desired feeling, is a deadly situation for users of some drugs, particularly depressant drugs. As tolerance increases, the addict must take higher and higher doses of the drug, approaching the lethal dose. The **lethal dose** of a drug is the amount of drug that will cause the user to die, and it does not change as tolerance builds.

If the drug supply is cut off, the addict will go through **withdrawal,** a physical and mental response to the lack of the drug. The symptoms of withdrawal vary, depending on the drug being used and the duration of use. Symptoms may include nausea, headache, insomnia, breathing difficulties, depression, mental instability, and seizures. Withdrawal from addiction to some depressant drugs, such as alcohol and barbiturates, can be life threatening. Addicts undergoing withdrawal are often hospitalized so that their responses can be monitored. Although drug users develop an emotional dependence on a drug, tolerance and withdrawal are physiological effects of drug use. Figure 53-6 shows what happens in neurons of a person addicted to cocaine. The excitatory effect sought by users of cocaine is probably due to the drug's action on neurons that use the neurotransmitters **dopamine** and norepinephrine, NE.

Word Roots and Origins

tolerance

from the Latin *tolerare,* meaning "to bear"

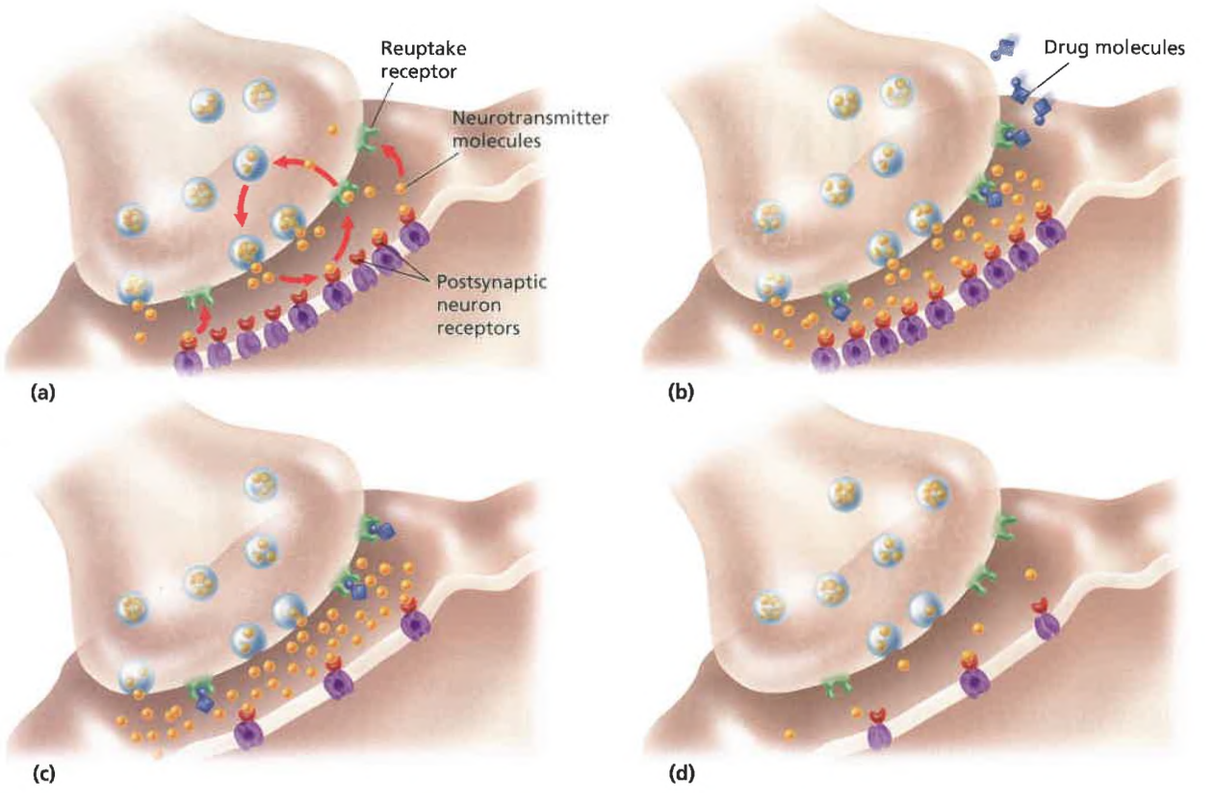


FIGURE 53-6

(a) At a normal NE synapse, neurotransmitter molecules are removed by reuptake receptors. (b) Cocaine and certain other drugs bind at reuptake receptors, blocking them. Neurotransmitter molecules remain in the synaptic cleft. (c) The overstimulated postsynaptic neuron reduces its number of receptors over time to normalize firing. (d) When the drug is removed, the number of neurotransmitter molecules drops to normal—a level too low to stimulate the altered postsynaptic neuron normally.

Neural Changes

Recall from Chapter 50 that when an axon terminal receives a signal—an action potential—it releases molecules of neurotransmitter into the synaptic cleft. In dopamine and NE neurons, and in many other kinds of neurons, neurotransmitter molecules are removed from the synaptic cleft when they bind to reuptake receptors on the presynaptic (neurotransmitter-releasing) neuron, as shown in Figure 53-6a. **Reuptake receptors** are molecular transporters that move neurotransmitter molecules back into the presynaptic neuron. Cocaine acts by binding at these presynaptic reuptake receptors, stopping their function. As a result, a large number of neurotransmitter molecules collect in the synaptic cleft, as shown in Figure 53-6b. These excess neurotransmitter molecules in the synapse excite the postsynaptic neuron to an abnormal degree, increasing firing rate. This excitatory response in dopamine and NE neurons in the brain provides the sensation sought by the drug user.

