23.9 Annelida—Segmented Worms

The annelid worms are bilaterally symmetrical and have a body structure consisting of repeating segments (figure 23.19). Most of the segments are very similar to one another, although there is usually some specialization of anterior segments into a head, and there may be specialization related to reproduction and digestion. Each segment has a coelomic cavity. They have well-developed muscular, circulatory, digestive, excretory, and nervous systems. There are three major types of annelid worms (figure 23.20).

Polychaetes are primarily benthic, marine worms that have paddlelike appendages on each segment. They have a well-developed head region with sense organs and a mouth. Some live in tubes and are filter feeders. Others burrow in mud or sand; some swim in search of food. Most polychaetes have separate sexes and release eggs and sperm into the ocean, where fertilization takes place. The fertilized egg develops into a ciliated larva known as a trochophore larva; it is planktonic and eventually metamorphoses into the adult form of the worm.

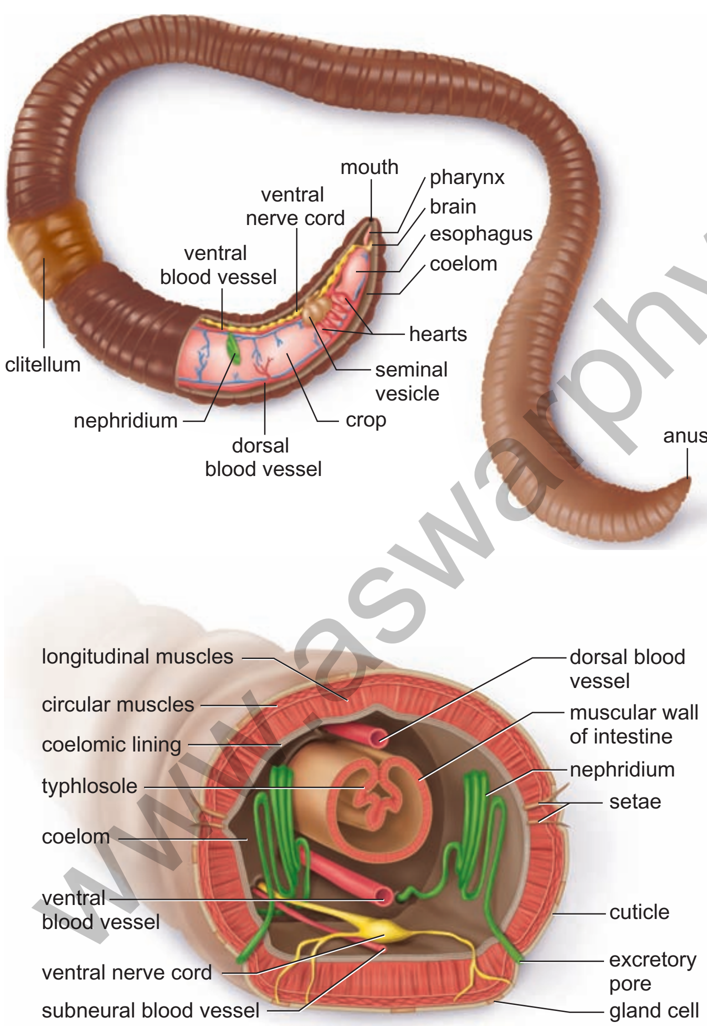


FIGURE 23.19 Annelid Structure
An earthworm shows the major features of annelid structure. Annelids are bilaterally symmetrical, segmented, and have complex organ systems and a coelom.

Oligochaetes live in moist soil or freshwater. The most commonly seen members of this group are the various kinds of earthworms. They differ from polychaetes in that they do not have appendages and a well-developed head region. They

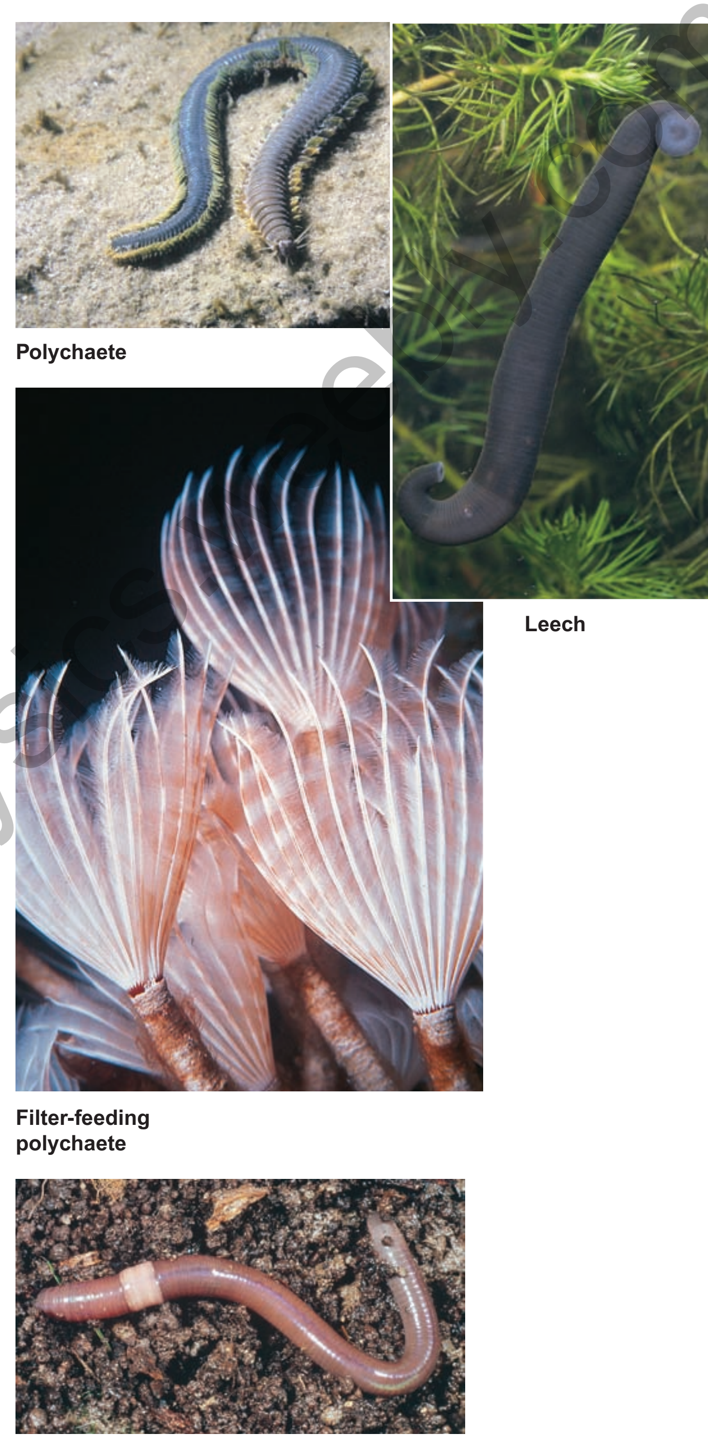


FIGURE 23.20 Annelid Diversity
There are three major types of annelid worms. Polychaete worms are primarily marine worms. Some live in tubes and obtain food by filtering water. Others are free to move and are omnivores or carnivores. Oligochaetes (earthworms) burrow through soil and eat organic matter. Leeches either are carnivores or suck the blood of other animals.

are also hermaphroditic (have both sets of sex organs in the same individual). Mating between two earthworms results in each receiving sperm from the other. Earthworms are extremely important soil organisms. They eat organic matter in the soil or come to the surface to eat dead leaves and other organic matter. As they burrow through the soil, they create spaces, which allow water and air to penetrate the soil. They are also important food organisms to many other animals.

Leeches live in freshwater or moist terrestrial environments. They have suckers, which allow them to hold on to objects. Some are free-swimming carnivores, but many feed on the blood of various vertebrates. They attach to their victims, rasp a hole through the skin, and suck blood. They produce an anticoagulant, which aids in their blood-feeding lifestyle.

23.9 CONCEPT REVIEW

23. List three structural characteristics of annelids.
24. What are the three kinds of segmented worms?

23.10 Mollusca

Like most other forms of animal life, the mollusks originated in the ocean, and, even though some forms have made the move to freshwater and terrestrial environments, most still live in the oceans. The members of this phylum display a true body cavity, a coelom. Reproduction is generally sexual; some species have separate sexes and others are hermaphroditic. They range from microscopic organisms to the giant squid, which is up to 18 meters long. A primary characteristic of mollusks is the presence of a soft body enclosed by a hard shell. They are not segmented but have three distinct body regions: the mantle, the foot, and the visceral mass. The mantle produces a shell and is involved in gas exchange, the foot is involved in movement, and the visceral mass contains the organs of digestion, circulation, and reproduction. Most of the mollusks have a tonguelike structure known as a radula, which has teeth on it. They use the radula like a rasp to scrape away at food materials and tear them to tiny particles that are ingested (figure 23.21).

Except for the squids and octopuses, mollusks are slow-moving benthic animals. Some are herbivores and feed on marine algae; others are scavengers and feed on dead organic matter. A few are even predators of other slow-moving or sessile neighbors. As with most other marine animals, the mollusks produce a free-swimming larval stage, which aids in dispersal. It is a ciliated trochophore larva similar to that seen in the annelids.

There are several kinds of mollusks; the most commonly observed are the chitons, bivalves, snails, and octopuses and squids (figure 23.22).

The chitons are a primitive group of marine mollusks that have a series of eight shell plates along their back. They generally live on rocky surfaces and use their radula to scrape algae from the rocks. They can clamp onto their rocky substrate when disturbed. Many species are common along rocky shores.

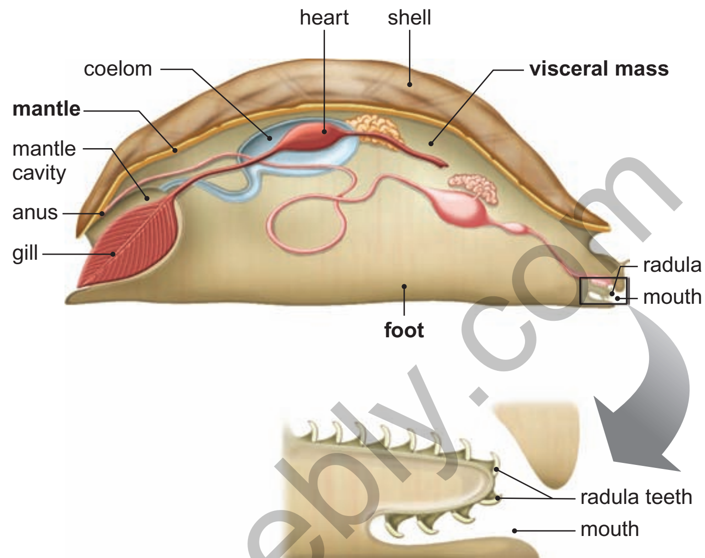


FIGURE 23.21 Mollusk Structure
Mollusks are bilaterally symmetrical organisms with a coelom and a body composed of three body regions: the foot, the mantle, and the visceral mass.

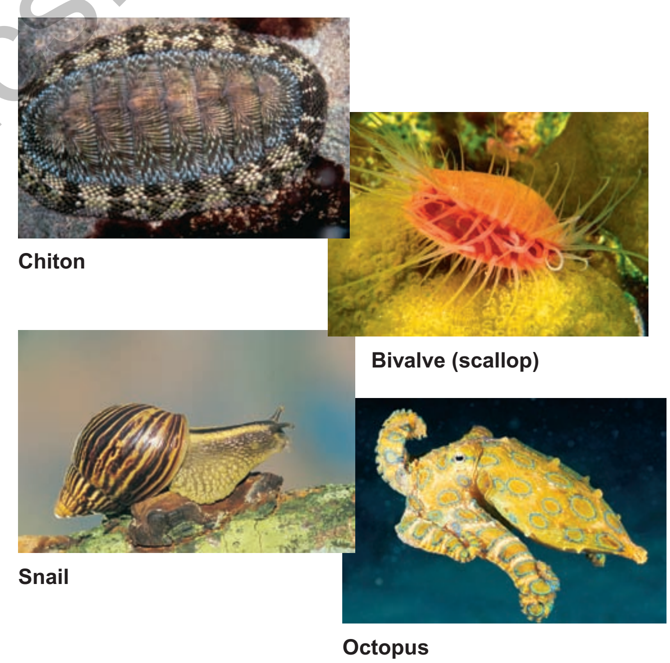


FIGURE 23.22 Mollusk Diversity
Mollusks range in complexity from small, slow-moving, grazing animals, such as chitons and snails, to clams, which are filter feeders, to intelligent, rapidly moving carnivores, such as octopuses.

