

health focus

Protecting Vision and Hearing

A serious loss of vision and hearing can occur as we age. Therefore we should start protecting our eyes and ears when we are young.

Preventing a Loss of Vision

Although flying objects sometimes penetrate the cornea and damage the iris, lens, or retina, careless use of contact lenses is the most common cause of injuries to the eye. Injuries cause only 4% of all cases of blindness; the most frequent causes are retinal disorders, glaucoma, and cataracts, in that order. Retinal disorders are varied. In diabetic retinopathy, which blinds many people between the ages of 20 and 74, capillaries to the retina burst, and blood spills into the vitreous humor. Careful regulation of blood glucose levels in these patients may be protective. In macular degeneration, the cones are destroyed because thickened choroid vessels no longer function as they should. Glaucoma occurs when the drainage system of the eyes fails, so that fluid builds up and destroys nerve fibers responsible for peripheral vision. Eye doctors always check for glaucoma, but it is advisable to be aware of the disorder in case it comes on quickly. Those who have experienced acute glaucoma report that the eyeball feels as heavy as a stone. Cataracts occur in 50% of people between the ages of 65 and 74, and in 70% of those ages 75 or older. In cataracts, cloudy spots on the lens of the eye eventually pervade the whole lens. The milky yellow-white lens scatters incoming light and blocks vision. The extent of visual impairment depends on the size and density of the cataract, and where it is located in the lens. A dense, centrally placed cataract causes severe blurring of vision.

There are preventive measures that we can take to reduce the chance of defective vision as we age. It is recommended, therefore, that everyone, especially those who live in sunny climates or work outdoors, wear glass, not plastic, sunglasses to absorb ultraviolet light. Large lenses worn close to the eyes offer further protection. Special-purpose lenses that block at least 99% of UV-B, 60% of UV-A, and 20–97% of visible light are good for bright sun combined with sand, snow, or water. Health-care providers have found an increased incidence of cataracts in heavy cigarette smokers. In men, smoking 20 cigarettes or more a day, and in women,

smoking more than 35 cigarettes a day, doubles the risk of cataracts. It is possible that smoking reduces the delivery of blood and therefore nutrients to the lens.

Preventing a Loss of Hearing

Especially when we are young, the middle ear is subject to infections that can lead to hearing impairment if they are not treated promptly by a physician. The mobility of ossicles decreases with age, and in the condition called otosclerosis, new filamentous bone grows over the stirrup, impeding its movement. Surgical treatment is the only remedy for this type of conduction deafness. However, age-associated nerve deafness due to stereocilia damage from exposure to loud noises is preventable. Hospitals are now aware that even the ears of the newborn need to be protected from noise and are taking steps to make sure neonatal intensive care units and nurseries are as quiet as possible.

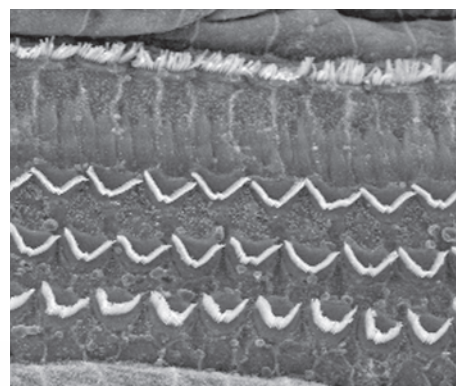
In today's society, exposure to excessive noise is commonplace. Noise is measured in decibels, and any noise above a level of 80 decibels could result in damage to the hair cells of the organ of Corti. Eventually, the stereocilia and then the hair cells disappear completely (Fig. 38A). If listening to city traffic for extended periods can damage hearing, it stands to reason that frequent attendance at rock concerts, constantly playing a stereo loudly, or using earphones at high volume are also damaging to hearing.

However, by the time symptoms are noticed, some degree of hearing has already been irreversibly destroyed.

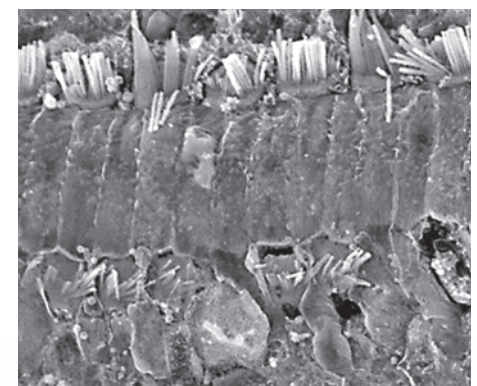
Aside from loud music, noisy indoor or outdoor equipment, such as a rug-cleaning machine or a chain saw, is also troublesome. Even motorcycles and recreational vehicles such as snowmobiles and motocross bikes can contribute to a gradual loss of hearing. Exposure to intense sounds of short duration, such as a burst of gunfire, can result in an immediate hearing loss. The butt of the rifle offers some protection to the ear nearest the gun when it is shot, so it is the opposite ear that often suffers a loss of hearing.

The first hint of noise-induced hearing loss could be temporary hearing loss, a “full” feeling in the ears, muffled hearing, or tinnitus (e.g., ringing in the ears). If you have any of these symptoms, take steps immediately to prevent further damage. If exposure to noise is unavoidable, specially designed noise-reduction earmuffs are available, and it is also possible to purchase earplugs made from a compressible, spongelike material at the drugstore or sporting-goods store. These earplugs are not the same as those worn for swimming, and they should not be used interchangeably.

Finally, people need to be aware that some medicines are ototoxic. Anticancer drugs, most notably cisplatin, and certain antibiotics (e.g., streptomycin, kanamycin, gentamicin) make the ears especially susceptible to hearing loss.



a.



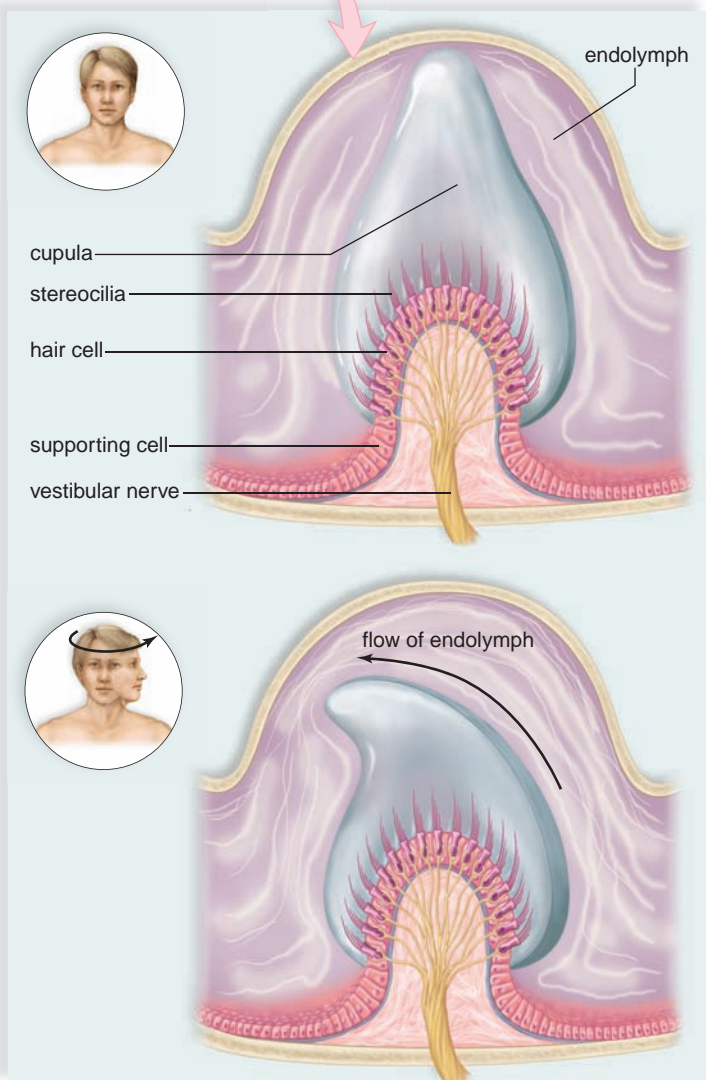
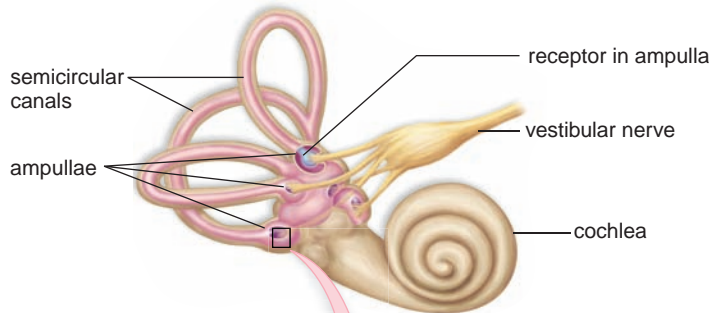
b.

FIGURE 38A Hearing loss.

a. Normal hair cells in the organ of Corti of a guinea pig. **b.** Damaged hair cells in the organ of Corti of a guinea pig. This damage occurred after 24-hour exposure to a noise level typical of a rock concert.

Sense of Balance

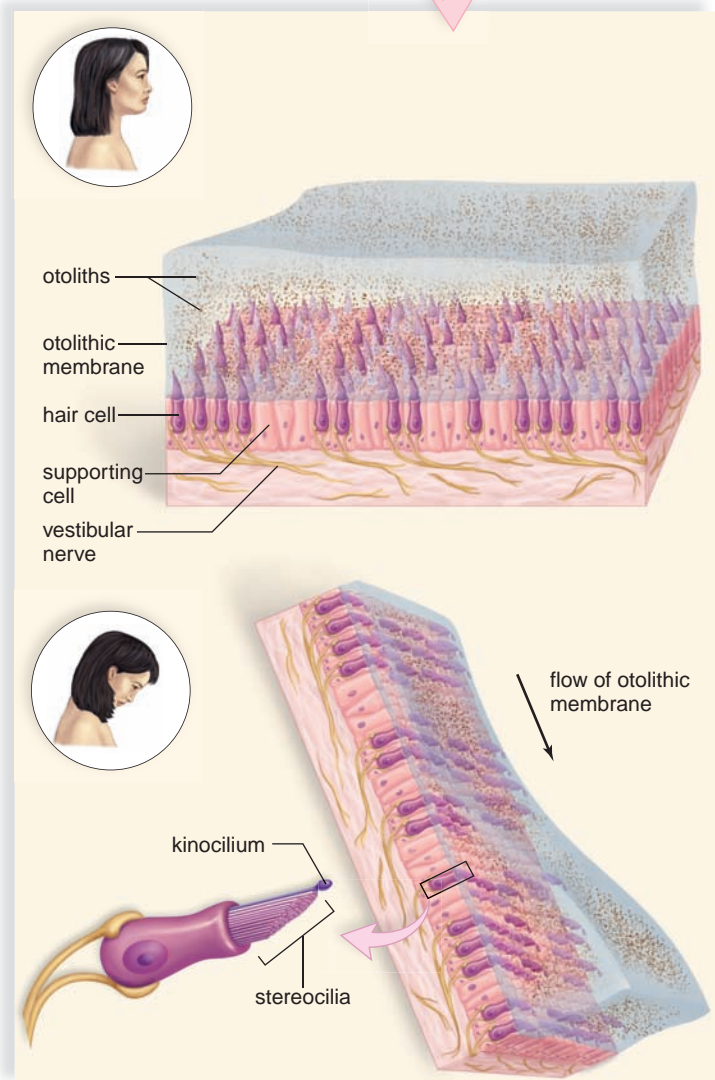
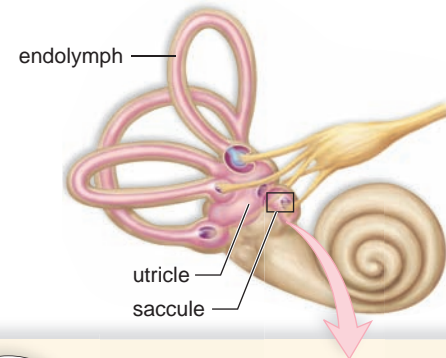
Mechanoreceptors in the semicircular canals detect rotational and/or angular movement of the head (**rotational equilibrium**), while mechanoreceptors in the utricle and saccule detect straight-line movement of the head in any direction (**gravitational equilibrium**).



a. Rotational equilibrium: receptors in ampullae of semicircular canal

Rotational Equilibrium

Rotational equilibrium (Fig. 38.12a) involves the semicircular canals, which are arranged so that there is one in each dimension of space. The base of each of the three canals, called the ampulla, is slightly enlarged. Little hair cells, whose stereocilia are embedded within a gelatinous material called a cupula, are



b. Gravitational equilibrium: receptors in utricle and saccule of vestibule

FIGURE 38.12 Mechanoreceptors for equilibrium.

a. Rotational equilibrium. The ampullae of the semicircular canals contain hair cells with stereocilia embedded in a cupula. When the head rotates, the cupula is displaced, bending the stereocilia. Thereafter, nerve impulses travel in the vestibular nerve to the brain. **b.** Gravitational equilibrium. The utricle and the saccule contain hair cells with stereocilia embedded in an otolithic membrane. When the head bends, otoliths are displaced, causing the membrane to sag and the stereocilia to bend. If the stereocilia bend toward the kinocilium, the longest of the stereocilia, nerve impulses increase in the vestibular nerve. If the stereocilia bend away from the kinocilium, nerve impulses decrease in the vestibular nerve. This difference tells the brain in which direction the head moved.

found within the ampullae. Because there are three semicircular canals, each ampulla responds to head movement in a different plane of space. As fluid (endolymph) within a semicircular canal flows over and displaces a cupula, the stereocilia of the hair cells bend, and the pattern of impulses carried by the vestibular nerve to the brain changes. The brain uses information from the hair cells within ampulla of the semicircular canals to maintain equilibrium through appropriate motor output to various skeletal muscles that can right our present position in space as need be.

Vertigo is dizziness and a sensation of rotation. It is possible to simulate a feeling of vertigo by spinning rapidly and stopping suddenly. When the eyes are rapidly jerked back to a midline position, the person feels like the room is spinning. This shows that the eyes are also involved in our sense of equilibrium.

Gravitational Equilibrium

Gravitational equilibrium (Fig. 38.12*b*) depends on the **utricle** and **sacculus**, two membranous sacs located in the vestibule. Both of these sacs contain little hair cells, whose stereocilia are embedded within a gelatinous material called an otolithic membrane. Calcium carbonate (CaCO_3) granules, or **otoliths**, rest on this membrane. The utricle is especially sensitive to horizontal (back and forth) movements of the head, while the sacculus responds best to vertical (up and down) movements.

When the head is still, the otoliths in the utricle and the sacculus rest on the otolithic membrane above the hair cells. When the head moves in a straight line, the otoliths are displaced and the otolithic membrane sags, bending the stereocilia of the hair cells beneath. If the stereocilia move toward the largest stereocilium, called the kinocilium, nerve impulses increase in the vestibular nerve. If the stereocilia move away from the kinocilium, nerve impulses decrease in the vestibular nerve. If you are up-

side down, nerve impulses in the vestibular nerve cease. These data tell the brain the direction of the movement of the head.

Sensory Receptors in Other Animals

The **lateral line** system of fishes (Fig. 38.13*a*) guides them in their movements and in locating other fishes, including predators and prey and mates. The system detects water currents and pressure waves from nearby objects in the same manner as the sensory receptors in the human ear. In bony fishes, the sensory receptors are located within a canal that has openings to the outside. A lateral line receptor is a collection of hair cells with cilia embedded in a gelatinous cupula. When the cupula bends due to pressure waves, the hair cells initiate nerve impulses.

Gravitational equilibrium organs, called statocysts (Fig. 38.13*b*), are found in cnidarians, molluscs, and crustaceans, which are arthropods. These organs give information only about the position of the head; they are not involved in the sensation of movement. When the head stops moving, a small particle called a statolith stimulates the cilia of the closest hair cells, and these cilia generate impulses, indicating the position of the head.

Check Your Progress

38.3

1. Determine whether each of the following belongs to the outer, middle, or inner ear: **a.** ossicles; **b.** pinna; **c.** semicircular canals; **d.** cochlea; **e.** vestibule; **f.** auditory canal.
2. List, in order, the structures that must conduct a sound wave from the time it enters the auditory canal until it reaches the cochlea.
3. Which structures of the inner ear are responsible for gravitational equilibrium? Rotational equilibrium?

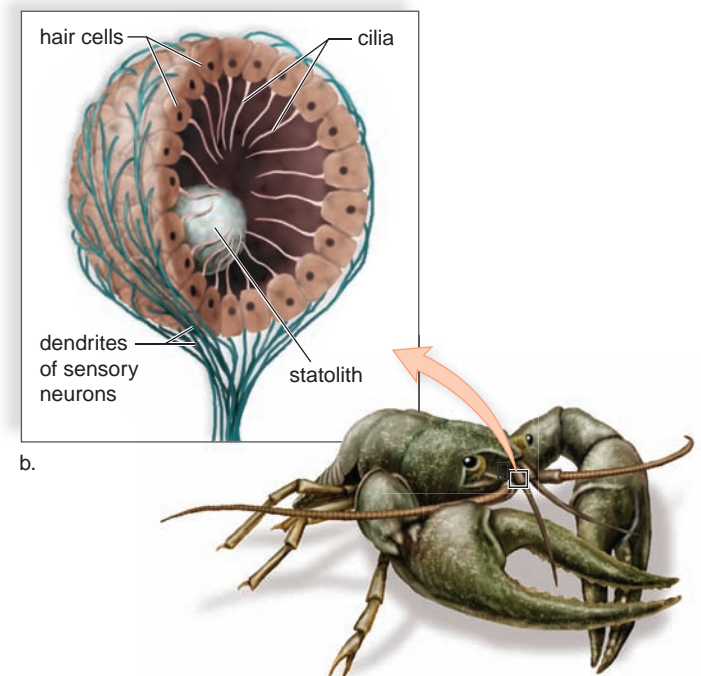
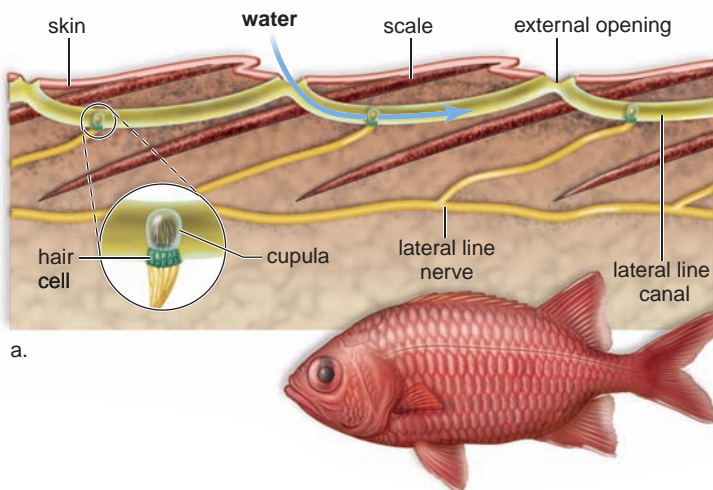


FIGURE 38.13 Sensory receptors in other animals.

a. Hairs located within cupulas of a lateral line detect wave vibrations and currents, helping to guide fish movements in order to locate predators and prey and mates. **b.** Within a statocyst, a small particle (the statolith) comes to rest on hair cells and tells a crustacean the position of its head.

Connecting the Concepts

An animal's information exchange with the internal and external environment is dependent on just a few types of sensory receptors. We have examined chemoreceptors, such as taste cells and olfactory cells; photoreceptors, such as eyes; and mechanoreceptors, such as the hair cells for hearing and balance. The senses are not equally developed in all animals. Male moths have chemoreceptors on the filaments of their antennae to detect minute amounts of an airborne sex attractant released by a female. This is certainly a more efficient method than searching for a mate by sight.

Birds that live in forested areas signal that a territory is occupied by singing because it is difficult to see a bird in a tree, as most birds know. On the other hand, hawks have such a keen sense of sight that they are able

to locate a small mouse far below them. Insectivorous bats have an unusual adaptation for finding prey in the dark. They send out a series of sound pulses and listen for the echoes that come back. The time it takes for an echo to return indicates the location of an insect. A unique adaptation is found among the so-called electric fishes of Africa and Australia. They have electroreceptors that can detect disturbances in an electrical current they emit into the water. These disturbances indicate the location of obstacles and prey.

Animals that migrate use various senses to find their way. Salmon hatch in a freshwater stream but drift to the ocean as larvae. By the end of the third or fourth year, they migrate back to where they were hatched. Like other migrating animals, they apparently

can use the sun as a compass to find their way back to the vicinity of their home river, but then salmon switch to a sense of smell to find the exact location of their hatching. Perhaps the odor of the plants and soil in this stream was imprinted on the nervous system of the larval fish.

Through the evolutionary process, animals tend to rely on those stimuli and senses that are adaptive to their particular environment and way of life. In all cases, sensory receptors generate nerve impulses that travel to the brain, where sensation occurs. In mammals, and particularly human beings, integration of the data received from various sensory receptors results in perception of events occurring in the external environment.

summary

38.1 Chemical Senses

Chemoreception is found universally in animals and is, therefore, believed to be the most primitive sense.

Human olfactory cells and taste buds are chemoreceptors. They are sensitive to chemicals in water and air.

38.2 Sense of Vision

Vision is dependent on the eye, the optic nerves, and the visual areas of the cerebral cortex. The eye has three layers. The outer layer, the sclera, can be seen as the white of the eye; it also becomes the transparent bulge in the front of the eye called the cornea. The middle pigmented layer, called the choroid, absorbs stray light rays. The rod cells (sensory receptors for dim light) and the cone cells (sensory receptors for bright light and color) are located in the retina, the inner layer of the eyeball. The cornea, the humors, and especially the lens bring the light rays to focus on the retina. To see a close object, accommodation occurs as the lens rounds up.

When light strikes rhodopsin within the membranous disks of rod cells, rhodopsin splits into opsin and retinal. A cascade of reactions leads to the closing of ion channels in a rod cell's plasma membrane. Inhibitory transmitter molecules are no longer released, and nerve impulses are carried in the optic nerve to the brain.

Integration occurs in the retina, which is composed of three layers of cells: the rod and cone layer, the bipolar cell layer, and the ganglion cell layer. Integration also occurs in the visual areas of the cerebral cortex.

38.3 Senses of Hearing and Balance

Hearing in humans is dependent on the ear, the cochlear nerve, and the auditory areas of the cerebral cortex. The ear is divided into three parts. The outer ear consists of the pinna and the auditory canal, which direct sound waves to the middle ear. The middle ear begins with the tympanic membrane and contains the ossicles (malleus, incus, and stapes). The malleus is attached to the tympanic membrane, and the stapes is attached to the oval window, which is covered by membrane. The inner ear contains

the cochlea and the semicircular canals, plus the utricle and saccule.

Hearing begins when the outer and middle portions of the ear convey and amplify the sound waves that strike the oval window. Its vibrations set up pressure waves within the cochlea, which contains the organ of Corti, consisting of hair cells whose stereocilia are embedded within the tectorial membrane. When the stereocilia of the hair cells bend, nerve impulses begin in the cochlear nerve and are carried to the brain.

The ear also contains receptors for our sense of equilibrium. Rotational equilibrium is dependent on the stimulation of hair cells within the ampullae of the semicircular canals. Gravitational equilibrium relies on the stimulation of hair cells within the utricle and the saccule.

understanding the terms

blind spot	708	organ of Corti	710
camera-type eye	704	ossicle	709
chemoreceptor	702	otolith	713
choroid	705	outer ear	709
ciliary muscle	706	panoramic vision	704
cochlea	709	photoreceptor	704
compound eye	704	pupil	705
cone cell	707	retina	705
conjunctiva	705	rhodopsin	707
cornea	705	rod cell	707
fovea centralis	705	rotational equilibrium	712
gravitational		saccule	713
equilibrium	712	sclera	704
inner ear	709	semicircular canal	709
iris	705	stereoscopic vision	704
lateral line	713	taste bud	702
lens	705	tympanic membrane	709
mechanoreceptor	709	utricle	713
middle ear	709	vestibule	709
olfactory cell	702	visual accommodation	706

Match the terms to these definitions:

- _____ Photoreceptor, composed of many independent units, which is typical of arthropods.
- _____ Inner layer of the eyeball containing the photoreceptors—rod cells and cone cells.
- _____ Outer, white, fibrous layer of the eye that surrounds the eye except for the transparent cornea.
- _____ Receptor that is sensitive to chemical stimulation—for example, receptors for taste and smell.
- _____ Specialized region of the cochlea containing the hair cells for sound detection and discrimination.

reviewing this chapter

- Discuss the structure and the function of human chemoreceptors. 702–3
- In general, how does the eye in arthropods differ from that in humans? 704–5
- What types of animals have eyes that are constructed like the human eye? 704
- Name the parts of the human eye, and give a function for each part. 704–5
- Explain focusing and accommodation in terms of the anatomy of the human eye. 706–7
- Contrast the location and the function of rod cells to those of cone cells. 707
- Explain the process of integration in the retina and the brain. 708
- Describe the structure of the human ear. 709
- Describe how we hear. 710
- Describe the role of the semicircular canals, utricle, and saccule in balance. 712–13

testing yourself

Choose the best answer for each question.

- A sensory receptor
 - is the first portion of a reflex arc.
 - initiates nerve impulses.
 - is specific for one type of stimulus.
 - is associated with a sensory neuron.
 - All of these are correct.
- Which of these gives the correct path for light rays entering the human eye?
 - sclera, retina, choroid, lens, cornea
 - fovea centralis, pupil, aqueous humor, lens
 - cornea, pupil, lens, vitreous humor, retina
 - optic nerve, sclera, choroid, retina, humors
 - All of these are correct.
- Which gives an incorrect function for the structure?
 - lens—focusing
 - iris—regulation of amount of light
 - choroid—location of cones
 - sclera—protection
 - fovea centralis—acute vision
- Retinal is
 - a derivative of vitamin A.
 - sensitive to light energy.
 - a part of rhodopsin.
 - found in rod cells.
 - All of these are correct.

- Which association is incorrect?
 - taste buds—humans
 - compound eye—arthropods
 - camera-type eye—squid
 - statocysts—sea stars
 - chemoreceptors—planarians
- Which one of these wouldn't you mention if you were tracing the path of sound vibrations?
 - auditory canal
 - tympanic membrane
 - semicircular canals
 - cochlea
 - ossicles
- Which one of these correctly describes the location of the organ of Corti?
 - between the tympanic membrane and the oval window in the inner ear
 - in the utricle and saccule within the vestibule
 - between the tectorial membrane and the basilar membrane in the cochlear canal
 - between the outer and inner ear within the semicircular canals
- Which of these pairs is mismatched?
 - semicircular canals—inner ear
 - utricle and saccule—outer ear
 - auditory canal—outer ear
 - ossicles—middle ear
 - cochlear nerve—inner ear
- Both olfactory receptors and sound receptors have cilia, and they both
 - are chemoreceptors.
 - are a part of the brain.
 - are mechanoreceptors.
 - initiate nerve impulses.
 - All of these are correct.

- Which of these is an incorrect difference between olfactory receptors and equilibrium receptors?

Olfactory receptors

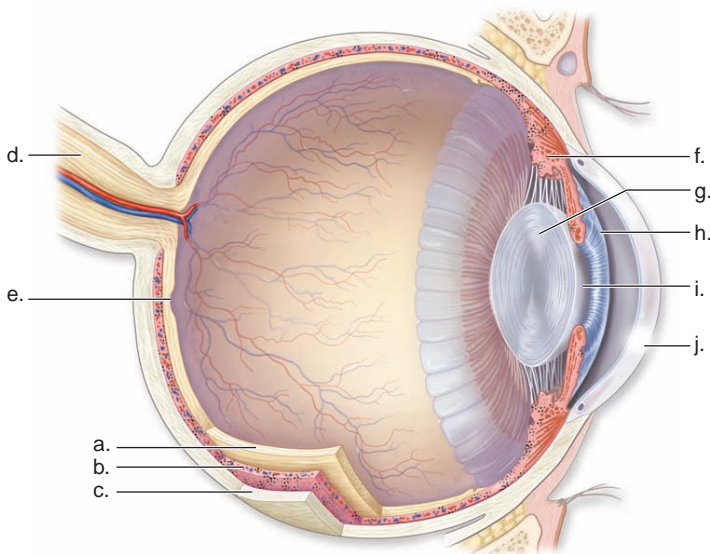
- located in nasal cavities
- chemoreceptors
- respond to molecules in air
- communicate with brain via a tract
- All of these contrasts are correct.