In response to this chronic surplus of neurotransmitter, the postsynaptic (neurotransmitter-receiving) neurons reduce their number of neurotransmitter receptors over time, as shown in Figure 53-6c. This response is the body's attempt to restore homeostasis in these neurons. As you can see in Figure 53-6d, when the drug is removed, the number of neurotransmitter molecules in the synaptic cleft decreases. (They are taken up by the presynaptic neuron, as is normal.) However, this now-normal level of neurotransmitter is not sufficient to stimulate the postsynaptic neuron, with its now-reduced number of receptors, and transmission of the signal is disrupted.

DRUGS OF ABUSE

Drugs that affect the functioning of the central nervous system are known as **psychoactive drugs.** Psychoactive drugs are often addictive, and possession of many types of psychoactive drugs is illegal. Table 53-4 lists the broad categories of frequently abused drugs; all groups but one, the steroids, are primarily psychoactive.

TABLE 53-4 *Common Drugs of Abuse*

Drug	Short-term effects	Dangers of use
Depressants • Alcohol • Barbiturates • Tranquilizers • Nonbarbiturate sleeping drugs	temporary sense of well-being, impaired judgment, impaired sensory perception, loss of motor control, confusion, sedation	emotional depression, liver damage, brain and peripheral nerve damage, respiratory failure (Withdrawal from alcohol or barbiturates can cause death; withdrawal should be medically supervised.)
Narcotics • Codeine • Heroin • Morphine • Synthetic opiates	temporary feeling of euphoria, impaired reflexes, impaired sensory perception, sedation	coma, respiratory failure
Stimulants • Amphetamines • Caffeine • Cocaine/crack cocaine	temporary feeling of exhilaration and energy, distorted thoughts, irritability, anxiety, restlessness, insomnia, elevated blood pressure, increased heart rate	sleep disturbances, irregular heartbeat; with amphetamines and cocaine, paranoia, delusions, hallucinations, loss of coordination, permanent brain damage, respiratory paralysis, cardiac arrest
Hallucinogens • Amphetamine-like drugs • Ecstasy (MDMA) • Marijuana/hashish • LSD • Mescaline/peyote • PCP (phencyclidine) • Psilocybe mushrooms	temporary dreamlike sense of detachment from surroundings, sensory distortion, hallucinations, delusions, anxiety, slurred speech, numbness, bizarre or violent behavior	mental depression, "flashbacks," paranoia, genetic damage; with marijuana, amotivational syndrome
Inhalants • Aerosol propellants • Alkyl nitrates • Anesthetic gases • Solvents in glue, paint, correction fluid, marking pens, gasoline additives	disorientation, confusion, memory loss; with anesthetic gases, sedation	severe permanent brain damage, hearing loss, limb spasms, bone marrow damage, liver and kidney damage, cardiac arrest; with anesthetic gases, respiratory failure
Anabolic steroids	increase of muscle mass, fluid retention, insomnia, depression	cancer, liver disease, stunted growth, heart disease, heart attack