Snails have a coiled shell. Most snails are benthic marine organisms, but some live in freshwater and moist terrestrial habitats. Slugs are a kind of snail that does not have a shell. Snails and slugs are extremely common and there are a huge number of different species. Many marine snails are carnivores.

The bivalves (clams, oysters, and mussels) are benthic marine and freshwater mollusks that have two shells. They also differ from other mollusks in that they are filter feeders and lack a radula.

Squids and octopuses have no external shell although a related organism—the nautilus—has a shell. They are marine animals that are active, rapidly moving predators. Squids are free-swimming predators, whereas octopuses are benthic and use ambushing as a way to capture prey.

23.10 CONCEPT REVIEW

25. Describe the general body plan of mollusks.
26. How does the lifestyle of a squid differ from that of a chiton?

23.11 Arthropoda

The arthropods are the most successful group of animals on Earth. The earliest arthropods were marine, and today arthropods are found as plankton, nekton, and benthic animals. However, the most successful group of animals is the terrestrial insects. Over three-fourths of the species of animals are arthropods, and over three-fourths of the arthropods are insects.

Arthropods have an external skeleton composed of chitin. Their bodies are segmented, but the segmentation is highly modified, compared with that of the annelids. There is generally a head region, and the segments that follow may be modified into regions as well. Many of the segments have paired appendages. Both the body and the appendages are jointed.

Because they have an exoskeleton, in order to grow they must shed their skeleton and manufacture a new, larger one at intervals. They have well-developed nervous, muscular, respiratory, circulatory, and reproductive systems (figure 23.23).

There are many types of arthropods: crustaceans, millipedes, centipedes, arachnids, and insects (figure 23.24). Nearly all crustaceans are aquatic (both marine and freshwater) but range in size from large crabs and lobsters to tiny, planktonic organisms and sessile barnacles. Crustaceans are typically omnivores, which feed on a variety of living and dead materials.

Millipedes and centipedes have long bodies with many legs, and all the posterior segments are similar to one another. The earliest fossils of terrestrial animals are of this type.

The arachnids are the scorpions, spiders, mites, and ticks. They are very successful as land animals. Mites are extremely common as soil organisms. Spiders are carnivores, and most ticks are blood feeders.

Insects are terrestrial animals with a body divided into three regions: head, thorax, and abdomen. They have three pairs of legs, and most species have wings.

23.11 CONCEPT REVIEW

27. List three characteristics typical of all arthropods.
28. How do crustaceans and insects differ structurally?

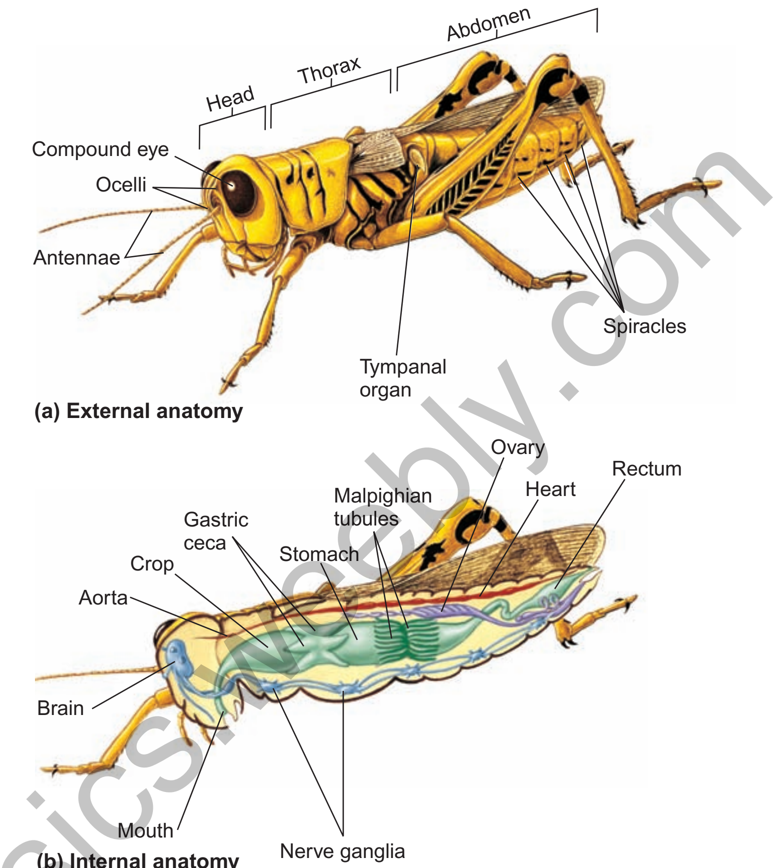


FIGURE 23.23 Arthropod Structure—Grasshopper
(a) Arthropods have an external skeleton and segments that are modified into special body regions. They have jointed appendages. *(b)* They have complex organ systems.

23.12 Echinodermata

The echinoderms represent a completely different line of evolution from other invertebrates. They are actually more closely related to the vertebrates than to other invertebrates. Echinoderms, along with chordates, have an embryological development, in which the anus is the first opening of the gut to form. Such animals are called deuterostomes. In all other triploblastic organisms, the mouth is the first opening of the gut to form; these are called protostomes. All echinoderms are marine benthic animals and are found in all regions, from the shoreline to the deep portions of the ocean. Echinoderms are the most common type of animal on much of the ocean floor. Most species are free-moving and either are carnivores or feed on detritus.

They are unique among the more advanced invertebrates in that they display radial symmetry. They have a five-part radial symmetry; thus, they have five arms or regions of the body that project from a central axis. However, the larval stage has bilateral symmetry, leading many biologists to believe that the echinoderm ancestors were bilaterally symmetrical.

Another unique characteristic of this group is their water vascular system (figure 23.25). In this system, water is taken in

FIGURE 23.24 **Arthropod Diversity**
Arthropods are the most successful group of organisms on Earth.

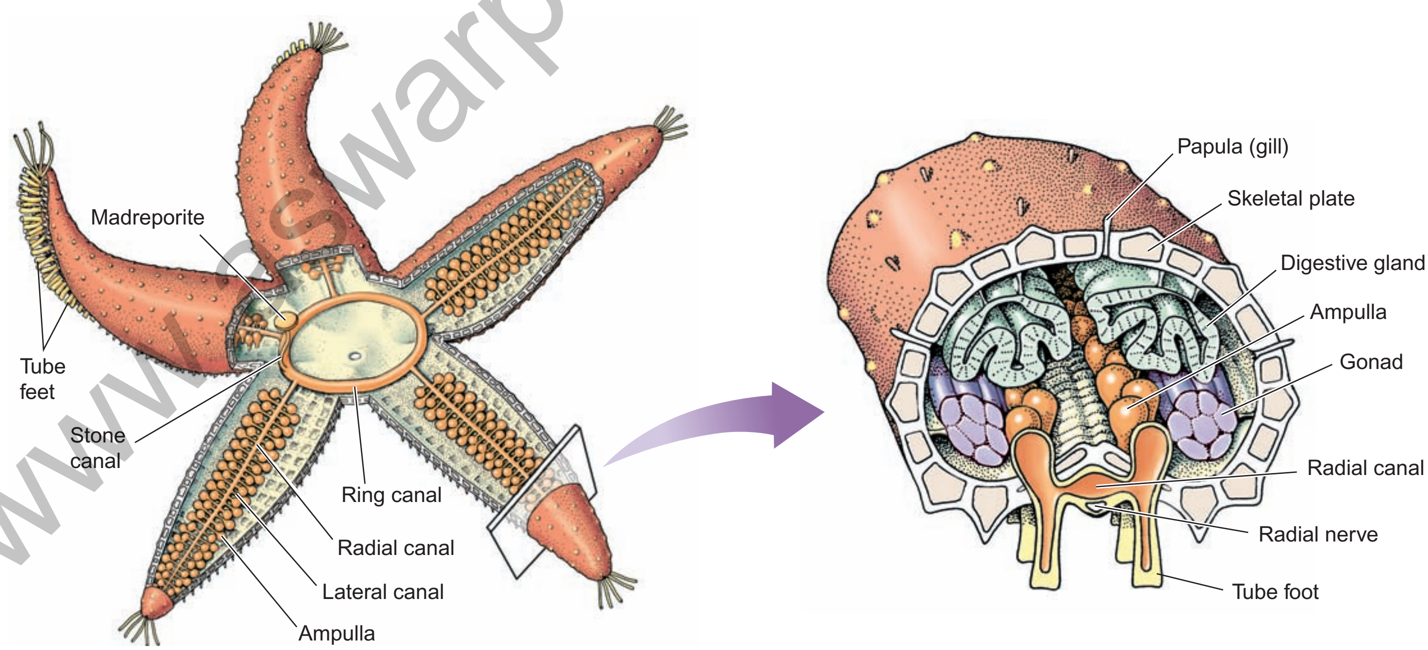


FIGURE 23.25 **Water Vascular System**
Echinoderms move by means of a water vascular system. Water enters the system through an opening, travels to the radial canals, and is forced into the tube feet.

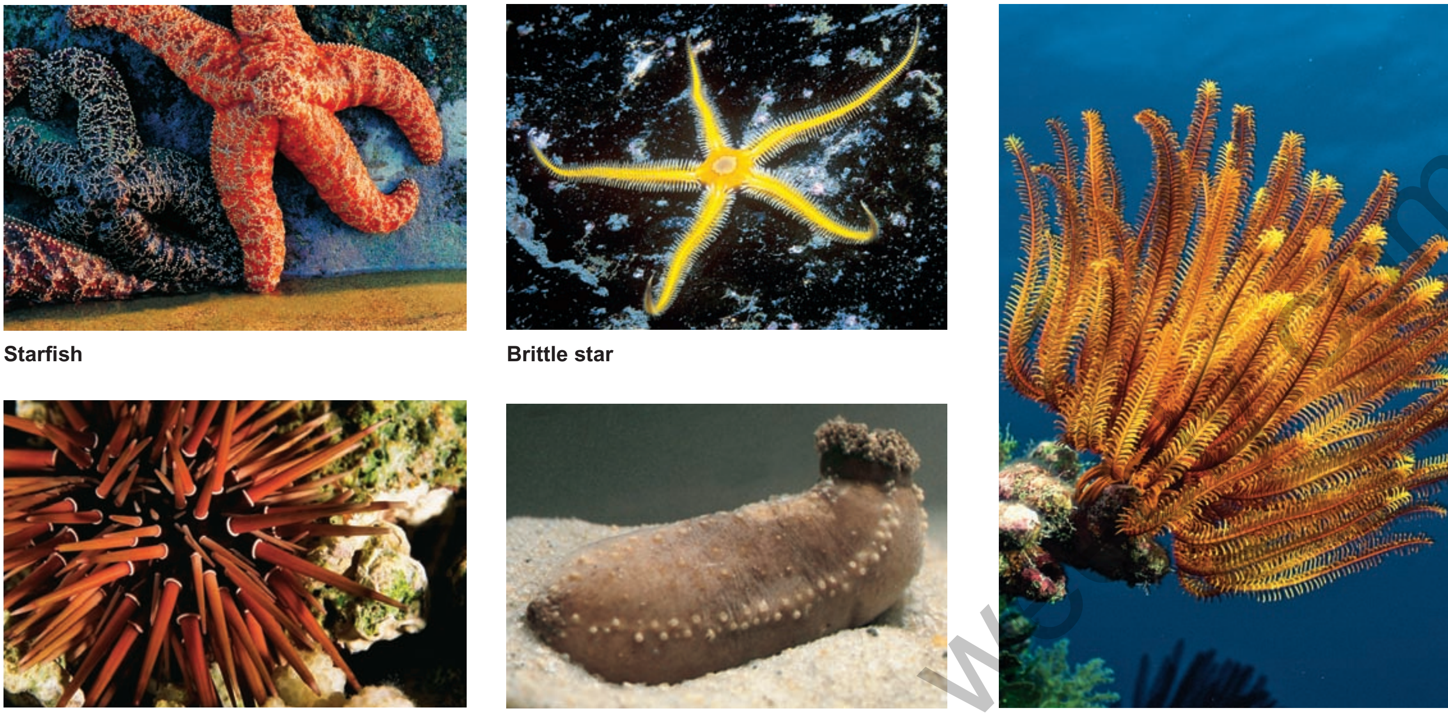


FIGURE 23.26 Echinoderm Diversity
Echinoderms have a five-part radial symmetry and an internal skeleton. Many of them have spines that protrude from the surface. There are five major types of echinoderms: starfish, brittle stars, sea urchins, sea cucumbers, and crinoids (feather stars).

through a structure on the top side of the animal and then moves through a series of canals. The passage of water through this water vascular system is involved in the organism's locomotion.