Equilibrium receptors

- located in the inner ear
- mechanoreceptors
- respond to movements of the body
- communicate with brain via vestibular nerve

- Stimulation of hair cells in the semicircular canals results from the movement of
 - endolymph.
 - aqueous humor.
 - basilar membrane.
 - otoliths.
- To focus on objects that are close to the viewer,
 - the suspensory ligaments must be pulled tight.
 - the lens needs to become more rounded.
 - the ciliary muscle will be relaxed.
 - the image must focus on the area of the optic nerve.
- Which abnormality of the eye is incorrectly matched?
 - astigmatism—either the lens or cornea is not even
 - farsightedness—eyeball is shorter than usual
 - nearsightedness—image focuses behind the retina
 - color blindness—genetic disorder in which certain types of cones may be missing

14. Which of these would allow you to know that you were upside down, even if you were in total darkness?
 - a. utricle and saccule
 - b. cochlea
 - c. semicircular canals
 - d. tectorial membrane
15. The thin, darkly pigmented layer that underlies most of the sclera is the
 - a. conjunctiva.
 - b. cornea.
 - c. retina.
 - d. choroid.
16. Adjustment of the lens to focus on objects close to the viewer is called
 - a. convergence.
 - b. accommodation.
 - c. focusing.
 - d. constriction.
17. The middle ear is separated from the inner ear by
 - a. the oval window.
 - b. the tympanic membrane.
 - c. the round window.
 - d. Both a and c are correct.
18. Label this diagram of the human eye. State a function for each structure labeled.



2. A man who has spent many years serving on submarines complains of hearing loss, particularly the inability to hear high tones. When a submarine submerges, the inside air pressure intensifies. What hypothesis or hypotheses might explain hearing loss in this individual?

bioethical issue

Preventable Hearing Loss

The National Institute on Deafness and Other Communication Disorders (NIDCD) tells us that, of the approximately 28 million people in the United States with hearing loss, over one-third have been affected to some degree by noise exposure. As you learned in the Health Focus on page 711, there are simple steps one can take to prevent noise-induced hearing loss, such as wearing ear protection when engaged in loud activities such as mowing the lawn. Portable music devices are common culprits in hearing loss: If you can hear sound coming from someone's earphones from a distance of 3 feet, that person is inflicting a damaging level of noise on him- or herself.

It's clear that for many of us, our own behavior contributes to the occurrence of hearing loss. Should we be responsible in our actions and take all possible steps to safeguard our hearing? Or, should we simply rely on medical science to help us once our hearing has been lost? Those with hearing loss may cope by using hearing aids, which can be costly and do not restore one's hearing to "normal." A new device, called a cochlear implant, can compensate for damaged hair cells by directly stimulating the auditory nerve. However, the device must be surgically implanted, requires extensive postsurgical rehabilitation, does not replicate unassisted hearing, and is extremely expensive. Today, most health insurance provides at least partial assistance for hearing aids and cochlear implants. However, it is estimated that over the past 30 years, the number of people in the United States with hearing loss has doubled. Therefore, health insurance costs must rise in order to assist those with hearing loss.

What is your responsibility as an individual when it comes to protecting your own hearing? Does this responsibility change if you are in a group, say, taking a road trip in a car with the stereo turned all the way up? If you are aware that a friend is damaging his or her own hearing in preventable ways, should you say anything? What is society's responsibility for educating its members about the importance of hearing protection?

Biology website

The companion website for *Biology*, provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

<http://www.mhhe.com/maderbiology10>

thinking scientifically

1. The density of taste buds on the tongue can vary. Some obese individuals have a lower density of taste buds than usual. Assume that taste perception is related to taste bud density. If so, what hypothesis would you test to see if there is a relationship between taste bud density and obesity?

39

Locomotion and Support Systems

When Paul Hamm, a champion gymnast, does handstands on rings, his muscular and skeletal systems are working together under the control of his nervous system. The same is true when eagles fly and fish swim or when animals feed, escape prey, reproduce, or simply play. Although not all animals have muscles and bones, they all use contractile fibers to move about. In planarians, hydras, and earthworms, muscles push against body fluids located inside either a gastrovascular cavity or a coelom.

Only in vertebrates are muscles attached to a bony endoskeleton. Both the skeletal system and the muscular system contribute to homeostasis. Aside from giving the body shape and protecting internal organs, the skeleton serves as a storage area for inorganic calcium and produces blood cells. The skeleton also protects internal organs while supporting the body against the pull of gravity. While contributing to body movement, the skeletal muscles give off heat, which warms the body. This chapter compares locomotion in animals and reviews the musculoskeletal system of vertebrates.

Gymnastics requires coordination between the nervous and support systems.



39.1 DIVERSITY OF SKELETONS

- Animals have one of three types of skeletons: a hydrostatic skeleton, an exoskeleton, or an endoskeleton. 718
- The strong but flexible skeleton of arthropods and vertebrates is adaptive for locomotion on land. 718–19

39.2 THE HUMAN SKELETAL SYSTEM

- The cartilaginous skeleton of the fetus is converted to a skeleton of bone, which continually undergoes remodeling. 720
- There are two types of bone tissue (compact bone and spongy bone) that differ in structure and function. 720–21
- The human skeleton is divided into these portions: The axial skeleton consists of the skull, the vertebral column, the ribs, and the sternum. The appendicular skeleton contains the pectoral and pelvic girdles and the limbs. 722–25
- The human skeleton is jointed; the joints differ in movability. 725

39.3 THE HUMAN MUSCULAR SYSTEM

- Macroscopically, human skeletal muscles work in antagonistic pairs and exhibit tone. 727
- Microscopically, muscle fiber contraction is dependent on filaments of both actin and myosin, and also on a ready supply of calcium ions (Ca^{2+}) and ATP. 728–29
- Motor nerve fibers release ACh at a neuromuscular junction, and thereafter a muscle fiber contracts. 730–31

39.1 Diversity of Skeletons

Skeletons serve as support systems for animals, providing rigidity, protection, and surfaces for muscle attachment. Several different kinds of skeletons occur in the animal kingdom. Cnidarians, flatworms, roundworms, and annelids have a hydrostatic skeleton. Typically, molluscs and arthropods have an **exoskeleton** (external skeleton) composed of calcium carbonate or chitin, respectively. Sponges, echinoderms, and vertebrates possess an **endoskeleton** (internal skeleton). The endoskeleton of sponges consists of mineralized spicules and spongin. In echinoderms, the endoskeleton is composed of calcareous plates and in vertebrates, the endoskeleton is comprised of cartilage, bone, or both.

Hydrostatic Skeleton

In animals that lack a hard skeleton, a fluid-filled gastrovascular cavity or a fluid-filled coelom can act as a hydrostatic skeleton. A **hydrostatic skeleton** [Gk. *hydrias*, water, and *stasis*, standing] offers support and resistance to the contraction of muscles so that mobility results. As analogies, consider that a garden hose stiffens when filled with water, and that a water-filled balloon changes shape when squeezed at one end. Similarly, an animal with a hydrostatic skeleton can change shape and perform a variety of movements.

Hydras and planarians use their fluid-filled gastrovascular cavity as a hydrostatic skeleton. When muscle fibers at the base of epidermal cells in a hydra contract, the body or tentacles shorten rapidly. Planarians usually glide over a substrate with the help of muscular contractions that control the body wall and cilia. Roundworms have a fluid-filled pseudocoelom and move in a whiplike manner when their longitudinal muscles contract. Annelids, such as earthworms, are segmented and have septa that divide the coelom into compartments (Fig. 39.1). Each segment has its own set of longitudinal and circular muscles and its own nerve supply, so each segment or group of segments may

function independently. When circular muscles contract, the segments become thinner and elongate. When longitudinal muscles contract, the segments become thicker and shorten. By alternating circular muscle contraction and longitudinal muscle contraction and by using its setae to hold its position during contractions, the animal moves forward.

Muscular Hydrostat

Even animals that have an exoskeleton or an endoskeleton move selected body parts by means of muscular hydrostats, meaning that fluid contained within certain muscle fibers assists movement of that part. Muscular hydrostats are used by clams to extend their muscular foot and by sea stars to extend their tube feet. Spiders depend on them to move their legs, and moths depend on them to extend their proboscis. In vertebrates, movement of an elephant's trunk involves a muscular hydrostat that allows the animal to reach as high as 23 feet, or pick up a morsel of food, or pull down a tree.

Exoskeletons and Endoskeletons

Molluscs, arthropods, and vertebrates have rigid skeletons. The exoskeleton of molluscs and arthropods protects and supports these animals and provides a location for muscle attachment. Strength of an exoskeleton can be improved by increasing its thickness and weight, but this leaves less room for internal organs.

In molluscs, such as snails and clams, a thick and non-mobile calcium carbonate shell is primarily used for protection against the environment and predators. A mollusc's shell can grow as the animal grows.

The exoskeleton of arthropods, such as insects and crustaceans, is composed of chitin, a strong, flexible nitrogenous polysaccharide. Their exoskeleton protects them against wear and tear, predators, and drying out—an important feature for arthropods that live on land. The jointed and movable exoskeleton of arthropods is particularly suitable for terrestrial life in another way. The jointed and movable appendages allow

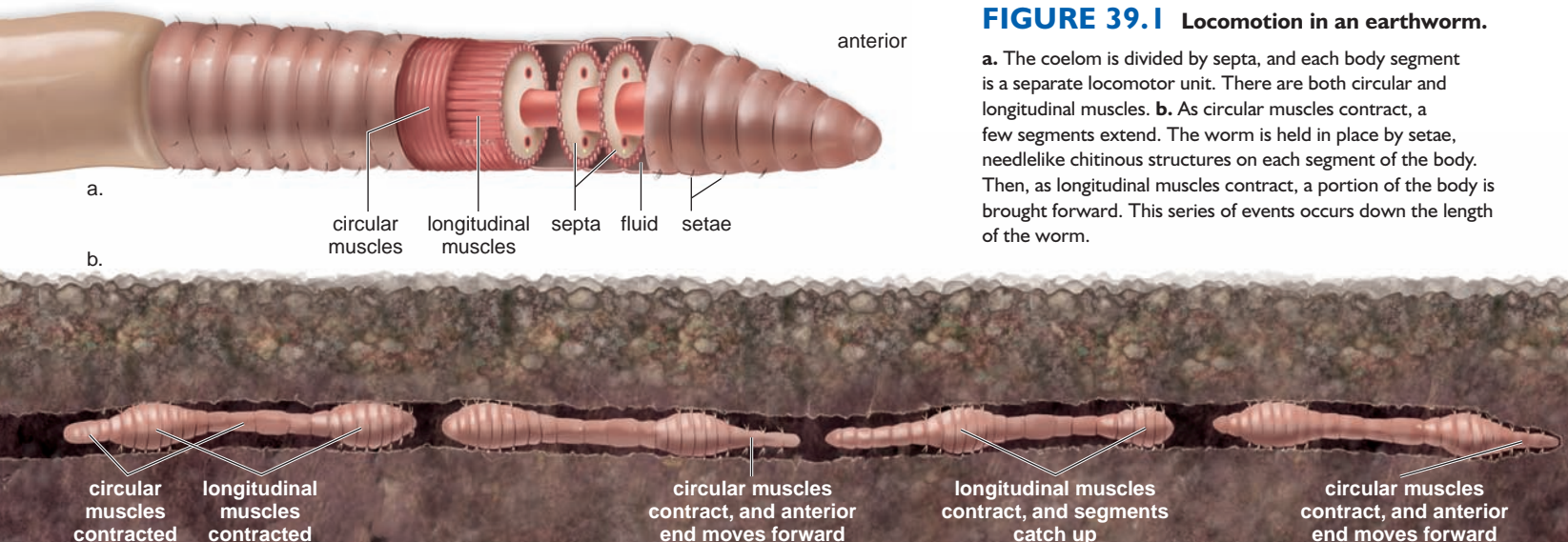


FIGURE 39.1 Locomotion in an earthworm.

a. The coelom is divided by septa, and each body segment is a separate locomotor unit. There are both circular and longitudinal muscles. **b.** As circular muscles contract, a few segments extend. The worm is held in place by setae, needlelike chitinous structures on each segment of the body. Then, as longitudinal muscles contract, a portion of the body is brought forward. This series of events occurs down the length of the worm.



FIGURE 39.2 Exoskeleton.

Exoskeletons support muscle contraction and prevent drying out. The chitinous exoskeleton of an arthropod is shed as the animal molts; until the new skeleton dries and hardens, the animal is more vulnerable to predators, and muscle contractions may not translate into body movements. In this photo, a dog-day cicada, *Tibicen*, has just finished molting.

flexible movements. To grow, however, arthropods must molt to rid themselves of an exoskeleton that has become too small (Fig. 39.2). Until the new exoskeleton dries and hardens, the animals are more vulnerable to predators.

Both echinoderms and vertebrates have an endoskeleton. The skeleton of echinoderms consists of spicules and plates of calcium carbonate embedded in the living tissue of the body wall. In contrast, the vertebrate endoskeleton is living tissue. Sharks and rays have skeletons composed only of cartilage. Other vertebrates, such as bony fishes, amphibians, reptiles, birds, and mammals, have endoskeletons composed of bone and cartilage. The advantages of the jointed vertebrate endoskeleton are listed in Figure 39.3. An endoskeleton grows with the animal, and molting is not required. It supports the weight of a large animal without limiting the space for internal organs. An endoskeleton also offers protection to vital internal organs, but it is protected by the soft tissues around it. Injuries to soft tissue are usually easier to repair than injuries to a hard skeleton. The vertebrate endoskeleton is also jointed, allowing for complex movements such as swimming, jumping, flying, and running.

Check Your Progress

39.1

1. Identify the type of skeleton of each of the following animals: butterfly, crow, shrimp, oyster, and sea urchin.
2. Stick out your tongue. What type of muscular support system makes this possible?
3. A dead earthworm loses its cylindrical shape, becoming limp and flattened. Why?



Advantages of Jointed Endoskeleton

- Can grow with the animal
- Supports the weight of large animal
- Protects vital internal organs
- Is protected by outer tissues
- Allows flexible movements



FIGURE 39.3

The vertebrate endoskeleton.

The jointed vertebrate endoskeleton has the advantages listed. In addition, an endoskeleton lends itself to adaptation to the environment. Vertebrates move in various ways (e.g., jumping, flying, swimming, running).

39.2 The Human Skeletal System

The human skeletal system has many functions that contribute to homeostasis.

The rigid skeleton supports the body. An endoskeleton grows with the body, and molting, as seen in arthropods, is not needed.

The skeleton protects vital internal organs, such as the brain, heart, and lungs. The bones of the skull protect the brain, the rib cage protects the heart and lungs. The vertebrae protect the spinal cord, which makes nervous connections to all the muscles of the limbs.

The skeleton provides sites for muscle attachment, making movement possible. While articulations (joints) occur between all the bones, we associate body movement particularly with jointed appendages.

The skeleton serves as an important storage reservoir for ions, such as calcium and phosphorus. All bones have a matrix that contains calcium phosphate, a source of calcium ions and phosphate ions in the blood.

The skeleton produces blood cells. Blood cells and other blood elements are produced within the red bone marrow of the skull, ribs, sternum, pelvis, and long bones.

Bone Growth and Renewal

Most of the bones of the human skeleton are composed of cartilage during prenatal development. Because the cartilaginous structures are shaped like the future bones, they provide “models” of these bones. The cartilaginous models are converted to bones when calcium salts are deposited in the matrix (nonliving material), first by the cartilage cells and later by bone-forming cells called **osteoblasts** [Gk. *osteon*, bone, and *blastos*, bud]. This type of bone is called endochondral bone, or replacement bone. The conversion of cartilaginous models to bones is called endochondral ossification.

There are also examples of ossification that have no previous cartilaginous model. This type of ossification occurs in the dermis and forms bones called dermal bones. Several dermal bones include the mandible (lower jaw), certain bones of the skull, and the clavicle (collarbone). During intramembranous ossification, fibrous connective tissue membranes give support as ossification begins.

Endochondral ossification of a long bone begins in a region called a primary ossification center, located in the middle of the cartilaginous model. In the primary ossification center, the cartilage is broken down and invaded by blood vessels, and cells in the area mature into bone-forming osteoblasts. Later, secondary ossification centers form at the ends of the model. A cartilaginous *growth plate* remains between the primary ossification center and each secondary center. As long as these plates remain, growth is possible. The rate of growth is controlled by hormones, particularly growth hormone (GH) and the sex hormones. Eventually, the plates become ossified, causing the primary and secondary centers of ossification to fuse, and the bone stops growing.

In the adult, bone is continually being broken down and built up again. Bone-absorbing cells, called **osteoclasts** [Gk. *osteon*, bone, and *klastos*, broken in pieces], break down bone, remove worn cells, and deposit calcium in the blood. In this way, osteoclasts help maintain the blood calcium level and contribute to homeostasis. Among other functions, calcium ions play a major role in muscle contraction and nerve conduction. The blood calcium level is closely regulated by the antagonistic hormones parathyroid hormone (PTH) and calcitonin. PTH promotes the activity of osteoclasts, and calcitonin inhibits their activity to keep the blood calcium level within normal limits.

Assuming that the blood calcium level is normal, bone destruction caused by the work of osteoclasts is repaired by osteoblasts. As they form bone, osteoblasts take calcium from the blood. Eventually, some of these cells get caught in the matrix (nonliving material) they secrete and are converted to **osteocytes** [Gk. *osteon*, bone, and *kytos*, cell], the cells found within the lacunae of osteons. Adults are thought to require more calcium in the diet than do children to promote the work of osteoblasts.

Through this process of remodeling, old bone tissue is replaced by new bone tissue. Osteoclasts and osteoblasts work together to heal broken bones by breaking down and building bone at the site of the damage. Therefore, the thickness of bones can change, depending on exercise and hormone balances. As discussed in the Health Focus on page 726, a thinning of the bones called osteoporosis can occur as we age if proper precautions are not taken.

Anatomy of a Long Bone

A long bone, such as the humerus, illustrates principles of bone anatomy. When the bone is split open, as in Figure 39.4, the longitudinal section shows that it is not solid but has a cavity called the medullary cavity bounded at the sides by compact bone and at the ends by spongy bone. Beyond the spongy bone, there is a thin shell of compact bone and finally a layer of hyaline cartilage. The cavity of an adult long bone usually contains yellow bone marrow, which is a fat-storage tissue.

Compact bone contains many osteons (Haversian systems), where osteocytes lie in tiny chambers called lacunae. The lacunae are arranged in concentric circles around central canals that contain blood vessels and nerves. The lacunae are separated by a matrix of collagen fibers and mineral deposits, primarily calcium and phosphorus salts.

Spongy bone has numerous bony bars and plates separated by irregular spaces. Although lighter than compact bone, spongy bone is still designed for strength. Just as braces are used for support in buildings, the solid portions of spongy bone follow lines of stress. The spaces in spongy bone are often filled with **red bone marrow**, a specialized tissue that produces blood cells. This is an additional way the skeletal system assists homeostasis. As you know, red blood cells transport oxygen, and white blood cells are a part of the immune system, which fights infection.

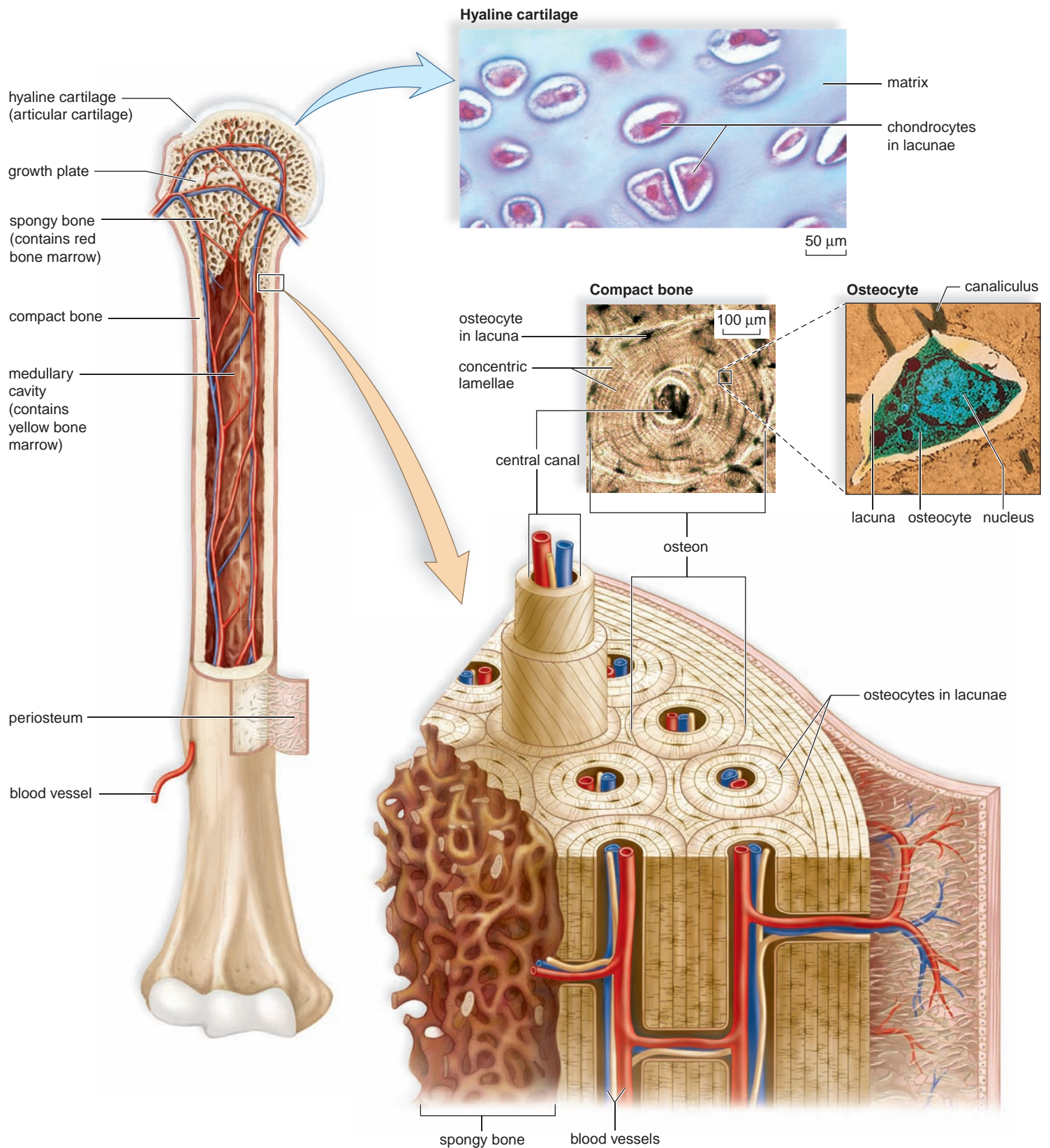


FIGURE 39.4 Anatomy of a long bone.

Left: A long bone is encased by fibrous membrane (periosteum) except where it is covered at the ends by hyaline cartilage (see micrograph). Spongy bone located beneath the cartilage may contain red bone marrow. The central shaft contains yellow bone marrow and is bordered by compact bone, which is shown in the enlargement and micrograph (*right*).

The Axial Skeleton

The **axial skeleton** [L. *axis*, axis, hinge; Gk. *skeleton*, dried body] lies in the midline of the body and consists of the skull, the vertebral column, the thoracic cage, the sacrum, and the coccyx (blue labels in Fig. 39.5). A total of 80 bones make up the axial skeleton.

The Skull

The skull, which protects the brain, is formed by the cranium and the facial bones (Fig. 39.6). In newborns, certain bones of the cranium are joined by membranous regions called **fontanels** (or “soft spots”), all of which usually close and become **sutures** by the age of two years. The bones of the cranium contain the sinuses [L. *sinus*, hollow], air spaces lined by mucous membrane that reduce the weight of the skull and give a resonant sound to the voice. Two sinuses, called the mastoid sinuses, drain into the middle ear. Mastoiditis, a condition that can lead to deafness, is an inflammation of these sinuses.

The major bones of the cranium have the same names as the lobes of the brain. On the top of the cranium, the frontal bone forms the forehead, and the parietal bones extend to the sides. Below the much larger parietal bones, each temporal bone has an opening that leads to the middle ear. In the rear of the skull, the occipital bone curves to form the base of the skull. At the base of the skull, the spinal cord passes upwards through

a large opening called the **foramen magnum** [L. *foramen*, hole, and *magnus*, great, large] and becomes the brain stem.

The temporal and frontal bones are cranial bones that contribute to the face. The sphenoid bones account for the flattened areas on each side of the forehead, which we call the temples. The frontal bone not only forms the forehead, but it also has supraorbital ridges where the eyebrows are located. Glasses sit where the frontal bone joins the nasal bones.

The most prominent of the facial bones are the mandible [L. *mandibula*, jaw], the maxillae, the zygomatic bones, and the nasal bones. The mandible, or lower jaw, is the only freely movable portion of the skull (Fig. 39.6), and its action permits us to chew our food. It also forms the “chin.” Tooth sockets are located in the mandible and on the maxillae, which form the upper jaw and a portion of the hard palate. The zygomatic bones are the cheekbone prominences, and the nasal bones form the bridge of the nose. Other bones make up the nasal septum, which divides the nose cavity into two regions.

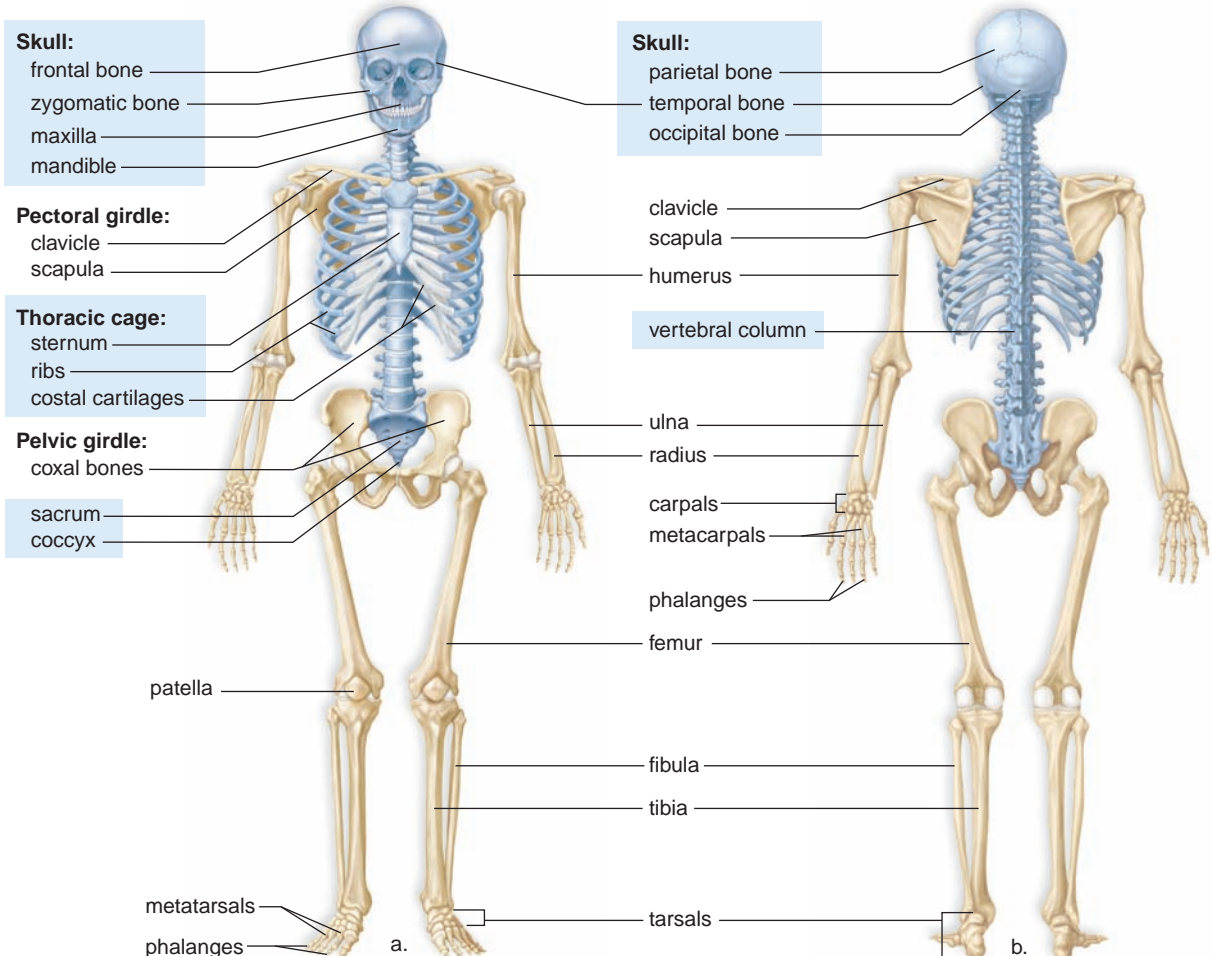
Whereas the ears are formed only by cartilage and not by bone, the nose is a mixture of bones, cartilage, and connective tissues. The lips and cheeks have a core of skeletal muscle.