FIGURE 53-7
Several narcotic drugs are made from the resin of the opium poppy.

Marijuana

One of the hallucinogens listed in Table 53-4 is marijuana, which comes from the flowers, leaves, and seeds of *Cannabis sativa,* the hemp plant. The active ingredient in marijuana is 9-tetrahydrocannabinol, or THC. When smoked, or when heated and then eaten, marijuana produces feelings of disorientation in space and time. Continual use of marijuana can lead to addiction and a suppressed activity level referred to as **amotivational syndrome.**

Cocaine

One of the illegal stimulants listed in Table 53-4 is cocaine. Cocaine is a white powder that is extracted from the leaves of the coca plant, *Erythroxylon coca*. Cocaine is generally inhaled, although it can be injected. Crack cocaine is a smokable form of the drug. Cocaine is a powerful stimulant that raises heart rate, blood pressure, and body temperature. A single dose of cocaine can cause a heart attack. Cocaine is one of the most addictive drugs known.

Opium

Figure 53-7 shows the poppy plant, *Papaver somniferum,* from which the resinous extract opium is obtained. Opium is used to make morphine and codeine, prescription drugs used to alleviate pain. Heroin, an illegal drug, is a semisynthetic, more potent form of morphine. Morphine, codeine, heroin, and similar synthetic drugs are known as narcotics. A **narcotic** is a pain-relieving drug that also induces sedation and sleep. Tolerance and addiction to narcotics occur rapidly.

Narcotics work by mimicking natural painkillers that are produced by the body. Natural painkillers include a class of neurotransmitters known as **enkephalins** (en-KEF-uh-linz). When enkephalins bind to receptor proteins in spinal neurons, they block action potentials from reaching the brain, where they would be interpreted as pain. Narcotics bind to the same receptor sites that enkephalins bind to, triggering and amplifying the body's own pain-blocking system.

At times, morphine is used under medical supervision when the intensity or duration of pain is too much for a person to bear. However, keep in mind that pain plays an important role in the body. Pain makes you aware of some damage that has occurred to a body part or of some malfunction that has occurred in a physiological process. In effect, pain can tell you that an organ system is not operating at its normal level of performance—something that is critical for good health.

SECTION 53-3 REVIEW

1. Name five types of psychoactive drugs.
2. What is tolerance to a drug?
3. How does withdrawal affect the body?
4. Explain how cocaine affects NE neurons.
5. Why is drug addiction considered a physical problem in addition to being a psychological problem?
6. **CRITICAL THINKING** Why are long-term drug users, who have built a large degree of tolerance, endangered by their effective dose?

CHAPTER 53 REVIEW

SUMMARY/VOCABULARY

53-1

- A drug is a chemical compound that affects either the structure of a body part or the functioning of a physiological process. A drug can be introduced into the body orally, by injection, by being placed under the tongue, through inhalation, or by application to the skin.
- Prescription drugs are prescribed by a doctor or dentist. Nonprescription drugs can be purchased without a prescription.
- Taking more than one drug at the same time can cause a harmful drug interaction.
- Overuse of prescription drugs can lead to serious problems. Overuse of antibiotics has fostered the evolution of increasing numbers of resistant bacteria.