They have a hard, jointed internal skeleton covered by a thin skin. Many of them have spines that are part of the skeleton and project from the animal.

There are five major types of echinoderms: starfish, brittle stars, sea urchins, sea cucumbers, and crinoids (figure 23.26). Starfish, brittle stars, and sea urchins move slowly along the ocean bottom and feed primarily on detritus. Some starfish are carnivores that eat clams. Crinoids are sessile, and many of them are stalked. Because they have five arms that are often feather-like, they are often called sea lilies or feather stars. They are filter feeders. Sea cucumbers are sausage-shaped organisms that lie on the bottom or burrow in the mud. Some are detritus feeders and some are filter feeders.

23.12 CONCEPT REVIEW

29. Describe the general body plan of an echinoderm.
30. What is a water vascular system, and what does it do?

23.13 Chordata

The chordates are a diverse group of animals. They have a hollow nerve cord down the back of the body; they have a flexible rod just below the nerve cord, known as the notochord; they have a tail, which extends beyond the anus; and they have a region posterior to the mouth, known as a pharynx, that has pouches in it. The most primitive chordates are small marine organisms that have a notochord but no backbone. They are *Branchiostoma* (formerly named *Amphioxus*) and tunicates. *Branchiostoma* has a notochord as an adult, but the tunicates have only a notochord in the tail region during the larval stage (figure 23.27). However, most chordates are vertebrates (animals with a backbone) and only have a notochord during their embryonic stages. In the aquatic chordates the pouches in the pharynx region form gill slits. In terrestrial vertebrates, these pouches are obvious in embryos but are highly modified in the adults.

There are several kinds of vertebrates that have always been aquatic organisms and are commonly called fishes. Hagfish and lampreys lack jaws and are the most primitive of the fish. Hagfish are strictly marine forms and are scavengers; lampreys are mainly marine but can also be found in freshwater (figure 23.28). Adult lampreys suck blood from their larger fish hosts. Lampreys reproduce in freshwater

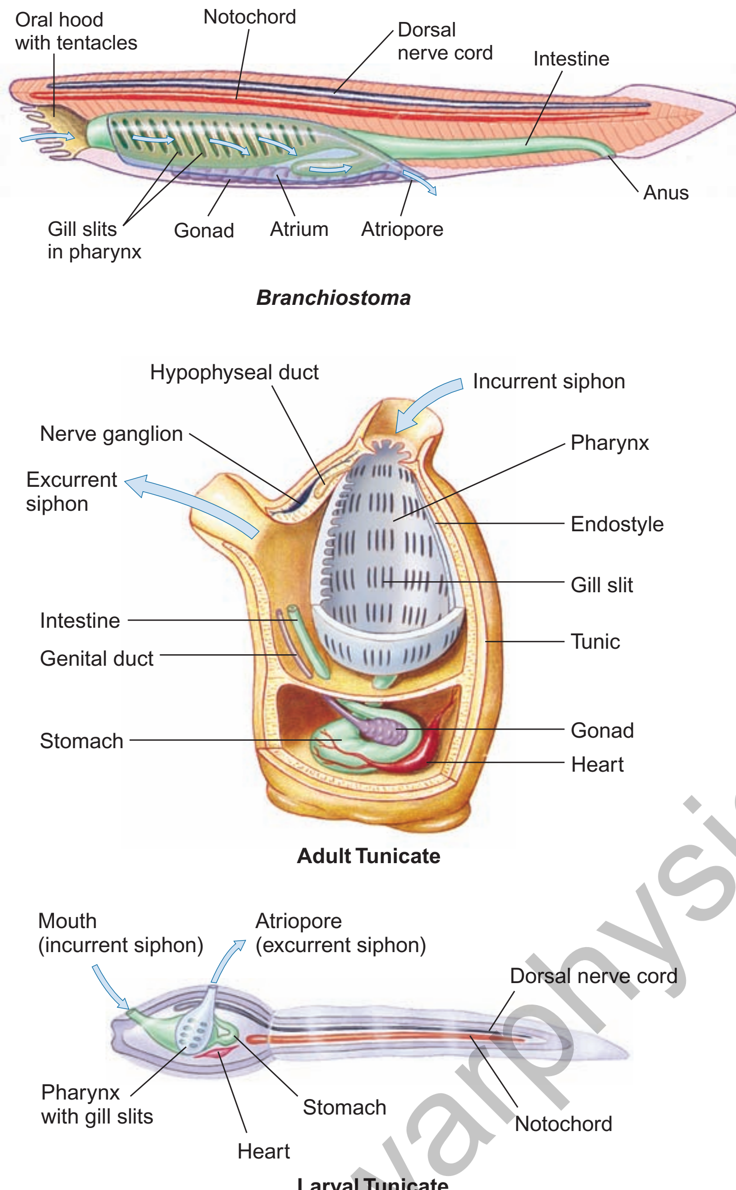


FIGURE 23.27 Invertebrate Chordates
Branchiostoma and tunicates are invertebrate chordates. They have a notochord but no backbone of vertebrae. Tunicates have a larval stage that has a notochord in the tail. Most tunicates change into a saclike body form that is sessile. *Branchiostoma* lives in the sand on the ocean floor. Both organisms are filter feeders.


(a) Lamprey mouth


(b) Lampreys on carp

FIGURE 23.28 The Lamprey
The lamprey uses its round mouth *(a)* to attach to a fish and then *(b)* to suck blood from the fish.

streams, where the eggs develop into filter-feeding larvae. After several years, the larvae change to adults and migrate to open water.

Sharks and rays are marine animals that have an internal skeleton made entirely of cartilage (figure 23.29). These animals have no swim bladder to adjust their body density in order to maintain their position in the water; therefore, they must constantly swim or they will sink. Rays feed by gliding along the bottom and dredging up food, usually invertebrates.


(a) Silvertip shark


(b) Blue-spotted stingray

FIGURE 23.29 Cartilaginous Fish
Although *(a)* sharks and *(b)* rays are large animals, they do not have bones; their skeletal system is made entirely of cartilage.

Sharks are predatory and feed primarily on other fish. They travel great distances in search of food. Most species of sharks grow no longer than a meter. The whale shark, the largest, grows to 16 meters, but it is strictly a filter feeder.

The bony fish are the class most familiar to us (figure 23.30). Their skeleton is composed of bone. Most species have a swim bladder and can regulate the amount of gas in the bladder to control their density. Thus, the fish can remain at a given level in the water without expending large amounts of energy. Bony fish are found in marine and freshwater habitats, and some, such as salmon, can live in both. There are many kinds of bony fish. Some are bottom-dwelling, whereas others are wide-ranging in the open water. Some fish are highly territorial and remain in a small area their entire lives. Of the many kinds, some feed primarily on algae and detritus. However, many are predators.

The remaining groups of vertebrates (amphibians, reptiles, birds, and mammals) all are terrestrial animals. The amphibians are transitional organisms, which must return to water to reproduce and have aquatic larval stages. Reptiles, birds, and mammals have become very successful terrestrial animals. They are discussed in section 23.14.

23.13 CONCEPT REVIEW

31. List three characteristics shared by all chordates.
32. How does a shark differ from most freshwater fish?

Lined sweet lips

Sea horse

FIGURE 23.30 Bony Fish
Bony fish have a skeleton composed of bone. Most fish have a streamlined body and are strong swimmers. A few, such as the sea horse, have unusual body shapes and are relatively sedentary.

23.14 Adaptations to Terrestrial Life

There is fossil evidence of land plants and fungi at about 480 million years ago, during the Ordovician period, and vascular plants were well established on land by the time terrestrial animals show up in the fossil record at about 420 million years ago. Thus, plants and fungi served as a source of food and shelter for the animals.

All animals that live on land must overcome certain common problems. Terrestrial animals must have:

1. a moist membrane that allows for an adequate gas exchange between the atmosphere and the organism,
2. a means of support and locomotion suitable for land travel,
3. methods to conserve internal water,
4. a means of reproduction and early embryonic development in which large amounts of water are not required, and
5. methods to survive the rapid and extreme climatic changes that characterize many terrestrial habitats.

When the first terrestrial animals evolved, there were many unfilled niches; therefore, much adaptive radiation occurred, resulting in a large number of different animal species. Of all the many phyla of animals in the ocean, only a few made the transition from the ocean to the extremely variable environments found on the land. The annelids (earthworms and leeches) and the mollusks (land snails) have terrestrial species but are confined to moist habitats. Many of the arthropods (centipedes, millipedes, scorpions, spiders, mites, ticks, and insects) and vertebrates (reptiles, birds, and mammals) adapted to a wide variety of drier terrestrial habitats.

Terrestrial Arthropods

There are five kinds of terrestrial arthropods: crustaceans, millipedes, centipedes, arachnids (mites, ticks, spiders, scorpions), and insects. The few terrestrial crustaceans are generally confined to moist environments. The first terrestrial animals were millipedes, which are known from the fossil record from over 400 million years ago. Flightless insects also are early terrestrial organisms. The exoskeleton of marine arthropods was important in allowing some of their descendents to adapt to land. It provides the support needed in the less buoyant air and serves as a surface for muscle attachment that permits rapid movement. The exoskeleton of most terrestrial arthropods has a waterproof, waxy coating that reduces water loss.

Terrestrial arthropods have an internal respiratory system that prevents the loss of water from their respiratory surface. They have a tracheal system of thin-walled tubes extending into all regions of the body, thus providing a large surface area for gas exchange (figure 23.31a). These tubes have small openings to the outside, which reduce the amount of water lost to the environment. Another important method of conserving water in insects and spiders is the presence of Malpighian tubules, thin-walled tubes that surround the gut and reabsorb water from nitrogenous wastes prior to their excretion (figure 23.31b).

Internal fertilization is typical of terrestrial arthropods. It involves copulation, in which a penis is used to insert the sperm into the reproductive tract of the female (insects, millipedes) or the production of special sperm-containing sacs (spermatophores) that are picked up by the female (spiders, centipedes). This is important because both the sperm and egg are protected from drying.

Terrestrial arthropods have evolved a number of characteristics that assure their survival under hostile environmental conditions. Many seek out sheltered sites and become inactive during periods of cold or drought. Often this involves changes in physiology that protect against freezing or prevent water loss. In addition, their rapid reproductive rate can replace the large number that die. Most of a population may be lost because of an unsuitable environmental change, but, when favorable conditions return, the remaining individuals can quickly increase in number. Many have complex life cycles that involve larval stages that occupy different niches from the adults. For example, butterflies have larval stages that feed on the leaves of plants and grow rapidly. The adults feed on the nectar of flowers and are primarily involved in sexual reproduction that involves mating and laying of the eggs on appropriate host plants (figure 23.32).

The terrestrial arthropods occupy an incredible variety of niches. Many insects are herbivores that compete directly with humans for food. They are capable of decimating plant populations that serve as human food. Many farming practices, including the use of pesticides, are directed at controlling insect populations. Other kinds of insects, as well as spiders and centipedes, are carnivores that feed primarily on arthropods and other small animals. Mites and millipedes feed primarily on decaying material and the fungi and bacteria that are part of decaying material. Insects have evolved in concert with the flowering plants; their role in pollination is well understood. Bees, butterflies, and beetles transfer pollen from one flower to another as they visit the flowers in search

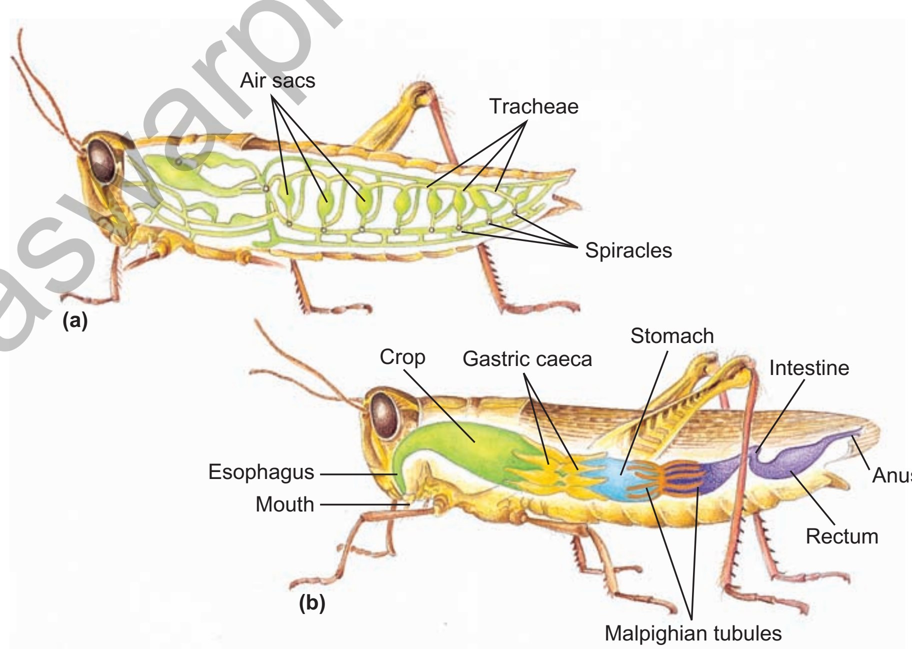


FIGURE 23.31 **Insect Respiratory and Waste-Removal Systems**
(a) Spiracles are openings in the exoskeleton of insects and other terrestrial arthropods. These openings connect to a series of tubes (tracheae) that allow for the transportation of gases in the insect's body. *(b)* Malpighian tubules are used in the elimination of waste materials and the reabsorption of water into the arthropod body. Both systems are means of conserving body water.