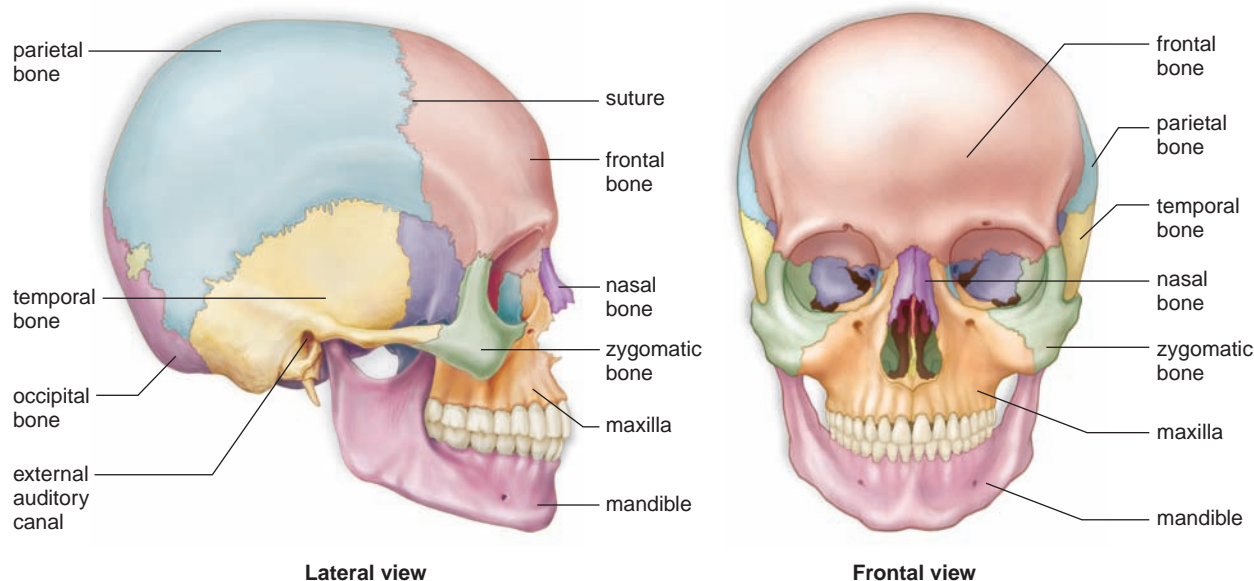
The Vertebral Column and Rib Cage

The **vertebral column** [L. *vertebra*, bones of backbone] supports the head and trunk and protects the spinal cord and the roots of the spinal nerves. It is a longitudinal axis that

FIGURE 39.5
The human skeleton.

a. Anterior view.
b. Posterior view.
The bones of the axial skeleton are in blue and the rest is the appendicular skeleton.



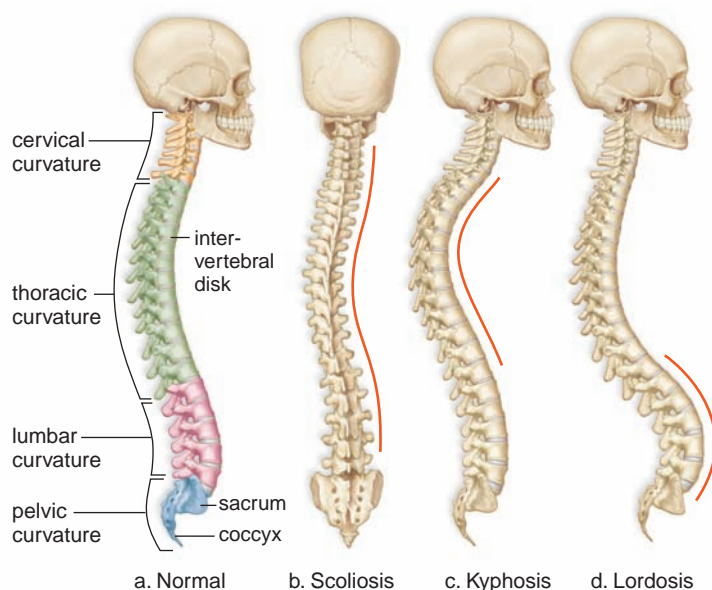
**FIGURE 39.6****The skull.**

The skull consists of the cranium and the facial bones. The frontal bone is the forehead; the zygomatic arches form the cheekbones, and the maxillae form the upper jaw. The mandible has a projection we call the chin.

serves either directly or indirectly as an anchor for all the other bones of the skeleton.

Twenty-four vertebrae make up the vertebral column. Seven cervical vertebrae are located in the neck; 12 thoracic vertebrae are in the thorax; 5 lumbar vertebrae are in the lower back; 5 fused sacral vertebrae form a single sacrum; and several fused vertebrae are in the coccyx, or tailbone. Normally, the vertebral column has four curvatures that provide more resilience and strength for an upright posture than could a straight column. Abnormal curvatures also occur (Fig. 39.7).

Intervertebral disks, composed of fibrocartilage between the vertebrae, provide padding. They prevent the vertebrae from grinding against one another and absorb shock caused by movements such as running, jumping, and even walking.

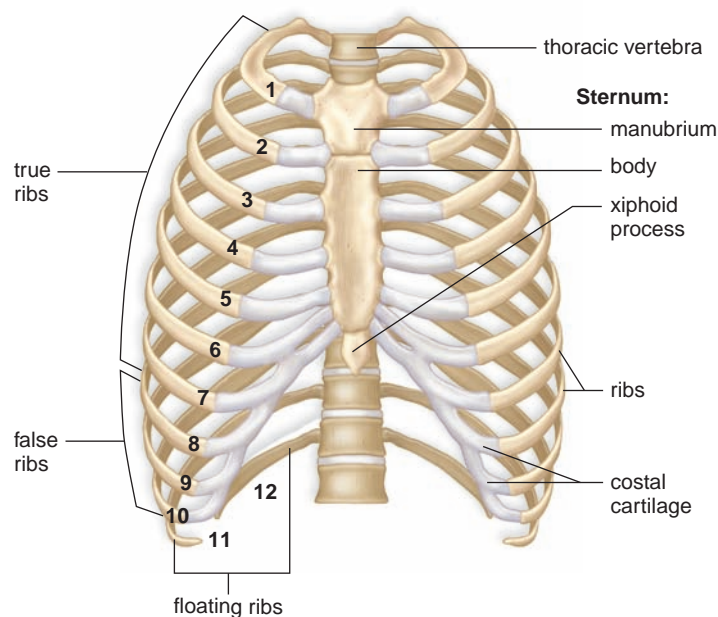
**FIGURE 39.7** Spinal curvatures.

a. The vertebral column normally has four curvatures. b. Scoliosis is abnormal lateral (sideways) curvature. c. Kyphosis is abnormal thoracic curvature. d. Lordosis is abnormal lumbar curvature.

The presence of the disks allows the vertebrae to move as we bend forward, backward, and from side to side. Unfortunately, these disks become weakened with age and can herniate and rupture. Pain results if a disk presses against the spinal cord and/or spinal nerves. The body may heal itself, or the disk can be removed surgically. If so, the vertebrae can be fused together, but this limits the flexibility of the body.

Rib Cage. The thoracic vertebrae are a part of the rib cage. The rib cage also contains the ribs, the costal cartilages, and the sternum, or breastbone (Fig. 39.8).

There are 12 pairs of ribs. The upper 7 pairs are “true ribs” because they attach directly to the sternum. The lower 5 pairs do not connect directly to the sternum and are called the “false ribs.” Three pairs of false ribs attach by means of

**FIGURE 39.8** The rib cage.

The rib cage consists of the thoracic vertebrae, the 12 pairs of ribs, the costal cartilages, and the sternum, or breastbone.

a common cartilage, and 2 pairs are “floating ribs” because they do not attach to the sternum at all.

The rib cage demonstrates how the skeleton is protective but also flexible. The rib cage protects the heart and lungs; yet it swings outward and upward upon inspiration and then downward and inward upon expiration.

The Appendicular Skeleton

The **appendicular skeleton** [L. *appendicula*, dim. of *appendix*, appendage] consists of the bones within the pectoral and pelvic girdles and the attached limbs (see Fig. 39.5). The pectoral (shoulder) girdle and upper limbs are specialized for flexibility, but the pelvic girdle (hipbones) and lower limbs are specialized for strength. A total of 126 bones make up the appendicular skeleton.

The Pectoral Girdle and Upper Limb

The components of the **pectoral girdle** [Gk. *pechys*, forearm] are only loosely linked together by ligaments (Fig. 39.9). Each clavicle (collarbone) connects with the sternum and the scapula (shoulder blade), but the scapula is held in place only by muscles. This allows it to glide and rotate on the clavicle. The single long bone in the arm, the humerus, has a smoothly

rounded head that fits into a socket of the scapula. The socket, however, is very shallow and much smaller than the head. Although this means that the arm can move in almost any direction, there is little stability. Therefore, this is the joint that is most apt to dislocate. The opposite end of the humerus meets the two bones of the lower arm, the ulna and the radius, at the elbow. (The prominent bone in the elbow is the topmost part of the ulna.) When the upper limb is held so that the palm is turned frontward, the radius and ulna are about parallel to one another. When the upper limb is turned so that the palm is next to the body, the radius crosses in front of the ulna, a feature that contributes to the easy twisting motion of the forearm.

The many bones of the hand increase its flexibility. The wrist has eight carpal bones, which look like small pebbles. From these, five metacarpal bones fan out to form a framework for the palm. The metacarpal bone that leads to the thumb is placed in such a way that the thumb can reach out and touch the other digits. (Digits is a term that refers to either fingers or toes.) Beyond the metacarpals are the phalanges, the bones of the fingers and the thumb. The phalanges of the hand are long, slender, and lightweight.

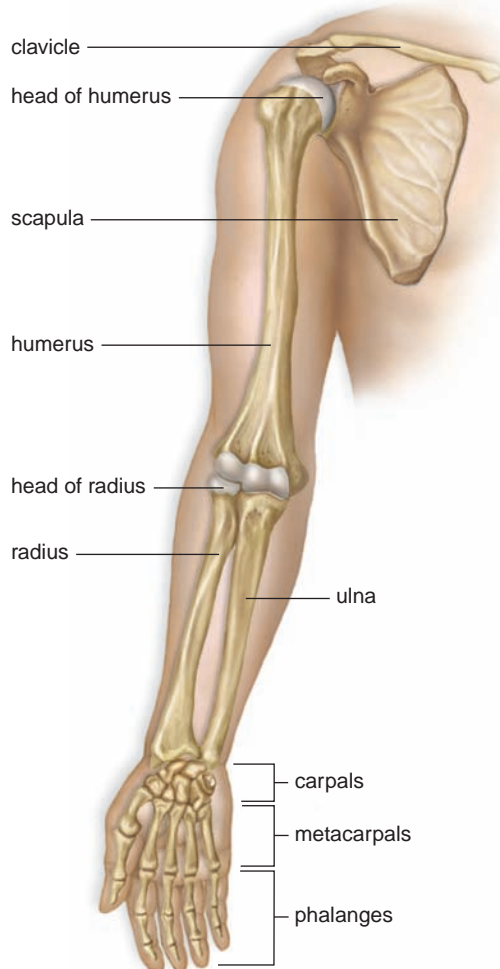


FIGURE 39.9 Bones of the pectoral girdle and upper limb.

The humerus is known as the “funny bone” of the elbow. The sensation upon bumping it is due to the activation of a nerve that passes across its end.

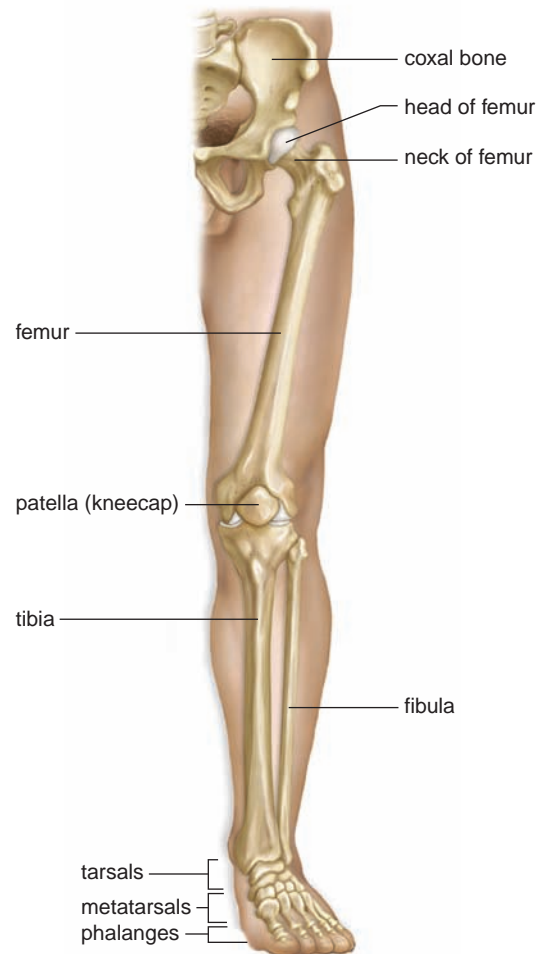


FIGURE 39.10 Bones of the pelvic girdle and lower limb.

The femur is our strongest bone—it withstands a pressure of 540 kg per 2.5 cm³ when we walk.

The Pelvic Girdle and Lower Limb

The **pelvic girdle** [L. *pelvis*, basin] (Fig. 39.10) consists of two heavy, large coxal bones (hipbones). The coxal bones are anchored to the sacrum, and together these bones form a hollow cavity called the pelvic cavity. The wider pelvic cavity in females than males accommodates pregnancy and childbirth. The weight of the body is transmitted through the pelvis to the lower limbs and then onto the ground. The largest bone in the body is the femur, or thighbone.

In the leg, the larger of the two bones, the tibia, has a ridge we call the shin. Both of the bones of the leg have a prominence that contributes to the ankle—the tibia on the inside of the ankle and the fibula on the outside of the ankle. Although there are seven tarsal bones in the ankle, only one receives the weight and passes it on to the heel and the ball of the foot. If you wear high-heeled shoes, the weight is thrown toward the front of your foot. The metatarsal bones participate in forming the arches of the foot. There is a longitudinal arch from the heel to the toes and a transverse arch across the foot. These provide a stable, springy base for the body. If the tissues that bind the metatarsals together become weakened, “flat feet” are apt to result. The bones of the toes are called phalanges, just as are those of the fingers, but in the foot the phalanges are stout and extremely sturdy.

Classification of Joints

Bones are connected at the **joints**, which are classified as fibrous, cartilaginous, and synovial. Fibrous joints, such as the sutures that exist between the cranial bones, are immovable. Cartilaginous joints, such as those between the vertebrae, are slightly movable. The vertebrae are also separated by disks, which increase their flexibility. The two hipbones are slightly movable because they are ventrally joined by cartilage. Owing to hormonal changes, this joint becomes more flexible during late pregnancy, allowing the pelvis to expand during childbirth.

In freely movable **synovial joints**, the two bones are separated by a cavity. **Ligaments**, composed of fibrous connective tissue, bind the two bones to each other, holding them in place as they form a capsule. In a “double-jointed” individual, the ligaments are unusually loose. The joint capsule is lined by synovial membrane, which produces synovial fluid, a lubricant for the joint.

The knee is an example of a synovial joint (Fig. 39.11). In the knee, as in other freely movable joints, the bones are capped by a layer of articular cartilage. In addition, there are crescent-shaped pieces of cartilage between the bones called menisci [Gk. *meniscus*, crescent]. These give added stability, helping to support the weight placed on the knee joint. Unfortunately, athletes often suffer injury of the meniscus, known as torn cartilage. Thirteen fluid-filled sacs called bursae (sing., **bursa**) occur around the knee joint. Bursae ease friction between tendons and ligaments and between tendons and bones. Inflammation of the bursae is called bursitis. Tennis elbow is a form of bursitis.

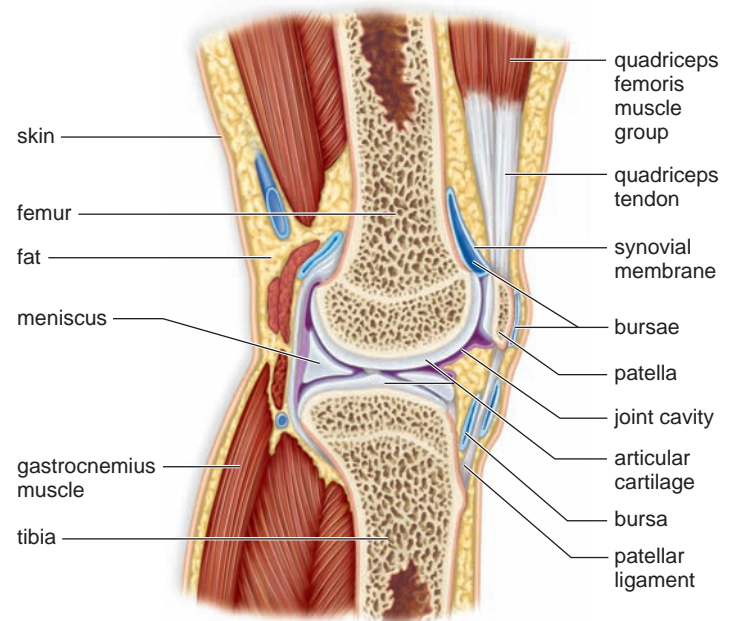


FIGURE 39.11 Knee joint.

The knee joint is an example of a synovial joint. The cavity between the bones is encased by ligaments and lined by synovial membrane. The patella (kneecap) serves to guide the quadriceps tendon over the joint when flexion or extension occurs.

There are different types of movable joints. The knee and elbow joints are hinge joints because, like a hinged door, they largely permit movement in one direction only. In a pivot joint, a small, cylindrical projection of one bone pivots within the ring formed of bone and ligament of another bone, making rotation possible. The joint between the first two cervical vertebrae, which permits side-to-side movement of the head, is an example of a pivot joint. More movable are the ball-and-socket joints; for example, the ball of the femur fits into a socket on the hipbone. Ball-and-socket joints allow movement in all planes and even rotational movement.

Synovial joints are subject to arthritis. In rheumatoid arthritis, the synovial membrane becomes inflamed and thickened. Degenerative changes take place that make the joint almost immovable and painful to use. There is evidence that these effects are brought on by an autoimmune reaction. In old-age arthritis, or osteoarthritis, the cartilage at the ends of the bones disintegrates so that the two bones become rough and irregular. This type of arthritis is apt to affect the joints that have received the greatest use over the years.

Check Your Progress

39.2

1. What are bone-forming and bone-absorbing cells called? Name the cells that reside in the lacunae of osteons.
2. Determine whether each of the following bones belongs to the axial or appendicular skeleton: sacrum, frontal bone, humerus, tibia, vertebra, coxal bone, temporal bone, scapula, and sternum.

health focus

You Can Avoid Osteoporosis

Osteoporosis is a condition in which the bones are weakened due to a decrease in the bone mass that makes up the skeleton. Throughout life, bones are continuously re-modeled. While a child is growing, the rate of bone formation is greater than the rate of bone breakdown. The skeletal mass continues to increase until ages 20 to 30. After that, there is an equal rate of formation and breakdown of bone mass until ages 40 to 50. Then, reabsorption begins to exceed formation, and the total bone mass slowly decreases.

Over time, men are apt to lose 25% and women to lose 35% of their bone mass. But we have to consider that men tend to have denser bones than women anyway, and their testosterone (male sex hormone) level generally does not begin to decline significantly until after age 65. In contrast, the estrogen (female sex hormone) level in women begins to decline at about age 45. Since sex hormones play an important role in maintaining bone strength, this difference means that women are more likely than men to suffer a higher incidence of fractures, involving especially the hip vertebrae, long bones, and pelvis. Although osteoporosis may at times be the result of various disease processes, it is essentially a disease that occurs as we age. An estimated 10 million people in the United States have osteoporosis, which results in 1.5 million fractures each year.

How to Avoid Osteoporosis

Everyone can take measures to avoid having osteoporosis when they get older. Adequate dietary calcium throughout life is an important protection against osteoporosis. The U.S. National Institutes of Health recommend a calcium intake of 1,200–1,500 mg per day during puberty. Males and females require 1,000 mg per day until the age of 65 and 1,500 mg per day after age 65. In older women 1,500 mg per day is especially desirable.

A small daily amount of vitamin D is also necessary for the body to use calcium correctly. Exposure to sunlight is required to allow skin to synthesize a precursor to vitamin D. If you reside on or north of a “line” drawn from Boston to Milwaukee, to Minneapolis, to

Boise, chances are you’re not getting enough vitamin D during the winter months. Therefore, you should avail yourself of vitamin D present in fortified foods such as low-fat milk and cereal.

Very inactive people, such as those confined to bed, lose bone mass 25 times faster than people who are moderately active. On the other hand, a regular, moderate, weight-bearing exercise like walking or jogging is another good way to maintain bone strength (Fig. 39A).

Postmenopausal women with any of the following risk factors should have an evaluation of their bone density:

- white or Asian race
- thin body type
- family history of osteoporosis
- early menopause (before age 45)
- smoking
- a diet low in calcium, or excessive alcohol consumption and caffeine intake
- sedentary lifestyle

Presently bone density is measured by a method called dual energy X-ray absorptiometry (DEXA). This test measures bone density based on the absorption of photons generated by an X-ray tube. Soon there may be blood and urine tests to detect the biochemical markers of bone loss. Then it will be made easier for physicians to screen older women and at-risk men for osteoporosis.

If the bones are thin, it is worthwhile to take all possible measures to gain bone density because even a slight increase can significantly reduce fracture risk. Hormone therapy includes black cohosh, which is a phytoestrogen (estrogen made by a plant as opposed to an animal). Calcitonin is a naturally occurring hormone whose main site of action is the skeleton, where it inhibits the action of osteoclasts, the cells that break down bone. Also, alendronate is a drug that acts similarly to calcitonin. After three years of alendronate therapy, an increase in spinal density by about 8% and hip density by about 7% is obtained. Promising new drugs include slow-release fluoride therapy and certain growth hormones. These medications stimulate the formation of new bone.



FIGURE 39A Preventing osteoporosis.

Weight-lifting exercise, when we are young, can help prevent osteoporosis when we are older. **a.** Normal bone growth compared with bone from a person with **(b)** osteoporosis. **c.** An elderly person with osteoporosis.

39.3 The Human Muscular System

Three types of muscle tissue can be found in humans: smooth, cardiac, and skeletal muscle. Skeletal muscle, or striated voluntary muscle, is important in maintaining posture, providing support, and allowing for movement. In addition, skeletal muscle is important in homeostasis by helping maintain a constant body temperature. The contraction of skeletal muscle causes ATP breakdown, releasing heat that is distributed about the body.

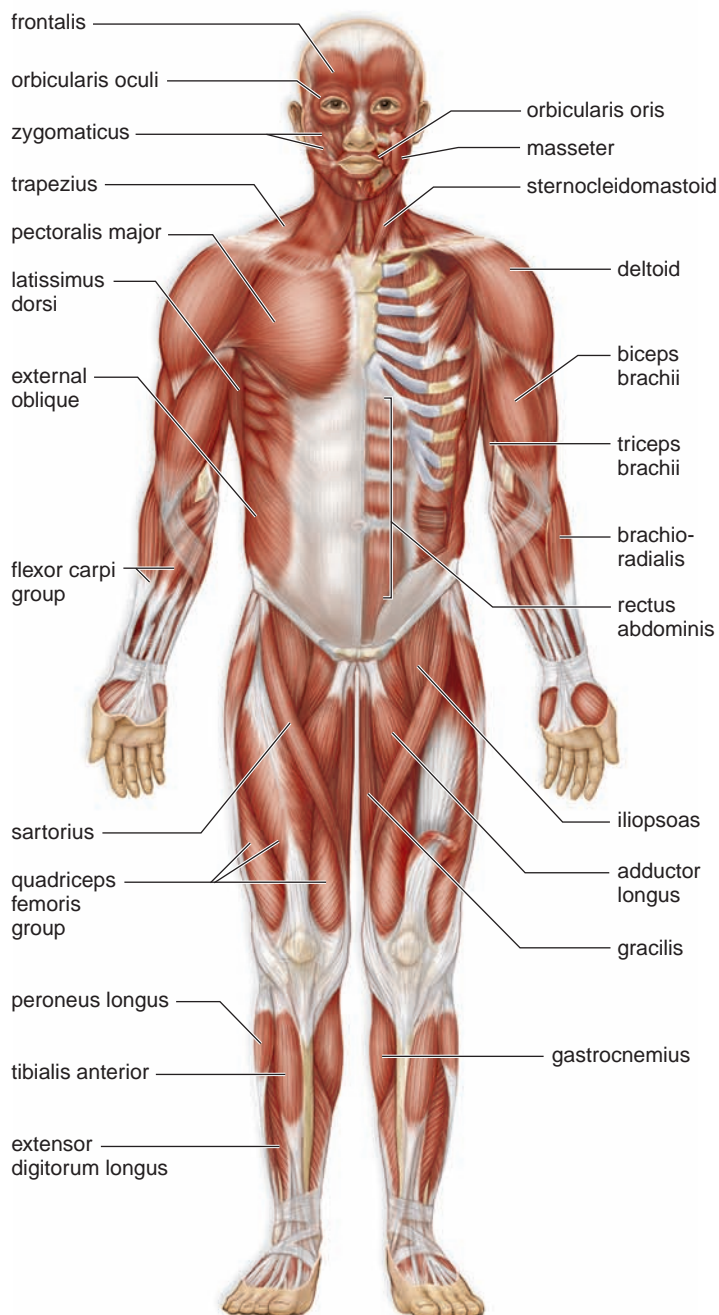


FIGURE 39.12 Human musculature.

Anterior view of some of the major superficial skeletal muscles.

Macroscopic Anatomy and Physiology

The nearly 700 skeletal muscles and their associated tissues make up approximately 40% of the weight of an average human. Several of the major superficial muscles are illustrated in Figure 39.12. Skeletal muscles are attached to the skeleton by bands of fibrous connective tissue called **tendons** [L. *tendo*, stretch]. When muscles contract, they shorten. Therefore, muscles can only pull; they cannot push. Because of this, skeletal muscles must work in antagonistic pairs. If one muscle of an antagonistic pair flexes the joint and bends the limb, the other one extends the joint and straightens the limb. Figure 39.13 illustrates this principle.

In the laboratory, if a muscle is given a rapid series of threshold stimuli (strong enough to bring about action potentials, as described on page 685), it can respond to the next stimulus without relaxing completely. In this way, muscle contraction summates until maximal sustained contraction, called **tetanus**, is achieved. Tetanic contractions ordinarily occur in the body's muscles whenever skeletal muscles are actively used. Even when muscles appear to be at rest, they exhibit **tone**, in which some of their fibers are contracting. Muscle tone is particularly important in maintaining posture. If all the fibers within the muscles of the neck, trunk, and legs were to suddenly relax, the body would collapse.