Vocabulary

dose (1066)
drug (1065)
nonprescription drug (1066)
prescription drug (1066)

53-2

- Tobacco contains more than 2,000 potentially toxic chemical compounds, including nicotine and tars. Nicotine is an addictive stimulant drug that increases the heart rate and decreases blood flow to the hands and feet.
- Tars paralyze the cilia lining the respiratory passages.
- Health problems associated with tobacco use include lung, lip, mouth, gum, bladder, and pancreatic cancers; chronic bronchitis; emphysema; heart attacks; and health problems in babies of smokers.
- Alcohol is a depressant drug that affects multiple organ systems. Alcohol interferes with normal brain function. Impairment caused by alcohol depends on the amount consumed; the person's body weight, gender, rate of consumption, and ability to metabolize alcohol; and the amount of food in the person's stomach.
- Health problems associated with prolonged, excessive alcohol consumption include high blood pressure, heart disease, fatty liver, alcoholic hepatitis, cirrhosis, and fetal alcohol syndrome. Alcohol can lead to the addiction known as alcoholism.

Vocabulary

addiction (1068)
alcoholic hepatitis (1072)
alcoholism (1072)
blood alcohol concentration (1070)
chronic bronchitis (1069)
cirrhosis (1072)
depressant (1070)
emphysema (1069)
fatty liver (1072)
fetal alcohol syndrome (1072)
nicotine (1068)
secondhand smoke (1070)
stimulant (1068)
tar (1068)

53-3

- Drug abuse can lead to addiction, in which the body undergoes physiological changes that result in a need for the drug.
- Drug addiction results in tolerance as the addict's body becomes less responsive to the drug. During withdrawal, an addict will experience both physical and mental reactions to the lack of the drug.
- Cocaine is an extremely addictive stimulant drug that causes repeated stimulation of NE neurons. Crack cocaine is a smokable form of the drug.
- Marijuana is a hallucinogen that produces feelings of disorientation in space and time. Prolonged use of marijuana can lead to amotivational syndrome.
- Morphine, codeine, and heroin are narcotics derived from opium. Narcotics are powerful painkillers that mimic the body's natural painkillers.

Vocabulary

amotivational syndrome (1076)
dopamine (1073)
effective dose (1073)
enkephalin (1076)
lethal dose (1073)
narcotic (1076)
psychoactive drug (1075)
reuptake receptor (1074)
tolerance (1073)
withdrawal (1073)

REVIEW

Vocabulary

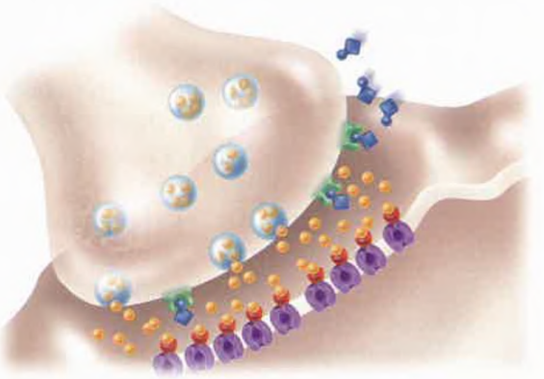
1. Define the term *drug*.
2. Identify two respiratory diseases caused by tobacco.
3. Identify two diseases caused by alcohol.
4. What is blood alcohol concentration, and what are some factors that affect it?
5. Describe the relationship between addiction, tolerance, and withdrawal.