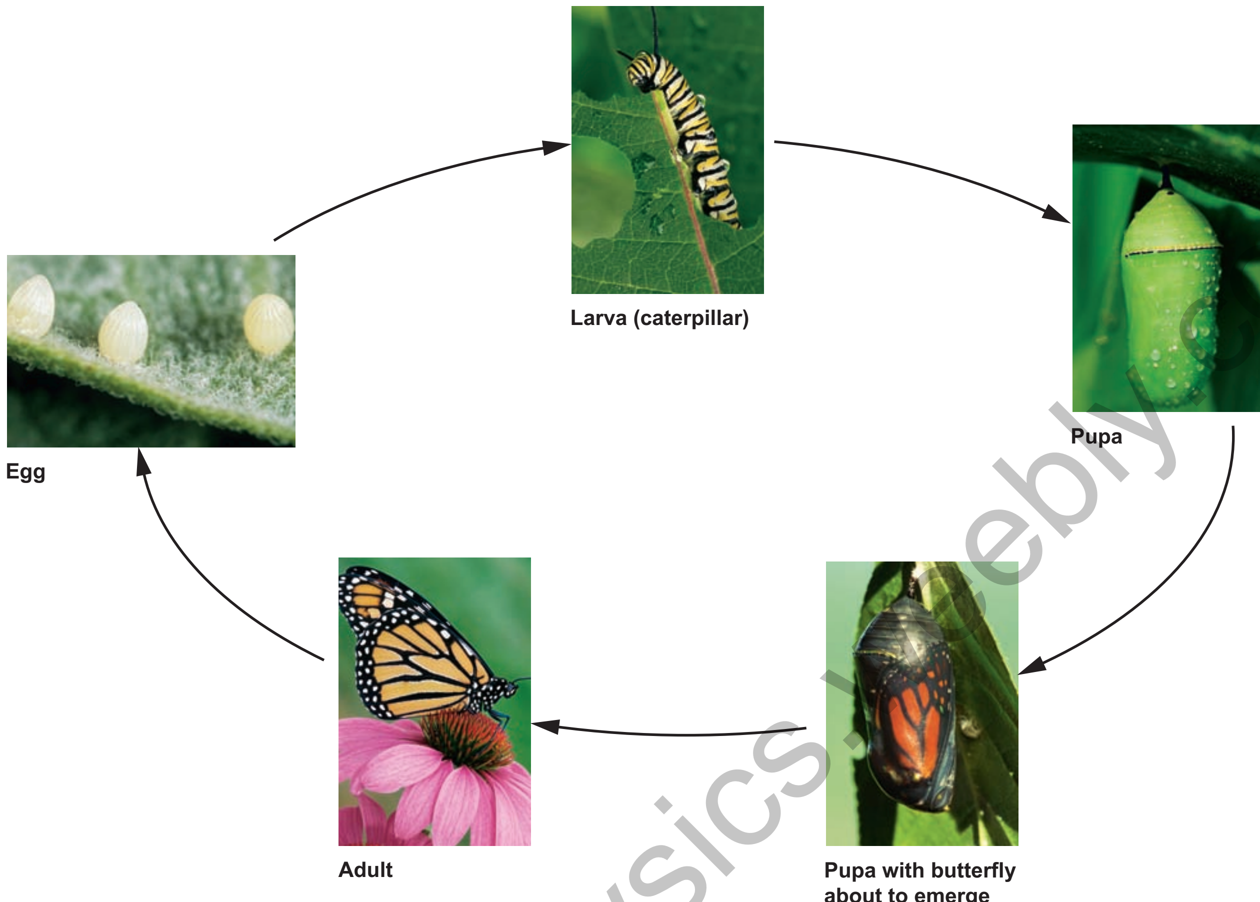


FIGURE 23.32 The Life History of a Monarch Butterfly
The adult female lays eggs on a milkweed plant. The fertilized egg hatches into the larval stage, known as a caterpillar, which feeds on the leaves of the milkweed plant. The caterpillar grows and eventually metamorphoses into a pupa. After emerging from the pupa, the adult's wings expand to their full size. The adults feed on the nectar of flowers. After mating, the female lays eggs and the life cycle starts over again.

of food. Many kinds of crops rely on bees for pollination, and farmers even rent beehives to ensure adequate pollination for fruit production.

Terrestrial Vertebrates

The first vertebrates on land were probably the ancestors of present-day amphibians (frogs, toads, and salamanders). The endoskeleton of vertebrates is an important prerequisite for life on land. It provides the support in the air and provides the places for muscle attachment necessary to movement. However, appendages are needed to move about. Certain bony fishes have lobe-fins, which can serve as primitive legs. It is likely that the amphibians evolved from a fish with modified fins (How Science Works 23.2). The first amphibians made the transition to land about 360 million years ago during the Devonian period. This was 50 million years after plants and arthropods had become established on land. Thus, when the first vertebrates developed the ability to live on land, shelter and food for herbivorous as well as carnivorous animals were available. But vertebrates faced the same problems that the insects, spiders and other invertebrates faced in their transition to life on land.

Amphibians

Amphibians are only minimally adapted to a terrestrial life. Although they have lungs they do not have an efficient method of breathing. They swallow air to fill the lungs and are able to accomplish some exchange of oxygen and carbon dioxide. However, most gas exchange occurs through their moist skin. In addition to needing water to keep their skin moist, amphibians must reproduce in water. When they mate, the female releases eggs into the water, and the male releases sperm amid the eggs. External fertilization occurs in the water, and the fertilized eggs must remain in water or they will dehydrate. Thus, amphibians live on "dry" land but are not found far from water, because they lose water through their moist skin and reproduction must occur in water. The most common present-day amphibians are frogs, toads, and salamanders (figure 23.33).

Frog tadpole

Frog

Salamander

Toad

FIGURE 23.33 Amphibians
Amphibian larvae (tadpoles) are aquatic organisms that have external gills and feed on vegetation. Most adult salamanders, frogs, and toads feed on insects, worms, and other small animals.

Reptiles

For 40 million years, amphibians were the only vertebrate animals on land. However, eventually they were replaced by reptiles, which were better adapted to life on land. In addition to having internal lungs, reptiles have a waterproof skin and water-conserving kidneys to reduce water loss. Furthermore, their reproduction involves internal fertilization, which protects the egg and sperm from drying. However, to be truly free of water it is necessary to have a specialized aquatic environment in which the embryo develops. This is accomplished with a special reproductive development known as an amniotic egg.

Reptiles became completely independent of an aquatic environment with the development of the amniotic egg, which protects the developing young from injury and dehydration (figure 23.34). The covering on the egg retains moisture and protects the developing young from dehydration while allowing for the exchange of gases. The reptiles were the first animals to develop such an egg.

The development of a means of internal fertilization and the amniotic egg allowed the reptiles to spread over much of the Earth and occupy a large number of previously unfilled niches. For about 200 million years, they were the only large vertebrate animals on land. The evolution of reptiles increased competition with the amphibians for food and space. The amphibians generally lost in this competition; consequently, most became extinct. Some evolved into present-day frogs, toads, and salamanders.

In a similar fashion, as birds and mammals evolved, many kinds of reptiles became extinct. However, there are still many kinds of reptiles present today. They include turtles, lizards, snakes, crocodiles, and alligators (figure 23.35).

Birds

The reptiles gave rise to two other groups of vertebrates: birds and mammals. About 65 million years ago, a mass extinction of many kinds of reptiles occurred. At that time, birds and mammals began to diversify and became the

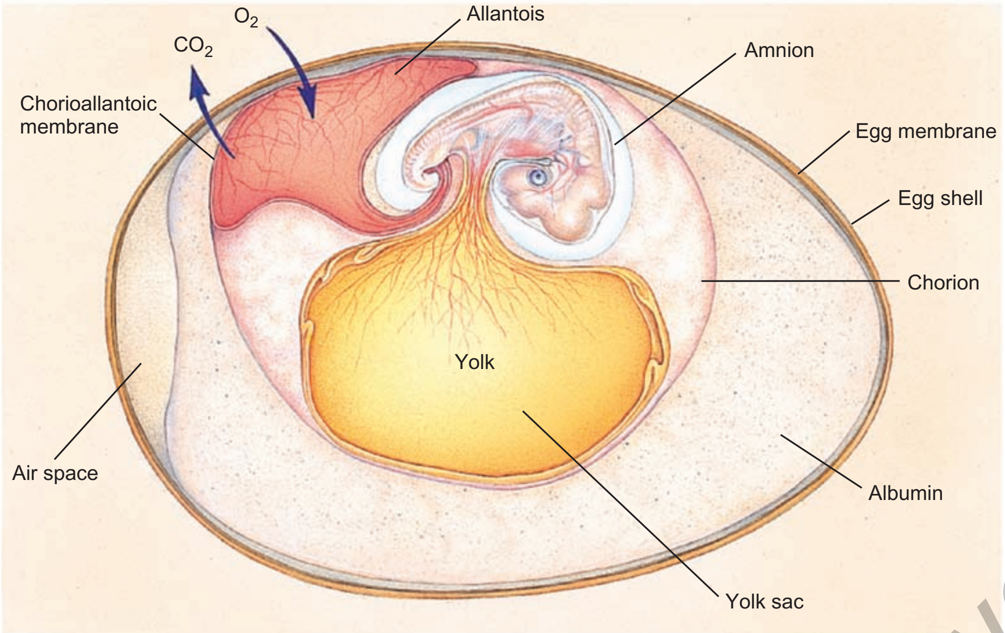


FIGURE 23.34 The Amniotic Egg An amniotic egg has a shell and a membrane that prevent the egg from dehydrating but still allow for the exchange of gases between the egg and the environment. The egg yolk provides a source of nourishment for the developing young. The embryo grows three extraembryonic membranes: the amnion is a fluid-filled sac that allows the embryo to develop in a liquid medium, the allantois collects the embryo's metabolic waste material and exchanges gases, and the chorion is a membrane that encloses the embryo and the other two membranes.

FIGURE 23.35 Reptiles Present-day reptiles include turtles, crocodiles and alligators, snakes, and lizards.

HOW SCIENCE WORKS 23.2

Coelacanth Discoveries

Sometimes, scientific discoveries are made because the right person is in the right place at the right time. In 1938, a coelacanth—a fish that was thought to have been extinct for about 80 million years—was discovered near the mouth of the Chalumna River on the east coast of South Africa. The fishing boat captain who caught the fish contacted Marjorie Courtney-Latimer, the director of the local museum in the town of East London. She immediately contacted a fish biologist, J. L. B. Smith, and the coelacanth became a scientific celebrity. The coelacanth was named *Latimeria chalumnae*, incorporating both Courtney-Latimer's name and the name of the Chalumna River in its name. Subsequently, it was discovered that the fish was probably a stray and that the center of the population was farther north in the waters between Mozambique and the island of Madagascar.

In 1997, a biologist, Mark Erdmann, saw a coelacanth in a market in Indonesia. He photographed the fish and questioned the fishers. He then returned to Indonesia and, over a 5-month period, interviewed over 200 fishers. Eventually, he discovered two fishermen who occasionally caught coelacanths. Eventually, he was rewarded with a live specimen, and it was eventually described as a new species, *Latimeria menadoensis*. Scientists used structural differences and DNA analysis as evidence that the Indonesian coelacanth was a different species from the African species.