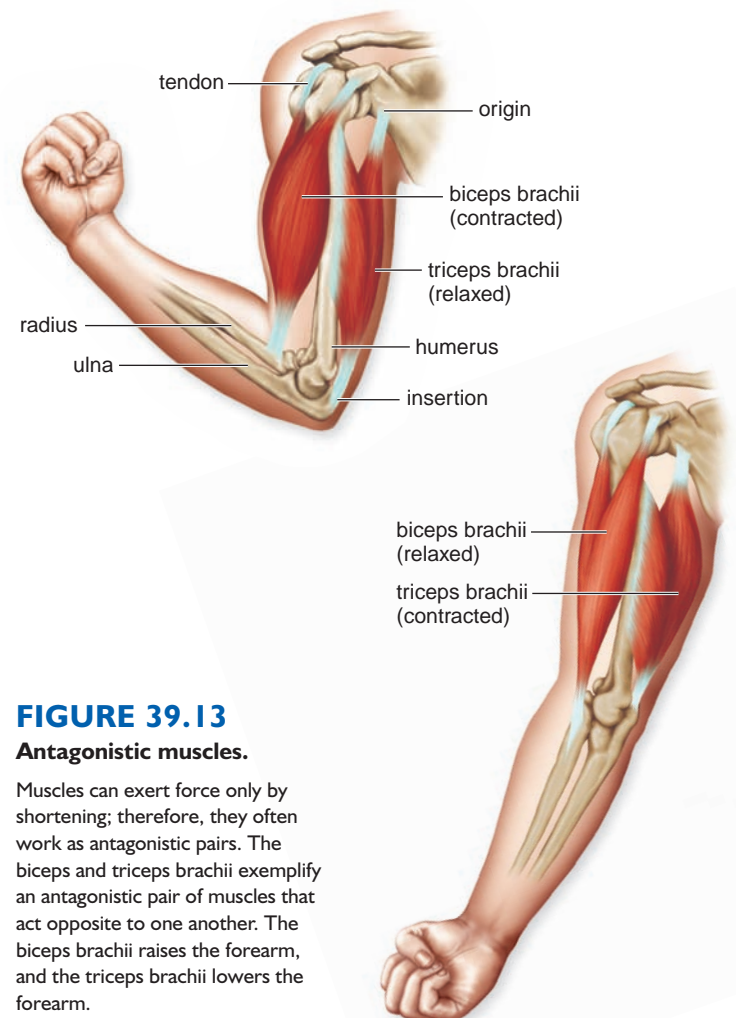


FIGURE 39.13
Antagonistic muscles.

Muscles can exert force only by shortening; therefore, they often work as antagonistic pairs. The biceps and triceps brachii exemplify an antagonistic pair of muscles that act opposite to one another. The biceps brachii raises the forearm, and the triceps brachii lowers the forearm.

Microscopic Anatomy and Physiology

A vertebrate skeletal muscle is composed of a number of muscle fibers in bundles. Each muscle fiber is a cell containing the usual cellular components, but some components have special features (Fig. 39.14). The **sarcolemma**, or plasma membrane [Gk. *sarkos*, flesh, and *lemma*, sheath], forms a T (for transverse) system. The T tubules penetrate, or dip down, into the cell so that they come into contact—but do not fuse—with expanded portions of modified endoplasmic reticulum, called the **sarcoplasmic reticulum**. These expanded portions serve as storage sites for calcium ions (Ca^{2+}), which are essential for muscle contraction. The sarcoplasmic reticulum encases hundreds and sometimes even thousands of **myofibrils** [Gk. *myos*, muscle; L. *fibra*, thread], which are the contractile portions of muscle fiber.

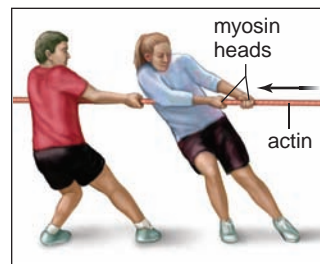
A myofibril has many sarcomeres. Myofibrils are cylindrical in shape and run the length of the muscle fiber. The light microscope shows that a myofibril has light and dark bands called striations. It is these bands that cause skeletal muscle to appear striated. The electron microscope reveals that the striations of myofibrils are formed by the placement of protein filaments within contractile units called **sarcomeres** [Gk. *sarkos*, flesh, and *meros*, part].

Examining sarcomeres when they are relaxed shows that a sarcomere extends between two dark lines called the Z lines. There are two types of protein filaments: thick filaments made up of **myosin**, and thin filaments made up of **actin**. The I band is light colored because it contains only actin filaments attached to a Z line. The dark regions of the A band contain overlapping actin and myosin filaments, and its H zone has only myosin filaments.

Sliding Filament Model

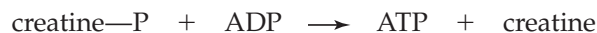
Examining muscle fibers when contracted shows that the sarcomeres within the myofibrils have shortened. When a sarcomere shortens, the actin (thin) filaments slide past the myosin (thick) filaments and approach one another. This causes the I band to shorten and the H zone to nearly or completely disappear. The movement of actin filaments in relation to myosin filaments is called the **sliding**

filament model of muscle contraction. During the sliding process, the sarcomere shortens, even though the filaments themselves remain the same length. When you play “tug of war,” your hands grasp the rope, pull, let go, attach farther down the rope, and pull again. The myosin heads are like your hands—grasping, pulling, letting go, and then repeating the process.



The participants in muscle contraction have the functions listed in Table 39.1. ATP supplies the energy for muscle contraction. Although the actin filaments slide past the myosin filaments, it is the myosin filaments that do the work. Myosin filaments break down ATP and form cross-bridges that attach to and pull the actin filaments toward the center of the sarcomere.

ATP. ATP provides the energy for muscle contraction. Although muscle cells contain *myoglobin*, a molecule that stores oxygen, cellular respiration does not immediately supply all the ATP that is needed. In the meantime, muscle fibers rely on *creatine phosphate* (phosphocreatine), a storage form of high-energy phosphate. Creatine phosphate cannot directly participate in muscle contraction. Instead, it anaerobically regenerates ATP by the following reaction:



This reaction occurs in the midst of sliding filaments, and therefore, this method of supplying ATP is the speediest energy source available to muscles.

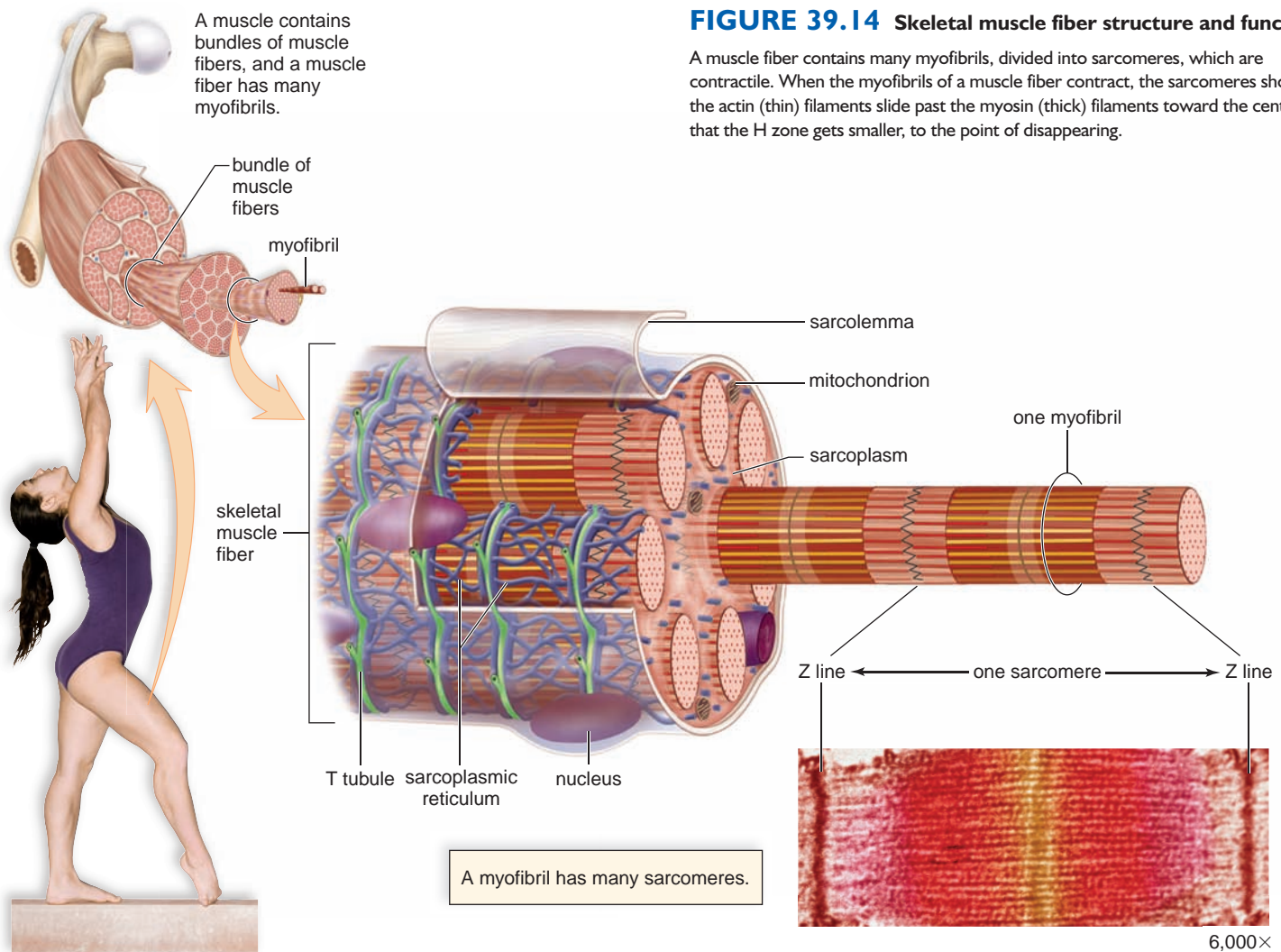
When all of the creatine phosphate is depleted, mitochondria may by then be producing enough ATP for muscle contraction to continue. If not, fermentation is a second way for muscles to supply ATP without consuming oxygen. Fermentation, which is apt to occur when strenuous exercise first begins, supplies ATP for only a short time, and lactate builds up. Whether lactate causes muscle aches and fatigue upon exercising is now being questioned.

We all have had the experience of needing to continue deep breathing following strenuous exercise. This continued intake of oxygen, which is required to complete the metabolism of lactate and restore cells to their original energy state, represents an **oxygen debt**. The lactate is transported to the liver, where 20% of it is completely broken down to carbon dioxide (CO_2) and water (H_2O). The ATP gained by this respiration is then used to reconvert 80% of the lactate to glucose. In persons who train, the number of mitochondria increases, and there is a greater reliance on them rather than on fermentation to produce ATP. Less lactate is produced, and there is less oxygen debt.

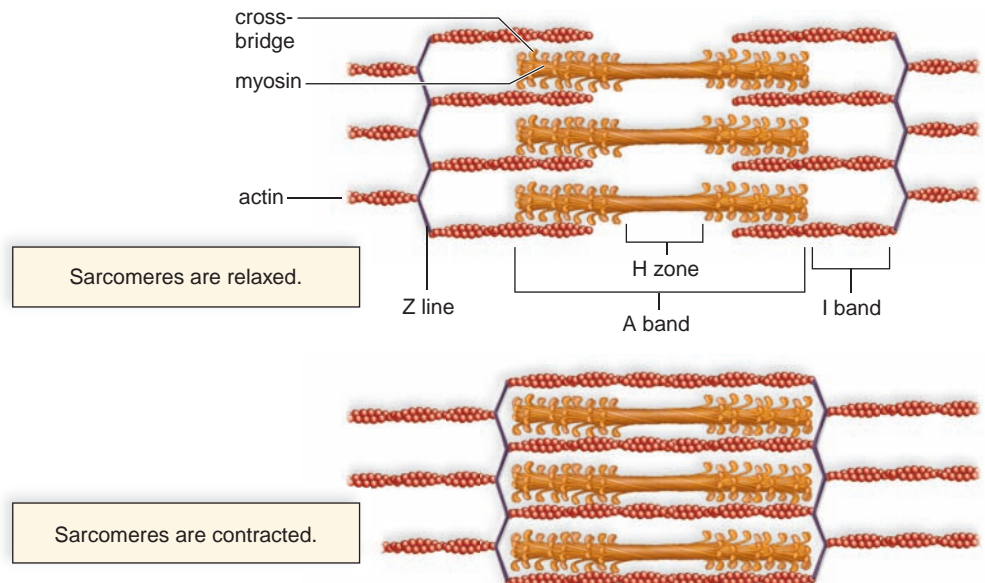
TABLE 39.1

Muscle Contraction

Name	Function
Actin filaments	Slide past myosin, causing contraction
Ca^{2+}	Needed for myosin to bind to actin
Myosin filaments	Pull actin filaments by means of cross-bridges; are enzymatic and split ATP
ATP	Supplies energy for muscle contraction

**FIGURE 39.14** Skeletal muscle fiber structure and function.

A muscle fiber contains many myofibrils, divided into sarcomeres, which are contractile. When the myofibrils of a muscle fiber contract, the sarcomeres shorten: the actin (thin) filaments slide past the myosin (thick) filaments toward the center so that the H zone gets smaller, to the point of disappearing.



Muscle Innervation

Muscles are stimulated to contract by motor nerve fibers. Nerve fibers have several branches, each of which ends at an axon terminal that lies in close proximity to the sarcolemma of a muscle fiber. A small gap, called a synaptic cleft, separates the axon terminal from the sarcolemma. This entire region is called a **neuromuscular junction** (Fig. 39.15).

Axon terminals contain synaptic vesicles that are filled with the neurotransmitter acetylcholine (ACh).

When nerve impulses traveling down a motor neuron arrive at an axon terminal, the synaptic vesicles release ACh into the synaptic cleft. ACh quickly diffuses across the

cleft and binds to receptors in the sarcolemma. Now the sarcolemma generates impulses that spread over the sarcolemma and down T tubules to the sarcoplasmic reticulum. The release of calcium from the sarcoplasmic reticulum causes the filaments within sarcomeres to slide past one another. Sarcomere contraction results in myofibril contraction, which in turn results in muscle fiber, and finally muscle, contraction.

Once a neurotransmitter has been released into a neuromuscular junction and has initiated a response, it is removed from the junction. When the enzyme acetylcholinesterase (AChE) breaks down acetylcholine, muscle contraction ceases due to reasons we will discuss next.

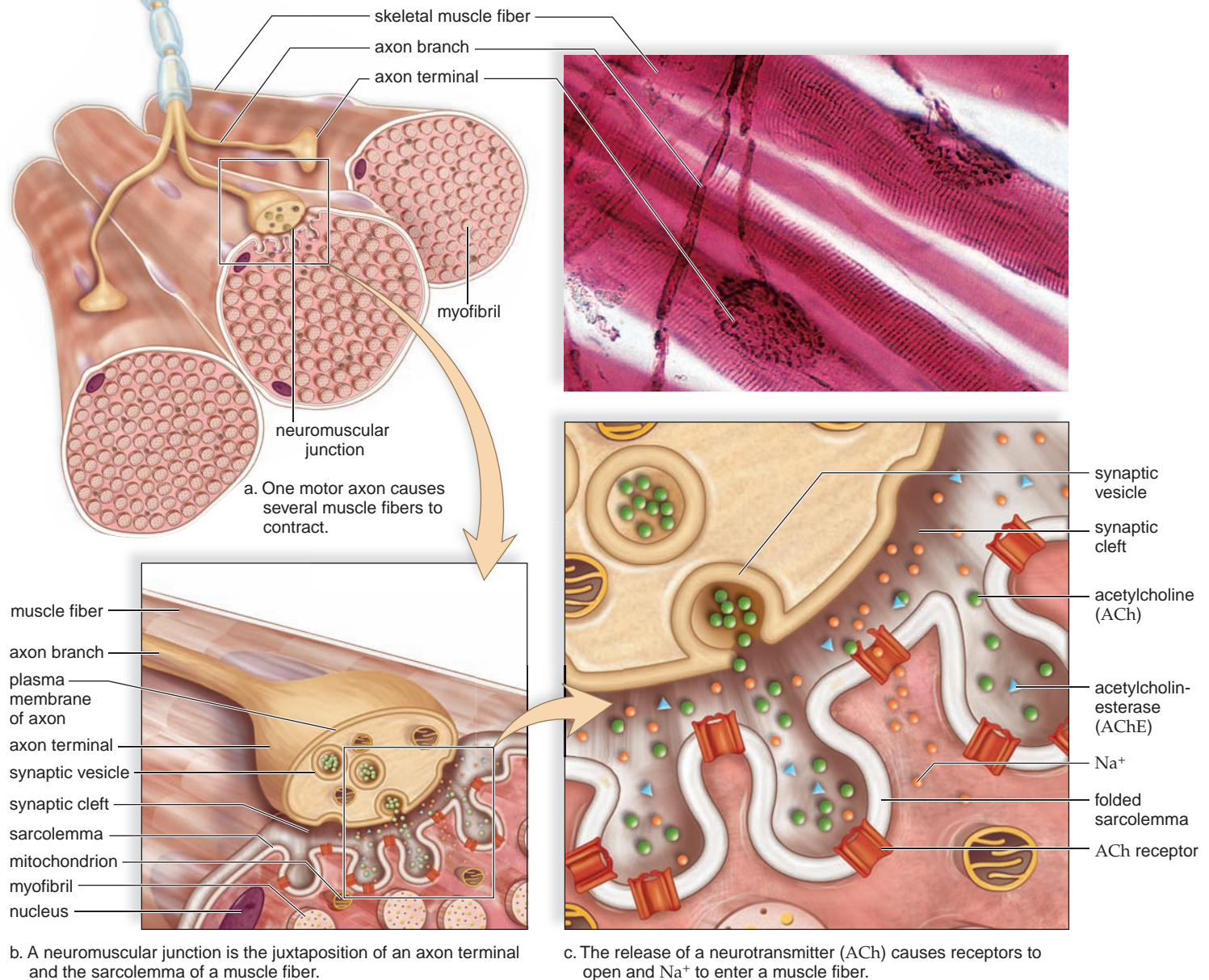
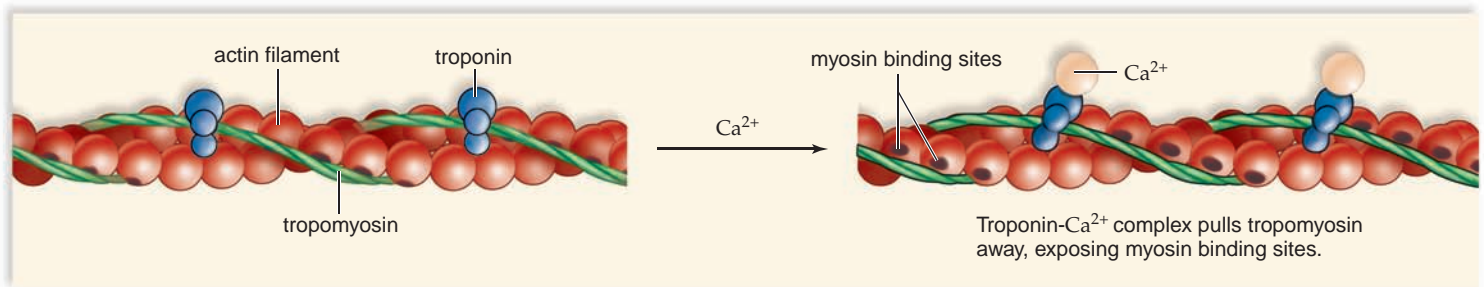
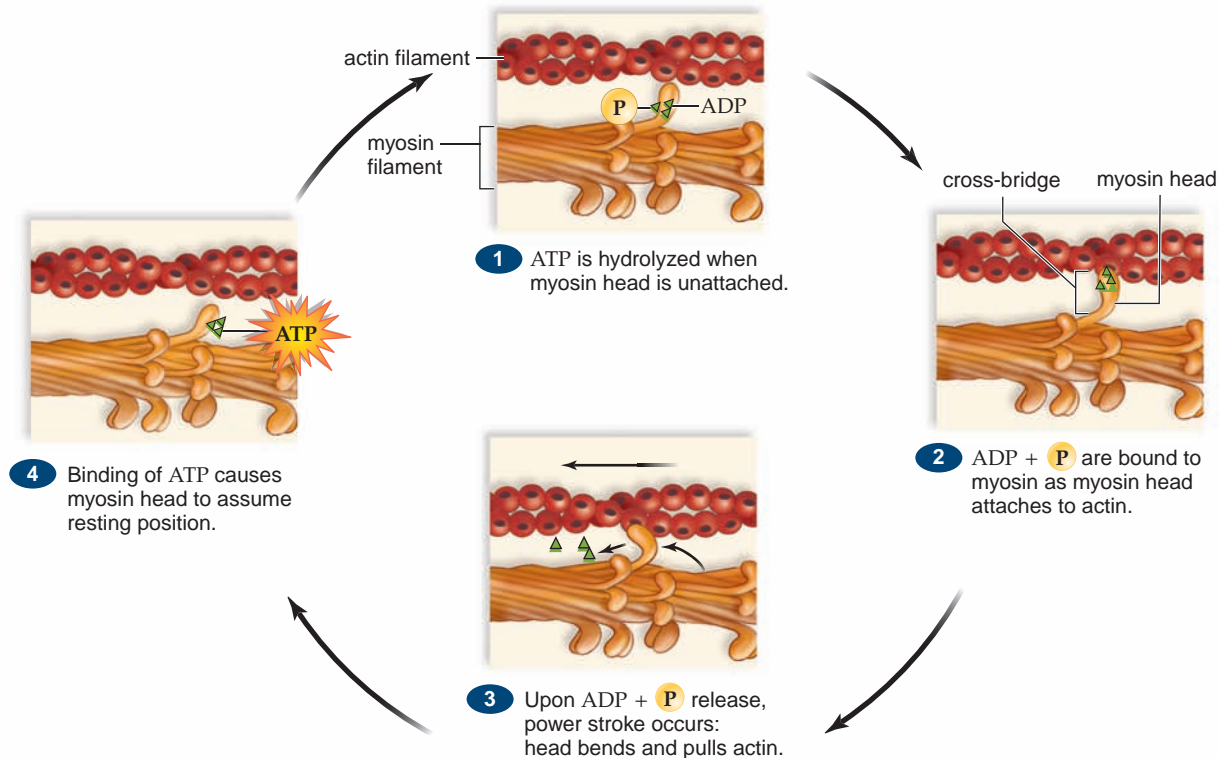


FIGURE 39.15 Neuromuscular junction.

The branch of a motor nerve fiber ends in an axon terminal that meets but does not touch a muscle fiber. A synaptic cleft separates the axon terminal from the sarcolemma of the muscle fiber. Nerve impulses traveling down a motor fiber cause synaptic vesicles to discharge a neurotransmitter that diffuses across the synaptic cleft. When the neurotransmitter is received by the sarcolemma of a muscle fiber, impulses begin that lead to muscle fiber contraction.

a. Function of Ca^{2+} 

b. Function of myosin

FIGURE 39.16**The role of calcium and myosin in muscle contraction.**

a. Upon release, calcium binds to troponin, exposing myosin binding sites. b. After breaking down ATP **1**, myosin heads bind to an actin filament **2**, and later, a power stroke causes the actin filament to move **3**. When another ATP binds to myosin, the head detaches from actin **4**, and the cycle begins again. Although only one myosin head is featured, many heads are active at the same time.

Role of Calcium in Muscle Contraction

Figure 39.16 illustrates the placement of two other proteins associated with a thin filament, which is composed of a double row of twisted actin molecules. Threads of tropomyosin wind about an actin filament, and troponin occurs at intervals along the threads. Calcium ions (Ca^{2+}) that have been released from the sarcoplasmic reticulum combine with troponin. After binding occurs, the tropomyosin threads shift their position, and myosin binding sites are exposed.

Thick filaments are bundles of myosin molecules with double globular heads. Myosin heads function as ATPase enzymes, splitting ATP into ADP and P . This reaction activates the heads so that they bind to actin. The ADP and P remain on the myosin heads until the heads attach to actin, forming cross-bridges. Now, ADP and P are released, and this causes the cross-bridges to change their positions. This is the power stroke that pulls the thin filaments toward the middle of the sarcomere. When more ATP molecules bind to myosin heads, the cross-bridges are broken as the heads

detach from actin. The cycle begins again; the actin filaments move nearer the center of the sarcomere each time the cycle is repeated.

Contraction continues until nerve impulses cease and calcium ions are returned to their storage sites. The membranes of the sarcoplasmic reticulum contain active transport proteins that pump calcium ions back into the calcium storage sites, and muscle relaxation occurs. When a person or animal dies, ATP production ceases. Without ATP, the myosin heads cannot detach from actin, nor can calcium be pumped back into the sarcoplasmic reticulum. As a result, the muscles remain contracted, a phenomenon called *rigor mortis*.

Check Your Progress**39.3**

1. What is an “antagonistic pair” of muscles?
2. What are the microscopic levels of structure in a skeletal muscle?
3. What is the role of ATP in muscle contraction?

Connecting the Concepts

The adage that structure fits function is evident when one observes how different animals locomote. Among a group of widely diversified animals, such as mammals, various modes of locomotion have evolved. Humans are bipedal and walk on the soles of their feet formed by the tarsal and metatarsal bones. This form of locomotion allows the hands to be free and may have evolved from the habit of monkeys and apes to use only forelimbs as they swing through the branches of trees. Dexterity of hands and feet is actually the ancestral mammalian condition. In humans and apes, the bones of the hands and feet are not fused, and the wrist and ankle can rotate in three dimensions.

Carnivores, such as members of the cat family, walk on their toes. This is an obvious

adaptation to running—we also raise the heel and engage the toes in order to run faster. Hoofed mammals, such as horses and deer, have greatly elongated legs and run on the tips of their digits. The hoof of a horse is its third digit only. A cheetah can sprint faster than a horse, but a horse will eventually outdistance the cheetah because it has more endurance.

Mammals that jump, such as kangaroos and rabbits, have a squat shape and elongated hindlimbs that propel them forward. Several groups of arboreal mammals, including flying squirrels and sugar gliders, have membranes attached to their bodies that permit them to glide through the air from tree to tree. Among mammals, only bats truly fly. Their membranous wings are stretched between greatly elongated forelimbs and fingers.

In both birds and bats, the wing is moved downward and forward in one motion, and then backward and upward in another.

In terrestrial animals, the skeleton gives the body its shape but also supports it against the pull of gravity. Because water is buoyant, gravity is not much of a problem for aquatic animals, but a shape that reduces friction is quite helpful. Seals, sea lions, whales, and dolphins have a streamlined torpedo shape that facilitates movement through water. A whale has few protruding parts; a male's penis is completely hidden within muscular folds, and the teats of the female lie behind slits on either side of the genital area. Thus, we see that while locomotion chiefly involves musculoskeletal adaptations, other body systems are involved as well.

summary

39.1 Diversity of Skeletons

Three types of skeletons are found in the animal kingdom: hydrostatic skeleton (cnidarians, flatworms, and segmented worms); exoskeleton (certain molluscs and arthropods); and endoskeleton (vertebrates). The rigid but jointed skeleton of arthropods and vertebrates helped them colonize the terrestrial environment.

39.2 The Human Skeletal System

The human skeleton gives support to the body, helps protect internal organs, provides sites for muscle attachment, and is a storage area for calcium and phosphorus salts, as well as a site for blood cell formation.

Most bones are cartilaginous in the fetus but are converted to bone during development. A long bone undergoes endochondral ossification in which a cartilaginous growth plate remains between the primary ossification center in the middle and the secondary centers at the ends of the bones. Growth of the bone is possible as long as the growth plates are present, but eventually they too are converted to bone. Bone is constantly being renewed; osteoclasts break down bone, and osteoblasts build new bone. Osteocytes are in the lacunae of osteons; a long bone has a shaft of compact bone and two ends that contain spongy bone. The shaft contains a medullary cavity with yellow marrow, and the ends contain red marrow.

The human skeleton is divided into two parts: (1) the axial skeleton, which is made up of the skull, the vertebral column, the sternum, and the ribs; and (2) the appendicular skeleton, which is composed of the girdles and their appendages.

Joints are classified as immovable, like those of the cranium; slightly movable, like those between the vertebrae; and freely movable (synovial joints), like those in the knee and hip. In synovial joints, ligaments bind the two bones together, forming a capsule containing synovial fluid.

39.3 The Human Muscular System

Whole skeletal muscles can only shorten when they contract; therefore, they work in antagonistic pairs. For example, if one muscle flexes the joint and brings the limb toward the body, the other one extends the joint and straightens the limb. A muscle at rest exhibits tone, which is dependent on tetanic contractions.

A whole skeletal muscle is composed of muscle fibers. Each muscle fiber is a cell that contains myofibrils in addition to the usual cellular components. Longitudinally, myofibrils are divided into sarcomeres, which display the arrangement of actin and myosin filaments.