Multiple Choice

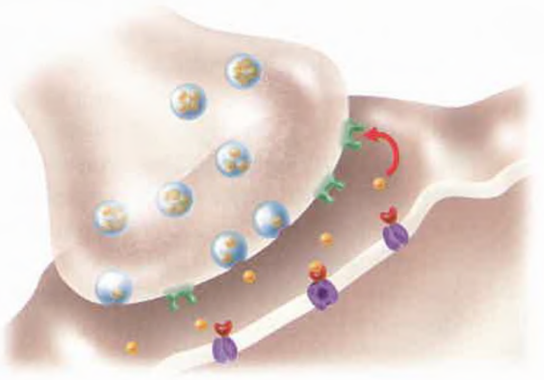
6. Drugs can be administered (a) orally (b) by injection (c) by inhalation (d) all of the above.
7. Tars (a) cause an increase in heart rate (b) are stimulants (c) paralyze cilia (d) are neurotransmitters.
8. Emphysema is (a) a degenerative lung disease (b) a form of cancer (c) an inflammation of the throat (d) a result of chewing tobacco.
9. Alcohol is a (a) stimulant (b) depressant (c) narcotic (d) steroid.
10. BAC specifically measures (a) the rate at which a person has been drinking (b) a person's genetic ability to metabolize alcohol (c) the amount of alcohol in a person's blood (d) the time at which a person was drinking.
11. Fetal alcohol syndrome can cause (a) low birth weight (b) heart defects (c) learning difficulties (d) all of the above.
12. Enkephalins are (a) natural painkillers (b) illegal drugs (c) stimulants (d) synthetic narcotics.
13. Addiction (a) occurs when the body becomes dependent on a drug (b) occurs when the supply of a drug is stopped (c) is easily reversed when the supply of a drug is stopped (d) is caused only by illegal drugs.
14. Depressants include (a) cocaine (b) barbiturates (c) nicotine (d) amphetamines.
15. Narcotics cause (a) an increased heart rate (b) increased alertness (c) decreased alertness (d) lung damage.

Short Answer

16. Describe a situation in which a nonprescription drug could be dangerous.
17. Describe the harmful effects of secondhand smoke.
18. What are some of the harmful effects of smoking during pregnancy?
19. Describe the specific effects of alcohol on the cells of the liver.
20. In what ways are mental capabilities diminished as BAC increases?
21. What are some potential effects of long-term, excessive alcohol use?
22. What is the relationship between fatty liver and cirrhosis?
23. What are psychoactive drugs?
24. In the figure below, explain what has just occurred in (a).
25. In the figure below, explain what has just occurred in (b).



(a)



(b)

CRITICAL THINKING

1. Alcohol is primarily a depressant drug. How do you explain the fact that consumption of alcohol sometimes results in a carefree attitude and a feeling of elation?
2. If you are given a 10-day course of an antibiotic for a bacterial infection and you take the medicine for only five days, how might the infectious bacteria respond?
3. Some infants are born addicted to a drug. Explain how this is possible.
4. Why is tolerance a deadly problem for long-term addicts of some drugs?
5. The table below shows typical blood alcohol concentration values for individuals of different weights. Use the table to answer the following.
   a. What is the blood alcohol concentration of a 140 lb person who has consumed three drinks in one hour?
   b. How many drinks would a 200 lb person have to consume in an hour to equal the BAC of a 140 lb person who consumed three drinks in an hour?
   c. At what weight (among those shown on the table) does a person's BAC rise most rapidly?