What was once thought to have been extinct for 80 million years can now be studied in the flesh. Over 200 specimens have been captured, and diving submarines have been used to observe coelacanths in the wild. They live in deep water and typically stay in caves during the day.

The coelacanth has several characteristics that make it of interest to biologists. Primary among them is the presence of

lobe fins. The fins are on short, limblike appendages that resemble stubby legs. Because of this, many biologists thought that coelacanths may have been the ancestors of terrestrial, four-legged vertebrates. Although most no longer feel this is the case, coelacanths do have several interesting characteristics. When they swim, they move their fins alternately in a manner similar to the way four-legged animals walk. They do not have a vertebral column but have a notochord that serves the same purpose as a spine. They have internal fertilization and the young develop from large eggs that are retained within the body of the mother and are born when they have completed development.

Sometimes accidental discoveries lead to a new body of scientific information.

dominant forms of vertebrates on land. Like the structures of their reptile ancestors, the skin, lungs, and kidneys of birds reduce water loss, and reproduction involves internal fertilization and the shelled amniotic egg.

They also have other adaptations that allow them to be successful as land animals. Birds are homeothermic and have feathers. As homeotherms, they have a high body temperature and a more rapid metabolic rate than reptiles. Feathers serve two primary functions in birds. They form an insulating layer, which helps prevent heat loss, and they provide structural surfaces enabling the birds to fly. There are several values to flight. Animals that fly are able to travel long distances in a short time and use less energy than animals that must walk or run. They are able to cross barriers, such as streams, lakes, oceans, bogs, ravines, or mountains, that other animals cannot easily cross. They can also escape many kinds of predators by taking flight quickly.

The exploitation of flight has shaped the entire structure and function of birds. The forelimbs are modified into wings for flight, although it is actually the flight feathers that provide most of the flight surface. Large breast muscles provide the power for flight. Feathers help provide a streamlined shape. Homeothermism enables a high constant temperature, which allows for the rapid wing beats typical of most birds. In addition, the skeleton is reduced in weight and the jaws lack teeth that are heavy. The beak performs some of the functions of the teeth and is lighter. Birds have successfully occupied many niches. Some are nectar feeders, some are carnivores, some are seedeaters, some are aquatic, and some have even lost their ability to fly (figure 23.36).

Because they are homeotherms, birds' eggs must be kept at a warm temperature. Thus, birds build nests, incubate their eggs, and care for their young.

Hummingbird

Eagle

Ostrich

FIGURE 23.36 Birds
Birds range in size from the small hummingbird with a rapid wingbeat to the large, flightless ostrich. In food habits, they range from the nectar-feeding hummingbird to the omnivorous ostrich and the carnivorous eagle.

Mammals

The first mammals appeared about 200 million years ago, when reptiles were at their most diverse. Like birds, mammals are homeotherms, with a high constant body temperature. Like reptiles and birds, they have a waterproof skin and water-conserving lungs and kidneys. However, they differ from birds in several respects. Their insulating covering is hair, rather than feathers, and they provide nourishment to their young with milk produced by special glands.

There are three categories of mammals. Monotremes (platypus and echidna) are egg-laying mammals whose young still develop in an external egg. Following hatching, the mother provides nourishment in the form of milk. The milk glands are widely distributed on her underside, and the young lap up the milk from her fur.

Marsupials (pouched mammals) have internal development of the young. However, the young are born in a very immature state and develop further in an external pouch in the belly region of the female. In the pouch, the young attach to a nipple. They continue their development and eventually begin to leave the pouch for periods of time until they are able to forage for themselves.

Placental mammals have a form of development in which the young remain within the female much longer. The embryo is attached to the wall of the uterus by an organ known as a placenta. In the placenta, capillaries from the circulatory systems of the mother and embryo are adjacent to one another. This allows for the exchange of materials between the developing young and the mother, and the young are born in a more advanced stage of development than is typical for marsupials. The young rely on milk as a source of food for some time before they begin to feed on their own (figure 23.37).

23.14 CONCEPT REVIEW

33. List the problems animals had to overcome to adapt to a terrestrial environment.
34. List four adaptations of arthropods that allow them to be successful terrestrial animals.
35. Why can't amphibians live in all types of terrestrial habitats?
36. What is the importance of the amniotic egg?
37. How does a marsupial differ from a placental mammal?

Summary

The 4 million known species of animals, which inhabit widely diverse habitats, are all multicellular and heterotrophic. Animal body shape is asymmetrical, radial, or bilateral. All animals with bilateral symmetry have a body structure composed of three layers.

Animal life originated in the ocean about 600 million years ago; for the first 200 million years, all animal life remained in the ocean. Many simple marine animals have life cycles that involve alternation of generations.

Many kinds of flatworms and nematodes have a parasitic lifestyle with complicated life cycles. A major ecological niche for many marine animals is the ocean bottom—the benthic zone. Many marine animals are planktonic. These zooplankton feed on phytoplankton and, in turn, are fed upon by larger, free-swimming marine animals—the nekton.

Animals that adapted to a terrestrial environment had to have (1) a moist membrane for gas exchange, (2) support and locomotion suitable for land, (3) a means of conserving body water, (4) a means of reproducing and providing for early embryonic development out of water, and (5) a means of surviving in rapid and extreme climatic changes.

Monotreme (echidna)

Placental mammal (zebra)

Marsupial (kangaroo)

FIGURE 23.37 **Mammals**
All mammals have hair and produce milk. However, there are three, very different kinds of mammals. Monotremes lay eggs. Marsupials have pouches; the young are born in an immature stage and are carried in the pouch while they finish their development. Placental mammals have a placenta, which connects the mother and embryo; they retain the young in the uterus for a longer period of time.

Key Terms

Use the interactive flash cards on the ***Concepts in Biology, 14/e*** *website to help you learn the meaning of these terms.*

acoelomate 509
asymmetry 507
bilateral symmetry 507
budding 512
coelom 509
diploblastic 507
ectoderm 507
ectotherms 507
endoderm 507
endoskeletons 510
endotherms 507
exoskeletons 510
homeotherms 506
invertebrates 505
medusa 512
mesenteries 509
mesoderm 507
nekton 511
poikilotherms 506
polyp 512
pseudocoelom 509
radial symmetry 507
segmentation 509
skeleton 510
triploblastic 507
vertebrates 505

Basic Review

1. The most abundant group of terrestrial animals is the
   a. mammals.
   b. birds.
   c. earthworms.
   d. insects.

2. The sponges and cnidarians
   a. reproduce sexually.
   b. are primarily marine.
   c. are not bilaterally symmetrical.
   d. All of the above are correct.
3. Which of the following animal groups shows radial symmetry?
   a. annelids
   b. echinoderms
   c. vertebrates
   d. None of the above is correct.
4. The most successful group of animals based on the number of species is the _______.
5. The three general parts of the mollusk body are the visceral mass, mantle, and _______.
6. Nematode worms are extremely common in soil. (T/F)
7. Which of the following organisms has a body consisting of a linear arrangement of similar segments?
   a. nematodes
   b. mollusks
   c. annelids
   d. cnidarians
8. All of the following animals have an amniotic egg except
   a. monotremes.
   b. marsupials.
   c. reptiles.
   d. birds.
9. Terrestrial animals have
   a. internal fertilization.
   b. a waterproof skin.
   c. a strong skeleton.
   d. All of the above are correct.
10. The two groups of animals that are homeotherms are the _______.
11. Which of the following animals is diploblastic?
   a. jellyfish
   b. starfish
   c. shark
   d. mammal
12. Annelid worms are
   a. diploblastic.
   b. coelomate.
   c. assymetrical.
   d. homeotherms.
13. Most marine animals have a free-swimming developmental stage called a _______.
14. The flatworms are
   a. triploblatic.
   b. acoelomate.
   c. poikilotherms.
   d. All of the above are correct.
15. Nematodes have a body cavity known as a _______.

Answers
1. d 2. d 3. b 4. arthropods 5. foot 6. T 7. c 8. b 9. d 10. birds and mammals 11. a 12. b 13. larva 14. d 15. pseudocoelom

Thinking Critically

Using Animals in Research
Animals have been used routinely as models for the development of medical techniques and strategies. They have also been used in the development of pharmaceuticals and other biomedical products, such as heart valves and artificial joints. The techniques necessary to perform heart, kidney, and other organ transplants were first refined using chimpanzees, rats, and calves. Antibiotics, hormones, and chemotherapeutic drugs have been tested for their effectiveness and for possible side effects using laboratory animals that are very sensitive and responsive to such agents. Biologists throughout the world have bred research animals that readily produce certain types of cancers that resemble the cancers found in humans. By using these animals instead of humans to screen potential drugs, the risk to humans is greatly reduced. The emerging field of biotechnology is producing techniques that enable researchers to manipulate the genetic makeup of organisms. Research animals are used to perfect these techniques and highlight possible problems.

Animal rights activists are very concerned about using animals for these purposes. They are concerned about research that seems to have little value in relation to the suffering these animals are forced to endure. Members of the American Liberation Front (ALF), an animal rights organization, vandalized a laboratory at Michigan State University where mink were used in research to assess the toxicity of certain chemicals. Members of this group poured acid on tables and in drawers containing data, smashed equipment, and set fires in the laboratory. This attack destroyed 32 years of research records, including data used for developing water-quality standards. In 1 year, 80 similar actions were carried out by groups advocating animal rights. What type of restrictions or controls should be put on such research? Where do you draw the line between "essential" and "nonessential" studies? Do you support the use of live animals in experiments that may alleviate human suffering?

CHAPTER 24

Materials Exchange in the Body

CHAPTER OUTLINE

Leeches Used in Modern Medicine

An ancient practice returns.

For thousands of years, bloodletting was an established medical practice. It was thought that "bad blood" or a "disturbance of the humors" was the cause of many diseases and maladies and that removing blood would cure the problem. One of the established methods for removing the blood was to attach blood-sucking leeches to a person. This was such a common practice in the 1700s and 1800s that a slang term for "doctor" was "leech." This method of bloodletting is also preserved in the scientific name of the European leech commonly used for this purpose—*Hirudo medicinalis*.

Today, leeches are used as an effective way to reduce swelling in patients who have had reconstructive and reattachment surgery. During these types of surgery, arteries are reattached to supply blood to the area. However, it is much more difficult to reattach veins that drain blood from the area. Thus, swelling occurs and creates a problem that can cause death of the cells in the affected parts. When fluid builds up and causes swelling, the cells in the area cannot receive oxygen and nutrients and get rid of wastes effectively. The cells die, and the surgery is a failure.

This is where the leech becomes important. An effective way to prevent swelling is to attach leeches to the affected area. The leeches rasp a hole in the skin and have anti-clotting molecules in their saliva, allowing them to feed on blood. As a result of their feeding activity, they remove the blood that builds up. This allows time for the establishment of veins and lymph vessels that carry this fluid away. As one leech becomes filled with blood and drops off, another is added until normal drainage through veins and lymph vessels is established.

- **Why does swelling occur with many kinds of surgeries?**
- **What role do veins play in normal circulation?**
- **How would you convince patients that the use of leeches is a necessary part of their recovery from surgery?**

Background Check

Concepts you should understand in order to get the most out of this chapter:
- The nature of acids, bases, salts, and buffers (chapter 2)
- The types of organic molecules and the roles they play (chapter 3)
- The structure of prokaryotic and eukaryotic cells (chapter 4)
- The concept of surface area-to-volume ratio (chapter 4)

24.1 The Basic Principles of Materials Exchange

Large, multicellular organisms, such as humans, consist of trillions of cells. Because many of these cells are buried within the organism far from the body surface, the body needs ways to solve its materials-exchange problems. Cells are highly organized units that require a constant flow of energy to maintain themselves. The energy they require is provided in the form of nutrient molecules. Oxygen is required for the efficient release of energy from the large, organic molecules that serve as fuel. Inevitably, as oxidation takes place, waste products form that are useless or toxic, and they must be removed. The five organ systems engaged in these efforts are the cardiovascular, lymphatic, respiratory, digestive, and excretory systems. All these organ systems are integrated, affecting one another in many ways. The interactions of these systems require regulation and specialization for them to maintain life.