The sliding filament model of muscle contraction says that myosin filaments have cross-bridges, which attach to and detach from actin filaments, causing actin filaments to slide and the sarcomere to shorten. (The H zone disappears as actin filaments approach one another.) Myosin breaks down ATP, and this supplies the energy for muscle contraction. Anaerobic creatine phosphate breakdown and fermentation quickly generate ATP. Sustained exercise requires cellular respiration for the generation of ATP.

Nerves innervate muscles. Nerve impulses traveling down motor neurons to neuromuscular junctions cause the release of ACh, which binds to receptors on the sarcolemma (plasma membrane of a muscle fiber). Impulses begin and move down T tubules that approach the sarcoplasmic reticulum (endoplasmic reticulum of muscle fibers), where calcium is stored. Thereafter, calcium ions are released and bind to troponin. The troponin-Ca²⁺ complex causes tropomyosin threads winding around actin filaments to shift their position, revealing myosin binding sites. Myosin filaments are composed of many myosin molecules with double globular heads. When myosin heads break down ATP, they are ready to attach to actin. The release of ADP + P causes myosin heads to change their position. This is the power stroke that causes the actin filament to slide toward the center of a sarcomere. When more ATP molecules bind to myosin, the heads detach from actin, and the cycle begins again.

understanding the terms

actin 728	osteocyte 720
appendicular skeleton 724	oxygen debt 728
axial skeleton 722	pectoral girdle 724
bursa 725	pelvic girdle 725
compact bone 720	red bone marrow 720
endoskeleton 718	sarcolemma 728
exoskeleton 718	sarcomere 728
fontanel 722	sarcoplasmic reticulum 728
foramen magnum 722	sliding filament model 728
hydrostatic skeleton 718	spongy bone 720
joint 725	suture 722
ligament 725	synovial joint 725
myofibril 728	tendon 727
myosin 728	tetanus 727
neuromuscular junction 730	tone 727
osteoblast 720	vertebral column 722
osteoclast 720	

Match the terms to these definitions:

- _____ Bone-forming cell.
- _____ Movement of actin filaments in relation to myosin filaments, which accounts for muscle contraction.
- _____ Muscle protein making up the thin filaments in a sarcomere; its movement shortens the sarcomere, yielding muscle contraction.
- _____ Part of the skeleton that consists of the pectoral and pelvic girdles and the bones of the arms and legs.
- _____ Portion of the skeleton that provides support and attachment for the arms.
- _____ Fluid-filled body cavity surrounded by layers of muscle fibers, which functions for body support and movement.

reviewing this chapter

- What are the three types of skeletons found in the animal kingdom and how do they differ? Cite animals that have these types of skeletons. 718–19
- Give several functions of the skeletal system in humans. How does the skeletal system contribute to homeostasis? 720
- Contrast compact bone with spongy bone. Explain how bone grows and is renewed. 720–21
- Distinguish between the axial and appendicular skeletons. 722–25
- List the bones that form the pectoral girdle and upper limb; the pelvic girdle and lower limb. 724–25
- How are joints classified? Describe the anatomy of a freely movable joint. 725
- Give several functions of the muscular system in humans. How does the muscular system contribute to homeostasis? 727
- Describe how muscles are attached to bones. What is accomplished by muscles acting in antagonistic pairs? 727
- Discuss the microscopic structural features of a muscle fiber and a sarcomere. What is the sliding filament model? 728–29
- Discuss the availability and the specific role of ATP during muscle contraction. What is oxygen debt, and how is it repaid? 728
- Describe the structure and function of a neuromuscular junction. 730
- Describe the cyclical events as myosin pulls actin toward the center of a sarcomere. 731

testing yourself

Choose the best answer for each question.

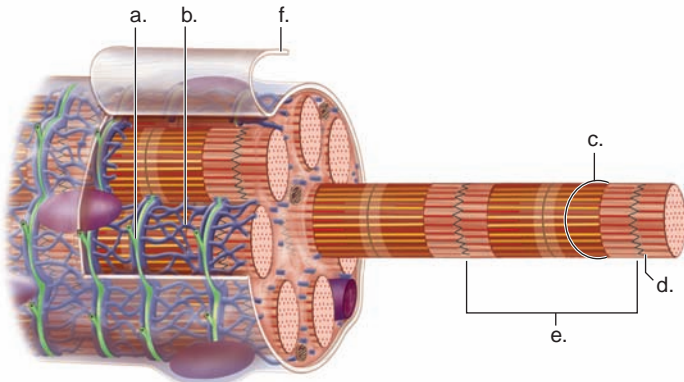
For questions 1–4, match each bone to the location in the key.

KEY:

- | | |
|--------------------|------------------|
| a. arm | d. pelvic girdle |
| b. forearm | e. thigh |
| c. pectoral girdle | f. leg |

- ulna
- tibia
- clavicle
- femur
- Spongy bone
 - is a storage area for fat.
 - contains red bone marrow, where blood cells are formed.
 - lends no strength to bones.
 - contributes to homeostasis.
 - Both b and d are correct.
- Which of these pairs is mismatched?
 - slightly movable joint—vertebrae
 - hinge joint—hip
 - synovial joint—elbow
 - immovable joint—sutures in cranium
 - ball-and-socket joint—hip
- The skeletal system does not
 - produce blood cells.
 - store minerals.
 - help produce movement.
 - store fat.
 - produce body heat.
- All blood cells—red, white, and platelets—are produced by which of the following?
 - yellow bone marrow
 - red bone marrow
 - periosteum
 - medullary cavity
- Which of the following is not a bone of the appendicular skeleton?
 - the scapula
 - a rib
 - a metatarsal bone
 - the patella
 - the ulna
- The vertebrae that articulate with the ribs are the
 - lumbar vertebrae.
 - sacral vertebrae.
 - thoracic vertebrae.
 - cervical vertebrae.
 - coccyx.
- In a muscle fiber,
 - the sarcolemma is connective tissue holding the myofibrils together.
 - the sarcoplasmic reticulum stores calcium.
 - both myosin and actin filaments have cross-bridges.
 - there is a T system but no endoplasmic reticulum.
 - All of these are correct.

12. When muscles contract,
 - a. sarcomeres shorten.
 - b. myosin heads break down ATP.
 - c. actin slides past myosin.
 - d. the H zone disappears.
 - e. All of these are correct.
13. Which of these is the direct source of energy for muscle contraction?
 - a. ATP
 - b. creatine phosphate
 - c. lactic acid
 - d. glycogen
 - e. Both a and b are correct.
14. Nervous stimulation of muscles
 - a. occurs at a neuromuscular junction.
 - b. involves the release of ACh.
 - c. results in impulses that travel down the T system.
 - d. causes calcium to be released from the sarcoplasmic reticulum.
 - e. All of these are correct.
15. A neuromuscular junction occurs between an axon terminal and
 - a. a muscle fiber.
 - b. a myofibril.
 - c. a myosin filament.
 - d. a sarcomere only.
 - e. Both a and d are correct.
16. When calcium is released from the sarcoplasmic reticulum, it binds to
 - a. myosin.
 - b. actin.
 - c. troponin.
 - d. sarcomeres.
 - e. Both b and d are correct.
17. At what point is ATP hydrolyzed?
 - a. just as myosin attaches to troponin
 - b. just before myosin attaches to actin
 - c. just when myosin pulls on actin
 - d. just when impulses move down a T tubule
18. ACh
 - a. is active at somatic synapses but not at neuromuscular junctions.
 - b. binds to receptors in the sarcolemma.
 - c. precedes the buildup of ATP in mitochondria.
 - d. is stored in the sarcoplasmic reticulum.
 - e. Both b and d are correct.
19. Label this diagram of a muscle fiber, using these terms: myofibril, Z line, T tubule, sarcomere, sarcolemma, sarcoplasmic reticulum.



thinking scientifically

1. It is observed that some motor neurons innervate only a few muscle fibers in the biceps brachii. Other motor neurons each innervate many muscle fibers. How might this observation correlate with our ability to pick up a pencil or a 2-liter soda bottle? On what basis would the brain bring about the correct level of contraction?
2. Some athletes believe that taking oral creatine will increase their endurance because it will increase the amount of phosphate available to their muscles for ATP synthesis. This statement can be regarded as two hypotheses: (a) oral creatine increases endurance, and (b) oral creatine increases the amount of creatine available in muscles for ATP synthesis. How could these two hypotheses be tested?

bioethical issue

Support Systems and Locomotion

A natural advantage does not bar an athlete from participating in and winning a medal in a particular sport at the Olympic Games. Nor are athletes restricted to a certain amount of practice or required to eliminate certain foods from their diets.

Athletes are, however, prevented from participating in the Olympic Games if they have taken certain performance-enhancing drugs. There is no doubt that regular use of drugs such as anabolic steroids leads to kidney disease, liver dysfunction, hypertension, increased aggression, and a myriad of other undesirable side effects (see Fig. 40.16, page 750). Even so, shouldn't the individual be allowed to take these drugs if he or she wants to? Anabolic steroids are synthetic forms of the male sex hormone testosterone. Taking large doses, along with strength training, leads to much larger muscles than otherwise. Extra strength and endurance can give an athlete an advantage in certain sports, such as racing, swimming, and weight lifting.

Should the Olympic committee outlaw the taking of anabolic steroids, and if so, on what basis? The basis can't be an unfair advantage, because some athletes naturally have an unfair advantage over other athletes. Should these drugs be outlawed on the basis of health reasons? Excessive practice or a purposeful decrease or increase in weight to better perform in a sport can also be injurious to one's health. In other words, how can you justify allowing some behaviors that enhance performance and not others?

Biology website

The companion website for *Biology* provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

<http://www.mhhe.com/maderbiology10>

40

Hormones and Endocrine Systems

hormones, chemical messengers of the endocrine system, cause a caterpillar to become a moth. One hormone, ecdysone, initiates molting of the exoskeleton as the caterpillar passes through a series of growth stages. A decline in the production of juvenile hormone triggers the final metamorphosis into an adult moth.

The endocrine system, in addition to the nervous system, coordinates the activities of the body's other organ systems and helps maintain homeostasis. In contrast to the nervous system, the endocrine system is not centralized, but consists of several organs scattered throughout the body. The hormones secreted by endocrine glands travel through the bloodstream and tissue fluid to reach their target tissues. The metabolism of a cell changes when it has a plasma membrane or nuclear receptor for that hormone. In this chapter, you will learn how hormones exert their slow but powerful influences on the body. You will see how the endocrine system maintains homeostasis when working properly, as well as some consequences of endocrine malfunction.



The tobacco hornworm (*Manduca sexta*) begins life as a caterpillar. The caterpillar molts and undergoes metamorphosis, as orchestrated by hormones.

40.1 ENDOCRINE GLANDS

- Hormones are either peptides or steroids that typically influence the metabolism of their target cells. 736–39

40.2 HYPOTHALAMUS AND PITUITARY GLAND

- The hypothalamus controls the function of the pituitary gland, which in turn controls several other glands. 740–42

40.3 OTHER ENDOCRINE GLANDS AND HORMONES

- The thyroid produces two hormones that speed metabolism and another that lowers the blood calcium level. The parathyroid glands produce a hormone that raises the blood calcium level. 743–44
- The adrenal medulla and the adrenal cortex are separate parts of the adrenal glands that have functions in relation to stress. 745–47
- The pancreas secretes hormones that help control the blood glucose level. 748–49
- The gonads produce the sex hormones, which control secondary sex characteristics. 750
- Tissues and organs having other functions also produce hormones (e.g., fat tissues produce leptin) and cells produce local hormones. 750–51

40.1 Endocrine Glands

The nervous system and the endocrine system work together to regulate the activities of the other systems. Both systems use chemical signals when they respond to changes that might threaten homeostasis, but they have different means of delivering these signals (Fig. 40.1). As discussed, the nervous system is composed of neurons. In this system, sensory receptors (specialized dendrites) detect changes in the internal and external environment. The CNS integrates the information and responds by stimulating muscles and glands. Communication depends on nerve impulses, conducted in axons, and neurotransmitters, which cross synapses. Axon conduction occurs rapidly and so does diffusion of a neurotransmitter across the short distance of a synapse. In other words, the nervous system is organized to respond rapidly to stimuli. This is particularly useful if the stimulus is an external event that endangers our safety—we can move quickly to avoid being hurt.

The **endocrine system** functions differently. The endocrine system is largely composed of glands (Fig. 40.2). These glands secrete **hormones**, which are carried by the bloodstream to target cells throughout the body. If a child is short for his or her age, it is because his or her blood didn't contain enough growth hormone produced by the anterior pituitary. Growth hormone stimulates the growth of long bones, and

in this way affects the height of an individual. It takes time to deliver hormones, and it takes time for cells to respond, but the effect is longer lasting. In other words, the endocrine system is organized for a slow but prolonged response.

Endocrine glands can be contrasted with exocrine glands. Exocrine glands have ducts and secrete their products into these ducts, which take them to the lumens of other organs or outside the body. For example, the salivary glands send saliva into the mouth by way of the salivary ducts. **Endocrine glands**, as stated, secrete their products into the bloodstream, which delivers them throughout the body. It must be stressed that only certain cells, called target cells, can respond to certain hormones. If a cell can respond to a hormone, the hormone and receptor proteins bind together as a key fits a lock.

It is of interest to note that both the nervous system and the endocrine system make use of negative feedback mechanisms. If the blood pressure falls, sensory receptors signal a control center in the brain. This center sends out nerve impulses to the arterial walls so that they constrict, and blood pressure rises. Now the sensory receptors are no longer stimulated, and the feedback mechanism is inactivated. Similarly, a rise in blood glucose level causes the pancreas to release insulin, which, in turn, promotes glucose uptake by the liver, muscles, and other cells of the body (Fig. 40.2). When the blood glucose level falls, the pancreas no longer secretes insulin.

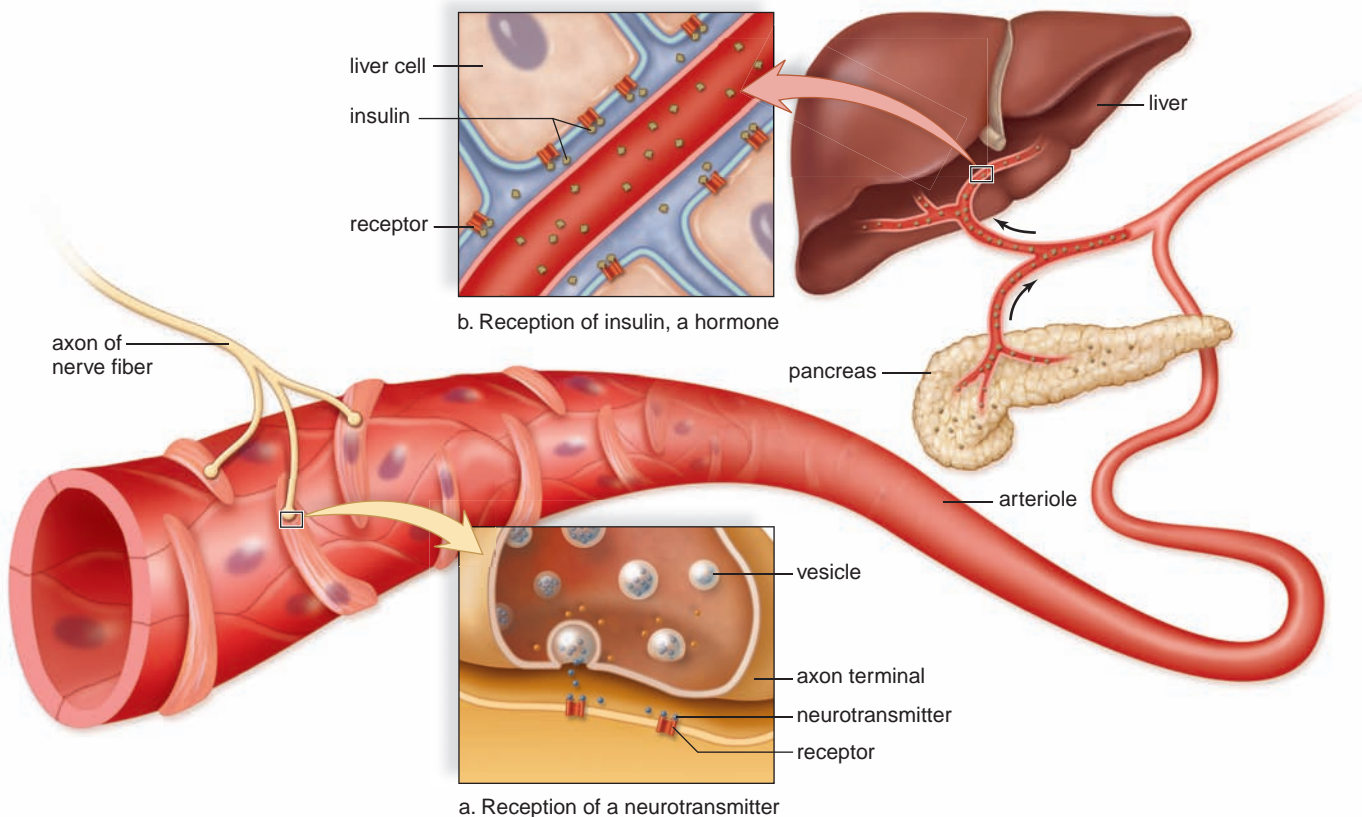


FIGURE 40.1 Modes of action of the nervous and endocrine systems.

a. Nerve impulses passing along an axon cause the release of a neurotransmitter. The neurotransmitter, a chemical signal, binds to a receptor and causes the wall of an arteriole to constrict. **b.** The hormone insulin, a chemical signal, travels in the cardiovascular system from the pancreas to the liver, where it binds to a receptor and causes liver cells to store glucose as glycogen.

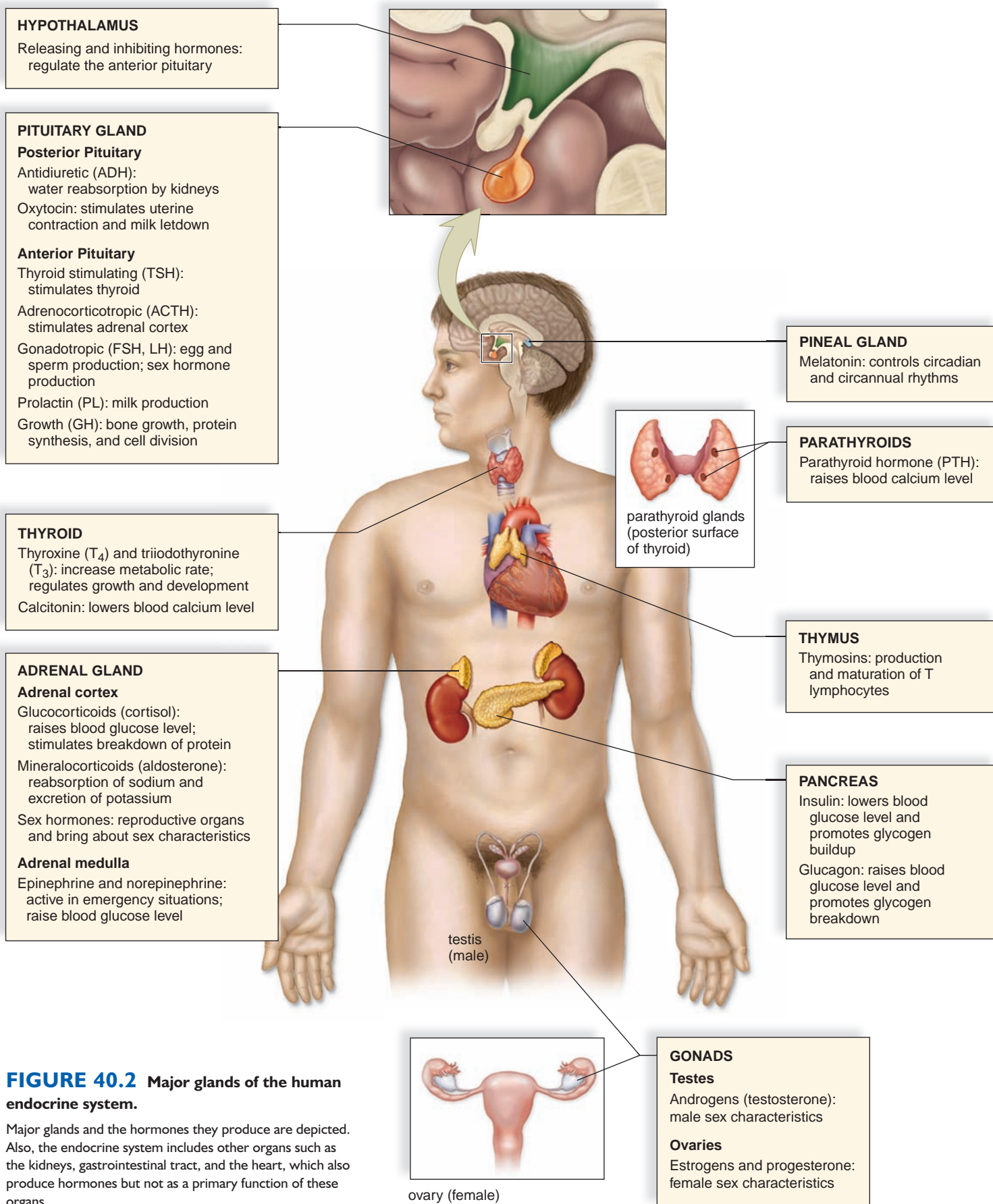


FIGURE 40.2 Major glands of the human endocrine system.

Major glands and the hormones they produce are depicted. Also, the endocrine system includes other organs such as the kidneys, gastrointestinal tract, and the heart, which also produce hormones but not as a primary function of these organs.

Hormones Are Chemical Signals

Like other **chemical signals**, hormones are a means of communication between cells, between body parts, and even between individuals. They typically affect the metabolism of cells that have receptors to receive them (Fig. 40.3). In a condition called androgen insensitivity, an individual has X and Y sex chromosomes, and the testes, which remain in the abdominal cavity, produce the sex hormone testosterone. However, the body cells lack receptors that are able to combine with testosterone, and the individual appears to be a normal female.

Like testosterone, most hormones act at a distance between body parts. They travel in the bloodstream from the gland that produced them to their target cells. Also counted as hormones are the secretions produced by neurosecretory cells in the hypothalamus, a part of the brain. They travel in the capillary network that runs between the hypothalamus and the pituitary gland. Some of these secretions stimulate the pituitary to secrete its hormones, and others prevent it from doing so.

Not all hormones act between body parts. As we shall see, prostaglandins are a good example of a *local hormone*. After prostaglandins are produced, they are not carried in the bloodstream; instead, they affect neighboring cells, sometimes promoting pain and inflammation. Also, growth factors are local hormones that promote cell division and mitosis.

Chemical signals that influence the behavior of other individuals are called **pheromones**. Pheromones have been released by other animals and a researcher has isolated one released by men that reduces premenstrual nervousness

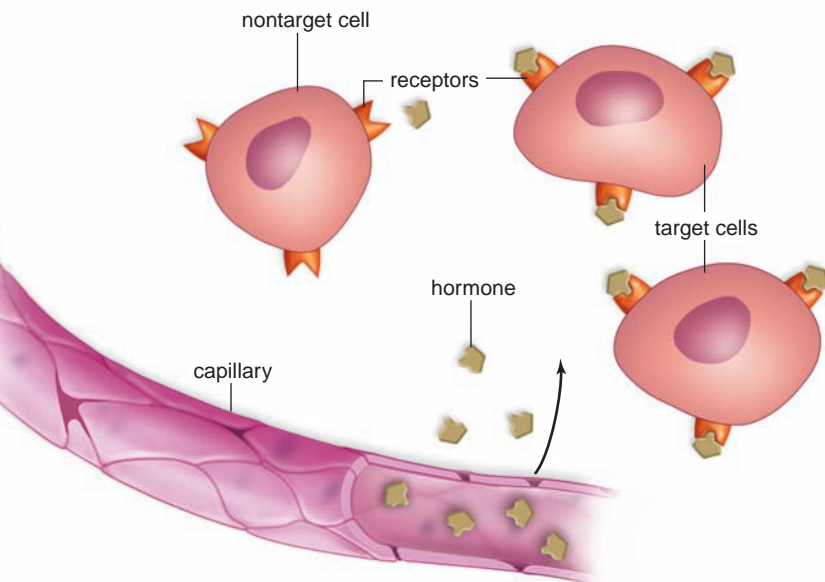


FIGURE 40.3 Target cell concept.

Most hormones are distributed by the bloodstream to target cells. Target cells have receptors for the hormone, and the hormone combines with the receptor as a key fits a lock.

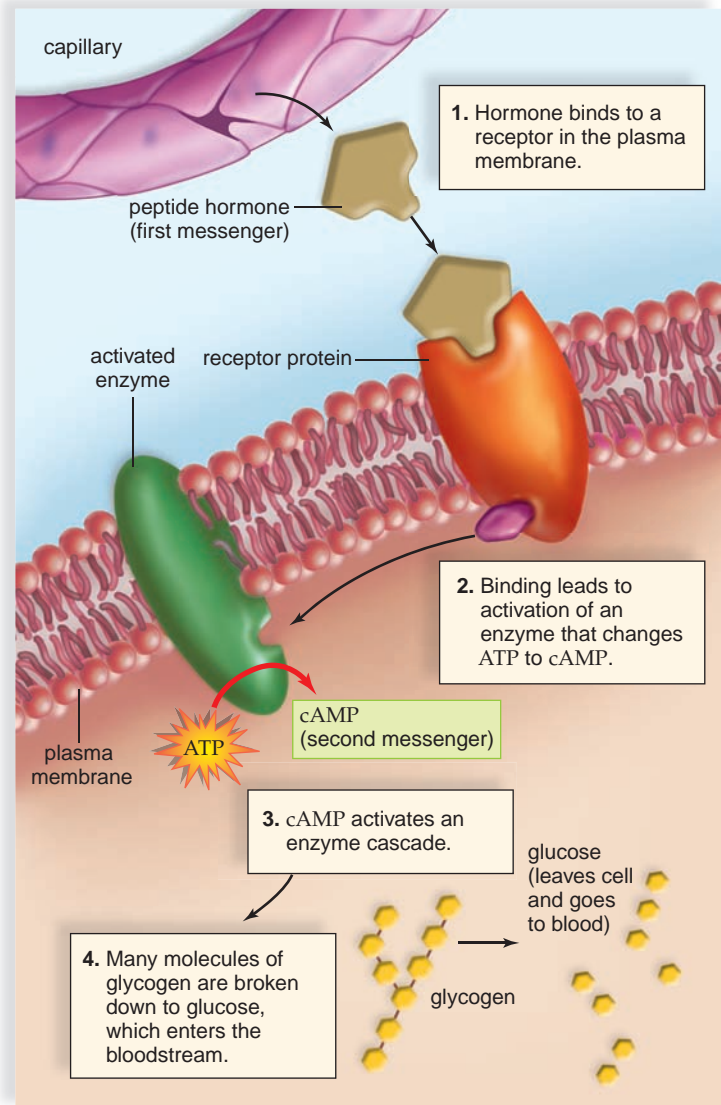


FIGURE 40.4 Peptide hormone.

The peptide hormone (first messenger) binds to a receptor in the plasma membrane. Thereafter, cyclic AMP (second messenger) forms and activates an enzyme cascade.

and tension in women. Women who live in the same household often have menstrual cycles in synchrony, perhaps because the armpit secretions of a woman who is menstruating affects the menstrual cycle of other women in the household.

The Action of Hormones

Hormones have a wide range of effects on cells. Some of these effects induce a target cell to increase its uptake of particular molecules, such as glucose, or ions, such as calcium. Some bring about an alteration of the target cell's structure in some way. Some simply influence cell metabolism. Growth hormone is a peptide hormone that influences cell metabolism leading to a change in the structure of bone. This hormone is a **peptide hormone**. The term

peptide hormone is used to include hormones that are peptides, proteins, glycoproteins, and modified amino acids. Growth hormone is a protein produced and secreted by the anterior pituitary. **Steroid hormones** have the same complex of four carbon rings because they are all derived from cholesterol.