Blood Alcohol Concentration (in mg of alcohol per mL of blood) and Its Effects

Drinks per hour	Body weight in pounds								Results
	100	120	140	160	180	200	220	240	
1	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	impairment
2	0.06	0.06	0.05	0.05	0.04	0.04	0.03	0.03	impairment
3	0.11	0.09	0.08	0.07	0.06	0.06	0.05	0.05	intoxication
4	0.15	0.12	0.11	0.09	0.08	0.08	0.07	0.06	intoxication
5	0.19	0.16	0.13	0.12	0.11	0.09	0.09	0.08	intoxication
6	0.23	0.19	0.16	0.14	0.13	0.11	0.10	0.09	intoxication
7	0.26	0.22	0.19	0.16	0.15	0.13	0.12	0.11	severe intoxication
8	0.30	0.25	0.21	0.19	0.17	0.15	0.14	0.13	severe intoxication

EXTENSION

1. In the 1960s, many pregnant women in Europe took the prescription drug thalidomide. Many of the women gave birth to children with severe deformities. In the United States this drug was not available because it had not undergone the lengthy testing required for approval. Find out what is required before a drug is made available to the public in the United States.
2. Investigate and report on the resources available in your local community for treating addiction to both social drugs and illegal drugs.
3. Read "Of Two Minds About Marijuana" in *Discover*, November 1999, on page 26. Why, according to the article, do schizophrenics have a higher rate of marijuana abuse than the general population? Explain why researchers say marijuana is not suitable to treat brain disorders.

CHAPTER 53

INTERACTIVE EXPLORATION

Exploring a Model of Cocaine Addiction

OBJECTIVES

- Simulate the effects of cocaine use on a synapse in the brain.
- Observe the effect of cocaine use on the number of receptors in a synapse.

MATERIALS

- computer with CD-ROM drive
- CD-ROM *Interactive Explorations in Biology: Human Biology*

Background

This interactive exploration enables you to learn about the physical basis of drug addiction by exploring the consequences of exposure of a neuron to cocaine. The exploration presents an animated diagram of a single neural synapse in a "pleasure center" in the human brain. You will explore the consequences of introducing cocaine into a normal neural synapse.

Prelab Preparation

1. Load and start the program Drug Addiction. Click the Topic Information button on the Navigation Palette. Read the focus questions, and review these concepts: The Synapse, Neurotransmitters, Transporters, Neuromodulators, Desensitization, and Addiction.
2. Now click the word *File* at the top left of the screen, and select Interactive Exploration Help. Listen to the instructions that explain the operation of the exploration. Click the Exploration button at the bottom right of the screen to begin the exploration. You will see an animated diagram like the one below.

Procedure

PART A Normal Synapse

First you will investigate how the synapse works when no cocaine is present.

1. Before beginning the simulation, record the number of receptors in the post-synaptic neuron. As the simulation runs, observe what happens to the Pleasure

FEEDBACK METERS

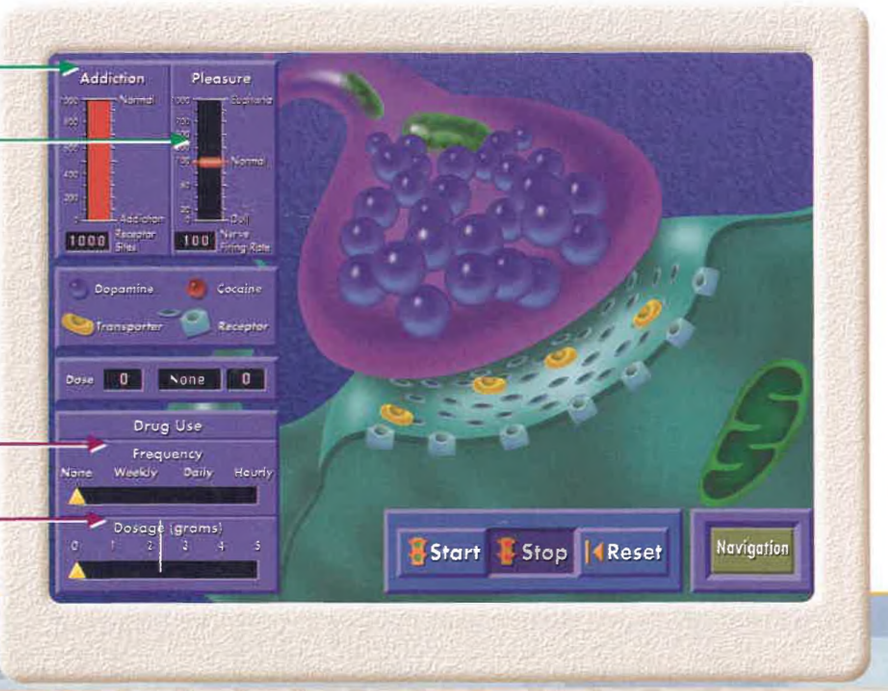
a Addiction Meter: *the number of receptors in the synapse*