24.1 CONCEPT REVIEW

1. Why do multicellular organisms have materials-exchange problems?

24.2 Circulation: The Cardiovascular System

The **cardiovascular system** of all vertebrates, including humans, is the organ system that pumps blood around the body; and consists of the blood, heart, and blood vessels. **Blood** is the fluid tissue that assists in the transport of materials and heat. The **heart** is a muscular pump that forces the blood from one part of the body to another. The heart pumps blood into blood vessels. **Arteries** are the vessels that carry blood away from the heart and distribute it to the organs. The blood flows through successively smaller arteries until it reaches tiny vessels called *capillaries*. **Capillaries** are the thinnest blood vessels where exchange of materials between the blood and tissues that surround the vessels takes place. The blood flows from the capillaries into **veins,** the vessels that return blood to the heart.

The Nature of Blood

Blood is a fluid tissue consisting of several kinds of cells and platelets, called **formed elements,** suspended in a watery solution called **plasma** (table 24.1). This fluid plasma also contains many kinds of dissolved molecules, including nutrients, wastes, salts and proteins. The blood's primary function is to transport molecules, cells, and heat from one part of the body to another. The major kinds of molecules distributed by the blood are respiratory gases (oxygen and carbon dioxide), nutrients of various kinds, waste products, disease-fighting cells and antibodies, and chemical messengers (hormones). Also, substances in the blood are capable of forming clots or plugs to prevent blood loss.

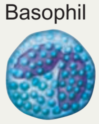
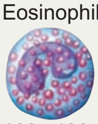
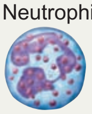
Heat is generated by metabolic activities and must be removed from the body. To handle excess body heat, blood is moved through the vessels to the surface of the body, where it can be radiated away. In addition, humans and some other animals have the ability to sweat. The evaporation of sweat (released from glands in the skin) from the body surface also gets rid of excess heat. If the body is losing heat too rapidly, blood is moved away from the skin, and metabolic heat is conserved. Vigorous exercise produces an excess of heat, so that, even in cold weather, blood is moved to the skin and the skin feels hot.

Formed Elements

The most numerous formed elements are **red blood cells (rbcs),** which are small, disk-shaped cells that lack a nucleus. Their primary function is to allow the blood to distribute respiratory gases efficiently (Outlooks 24.1). RBCs have the iron-containing pigment **hemoglobin,** the protein molecule to which oxygen molecules bind readily. Red blood cells transport oxygen around the body attached to their hemoglobin molecules. Very little oxygen is carried as free, dissolved oxygen in the plasma.

Because hemoglobin is inside red blood cells, some health problems can be diagnosed by counting the number of red blood cells a person has. If the number is low, the person's blood cannot carry oxygen efficiently and he or she tires easily. *Anemia* is a condition in which a person has reduced oxygen-carrying capacity. Anemia can also result when a person does not consume enough iron. Because iron is a central atom in hemoglobin molecules, people with an iron deficiency cannot manufacture sufficient hemoglobin; they can be anemic even if their number of red blood cells is normal.

TABLE 24.1 Components of Blood

Formed Elements	Function and Description	Source
Red blood cells (erythrocytes)  4 million–6 million per mm^3 blood	Transport O_2 and help transport CO_2 7–8 µm in diameter Bright red to dark purple, biconcave disks without nuclei	Red bone marrow
White blood cells (leukocytes) 4,000–11,000 per mm^3 blood	Fight infection	Red bone marrow
Granular leukocytes		
• Basophil  20–50 per mm^3 blood	10–12 µm in diameter Spherical cells with lobed nuclei; large, irregularly shaped, deep blue granules in cytoplasm	
• Eosinophil  100–400 per mm^3 blood	10–14 µm in diameter Spherical cells with bilobed nuclei; coarse, deep red, uniformly sized granules in cytoplasm	
• Neutrophil  3,000–7,000 per mm^3 blood	10–14 µm in diameter Spherical cells with multilobed nuclei; fine, pink granules in cytoplasm	
Agranular leukocytes		
• Lymphocyte  1,500–3,000 per mm^3 blood	5–17 µm in diameter (average 9–10 µm) Spherical cells with large, round nuclei	
• Monocyte  100–700 per mm^3 blood	10–24 µm in diameter Large, spherical cells with kidney-shaped, round, or lobed nuclei	
Platelets (thrombocytes)  150,000–300,000 per mm^3 blood	Aid clotting 2–4 µm in diameter Disk-shaped cell fragments with no nuclei; purple granules in cytoplasm	Red bone marrow

Plasma	Function	Source
Water (90–92% of plasma)	Maintains blood volume; transports molecules	Absorbed from intestine
Plasma proteins (7–8% of plasma)	Maintain blood osmotic pressure and pH	Liver
Albumin	Maintains blood volume and pressure	
Globulins	Transport; fight infection	
Fibrinogen	Clotting	
Salts (less than 1% of plasma)	Maintain blood osmotic pressure and pH; aid metabolism	Absorbed from intestine
Gases		
Oxygen Carbon dioxide	Cellular respiration End product of metabolism	Lungs Tissues
Nutrients Fats Glucose Amino acids	Food for cells	Absorbed from intestine
Nitrogenous waste Urea Uric acid	Excretion by kidneys	Liver
Other Hormones, vitamins, etc.	Aid metabolism	Varied

OUTLOOKS 24.1

Blood Doping

The use of performance-enhancing techniques and drugs in sports is not new. For example, one way to increase the amount of oxygen available to muscles is to inhale higher concentrations of the gas. You may have seen athletes breathing from an oxygen tank while on the sidelines during a sporting event. Another approach to increasing the amount of available oxygen is to increase the number of oxygen-carrying red blood cells. This can be accomplished in several ways. An athlete can have a pint of his or her blood removed and put into storage about three weeks before an event. During that time, the athlete's body replaces the removed red blood cells. Just before the event, the "donated" blood is transfused back into the athlete, increasing the total number of red blood cells. This method of enhancing an athlete's performance has been banned because it is considered to give an unfair advantage and because there can be dangerous side-effects.

Another technique involves artificially stimulating the body to produce more red blood cells by injecting the protein hormone erythropoietin, commonly referred as EPO. The kidney produces EPO, and after it is released into the bloodstream, it binds to receptors on stem cells in the red bone marrow, where it stimulates the production of new red blood cells. The increased red blood cell production in turn increases the oxygen-carrying capacity of the blood. This fact has resulted in some members of the athletic community using EPO as a performance-enhancing drug to artificially increase the amount of red blood cells.

Still another method of increasing available oxygen is the use of synthetic oxygen carriers, such as hemoglobin-based oxygen carriers (HBOCs) or perfluorocarbons (PFCs). These are purified proteins or chemicals that have the ability to carry oxygen. They can be useful in emergencies when human blood is not available, when the risk of blood infection is high, or when there is not enough time to properly cross-match donated blood with a recipient. However, their misuse for doping carries the risk of cardiovascular disease, in addition to other side-effects such as stroke, heart attack, or blood clot.

The use of blood transfusions, EPO, and synthetic oxygen carriers is prohibited under the World Anti-Doping Agency's (WADA) List of Prohibited Substances and Methods.

Red blood cells are also important in the transport of carbon dioxide. Carbon dioxide is a result of the normal aerobic cellular respiration of food materials in the cells of the body. If carbon dioxide is not eliminated, it causes the blood to become more acidic (lowers its pH), eventually resulting in death. Carbon dioxide can be carried in the blood in three forms: about 7% is dissolved in the plasma, about 23% is carried attached to hemoglobin molecules, and 70% is carried as bicarbonate ions. The enzyme carbonic anhydrase in red blood cells helps convert carbon dioxide into bicarbonate ions (HCO_3^-), which can be carried as dissolved ions in the plasma of the blood. The following reversible chemical equation shows the changes that occur.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

When the blood reaches the lungs, dissolved carbon dioxide is lost from the plasma, and carbon dioxide is released from the hemoglobin molecules. In addition, the bicarbonate ions reenter the red blood cells and can be converted back into molecular carbon dioxide by the same enzyme-assisted process that converts carbon dioxide to bicarbonate ions. The importance of this mechanism will be discussed in the section "Gas Exchange: The Respiratory System."

White blood cells (wbcs), also called leukocytes, are formed elements in the blood that lack hemoglobin and are involved in defending the body from disease-causing agents. There are several kinds of wbcs that vary in size and function (see table 24.1). When wbcs are stained with dyes and viewed under the microscope, they all have a conspicuous nucleus, and some kinds have granules in their cytoplasm. The granule-containing leukocytes are basophils, eosinophils, and neutrophils. Those without granules are lymphocytes and monocytes. All of these cells have specific roles to play in protecting the body from bacteria, viruses, fungi, worms, toxins, and cancer cells.

Platelets (also called thrombocytes), another kind of formed element in the blood, are actually fragments of a specific kind of white blood cell. Platelets are important in blood clotting. About 200 billion are formed each day. When a wound occurs, they collect at the site of the wound, where they form an initial plug and release compounds that cause other platelets to collect at the site. They also release compounds that begin a series of reactions among chemicals in

OUTLOOKS 24.2

Newborn Jaundice

Albumin transports bilirubin, a yellowish molecule that is a breakdown product of hemoglobin from destroyed rbcs. Normally, bilirubin is transported to the liver, where it is destroyed and the broken-down products are released with the bile into the intestine. However, some newborns become jaundiced (a yellowing of the skin and whites of the eyes) because their liver has not matured enough to do this important job. If bilirubin is allowed to accumulate in their blood, jaundiced babies can develop deafness, cerebral palsy, or brain damage. Placing babies under a special ultraviolet ("bili") light helps relieve the problem. The light has a wavelength that helps break down the bilirubin to a form that can be eliminated through the kidneys until the baby's liver matures and can adequately handle the bilirubin.

the plasma called clotting factors. There are at least 13 known clotting factors. The interactions of the various clotting factors ultimately result in the formation of fibers that trap platelets and blood cells and form a stronger plug than the initial platelet plug in the opening of the wound. Blood clots at the site of wounds are sometimes called scabs. They have a reddish or brownish color because they contain the leftovers of destroyed rbcs. Scabs are short-lived and are replaced by healthy tissue as the wound heals.

Plasma

Recall that plasma is the liquid part of the blood, consisting of water and dissolved materials, such as a variety of salts, proteins, nutrients, and waste products. Salts serve as buffers that help maintain the blood's pH. They also play a role in maintaining the proper osmotic balance between the blood and surrounding tissues.

Plasma proteins perform a variety of functions. The most plentiful plasma protein is albumin. It makes up about 60% of all plasma proteins, is the primary molecule involved in maintaining osmotic balance, and is also important in maintaining the proper blood pH. Albumin also assists in the transport of compounds that enter the blood (Outlooks 24.2). Globulins (antibodies), many of the clotting factors, regulatory proteins, and many other proteins circulate freely in the plasma.

Because the blood is under pressure from the pumping of the heart, it is normal for some fluid to leak from the smallest blood vessels (capillaries) into the surrounding tissues. This fluid that bathes the body's cells is called **tissue fluid.** It is similar to plasma but contains less dissolved albumin because the proteins are too large to pass through the walls of the capillaries, whereas salts can pass. Although the tissue fluid carries nutrients and other materials to the cells, it must be returned to the circulatory system, or swelling will occur. The albumin in the blood maintains the osmotic balance such that tissue fluid tends to return to the circulatory system.

In addition to water, salts, and proteins, plasma carries a variety of other important molecules. Nutrient molecules from the gut are carried to other locations, where they are modified, metabolized, or incorporated into cell structures. Amino acids and simple sugars are carried as dissolved molecules in the blood. Lipids, which are not water-soluble, are combined with proteins and carried as suspended particles called lipoproteins. Some organs manufacture or modify molecules for use elsewhere; therefore, they must constantly receive raw materials and distribute their products to the cells that need them through the blood. In addition, many kinds of hormones are produced by the brain, reproductive organs, digestive organs, and glands. These are secreted into the bloodstream and transported throughout the body. Tissues with appropriate receptors bind to these molecules and respond to these chemical messengers.

The Heart

Blood can perform its transportation function only if it moves. The heart is responsible for providing the energy to pump the blood throughout the body. For a fluid to flow through a tube, there must be a pressure difference between the two ends of the tube; water flows through pipes because it is under pressure. Because the pressure is higher behind a faucet than at the spout, water flows from the spout when the faucet is opened. The circulatory system can be understood from the same point of view. The heart is the muscular pump that provides the pressure necessary to propel the blood throughout the body. It must continue its cycle of contraction and relaxation or the blood stops flowing and the body's cells cannot obtain nutrients or get rid of wastes. Some cells, such as brain cells, are extremely sensitive to interruptions in the flow of blood, because they require a constant supply of glucose and oxygen. Others, such as muscle cells and skin cells, are much better able to withstand temporary interruptions of blood flow.