The Action of Peptide Hormones. Most hormonal glands secrete peptide hormones. The actions of peptide hormones can vary, and we will concentrate on what happens in muscle cells after the hormone epinephrine binds to a receptor in the plasma membrane (Fig. 40.4). In muscle cells, the reception of epinephrine leads to the breakdown of glycogen to glucose, which provides energy for ATP production. The immediate result of binding is the formation of **cyclic adenosine monophosphate (cAMP)**. Cyclic AMP contains one phosphate group attached to adenosine at two locations. Therefore, the molecule is cyclic. Cyclic AMP activates a protein kinase enzyme in the cell, and this enzyme, in turn, activates another enzyme, and so forth. The series of enzymatic reactions that follows cAMP formation is called an enzyme cascade. Because each enzyme can be used over and over again at every step of the cascade, more enzymes are involved. Finally, many molecules of glycogen are broken down to glucose, which enters the bloodstream.

Typical of a peptide hormone, epinephrine never enters the cell. Therefore, the hormone is called the **first messenger**, while cAMP, which sets the metabolic machinery in motion, is called the **second messenger**. To explain this terminology, let's imagine that the adrenal medulla, which produces epinephrine, is like the home office that sends out a courier (i.e., the hormone epinephrine is the first messenger) to a factory (the cell). The courier doesn't have a pass to enter the factory, so when he arrives at the factory, he tells a supervisor through the screen door that the home office wants the factory to produce a particular product. The supervisor (i.e., cAMP, the second messenger) walks over and flips a switch that starts the machinery (the enzymatic pathway), and a product is made.

The Action of Steroid Hormones. Only the adrenal cortex, the ovaries, and the testes produce steroid hormones. Thyroid hormones act similarly to steroid hormones, even though they have a different structure. Steroid hormones do not bind to plasma membrane receptors, and instead they are able to enter the cell because they are lipids (Fig. 40.5). Once inside, a steroid hormone binds to a receptor, usually in the nucleus but sometimes in the cytoplasm. Inside the nucleus, the hormone-receptor complex binds with DNA and activates certain genes. Messenger RNA (mRNA) moves to the ribosomes in the cytoplasm and protein (e.g., enzyme) synthesis follows. To continue our analogy, a steroid hormone is like a courier that has a pass to enter the factory (the cell). Once inside, he makes contact with the plant manager (DNA), who sees to it that the factory (cell) is ready to produce a product.

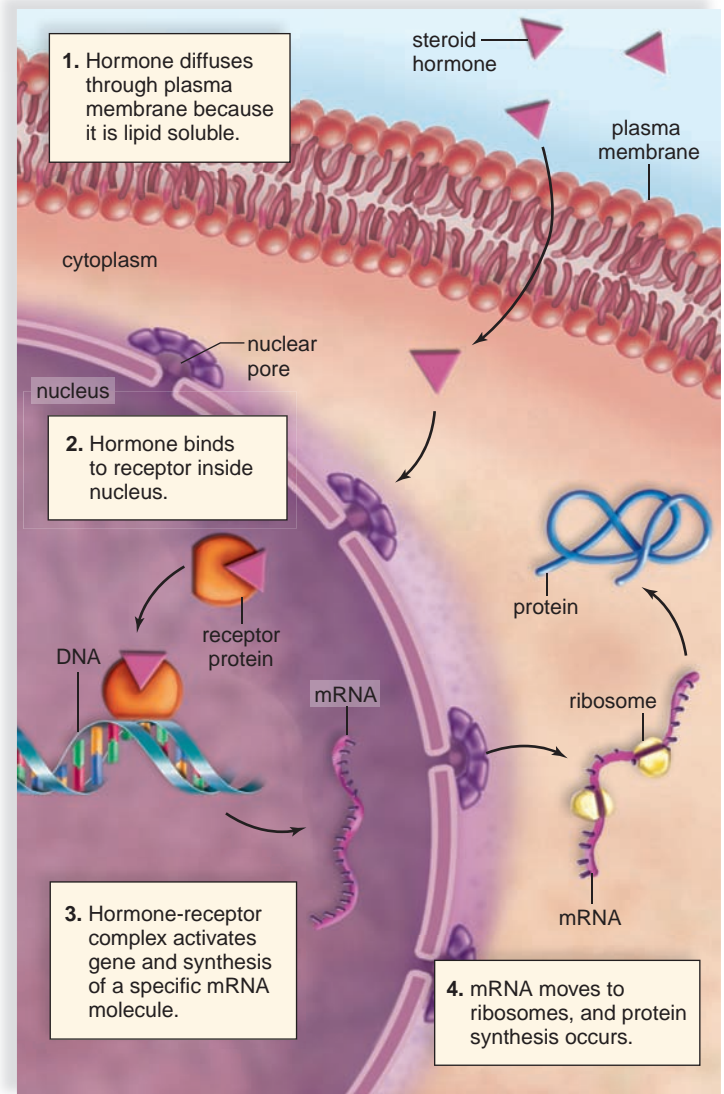


FIGURE 40.5 Steroid hormone.

A steroid hormone passes directly through the target cell's plasma membrane before binding to a receptor in the nucleus or cytoplasm. The hormone-receptor complex binds to DNA and gene expression follows.

Steroids act more slowly than peptides because it takes more time to synthesize new proteins than to activate enzymes already present in cells. Their action lasts longer, however.

Check Your Progress

40.1

1. What is the main difference between an endocrine gland and an exocrine gland?
2. Where are the receptors for peptide and steroid hormones found?
3. Which type of hormone, peptide or steroid, causes the formation of cAMP upon binding its receptor?

40.2 Hypothalamus and Pituitary Gland

The **hypothalamus** regulates the internal environment through the autonomic system. For example, it helps control heartbeat, body temperature, and water balance. The hypothalamus also controls the glandular secretions of the **pituitary gland** (hypophysis). The pituitary, a small gland about 1 cm in diameter, is connected to the hypothalamus by a stalklike structure. The pituitary has two portions: the posterior pituitary and the anterior pituitary.

Posterior Pituitary

Neurons in the hypothalamus called neurosecretory cells produce the hormones **antidiuretic hormone (ADH)** [Gk. *anti*, against; L. *ouresis*, urination] and **oxytocin** (Fig. 40.6, left). These hormones pass through axons into the **posterior pituitary**, where they are stored in axon endings. Certain neurons in the hypothalamus are sensitive to the water-salt balance of the blood. When these cells determine that the blood is too concentrated, ADH is released from the posterior pituitary. Upon reaching the kidneys, ADH causes water to be reabsorbed. As the blood becomes dilute, ADH is no longer released. This is an example of control by **negative feedback** because the *effect* of the hormone (to dilute blood) acts to shut down the *release* of the hormone. Negative feedback maintains stable conditions and homeostasis.

Inability to produce ADH causes diabetes insipidus (watery urine), in which a person produces copious amounts of urine with a resultant loss of ions from the blood. The condition can be corrected by the administration of ADH. The release of ADH is inhibited by the consumption of alcohol, which explains the frequent urination associated with drinking alcohol.

Oxytocin [Gk. *oxys*, quick, and *tokos*, birth], the other hormone made in the hypothalamus, causes uterine contractions during childbirth and milk letdown when a baby is nursing. The more the uterus contracts during labor, the more nerve impulses reach the hypothalamus, causing oxytocin to be released. Similarly, the more a baby suckles, the more oxytocin is released. In both instances, the release of oxytocin from the posterior pituitary is controlled by **positive feedback**—that is, the stimulus continues to bring about an effect that ever increases in intensity. Positive feedback is not a way to maintain stable conditions and homeostasis. Oxytocin may also play a role in the propulsion of semen through the male reproductive tract and may affect feelings of sexual satisfaction and emotional bonding.

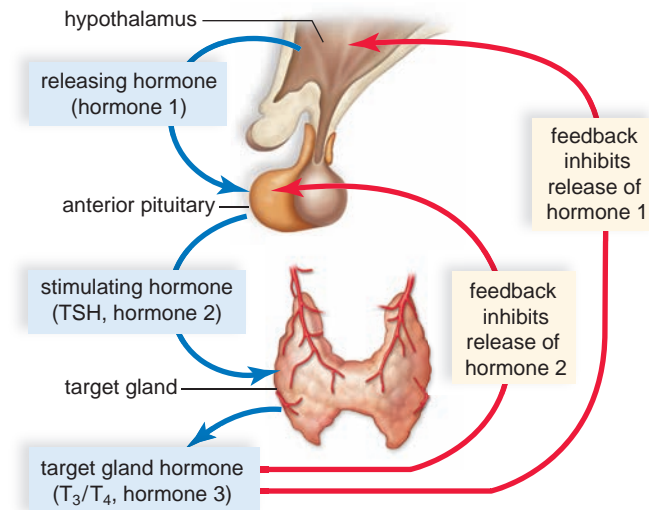
Anterior Pituitary

A portal system, consisting of two capillary systems connected by a vein, lies between the hypothalamus and the anterior pituitary (Fig. 40.6, right). The hypothalamus controls the anterior pituitary by producing **hypothalamic-releasing hormones**

and in some instances **hypothalamic-inhibiting hormones**. For example, there is a hypothalamic-releasing hormone that stimulates the anterior pituitary to secrete a thyroid-stimulating hormone and a hypothalamic-inhibiting hormone that prevents the anterior pituitary from secreting prolactin.

Anterior Pituitary Hormones Affecting Other Glands

Certain hormones produced by the **anterior pituitary** affect other glands. **Gonadotropic hormones** stimulate the gonads—the testes in males and the ovaries in females—to produce gametes and sex hormones. **Adrenocorticotrophic hormone (ACTH)** stimulates the adrenal cortex to produce glucocorticoid. **Thyroid-stimulating hormone (TSH)** stimulates the thyroid to produce thyroxine (T_4) and triiodothyronine (T_3). In each instance, these hormones are involved in a three-tier system and the blood level of the last hormone in the sequence exerts negative feedback control over the secretion of the first two hormones. This is how it works for TSH:



Anterior Pituitary Hormones Not Affecting Other Glands

Other types of hormones produced by the anterior pituitary are under the control of the hypothalamus, but they do not affect other endocrine glands. **Prolactin (PRL)** [L. *pro*, before, and *lactis*, milk] is produced in quantity only after childbirth. It causes the mammary glands in the breasts to develop and produce milk. It also plays a role in carbohydrate and fat metabolism.

Growth hormone (GH), or somatotrophic hormone, promotes skeletal and muscular growth. It stimulates the rate at which amino acids enter cells and protein synthesis occurs. It also promotes fat metabolism as opposed to glucose metabolism.

Melanocyte-stimulating hormone (MSH) [Gk. *mela*, black, and *kytos*, cell] causes skin-color changes in many fishes, amphibians, and reptiles having melanophores, special skin cells that produce color variations. The concentration of this hormone in humans is very low.

Effects of Growth Hormone

GH is one of the hormones produced by the anterior pituitary after being stimulated to do so by a releasing hormone from the hypothalamus (Fig. 40.6, right). The quan-

tity is greatest during childhood and adolescence, when most body growth is occurring. If too little GH is produced during childhood, the individual has **pituitary dwarfism**, characterized by normal proportions but small stature.

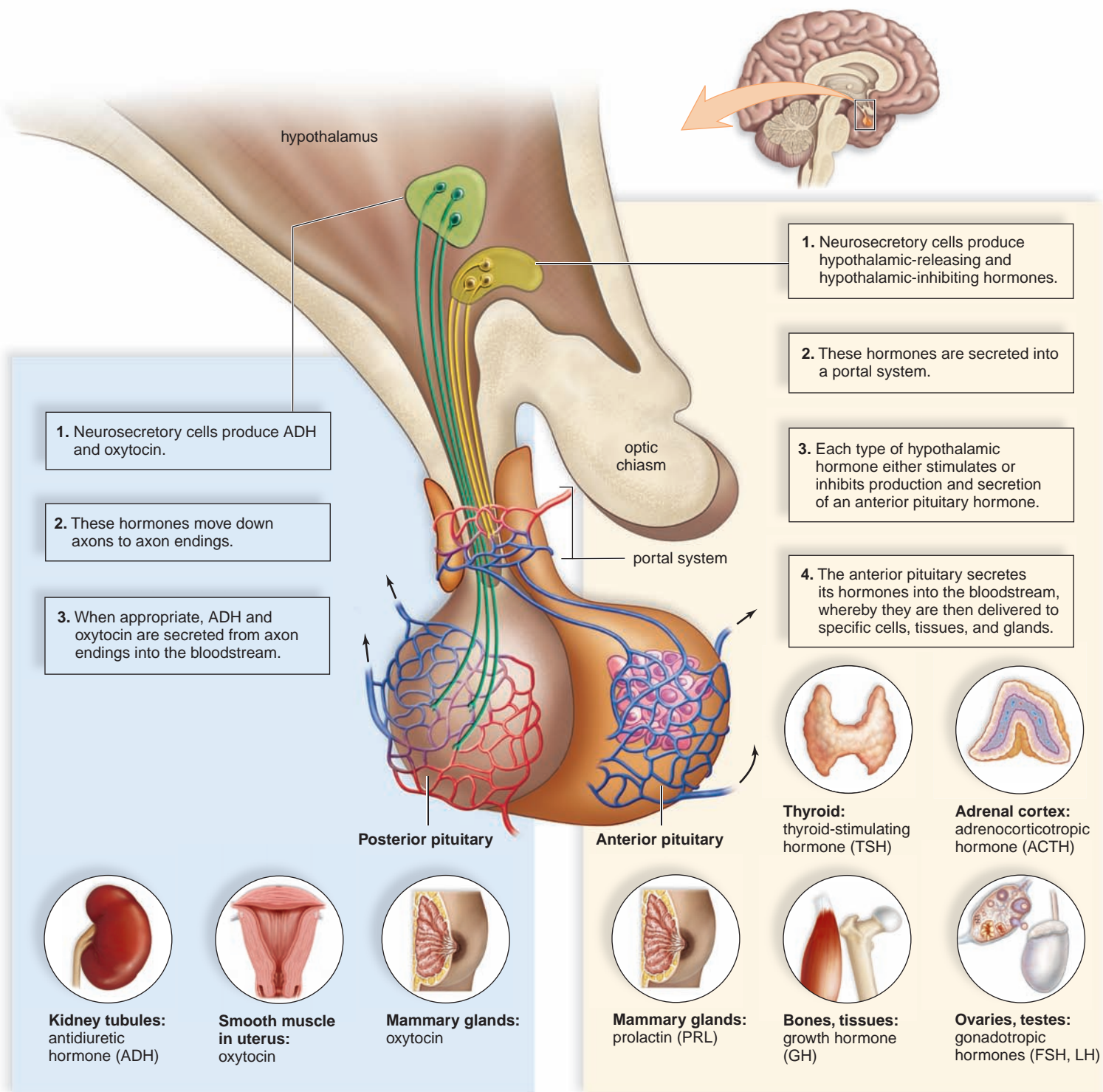


FIGURE 40.6 Hypothalamus and the pituitary.

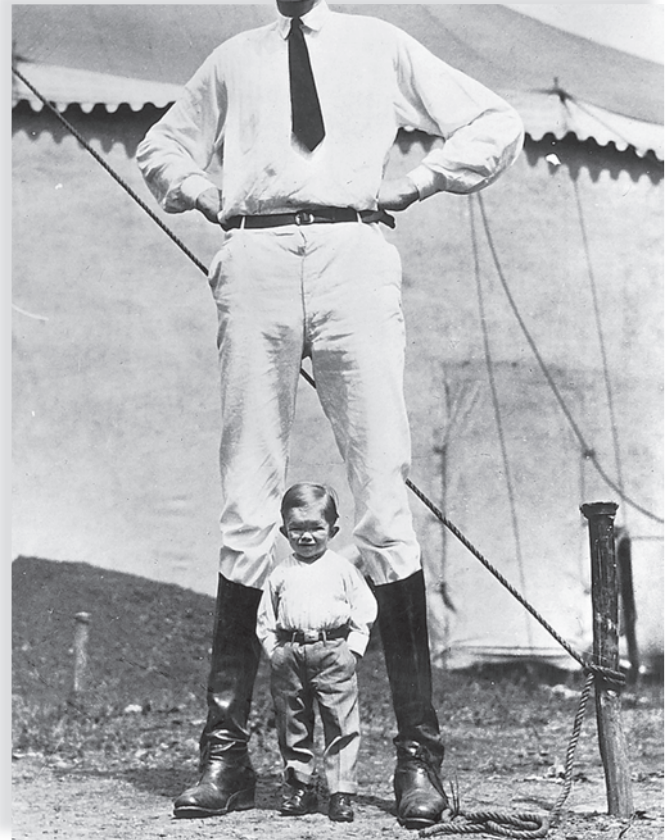
In this diagram, the name of the hormone is given below its target organ, which is depicted in the circle. *Left:* The hypothalamus produces two hormones, ADH and oxytocin, which are stored and secreted by the posterior pituitary. *Right:* The hypothalamus controls the secretions of the anterior pituitary, and the anterior pituitary controls the secretions of the thyroid, adrenal cortex, and gonads, which are also endocrine glands.

FIGURE 40.7**Effect of growth hormone.**

a. The amount of growth hormone produced by the anterior pituitary during childhood affects the height of an individual. Plentiful growth hormone produces very tall basketball players. **b.** Too much growth hormone can lead to gigantism, while an insufficient amount results in limited stature and even pituitary dwarfism.



a.



b.

Such children also have problems with low blood sugar (hypoglycemia), because GH normally helps oppose the effect of insulin on glucose uptake. Through the administration of GH, growth patterns can be restored and blood sugar problems alleviated. If too much GH is secreted, a person can become a giant (Fig. 40.7b). Giants usually have poor health, primarily because elevated GH cancels out the effects of insulin, promoting an illness called diabetes mellitus (see page 748).

On occasion, GH is overproduced in the adult, and a condition called **acromegaly** results. Since long bone growth is no longer possible in adults, only the feet, hands, and

face (particularly the chin, nose, and eyebrow ridges) can respond, and these portions of the body become overly large (Fig. 40.8).

Check Your Progress**40.2**

1. Where are the neurosecretory cells that produce ADH and oxytocin located? Where are these two hormones released into the bloodstream?
2. List the hormones produced by the anterior pituitary and give an example of the “three-tier” system.

FIGURE 40.8**Acromegaly.**

Acromegaly is caused by overproduction of GH in the adult. It is characterized by enlargement of the bones in the face, the fingers, and the toes as a person ages.



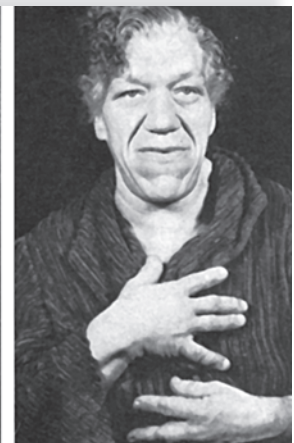
Age 9



Age 16



Age 33



Age 52

40.3 Other Endocrine Glands and Hormones

Thyroid and Parathyroid Glands

The **thyroid gland** [Gk. *thyreos*, large, door-shaped shield] is a large gland located in the neck, where it is attached to the trachea just below the larynx (see Fig. 40.2). The parathyroid glands are embedded in the posterior surface of the thyroid gland.

Thyroid Gland

The thyroid gland is the largest endocrine gland, weighing approximately 20 g. It is excessively red in appearance because of its high blood volume. It consists of two distinct lobes connected by a slender isthmus. The thyroid gland is composed of a large number of follicles, each a small spherical structure made of thyroid cells filled with the thyroid hormones triiodothyronine (T_3), which contains three iodine atoms, and **thyroxine** (T_4), which contains four iodine atoms.

Effects of Thyroid Hormones. To produce triiodothyronine and thyroxine, the thyroid gland actively acquires iodine. The concentration of iodine in the thyroid gland can increase to as much as 25 times that of the blood. If iodine is lacking in the diet, the thyroid gland is unable to produce the thyroid hormones. In response to constant stimulation by the anterior pituitary, the thyroid enlarges, resulting in a **simple goiter** (Fig. 40.9). Some years ago, it was discovered that the use of iodized salt allows the thyroid to produce the thyroid hormones and therefore helps prevent simple goiter.

Thyroid hormones increase the metabolic rate. They do not have a target organ; instead, they stimulate all the cells of the body to metabolize at a faster rate. More glucose is broken down, and more energy is used.

If the thyroid fails to develop properly, a condition called **congenital hypothyroidism** (cretinism) results (Fig. 40.9). Individuals with this condition are short and stocky and have had extreme hypothyroidism (undersecretion of thyroid hormone) since infancy or childhood. Thyroid hormone therapy can initiate growth, but unless treatment is begun within the first two months of life, mental retardation results. The occurrence of hypothyroidism in adults produces the condition known as **myxedema**, which is characterized by lethargy, weight gain, loss of hair, slower pulse rate, lowered body temperature, and thickness and puffiness of the skin. The administration of adequate doses of thyroid hormones restores normal function and appearance.

In the case of hyperthyroidism (oversecretion of thyroid hormone), or Graves disease, the thyroid gland is overactive, and a goiter forms. This type of goiter is called **exophthalmic goiter**. The eyes protrude (exophthalmos) because of edema in eye socket tissues and swelling of the muscles that move the eyes. The patient usually becomes hyperactive, nervous, and irritable and suffers from insomnia. In addition, the individual may have unusual sweating and heat sensitivity. Removal or destruction of a portion of the thyroid by means of radioactive iodine is sometimes effective in curing the condition. Hyperthyroidism can also be caused by a thyroid tumor, which is usually detected as a lump during physical examination. Again, the treatment is surgery in combination with administration of radioactive iodine. The prognosis for most patients is excellent.



a. Simple goiter

b. Congenital hypothyroidism

c. Exophthalmic goiter

FIGURE 40.9 Abnormalities of the thyroid.

a. An enlarged thyroid gland is often caused by a lack of iodine in the diet. Without iodine, the thyroid is unable to produce its hormones and continued anterior pituitary stimulation causes the gland to enlarge. **b.** Individuals who develop hypothyroidism during infancy or childhood do not grow and develop as others do. Unless medical treatment is begun, the body is short and stocky; mental retardation is also likely. **c.** In exophthalmic goiter, a goiter is due to an overactive thyroid, and the eye protrudes because of edema in eye socket tissue.

Calcitonin. Calcium (Ca^{2+}) plays a significant role in both nervous conduction and muscle contraction. It is also necessary for blood clotting. The blood calcium level is regulated in part by **calcitonin**, a hormone secreted by the thyroid gland when the blood calcium level rises. The primary effect of calcitonin is to bring about the deposit of calcium in the bones (Fig. 40.10, *above*). (It does this by temporarily reducing the activity and number of osteoclasts.) When the blood calcium lowers to normal, the release of calcitonin by the thyroid is inhibited, but a low level stimulates the release of **parathyroid hormone (PTH)** by the parathyroid glands.

Calcitonin is important in growing children but seems to have little effect in adults. It may be helpful in reducing bone loss in osteoporosis and in pregnant women. The deficiency of calcitonin is not linked with any specific disorder.

Parathyroid Glands

Many years ago, the four **parathyroid glands** were sometimes mistakenly removed during thyroid surgery because of their size and location. Parathyroid hormone causes the blood phosphate (HPO_4^{2-}) level to decrease and the blood calcium level to increase when the level is low.

PTH corrects a low blood calcium level in a number of ways. PTH promotes the activity of osteoclasts and the release of calcium from the bones. PTH also promotes the reabsorption of calcium by the kidneys so it is not excreted. In the kidneys, PTH also brings about activation of vitamin D. Vitamin D, in turn, stimulates the absorption of calcium from the intestine (Fig. 40.10, *below*). These effects bring the blood calcium level back to the normal range so that the parathyroid glands no longer secrete PTH.

When insufficient parathyroid hormone production (hypoparathyroidism) leads to a dramatic drop in the blood calcium level, **tetany** results. In **tetany**, the body shakes from continuous muscle contraction. This effect is brought about by increased excitability of the nerves, which initiate nerve impulses spontaneously and without rest.

In hyperparathyroidism, the blood calcium level becomes abnormally high. This disorder can cause the bones to become abnormally soft and fragile. In addition, it can cause the individual to become unusually irritable and prone to kidney stones.

Anatagonistic Hormones

Calcitonin and PTH are antagonistic hormones because their action is opposite to one another, and both hormones work together to regulate the blood calcium level. When the blood calcium level is low, the thyroid secretes calcitonin and when the blood calcium level is low, the parathyroid glands release PTH (Fig. 40.10).

You will have an opportunity to learn of other antagonistic hormones in the pages that follow. For example, the liver secretes both insulin and glucagon, which work together to maintain the blood glucose level.

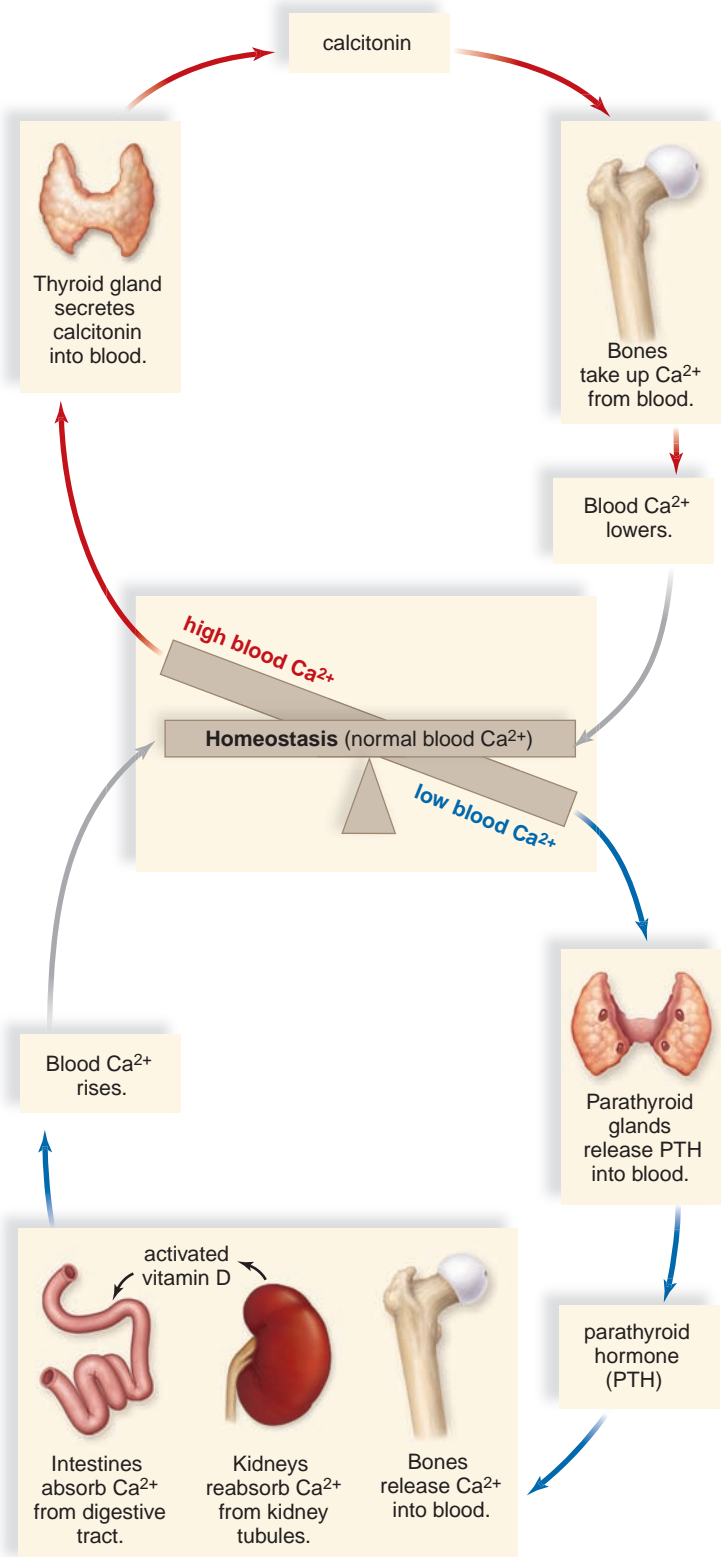


FIGURE 40.10 Regulation of blood calcium level.

Above: When the blood calcium (Ca^{2+}) level is high, the thyroid gland secretes calcitonin. Calcitonin promotes the uptake of Ca^{2+} by the bones, and therefore the blood Ca^{2+} level returns to normal. *Below:* When the blood Ca^{2+} level is low, the parathyroid glands release parathyroid hormone (PTH). PTH causes the bones to release Ca^{2+} and the kidneys to reabsorb Ca^{2+} and activate vitamin D; thereafter, the intestines absorb Ca^{2+} . Therefore, the blood Ca^{2+} level returns to normal.