b Pleasure Meter: *the number of receptors firing*

VARIABLES

c Frequency of Use: *changes the frequency at which cocaine is taken*

d Dosage: *varies the cocaine dosage from 0 to 5 g*



Meter and the Addiction Meter. Record the highest and lowest levels reached on the Pleasure Meter.

2. Click the Start button to begin the simulation. Observe what happens when neurotransmitter molecules (the blue spheres) are released into the synapse. For the purpose of this demonstration, each contact with a receptor on the other side of the synapse "fires" the postsynaptic neuron, producing a sensation of pleasure. Note carefully that in the normal synapse, the neurotransmitter molecules are recycled by the presynaptic neuron so that they do not accumulate in the synapse.
3. Allow the simulation to run for 3 to 4 minutes, noting any changes in the number of receptors (recorded by the Addiction Meter) and in the postsynaptic neuron's firing rate (recorded by the Pleasure Meter). End the simulation by clicking the Stop button.
4. Record the number of receptors in the postsynaptic neuron at the end of the simulation. Did the number of receptors change during the simulation? Explain why or why not.

PART B Data Collection

Now you will explore the effects of cocaine on the synapse.

5. Click the Reset button to clear the simulation.
6. Slide the Dosage indicator to 1 g and the Frequency of Use indicator to Weekly.
7. On a separate sheet of paper, create a six-column table like the one shown below.
8. Record the number of postsynaptic receptors in your table in the column labeled Addiction Meter: Start. Record the postsynaptic neuron firing rate in the column labeled Pleasure Meter: Start.
9. Click the Start button. For each dose of cocaine, you will see a burst of red spheres, representing cocaine, enter the synapse. What happens to the red spheres after they enter the synapse?
10. Based on what happens to the red spheres, explain why cocaine induces pleasurable sensations.
11. The simulation will run until five doses have been taken, which should require about 5 minutes. At the end of the simulation, record in your table the number of receptors and the postsynaptic neuron's firing rate.
12. How does the number of receptors in the synapse change with repeated cocaine doses?
13. Is this dose large and frequent enough to cause addiction? Explain your answer.
14. What was the highest level reached by the Pleasure Meter? Compare this level with the highest level reached without cocaine use, and account for the difference.
15. Explain how the simulation you carried out in Part A serves as a control for this simulation.
16. Click the Reset button to clear the simulation. Set the Frequency of Use Indicator at Weekly, but slide the Dosage indicator to 2 g. Repeat steps 8–14. How do the results of this simulation differ from those obtained with a 1 g dose?

Analysis and Conclusions

1. Based on your results, can you conclude that cocaine can be taken at a safe dose, at which addiction does not occur? Explain your answer.
2. Explain why people who are addicted to cocaine require higher and higher doses to produce pleasure.

Further Investigation

Selective serotonin reuptake inhibitors (SSRIs) constitute a relatively new class of antidepressants. Read about SSRIs, and write a short description of how they work; include names of specific drugs and the subclasses of serotonin receptors they target.

TABLE A CHANGES IN RECEPTOR NUMBER AND FIRING RATE AFTER COCAINE USE

	Addiction Meter: Start	Addiction Meter: End	Change in receptor number	Pleasure Meter: Start	Pleasure Meter: End	Change in firing rate
No drug (control)						
1 g cocaine/week						
2 g cocaine/week						