The hearts of humans, other mammals, and birds consist of four chambers and four sets of valves, that work together to ensure that blood flows in one direction only. Two of these chambers, the right and left **atria** (singular, *atrium*), are relatively thin-walled structures that collect blood from the major veins and empty it into the larger, more muscular **ventricles** (figure 24.1). Most of the blood is drawn in from the atria to the ventricles by the lowered pressure produced within the ventricles as they relax. The contraction of the thin-walled atria helps empty them more completely.

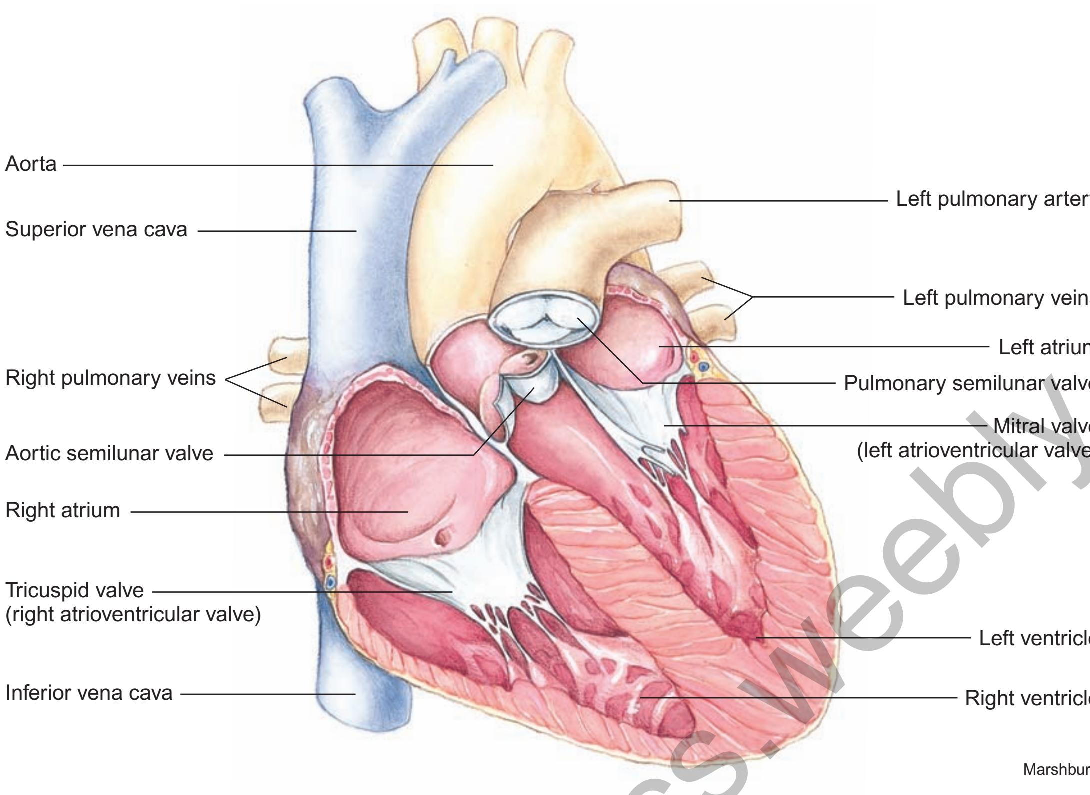


FIGURE 24.1 The Anatomy of the Heart
The heart consists of two thin-walled chambers, called atria, which contract to force blood into the two muscular ventricles. When the ventricles contract, the atrioventricular valves close, and blood is forced into the aorta and pulmonary artery. (The left atrioventricular valve is also known as the mitral or bicuspid valve and the right atrioventricular valve is also known as the tricuspid valve.) Semilunar valves in the aorta and pulmonary artery prevent the blood from flowing back into the ventricles when they relax.

The right and left ventricles are chambers with powerful muscular walls, whose contractions force blood to flow through the arteries to all parts of the body. The valves between the atria and the ventricles, the **atrioventricular valves,** are important one-way valves that allow blood to flow from the atria to the ventricles but prevent flow in the opposite direction. Similarly, there are valves in both the aorta and pulmonary artery, known as the **semilunar valves.** The **aorta** is the large artery that carries blood from the left ventricle to the body, and the **pulmonary artery** carries blood from the right ventricle to the lungs. The semilunar valves act as "check valves" to prevent blood from flowing back into the ventricles. If the atrioventricular or semilunar valves are damaged or function improperly, the heart's efficiency as a pump is diminished, and the person may have insufficient blood flow, which can cause shortness of breath, swelling in the feet, or other symptoms.

Malfunctioning heart valves are often diagnosed because they cause abnormal sounds—called heart murmurs—as the blood passes through them. Similarly, if the muscular walls of the ventricles are weakened because of infection, damage from a heart attack, or lack of exercise, the heart's pumping efficiency is reduced and the person develops symptoms such as shortness of breath, fatigue, or chest pain. Shortness of breath and fatigue result because the heart is not able to pump blood, and the oxygen and nutrients it contains, efficiently to the lungs, muscles, and other parts of the body. Chest pain is caused by an increase in the amount of lactic acid in the heart muscle, because the muscle is not getting sufficient oxygen to satisfy its needs. The heart receives blood from coronary arteries that are branches of the aorta; it is not nourished by the blood that flows through its chambers. If heart muscle does not get sufficient oxygen for a period of time, the portion of the heart muscle not receiving blood dies.

The right and left sides of the heart have slightly different jobs, because they pump blood to different parts of the body. The right side of the heart receives blood from the general body and pumps it through the pulmonary arteries to the lungs, where the exchange of oxygen and carbon dioxide takes place and the blood returns from the lungs to the left atrium. This is called **pulmonary circulation.** The larger, more powerful left side of the heart receives blood from the lungs, delivers it through the aorta to all other parts of the body, and returns it to the right atrium by way of the veins. This is known as **systemic circulation.** Both circulatory pathways are shown in figure 24.2. The systemic circulation is responsible for gas, nutrient, and waste exchange in all parts of the body except the lungs.

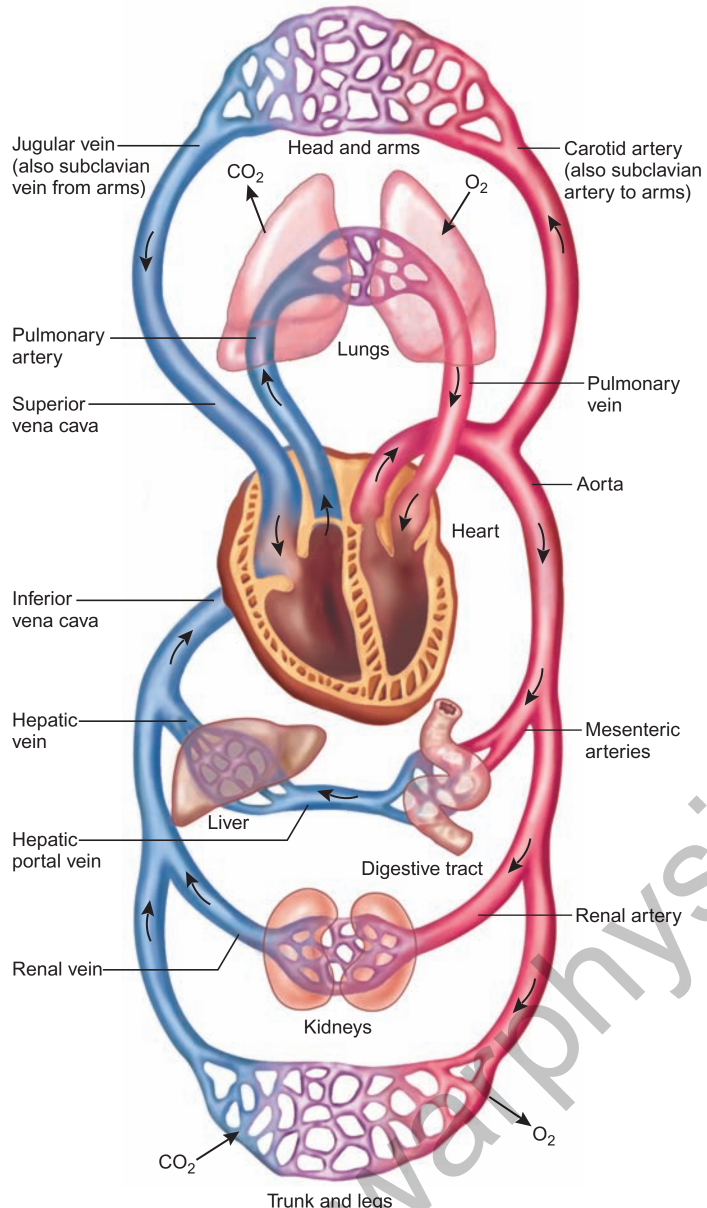


FIGURE 24.2 Pulmonary and Systemic Circulation
The right ventricle pumps blood that is poor in oxygen to the lungs by way of the pulmonary arteries, where it receives oxygen and turns bright red. The blood is then returned to the left atrium by way of four pulmonary veins. This part of the circulatory system is known as pulmonary circulation. The left ventricle pumps oxygen-rich blood by way of the aorta to all parts of the body except the lungs. This blood returns to the right atrium, depleted of its oxygen, by way of the superior vena cava from the head region and the inferior vena cava from the rest of the body. This portion of the circulatory system is known as systemic circulation.

Blood Vessels: Arteries, Veins, and Capillaries

Recall that arteries and veins are the tubes that transport blood from one place to another within the body. Arteries carry blood away from the heart. The contraction of the ventricle walls increases the pressure in the arteries. A typical pressure recorded in a large artery while the heart is in the process of contracting is about 120 millimeters of mercury (mmHg). This is known as the **systolic blood pressure.** The typical pressure recorded while the heart is relaxing is about 80 millimeters of mercury. This is known as the **diastolic blood pressure.** A blood pressure reading includes both numbers—for example, 120/80. (Originally, blood pressure was measured by how high the pressure of the blood caused a column of mercury [Hg] to rise in a tube. Although the devices used today have dials or digital readouts and contain no mercury, they are still calibrated in mmHg.)

Artery Structure and Function

The walls of arteries are relatively thick and muscular yet elastic (figure 24.3a). Healthy arteries have the ability to expand as blood is pumped into them and return to normal as the pressure drops. This ability to expand absorbs some of the pressure and reduces the peak pressure within the arteries, thus reducing the likelihood that they will burst. If arteries become hardened and less elastic, peak systolic blood pressure rises and the arteries are more likely to rupture. The elastic nature of the arteries also helps in blood flow. When the arteries return to normal from their stretched condition, they give a little push to the blood flowing through them.

Blood is distributed from the large aorta through smaller and smaller blood vessels to millions of tiny capillaries. Some of the smaller arteries, called **arterioles,** contract or relax to regulate the flow of blood to specific parts of the body. The major parts of the body that receive differing amounts of blood, depending on need, are the digestive system, muscles, and skin. When you exercise, blood flow to the muscles increases to accommodate their higher metabolic needs—the muscles need to take in more oxygen and glucose

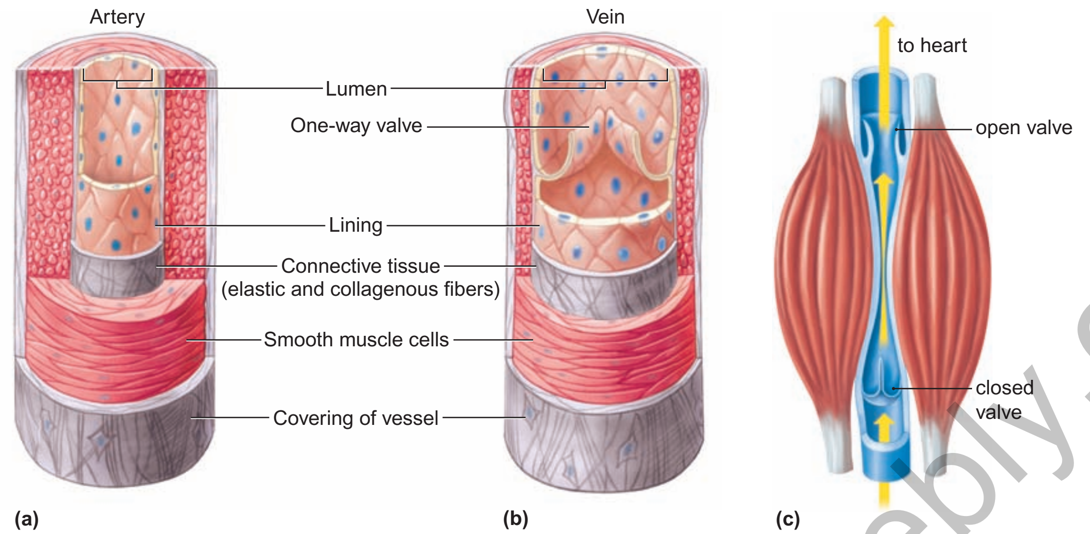


FIGURE 24.3 The Structure of Arteries and Veins
The walls of *(a)* arteries are much thicker than the walls of *(b)* veins. (The pressure in arteries is much higher than the pressure in veins.) The pressure generated by the ventricles of the heart forces blood through the arteries. Veins often have very low pressure. The valves in the veins prevent the blood from flowing backward, away from the heart. *(c)* Contractions of skeletal muscle along with valves in the veins help move blood in the veins back to the heart.

and to get rid of wastes. Exercise also results in an increased blood flow to the skin, which allows your body to get rid of excess heat. At the same time, the amount of blood flowing to the digestive system is reduced. Athletes do not eat a full meal before exercising. The additional blood flow to the digestive system reduces the amount of blood available to the muscles and lungs and they are not able to perform as well. In addition, muscular cramps can result if insufficient blood flows to the muscles.