Adrenal Glands

The **adrenal glands** [L. *ad*, toward, and *renis*, kidney] sit atop the kidneys (see Fig. 40.2). Each gland is about 5 cm long and 3 cm wide and weigh about 5 g. An adrenal gland consists of an inner portion called the **adrenal medulla** and an outer portion called the **adrenal cortex**. These portions, like the anterior pituitary and the posterior pituitary, have no physiological connection with one another.

The hypothalamus exerts control over the activity of both portions of the adrenal glands. It initiates nerve impulses that travel by way of the brain stem, spinal cord, and sympathetic nerve fibers to the adrenal medulla, which then secretes its hormones. The hypothalamus, by means of ACTH-releasing hormone, controls the anterior pituitary's secretion of ACTH, which in turn stimulates the adrenal cortex to secrete glucocorticoids. Stress of all types, including both emotional and physical trauma, prompts the hypothalamus to stimulate the adrenal glands.

Epinephrine (adrenaline) and **norepinephrine** (nor-adrenaline) produced by the adrenal medulla rapidly bring

about all the bodily changes that occur when an individual reacts to an emergency situation. The effects of these hormones are short-term (Fig. 40.11). Epinephrine and norepinephrine accelerate the breakdown of glucose to form ATP, trigger the mobilization of glycogen reserves in skeletal muscle, and increase the cardiac rate and force of contraction.

In contrast, the hormones produced by the adrenal cortex provide a long-term response to stress. The two major types of hormones produced by the adrenal cortex are the mineralocorticoids and the glucocorticoids. The **mineralocorticoids** regulate salt and water balance, leading to increases in blood volume and blood pressure. The **glucocorticoids** regulate carbohydrate, protein, and fat metabolism, leading to an increase in blood glucose level.

The adrenal cortex also secretes a small amount of male sex hormones and a small amount of female sex hormones in both sexes—that is, in the male, both male and female sex hormones are produced by the adrenal cortex, and in the female, both male and female sex hormones are also produced by the adrenal cortex.

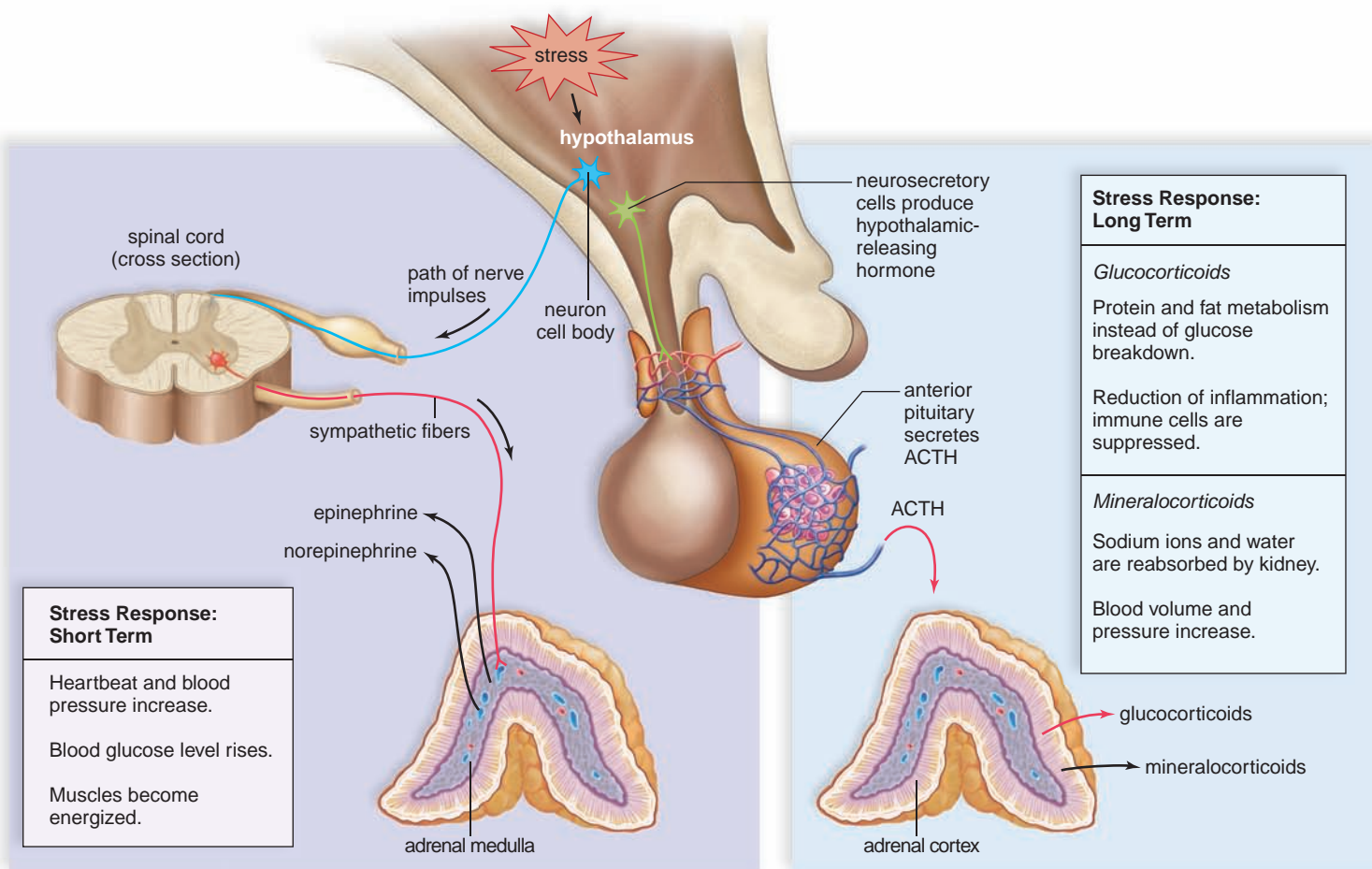


FIGURE 40.11 Adrenal glands.

Both the adrenal cortex and the adrenal medulla are under the control of the hypothalamus when they help us respond to stress. *Left:* Nervous stimulation causes the adrenal medulla to provide a rapid, but short-term, stress response. *Right:* ACTH from the anterior pituitary causes the adrenal cortex to release glucocorticoids. Independently, the adrenal cortex releases mineralocorticoids. The adrenal cortex provides a slower, but long-term, stress response.

Glucocorticoids

Cortisol is a biologically significant glucocorticoid produced by the adrenal cortex. Cortisol raises the blood glucose level in at least two ways: (1) It promotes the breakdown of muscle proteins to amino acids, which are taken up by the liver from the bloodstream. The liver then breaks down these excess amino acids to glucose, which enters the blood. (2) Cortisol promotes the metabolism of fatty acids rather than carbohydrates, and this spares glucose.

Cortisol also counteracts the inflammatory response, which leads to the pain and swelling of joints in arthritis and bursitis. The administration of cortisol in the form of cortisone aids these conditions because it reduces inflammation. Very high levels of glucocorticoids in the blood can suppress the body's defense system, including the inflammatory response that occurs at infection sites. Cortisone and other glucocorticoids can relieve swelling and pain from inflammation, but by suppressing pain and immunity, they can also make a person highly susceptible to injury and infection.

Mineralocorticoids

Aldosterone is the most important of the mineralocorticoids. Aldosterone primarily targets the kidney, where it promotes renal absorption of sodium (Na^+) and renal excretion of potassium (K^+).

The secretion of mineralocorticoids is not controlled by the anterior pituitary. When the blood sodium (Na^+) level and therefore blood pressure are low, the kidneys secrete **renin** (Fig. 40.12, *below*). Renin is an enzyme that converts the plasma protein angiotensinogen to angiotensin I, which is changed to angiotensin II by a converting enzyme found in lung capillaries. Angiotensin II stimulates the adrenal cortex to release aldosterone. The effect of this process, called the renin-angiotensin-aldosterone system, is to raise blood pressure in two ways: (1) angiotensin II constricts the arterioles, and (2) aldosterone causes the kidneys to reabsorb sodium. When the blood sodium level rises, water is reabsorbed, in part because the hypothalamus secretes ADH (see page 740). Then blood pressure rises to normal.

As you might suspect, there is an antagonistic hormone to aldosterone. When the atria of the heart are stretched due to increased blood volume, cardiac cells release a hormone called **atrial natriuretic hormone (ANH)**, which inhibits the secretion of aldosterone from the adrenal cortex. The effect of this hormone is to cause the excretion of sodium (Na^+)—that is, *natriuresis*. When sodium is excreted, so is water, and therefore blood pressure lowers to normal (Fig. 40.12, *above*).

Malfunction of the Adrenal Cortex

When the level of adrenal cortex hormones is low due to hyposecretion, a person develops **Addison disease**. The presence of excessive but ineffective ACTH causes bronzing of the skin because ACTH, like MSH, can lead to a buildup of melanin (Fig. 40.13). Other symptoms include weight loss,

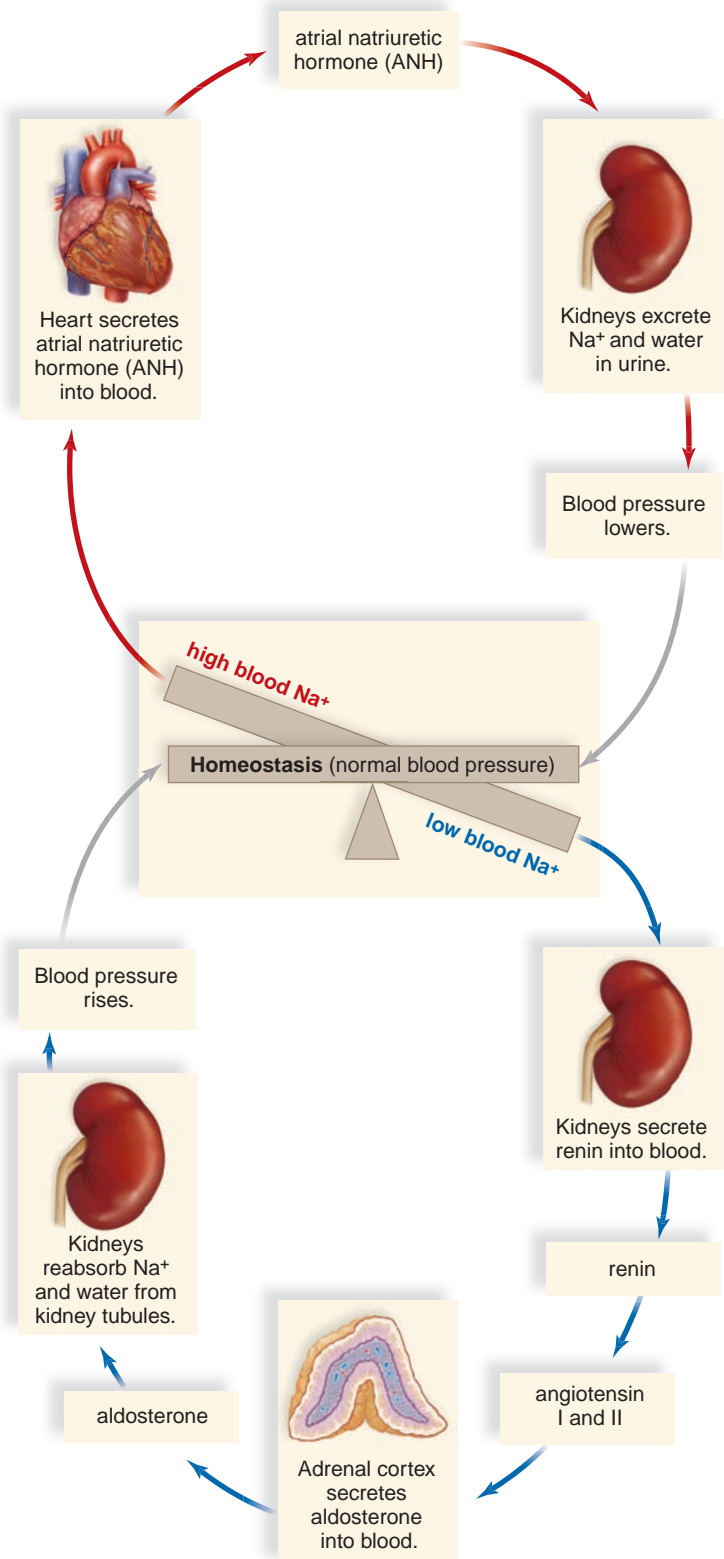


FIGURE 40.12 Regulation of blood pressure and volume.

Below: When the blood sodium (Na^+) level is low, a low blood pressure causes the kidneys to secrete renin. Renin leads to the secretion of aldosterone from the adrenal cortex. Aldosterone causes the kidneys to reabsorb Na^+ , and water follows, so that blood volume and pressure return to normal. *Above:* When the blood Na^+ is high, a high blood volume causes the heart to secrete atrial natriuretic hormone (ANH). ANH causes the kidneys to excrete Na^+ , and water follows. The blood volume and pressure return to normal.



a.



b.

FIGURE 40.13 Addison disease.

Addison disease is characterized by a peculiar bronzing of the skin, particularly noticeable in light-skinned individuals. Note the color of (a) the face and (b) the hands compared to the hand of an individual without the disease.

weakness, and hypotension (low blood pressure). Without cortisol, glucose cannot be replenished when a stressful situation arises. Even a mild infection can lead to death. The lack of aldosterone results in the loss of sodium and water, the development of low blood pressure, and possibly severe dehydration. Left untreated, Addison disease can be fatal.

When the level of adrenal cortex hormones is high due to hypersecretion, a person develops **Cushing syndrome** (Fig. 40.14). The excess cortisol results in a tendency toward diabetes mellitus as muscle protein is metabolized and

subcutaneous fat is deposited in the midsection. The trunk is obese, while the arms and legs remain a normal size. An excess of aldosterone and reabsorption of sodium and water by the kidneys lead to a basic blood pH and hypertension. The face is moon-shaped due to edema. Hypertension (high blood pressure) is common in patients with Cushing syndrome. Masculinization may occur in women because of excess adrenal male sex hormones. This is referred to as adrenogenital syndrome (AGS). In women with AGS, an increase in body hair, deepening of the voice, and beard growth may occur.



FIGURE 40.14 Cushing syndrome.

Cushing syndrome results from hypersecretion of hormones due to an adrenal cortex tumor. *Left:* Patient first diagnosed with Cushing syndrome. *Right:* Four months later, after therapy.

Pancreas

The **pancreas** (see Fig. 40.2) is a slender, pale-colored organ that lies transversely in the abdomen between the kidneys and near the duodenum of the small intestine. It is about 20 cm long and 3 cm thick and weighs about 80 g. The pancreas is rather lumpy in consistency and is composed of two types of tissue. Exocrine tissue produces and secretes digestive juices that go by way of ducts to the small intestine. Endocrine tissue, called the **pancreatic islets** (islets of Langerhans), produces and secretes the hormones insulin and glucagon directly into the blood. The majority of pancreas tissues are exocrine in nature.

Insulin is secreted when there is a high blood glucose level, which usually occurs just after eating (Fig. 40.15, *above*). Insulin stimulates the uptake of glucose by cells, especially liver cells, muscle cells, and adipose tissue cells. In liver and muscle cells, glucose is then stored as glycogen. In muscle cells, the breakdown of glucose supplies energy for protein metabolism, and in fat cells the breakdown of glucose supplies glycerol for the formation of fat. In these ways, insulin lowers the blood glucose level.

Glucagon is secreted from the pancreas, usually in between eating, when there is a low blood glucose level (Fig. 40.15, *below*). The major target tissues of glucagon are the liver and adipose tissue. Glucagon stimulates the liver to break down glycogen to glucose and to use fat and protein in preference to glucose as energy sources. Adipose tissue cells break down fat to glycerol and fatty acids. The liver takes these up and uses them as substrates for glucose formation. In these ways, glucagon raises the blood glucose level.

Diabetes Mellitus

Diabetes mellitus is a fairly common hormonal disease in which liver cells, and indeed most body cells, are unable to take up glucose as they should. Therefore, cellular famine exists in the midst of plenty, and the person becomes extremely hungry. As the blood glucose level rises, glucose, along with water, is excreted in the urine. Urination is frequent and the loss of water in this way causes the diabetic to be extremely thirsty.

The glucose tolerance test assists in the diagnosis of diabetes mellitus. After the patient is given 100 g of glucose, the blood glucose concentration is measured at intervals. In a diabetic, the blood glucose level rises greatly and remains elevated for several hours. In the meantime, glucose appears in the urine. In a nondiabetic, the blood glucose level rises somewhat and then returns to normal after about two hours.

Types of Diabetes. There are two types of diabetes mellitus. In *type 1 diabetes*, the pancreas is not producing insulin. This condition is believed to be brought on by exposure to an environmental agent, most likely a virus, whose presence causes cytotoxic T cells to destroy the pancreatic islets. The body turns to the metabolism of fat, which leads to the buildup of ketones in the blood, called *ketonuria*, and, in turn, to acidosis

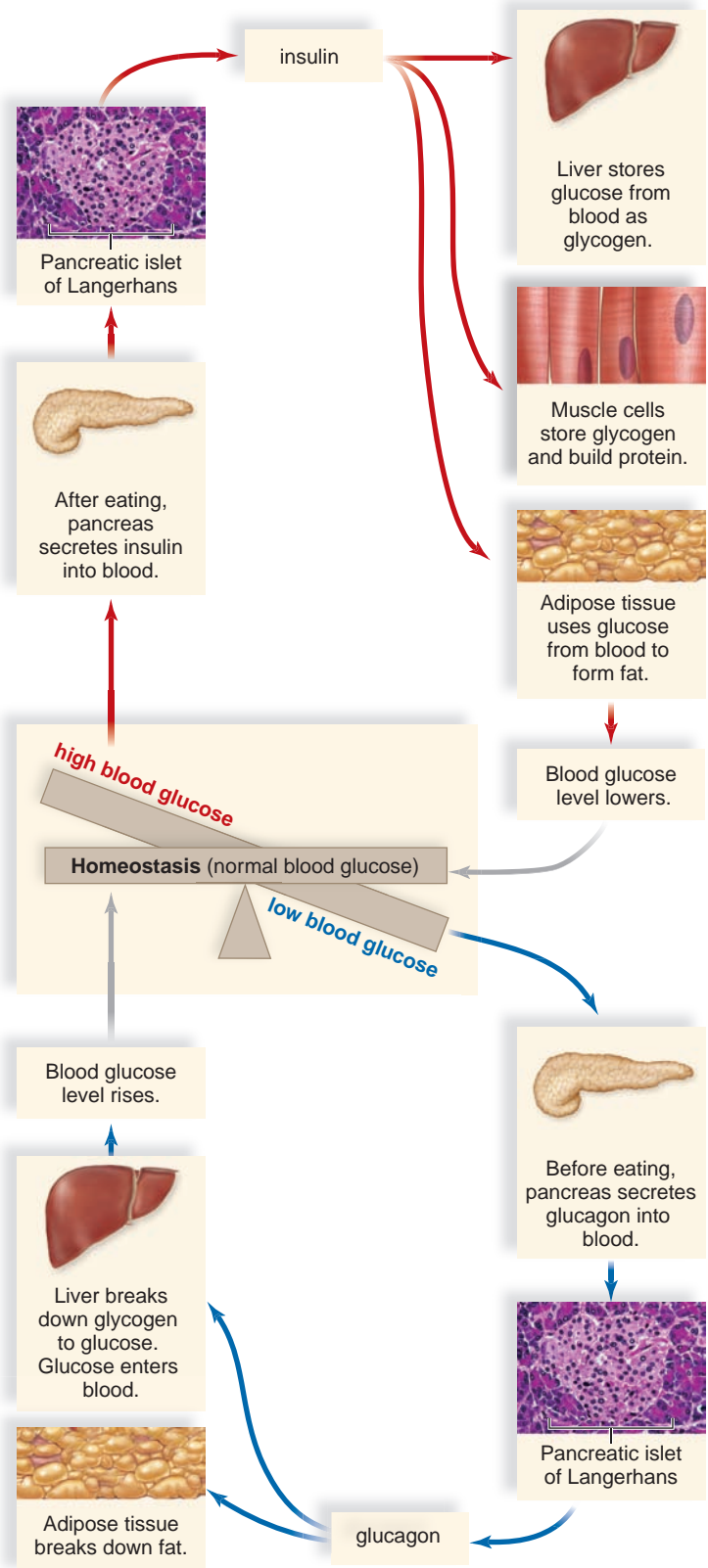


FIGURE 40.15 Regulation of blood glucose level.

Above: When the blood glucose level is high, the pancreas secretes insulin. Insulin promotes the storage of glucose as glycogen and the synthesis of proteins and fats (as opposed to their use as energy sources). Therefore, insulin lowers the blood glucose level to normal. *Below:* When the blood glucose level is low, the pancreas secretes glucagon. Glucagon acts opposite to insulin; therefore, glucagon raises the blood glucose level to normal.

science focus

Identifying Insulin as a Chemical Messenger

The pancreas is both an exocrine gland and an endocrine gland. It sends digestive juices to the duodenum by way of the pancreatic duct, and it secretes the hormones insulin and glucagon into the bloodstream. In 1920, physician Frederick Banting decided to try to isolate insulin in order to identify it as a chemical messenger. Previous investigators had been unable to do this because the enzymes in the digestive juices destroyed insulin (a protein) during the isolation procedure. Banting hit upon the idea of tying off the pancreatic duct, which he knew from previous research would lead to the degeneration only of the cells that produce digestive juices and not of the pan-

creatic islets (of Langerhans), where insulin is made. His professor, J. J. Macleod, made a laboratory available to him at the University of Toronto and also assigned a graduate student, Charles Best, to assist him. Banting and Best had limited funds and spent that summer working, sleeping, and eating in the lab. By the end of the summer, they had obtained pancreatic extracts that did lower the blood glucose level in diabetic dogs. Macleod then brought in biochemists, who purified the extract. Insulin therapy for the first human patient began in 1922, and large-scale production of purified insulin from pigs and cattle followed. Banting and Macleod received a Nobel Prize for their work

in 1923. The amino acid sequence of insulin was determined in 1953. Insulin is presently synthesized using recombinant DNA technology. Banting and Best performed the required steps given in the chart (lower left) to identify a chemical messenger.



FIGURE 40A Early insulin experiments. Charles H. Best and Sir Frederick Banting in 1921 with the first dog to be kept alive by insulin.

Steps to Identify a Chemical Messenger	Banting and Best
1. Identify the source of the chemical	Pancreatic islets are source
2. Identify the effect to be studied	Presence of pancreas in body lowers blood glucose
3. Isolate the chemical	Insulin isolated from pancreatic secretions
4. Show that the chemical has the effect	Insulin lowers blood glucose

(acid blood), which can lead to coma and death. As a result, the individual must have daily insulin injections. These injections control the diabetic symptoms but still can cause inconveniences, since either an overdose of insulin or missing a meal can bring on the symptoms of hypoglycemia (low blood sugar). These symptoms include perspiration, pale skin, shallow breathing, and anxiety. Because the brain requires a constant supply of glucose, unconsciousness can result. The cure is quite simple: Immediate ingestion of a sugar cube or fruit juice can very quickly counteract hypoglycemia.

It is possible to transplant a working pancreas into patients with type 1 diabetes. To do away with the necessity of taking immunosuppressive drugs after the transplant, fetal pancreatic islet cells have been injected into patients. Another experimental procedure is to place pancreatic islet cells in a capsule that allows insulin to get out but prevents antibodies and T lymphocytes from getting in. This artificial organ is implanted in the abdominal cavity. Recently, there has been progress in developing a vaccine to block the immune system's attack on islet cells. Such a vaccine, possibly used in conjunction with immunosuppressive drugs, may someday stop or even reverse type 1 diabetes.

Of the over 20.8 million people who now have diabetes in the United States, most have *type 2 diabetes*. Often,

the patient is obese—adipose tissue produces a substance that impairs insulin receptor function. Normally, but not in the type 2 diabetic, the binding of insulin to a receptor causes the number of glucose transporters to increase in the plasma membrane. Also, the blood insulin level is low and cells do not have enough insulin receptors.

It is possible to prevent or at least control type 2 diabetes by adhering to a low-fat, low-sugar diet and exercising regularly. If this fails, oral drugs that stimulate the pancreas to secrete more insulin and enhance the metabolism of glucose in the liver and muscle cells are available. It is projected that as many as 5 million Americans may have type 2 diabetes without being aware of it. Yet, the effects of untreated type 2 diabetes are as serious as those of type 1 diabetes.

Long-term complications of both types of diabetes are blindness, kidney disease, and cardiovascular disorders, including atherosclerosis, heart disease, stroke, and reduced circulation. The latter can lead to gangrene in the arms and legs. Pregnancy carries an increased risk of diabetic coma, and the child of a diabetic is somewhat more likely to be stillborn or to die shortly after birth. These complications of diabetes are not expected to appear if the mother's blood glucose level is carefully regulated and kept within normal limits.

Testes and Ovaries

The **testes** are located in the scrotum, and the **ovaries** are located in the pelvic cavity. The testes produce **androgens** (e.g., **testosterone**), which are the male sex hormones, and the ovaries produce **estrogens** and **progesterone**, the female sex hormones. The anterior pituitary releases the gonadotropic hormones, follicle-stimulating hormone (FSH), and luteinizing hormone (LH), and they control the secretions of the testes and ovaries in a three-tier system, as described on page 740.

Greatly increased testosterone secretion at the time of puberty stimulates the growth of the penis and the testes. Testosterone also brings about and maintains the male secondary sex characteristics that develop during puberty. Testosterone causes growth of a beard, axillary (underarm) hair, and pubic hair. It prompts the larynx and the vocal cords to enlarge, causing the voice to change. It is partially responsible for the muscular strength of males, and this is the reason some athletes take supplemental amounts of **anabolic steroids**, which are either testosterone or related chemicals. The dangerous effects of taking anabolic steroids are listed in Figure 40.16. Testosterone also stimulates oil and sweat glands in the skin; therefore, it is largely responsible for acne and body odor. Another side effect of testosterone is baldness. Genes for baldness are probably inherited by both sexes, but baldness is seen more often in males because of the presence of testosterone.

The female sex hormones, estrogen and progesterone, have many effects on the body. In particular, estrogens secreted at the time of puberty stimulate the growth of the uterus and the vagina. Estrogen [Gk. *oistros*, sexual heat; L. *genitus*, producing] is necessary for egg maturation and is largely responsible for the secondary sex characteristics in females, including female body hair and fat distribution. In general, females have a more rounded appearance than males because of a greater accumulation of fat beneath the

skin. Also, the pelvic girdle is wider in females than in males, resulting in a larger pelvic cavity. Both estrogen and progesterone are required for breast development and regulation of the uterine cycle, which includes monthly menstruation (discharge of blood and mucosal tissues from the uterus).

Pineal Gland

The **pineal gland**, which is located in the brain, produces the hormone **melatonin**, primarily at night. Melatonin is involved in our daily sleep-wake cycle; normally we grow sleepy at night when melatonin levels increase and awaken once daylight returns and melatonin levels are low (Fig. 40.17). Daily 24-hour cycles such as this are called **circadian rhythms** [L. *circum*, around, and *dies*, day], and circadian rhythms are controlled by an internal timing mechanism called a biological clock.

Based on animal research, it appears that melatonin also regulates sexual development. It has been noted that children whose pineal gland has been destroyed due to a brain tumor experience early puberty.

Thymus Gland

The **thymus gland** is a lobular gland that lies just beneath the sternum (see Fig. 40.2). This organ reaches its largest size and is most active during childhood. With aging, the organ gets smaller and becomes fatty. Lymphocytes that originate in the bone marrow and then pass through the thymus are transformed into T lymphocytes. The lobules of the thymus are lined by epithelial cells that secrete hormones called thymosins. These hormones aid in the differentiation of T lymphocytes packed inside the lobules. Although the hormones secreted by the thymus ordinarily work in the thymus, there is hope that these hormones could be injected into AIDS or cancer patients, where they would enhance T-lymphocyte function.

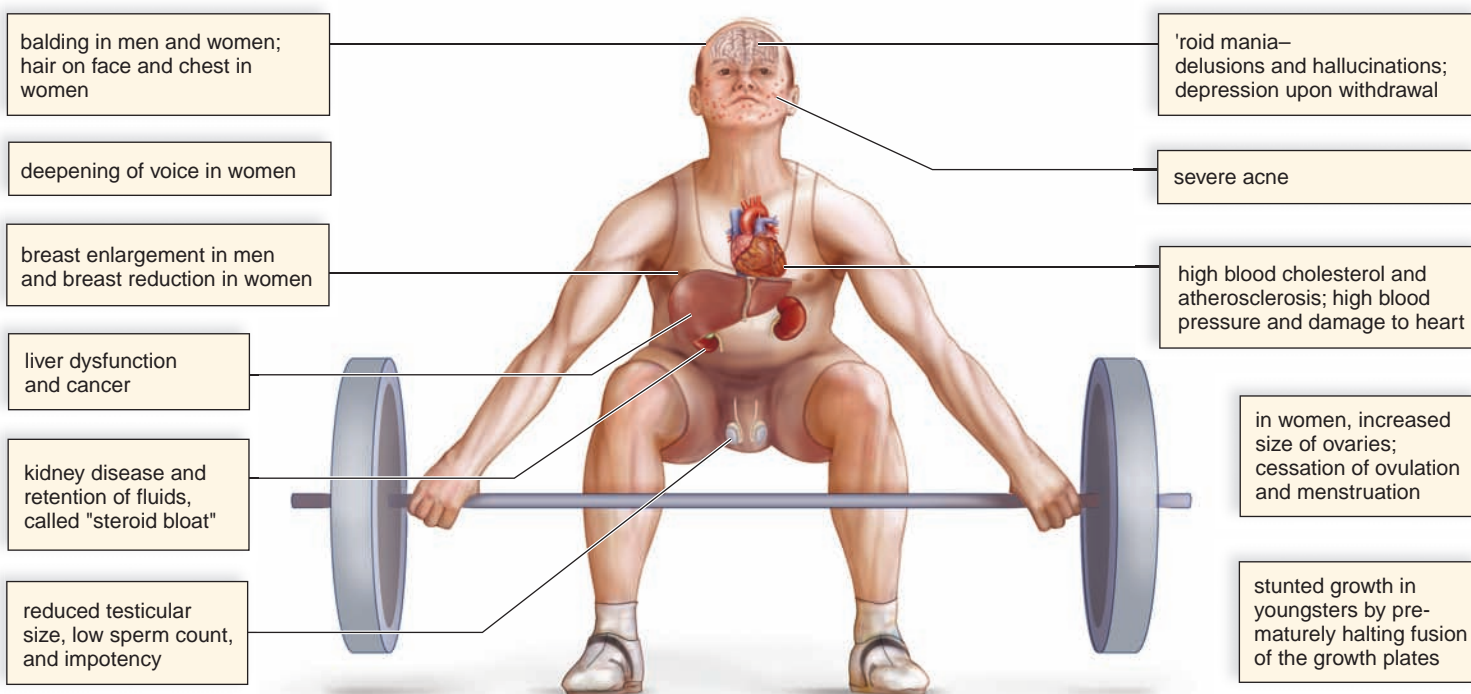


FIGURE 40.16 The effects of anabolic steroid use.

Other Hormones

Some hormones in the body, as exemplified by the ones discussed here, are produced by tissues/cells rather than by one of the glands.

Leptin

Leptin is a peptide hormone secreted by adipose (fat) tissue throughout the body. It was first described in the 1990s. One of its most interesting functions is its role in the feedback control of appetite. Leptin binds to neurons in the CNS that are concerned with the control of appetite. It can bring about feelings of satiation and can suppress appetite. Early researchers hoped that leptin could be used to control obesity in humans. Unfortunately, the trials have not yielded satisfactory results.

Erythropoietin

Erythropoietin (EPO) is a peptide hormone produced by the kidneys. It is released in response to low oxygen levels in kidney tissues. EPO serves to stimulate the production of red blood cells (erythropoiesis) and speed up the maturation of red blood cells. Under the influence of EPO, bone marrow can increase the rate of red blood cell production upward to 30 million per second. People with anemia, common in kidney disease, cancer, and AIDS, may be effectively treated with injections of recombinant EPO. In recent years, some athletes have practiced blood doping, in which EPO is used to improve performance by increasing the oxygen-carrying capacity of the blood. The potential dangers of blood doping far outweigh the temporary advantages. Because EPO increases the number of red blood cells, the blood becomes thicker, blood pressure can become elevated, and the athlete is at increased risk of a heart attack or stroke.

Local Hormones

Local hormones are produced by cells, and they act on neighboring cells. Examples include growth factors, cytokines, and prostaglandins. **Prostaglandins** are potent chemical signals produced within cells from arachidonate, a fatty acid. In the uterus, prostaglandins cause muscles to contract; therefore, they are implicated in the pain and discomfort of menstruation in some women. Also, prostaglandins mediate the effects of pyrogens, chemicals that are believed to reset the temperature regulatory center in the brain. Aspirin

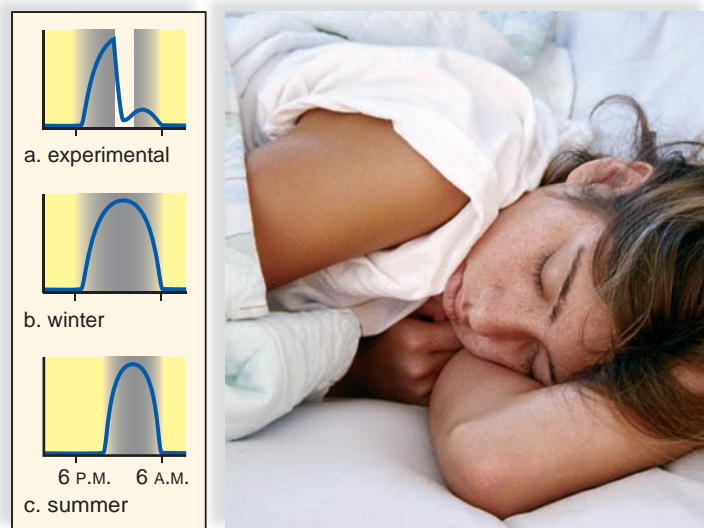


FIGURE 40.17 Melatonin production.

Melatonin production is greatest at night when we are sleeping. Light suppresses melatonin production (a), so its duration is longer in the winter (b) than in the summer (c).

reduces body temperature and controls pain because of its effect on prostaglandins.

Certain prostaglandins reduce gastric secretion and have been used to treat ulcers; others lower blood pressure and have been used to treat hypertension; and yet others inhibit platelet aggregation and have been used to prevent thrombosis. However, different prostaglandins have contrary effects, and it has been very difficult to successfully standardize their use. Therefore, prostaglandin therapy is still considered experimental.

Check Your Progress

40.3

1. How does the renin-angiotensin-aldosterone system raise blood pressure?
2. Name the source of each of the following hormones: aldosterone, melatonin, epinephrine, EPO, leptin, glucagon, ANH, cortisol, and calcitonin.
3. Which hormone stimulates osteoclasts? Which inhibits them?

Connecting the Concepts

The nervous system and the endocrine system are structurally and functionally related. The hypothalamus, a portion of the brain, controls the pituitary, an endocrine gland. The hypothalamus even produces the hormones that are released by the posterior pituitary. It also stimulates the release of hormones by the adrenal medulla. Neurosecretory cells in the hypothalamus also produce releasing hormones that control the activity of the anterior pituitary.

The nervous system is well known for bringing about an immediate response to environmental stimuli, as in the fight-or-flight reaction. Most often, the chemical signals released by the nervous system, called neurotransmitters, help maintain homeostasis. Heart rate, breathing rate, and blood pressure are all regulated to stay relatively constant. Hormones released by endocrine glands also help maintain homeostasis, especially by keeping the levels of calcium, so-

dium, glucose, and other blood constituents within normal limits.

The endocrine system is slower acting than the nervous system and often regulates processes that occur over days or even months. Hormones secreted into the bloodstream control whole body processes, such as growth and reproduction. In this chapter, we mentioned the effects of growth hormone, and in Chapter 41, we explore the activity of the hormones that influence reproduction.

summary

40.1 Endocrine Glands

The nervous system and the endocrine system both use chemical signals. Endocrine glands secrete hormones into the bloodstream, and from there they are distributed to target organs or tissues.

Hormones are a type of chemical signal that usually act at a distance between body parts. Hormones are either peptides or steroids. Reception of a peptide hormone at the plasma membrane activates an enzyme cascade inside the cell. Steroid hormones combine with a receptor in the cell, and the complex attaches to and activates DNA. Protein synthesis follows.

40.2 Hypothalamus and Pituitary Gland

Neurosecretory cells in the hypothalamus produce antidiuretic hormone (ADH) and oxytocin, which are stored in axon endings in the posterior pituitary until they are released.

The hypothalamus produces hypothalamic-releasing and hypothalamic-inhibiting hormones, which pass to the anterior pituitary by way of a portal system. The anterior pituitary produces several types of hormones, and some of these stimulate other hormonal glands to secrete hormones in a three-tier system.

40.3 Other Endocrine Glands and Hormones

The thyroid gland, controlled by TSH, requires iodine to produce thyroxine (T_4) and triiodothyronine (T_3), which increase the metabolic rate. If iodine is available in insufficient quantities, a simple goiter develops; if the thyroid is overactive, an exophthalmic goiter develops. The thyroid gland also produces calcitonin, which helps lower the blood calcium level. The parathyroid glands secrete parathyroid hormone, which raises the blood calcium and decreases the blood phosphate levels.

The adrenal glands respond to stress: Immediately, the adrenal medulla secretes epinephrine and norepinephrine, which bring about responses we associate with emergency situations. On a long-term basis, the adrenal cortex, controlled by ACTH, produces the glucocorticoids (e.g., cortisol) and the mineralocorticoids (e.g., aldosterone). Cortisol stimulates hydrolysis of proteins to amino acids that are converted to glucose; in this way, it raises the blood glucose level. Aldosterone causes the kidneys to reabsorb sodium ions (Na^+) and to excrete potassium ions (K^+). Addison disease develops when the adrenal cortex is underactive, and Cushing syndrome develops when the adrenal cortex is overactive.

The pancreatic islets secrete insulin, which lowers the blood glucose level, and glucagon, which has the opposite effect. The most common illness caused by hormonal imbalance is diabetes mellitus, which is due to the failure of the pancreas to produce insulin or the failure of the cells to take it up.

The gonads, controlled by gonadotropic hormones, produce the sex hormones; the pineal gland produces melatonin, which may be involved in circadian rhythms and the development of the reproductive organs; and the thymus secretes thymosins, which stimulate T-lymphocyte production and maturation.

Tissue and organs having other functions also produce hormones. Leptin is a newly described hormone that regulates appetite, and erythropoietin stimulates the production of red blood cells. Cells produce local hormones, for example, prostaglandins are produced and act locally.

understanding the terms

acromegaly 742	hypothalamus 740
Addison disease 746	leptin 751
adrenal cortex 745	melanocyte-stimulating hormone (MSH) 740
adrenal gland 745	melatonin 750
adrenal medulla 745	mineralocorticoid 745
adrenocorticotrophic hormone (ACTH) 740	myxedema 743
aldosterone 746	negative feedback 740
anabolic steroid 750	norepinephrine 745
androgen 750	ovary 750
anterior pituitary 740	oxytocin 740
antidiuretic hormone (ADH) 740	pancreas 748
atrial natriuretic hormone (ANH) 746	pancreatic islet 748
calcitonin 744	parathyroid gland 744
chemical signal 738	parathyroid hormone (PTH) 744
circadian rhythm 750	peptide hormone 738
congenital hypothyroidism 743	pheromone 738
cortisol 746	pineal gland 750
Cushing syndrome 747	pituitary dwarfism 741
cyclic adenosine monophosphate (cAMP) 739	pituitary gland 740
diabetes mellitus 748	positive feedback 740
endocrine gland 736	posterior pituitary 740
endocrine system 736	progesterone 750
epinephrine 745	prolactin (PRL) 740
erythropoietin (EPO) 751	prostaglandin 751
estrogen 750	renin 746
exophthalmic goiter 743	second messenger 739
first messenger 739	simple goiter 743
glucocorticoid 745	steroid hormone 739
gonadotropic hormone 740	testes 750
growth hormone (GH) 740	testosterone 750
hormone 736	tetany 744
hypothalamic-inhibiting hormone 740	thymus gland 750
hypothalamic-releasing hormone 740	thyroid gland 743
	thyroid-stimulating hormone (TSH) 740
	thyroxine (T_4) 743

Match the terms to these definitions:

- _____ Organ in the neck; secretes several important hormones, including thyroxine and calcitonin.
- _____ Common homeostatic control mechanism in which the output of a system shuts off or reduces the intensity of the original stimulus.
- _____ Organ that produces melatonin.
- _____ Type of hormone that binds to a plasma membrane receptor; results in activation of enzyme cascade.
- _____ Chemical substance secreted by one organism that influences the behavior of another.
- _____ Endocrine organ in which immature lymphocytes become T lymphocytes.
- _____ Testosterone and related chemicals used by some athletes to build muscle mass.
- _____ Appetite-suppressing peptide hormone produced by adipose tissue.

reviewing this chapter

- In what ways are the nervous and endocrine systems alike, and how are they different? 736
- Explain how steroid hormones and peptide hormones affect the metabolism of the cell. 738–39
- Give an example of the three-tier system and the negative feedback relationship among the hypothalamus, the anterior pituitary, and other endocrine glands. 740–41
- Explain the relationship of the hypothalamus to the posterior pituitary gland and to the anterior pituitary gland. List the hormones secreted by the posterior and anterior pituitary. 740–41
- Discuss the effect of there being too much or too little growth hormone when a young person is growing. What is the result if the anterior pituitary produces growth hormone in an adult? 741–42
- What two types of goiters are associated with a malfunctioning thyroid? Explain each type. 743
- How do the thyroid and the parathyroid work together to control the blood calcium level? 744
- How do the adrenal glands respond to stress? What hormones are secreted by the adrenal medulla, and what effects do these hormones have? 745
- Name the most significant glucocorticoid and mineralocorticoid, and discuss the function of each. Explain the symptoms of Addison disease and Cushing syndrome. 746–47
- Draw a diagram to explain how insulin and glucagon maintain the blood glucose level. Use your diagram to explain three major symptoms of type I diabetes mellitus. 748–49
- Name the other endocrine glands cited in this chapter, and discuss the functions of the hormones they secrete. Also, discuss the hormones not produced by endocrine glands. 750–51
- the ovaries and the testes.
- Both b and c are correct.
- Diabetes mellitus is associated with
 - too much insulin in the blood.
 - too much glucose in the blood.
 - blood that is too dilute.
 - All of these are correct.
- Which of these is not a pair of antagonistic hormones?
 - insulin—glucagon
 - calcitonin—parathyroid hormone
 - aldosterone—atrial natriuretic hormone (ANH)
 - thyroxine—growth hormone
- Which hormone and condition are mismatched?
 - cortisol—myxedema
 - growth hormone—acromegaly
 - thyroxine—goiter
 - parathyroid hormone—tetany
 - insulin—diabetes
- Which of the following hormones could affect fat metabolism?
 - growth hormone
 - thyroxine
 - insulin
 - glucagon
 - All of these are correct.
- The difference between type I and type 2 diabetes is that
 - for type 2 diabetes, insulin is produced but not used; type I results from lack of insulin production.
 - treatment for type 2 involves insulin injections, while type I can be controlled, usually by diet.
 - only type I can result in complications such as kidney disease, reduced circulation, or stroke.
 - type I can be a result of lifestyle, and type 2 is thought to be caused by a virus or other agent.
- Which of the following hormones is/are found in females?
 - estrogen
 - testosterone
 - follicle-stimulating hormone
 - Both a and c are correct.
 - All of these are correct.
- Parathyroid hormone causes
 - the kidneys to excrete more calcium ions.
 - bone tissue to break down and release calcium into the bloodstream.
 - fewer calcium ions to be absorbed by the intestines.
 - more calcium ions to be deposited in bone tissue.
- Hormones from all but which of the following glands can affect glucose levels in the body?
 - pancreas
 - adrenal glands
 - pituitary
 - hypothalamus
 - thymus
- Tropic hormones are hormones that affect other endocrine tissues. Which of the following would be considered a tropic hormone?
 - calcitonin
 - oxytocin
 - glucagon
 - melatonin
 - follicle-stimulating hormone
- One of the chief differences between endocrine hormones and local hormones is
 - the distance over which they act.
 - that one is a chemical signal and the other is not.
 - only endocrine hormones are made by humans.
 - All of these are correct.

testing yourself

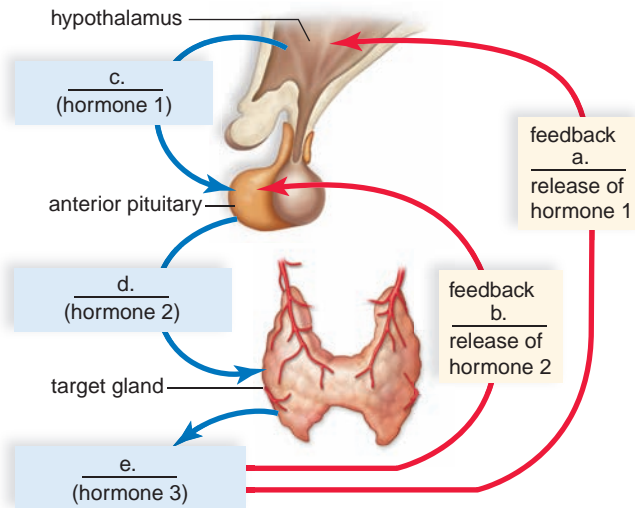
Choose the best answer for each question.

For questions 1–5, match each hormone to a gland in the key.

KEY:

- | | |
|------------------------|--------------------|
| a. pancreas | d. thyroid |
| b. anterior pituitary | e. adrenal medulla |
| c. posterior pituitary | f. adrenal cortex |
- cortisol
 - growth hormone (GH)
 - oxytocin storage
 - insulin
 - epinephrine
 - Which of the following relies on the activation of cAMP, a second messenger, to stimulate its target cells?
 - estrogen
 - aldosterone
 - glucagon
 - testosterone
 - The anterior pituitary controls the secretion(s) of both
 - the adrenal medulla and the adrenal cortex.
 - the thyroid and the adrenal cortex.

18. Peptide hormones
- are received by a receptor located in the plasma membrane.
 - are received by a receptor located in the cytoplasm.
 - bring about the transcription of DNA.
 - Both b and c are correct.
19. Complete this diagram by filling in blanks a–e.



For questions 20–25, match the function to a hormone in the key. Choose more than one answer if correct. Answers may be used more than once.

KEY:

- antidiuretic hormone
 - oxytocin
 - glucocorticoids
 - glucagon
 - parathyroid hormone
20. raises blood glucose level
21. stimulates uterine muscle contraction
22. stimulates water reabsorption by kidneys
23. stimulates release of milk by mammary glands
24. raise blood glucose and stimulate breakdown of protein
25. raises blood calcium level
26. Steroid hormones are secreted by
- the adrenal cortex.
 - the gonads.
 - the thyroid.
 - Both a and b are correct.
 - Both b and c are correct.
27. Steroid hormones
- bind to a receptor located in the plasma membrane.
 - cause the production of cAMP.
 - activate protein kinase.
 - stimulate the production of mRNA.
28. Which of the following statements about the pituitary gland is incorrect?
- The pituitary lies inferior to the hypothalamus.
 - Growth hormone and prolactin are secreted by the anterior pituitary.
 - The anterior pituitary and posterior pituitary communicate with each other.
 - Axons run between the hypothalamus and the posterior pituitary.

29. Prostaglandins
- have a consistent effect.
 - are useful in the treatment of cancer.
 - are carried in the blood.
 - stimulate other glands.
 - act locally.
30. Erythropoietin
- stimulates platelet production.
 - stimulates leukocyte production.
 - inhibits red blood cell production.
 - inhibits leukocyte production.
 - stimulates red blood cell production.

thinking scientifically

- Caffeine inhibits the breakdown of cAMP in the cell. Referring to Figure 40.4, how would this influence a stress response brought about by epinephrine?
- Both males and females can develop secondary sex characteristics of the opposite sex if they take enough of the appropriate sex hormone. Hypothesize the mechanism that would make this possible after reviewing Figure 40.4.

bioethical issue

Growth Hormone

Untreated GH deficiency in childhood results in pituitary dwarfism. If young children with GH deficiency receive daily GH injections through adolescence, most will attain normal stature. Few would argue that treatment of pituitary dwarfism is not justified. But is it justified to use GH therapy to make a child of normal height taller?

GH levels naturally decline with age, and there is evidence that treating older adults with GH boosts muscle mass and reduces body fat. Pills do not work, and GH injections are by prescription only and very expensive, being around \$1,000 a month. Furthermore, GH therapy can result in undesirable side effects, such as elevated blood sugar, fluid retention, and joint pain. Nevertheless, there is keen interest in GH therapy not only from those who wish to delay or avoid the effects of aging, but also from athletes in search of performance-enhancing substances. Thus far, like anabolic steroids and erythropoietin (EPO), GH is banned by most competitive sports authorities, including the U.S. and International Olympic Committees.

The existence of GH therapy raises questions about medical treatment for disease versus enhancement of an already healthy body. Under what circumstances is it suitable to increase a child's growth? Should the physical decline of aging be accepted, or should we try to maintain a youthful build using GH? If an athlete wants to make him- or herself more competitive using GH, and is willing to accept the risks, should therapy be permitted? Who decides?

Biology website

The companion website for *Biology* provides a wealth of information organized and integrated by chapter. You will find practice tests, animations, videos, and much more that will complement your learning and understanding of general biology.

<http://www.mhhe.com/maderbiology10>

41

Reproductive Systems

Sea horses are fishes with an unusual style of sexual reproduction: The males become pregnant and give birth to the young. When sea horses mate, the female deposits eggs in a special brood pouch on the male's abdomen, where they are fertilized by his sperm. The pouch seals and stays closed as the embryos develop, a process that can take 10 to 25 days depending on the species. Then, the pouch opens and muscular contractions expel the young sea horses. Although the evolutionary advantage conferred by male pregnancy in sea horses is not certain, some experts think it increases the efficiency of reproduction. The female does not have to wait until the completion of pregnancy for her eggs to mature and become ready for fertilization, so when the male has given birth, she is ready to mate and impregnate him again immediately.

In this chapter, you will learn about the mode of asexual reproduction that requires but a single parent and various modes of sexual reproduction that require production of gametes and fertilization. Most of the chapter focuses on the human female and male reproductive systems, which produce gametes and keep them from drying out—no external water is required for human reproduction.

Male potbelly sea horses with brood pouches holding 150–300 oocytes each.



41.1 HOW ANIMALS REPRODUCE

- Animals reproduce sexually, but some, on occasion, can reproduce asexually. Sexually reproducing animals have gonads for the production of gametes, and many have accessory organs for the storage and passage of gametes into or out of the body. Animals have various means of ensuring fertilization of gametes and protecting immature stages. 756–57

41.2 MALE REPRODUCTIVE SYSTEM

- The human male reproductive system continuously produces a large number of sperm that are transported within a fluid medium. 758–61
- Hormones control the production of sperm and maintain the primary and secondary sex characteristics of males. 761

41.3 FEMALE REPRODUCTIVE SYSTEM

- The human female reproductive system produces one secondary oocyte monthly and prepares the uterus to house the developing fetus. 762–63
- Hormones control the monthly reproductive cycle in females and play a significant role in maintaining pregnancy, should it occur. 763–66

41.4 CONTROL OF REPRODUCTION

- Birth control measures vary in effectiveness from those that are very effective to those that are minimally effective. Assisted methods of reproduction include in vitro fertilization followed by placement of the embryo in the uterus. 766–68

41.5 SEXUALLY TRANSMITTED DISEASES

- Several serious sexually transmitted diseases are prevalent among human beings. 770–73

41.1 How Animals Reproduce

Although the majority of animals reproduce sexually, a few groups of animals are also capable of asexual reproduction. In sexual reproduction, sex cells, or gametes, produced by the parents unite to form a genetically unique individual. In asexual reproduction, a single parent gives rise to offspring that are identical to the parent, unless mutations have occurred. The adaptive advantage of asexual reproduction is that organisms can reproduce rapidly and colonize favorable environments quickly.

Asexual Reproduction

Several types of invertebrates, such as sponges, cnidarians, flatworms, annelids, and echinoderms, can reproduce asexually. Sponges produce asexual gemmules that develop into new individuals. Cnidarians, such as hydras, can reproduce asexually by budding (Fig. 41.1). A new individual arises as an outgrowth (bud) of the parent. *Obelia* is dimorphic and has an asexual colonial stage and a sexually reproducing medusa stage.

You can horizontally cut a planarian into as many as ten pieces in the laboratory and get ten new planarians. The parasitic flatworms reproduce asexually during certain stages of their complicated life cycles. Several annelids, such as earthworms and sandworms, also have the ability to regenerate from fragments. Fragmentation, followed by regeneration, is seen among sponges and echinoderms as well. If a sea star is chopped up, it has the potential to regenerate into several new individuals.

Several types of flatworms, roundworms, crustaceans, annelids, insects, fishes, lizards, and even some turkeys have the ability to reproduce parthenogenetically. **Parthenogenesis**

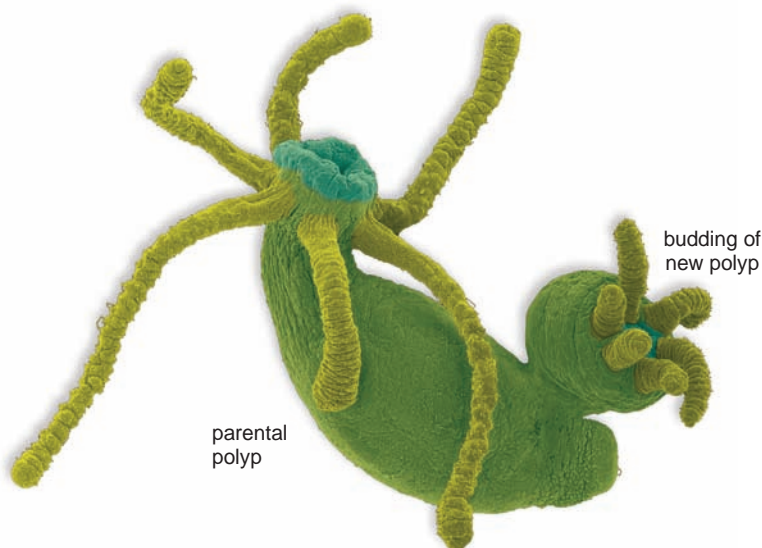


FIGURE 41.1 Reproduction in *Hydra*.

Hydras reproduce asexually and sexually. During asexual reproduction, a new polyp buds from the parental polyp. During sexual reproduction, temporary gonads develop in the body wall.

is a modification of sexual reproduction in which an unfertilized egg develops into a complete individual. In honeybees, the queen bee makes and stores sperm she uses to selectively fertilize eggs. Any unfertilized eggs become haploid males.

Sexual Reproduction

Usually during sexual reproduction, the egg of one parent is fertilized by the sperm of another. The majority of animals are *dioecious*, which means having separate sexes. *Monoecious*, or hermaphroditic, organisms have both male and female sex organs in the same body. Some hermaphroditic organisms, such as tapeworms, are capable of self-fertilization, but the majority, such as earthworms, practice cross-fertilization. Sequential hermaphroditism, or sex reversal, also occurs. In coral reef fishes called wrasses, a male has a harem of several females. If the male dies, the largest female becomes a male.

Animals usually produce gametes in specialized organs called **gonads**. Sponges are an exception to this rule because the collar cells lining the central cavity of a sponge give rise to sperm and eggs. Hydras and other cnidarians produce only temporary gonads in the fall, when sexual reproduction occurs. Animals in other phyla have permanent reproductive organs. The gonads are **testes**, which produce sperm, and **ovaries**, which produce eggs. Eggs or sperm are derived from **germ cells**, which become specialized for this purpose during early development. Other cells in a gonad support and nourish the developing gametes or produce hormones necessary to the reproductive process. The reproductive system also usually has a number of accessory structures, such as ducts and storage areas, that aid in bringing the gametes together.

Many aquatic animals, such as the fishes in Figure 41.2, practice external fertilization. Palolo worms release their eggs in the water only when the moon moves closer to the Earth, and the tides become somewhat higher than



FIGURE 41.2 Reproduction in anemonefish.

Fishes such as orange-fin anemonefish, *Amphiprion chrysopterus*, usually reproduce sexually. Sperm from the male fertilize eggs from the female in the water.