Vein Structure and Function

Veins collect blood from the capillaries and return it to the heart. The pressure in veins is very low. Some of the largest veins may have a blood pressure of 0.0 mmHg for brief periods. The walls of veins are not as muscular as those of arteries (figure 24.3b). Because of the low pressure, veins must have valves to prevent the blood from flowing backwards, away from the heart. Veins are often found on the surface of the body and are seen as blue lines. *Varicose veins* result when veins contain faulty valves, which do not allow the efficient return of blood to the heart. Therefore, blood pools in these veins, and they become swollen, bluish networks.

Because the pressure in veins is so low, muscular movements of the body are important in helping return blood to the heart. When the muscles of the body contract, they compress nearby veins, and this pressure pushes blood along in the veins. Because the valves allow blood to flow only toward the heart, this activity acts as an additional pump to help return blood to the heart (figure 24.3c). People who sit or stand for long periods without using their leg muscles tend to have a considerable amount of blood pool in the veins of their legs and lower body. Thus, less blood may be available to go to the brain, causing people to faint. Although the arteries are responsible for distributing blood to various parts of the body and arterioles regulate where blood goes, it is the function of capillaries to assist in the exchange of materials between the blood and cells.

Capillary Structure and Function

Capillaries are tiny, thin-walled tubes that receive blood from arterioles. They are so small that red blood cells must go through them in single file. They are so numerous that each cell in the body has a capillary located near it. It is estimated that there are about 1,000 square meters of capillary surface area in a typical human. Each capillary wall consists of a single layer of cells and, therefore, presents only a thin barrier to the diffusion of materials between the blood and the cells in the surrounding tissue. The flow of blood through these smallest blood vessels is relatively slow. This allows time for the diffusion of such materials as oxygen, glucose, and water from the blood to surrounding cells, and for the movement of waste products such as carbon dioxide, lactic acid, and ammonia from the cells into the blood.

It is also possible for liquid to flow through tiny spaces between the cells of most capillaries. This fluid, tissue fluid, bathes individual cells. This assists in the exchanges of materials between the blood and the cells. Ultimately this fluid must be returned to the circulatory system. Some simply diffuses back into the capillaries. The remainder is collected by lymph vessels and moves through these vessels until it empties into veins near the heart (figure 24.4).

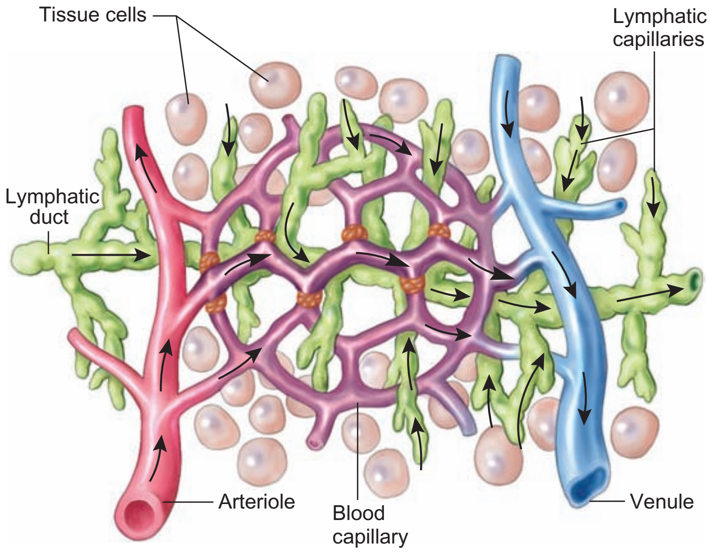


FIGURE 24.4 Capillaries
Capillaries are tiny blood vessels. Exchange of molecules between blood and tissues occurs by diffusion through the thin walls of capillaries. Some water and dissolved materials actually pass through the walls of capillaries and bathe cells. The lymph vessels collect any excess fluid and return it to the circulatory system.

24.2 CONCEPT REVIEW

2. List the functions of the salts and proteins found in the plasma.
3. What are the functions of the heart, arteries, veins, arterioles, blood, and capillaries?
4. How do red blood cells assist in the transportation of oxygen and carbon dioxide?

24.3 The Lymphatic System

The **lymphatic system** is a collection of lymph organs and thin-walled tubes (lymph vessels) that branch throughout the body. The lymphatic system plays three important roles: (1) It moves fat from the intestinal tract to the bloodstream, (2) it transports excess tissue fluid back to the cardiovascular system, and (3) it defends against harmful agents, such as bacteria and viruses (refer to chapter 26, Immunity). **Lymph** is tissue fluid that moves through this system.

Lymph vessels collect lymph and ultimately empty it into two large veins near the heart. Because the lymph vessels have valves to prevent backflow, lymph is moved one way through the vessels as a result of the contraction of the body's muscles. For this system to function properly, the person must be active, or the tissue fluid will not move into the lymph vessels and will build up, causing the tissue to swell, a condition called edema. Edema is common in circulatory disorders. Another cause of edema results from an increase in capillary permeability as a result of injury. Fluid moves from inside the blood vessels into the damaged tissue and is seen as swelling. A swollen sprained ankle or smashed thumb are examples you may have experienced. Figure 24.5 shows the structure of the lymphatic system.

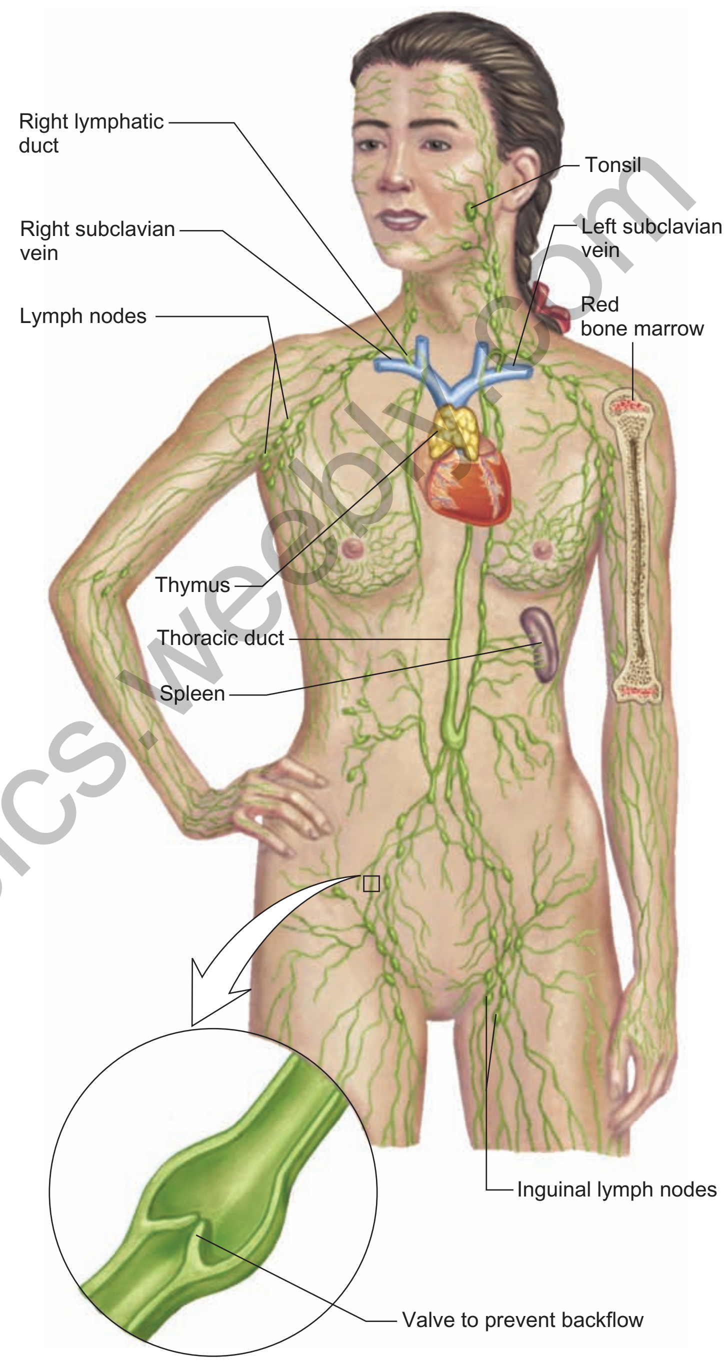


FIGURE 24.5 The Lymphatic System
Lymphatic vessels drain the tissue fluid that surrounds cells and return it to the cardiovascular system near the heart. The enlargement shows that lymphatic vessels have valves to prevent backflow. The lymph nodes, tonsils, spleen, thymus gland, and red bone marrow are lymph organs.

There are five types of lymph organs: (1) lymph nodes, (2) tonsils, (3) spleen, (4) thymus, and (5) red bone marrow.

Lymph nodes are small encapsulated bodies found along the lymph vessels that contain large numbers of white blood cells (wbc), particularly macrophages and lymphocytes that remove microorganisms and foreign particles from the lymph. As the lymph makes its way back to the circulatory system, it is filtered by lymph nodes. When nodes are actively engaged in this cleanup, they swell as the wbc population increases. During an examination, physicians palpate or feel the nodes (usually in the neck) to help determine if a person has an infection.

The tonsils are lymph organs located on either side of the throat. Adenoids are lymph organs located at the back of the nasal cavity. Their job, like that of lymph nodes, is to clean the lymph of pathogens. Because they are so close to the mouth and nose, they are likely to encounter pathogens and become swollen as the number of white blood cells increases. In the past, if tonsils repeatedly became "infected" and unable to manage pathogens, they were removed by a surgical procedure called a tonsillectomy. This procedure was performed on children who displayed chronic sore throats or infections. Today, the functions of tonsils are better understood and tonsillectomies are rarely performed.

The spleen also contains large numbers of white blood cells and filters the blood. It is about the size of a small pickle, located in the upper left side of the body just below the diaphragm. Its job is to clean the blood of pathogens and worn-out or damaged rbcs. Should the spleen be ruptured as a result of an accident or a wound, it may have to be removed. In such cases, the person loses an important blood-filtering and disease-fighting organ.

The thymus gland, located beneath the breastbone, is large and active in children. As a person ages, the thymus shrinks and may actually disappear. Its primary function is to produce wbcs, which are vital to the functioning of the immune system. These cells, called T-lymphocytes, are distributed from the thymus throughout the body and establish themselves in lymph nodes. Even though the thymus shrinks in size into adulthood, the descendants of the T-lymphocytes it produced earlier in life are still active throughout the lymphatic system.

The red bone marrow produces red and white blood cells and platelets. Stem cells found inside these bones continue to divide throughout a person's life, providing a continuous supply of rbcs and wbcs. Red bone marrow is found in most of a child's bones. In adults, the red bone marrow is only found in the pelvis (hipbone), sternum (breastbone), skull, clavicle (collarbone), ends of long bones, and vertebrae (backbone).

24.3 CONCEPT REVIEW

5. What purposes are served by the lymphatic system?
6. List the organs of the lymphatic system and describe the function of each.

24.4 Gas Exchange: The Respiratory System

The **respiratory system** is the organ system that moves air into and out of the body; it consists of the *lungs, trachea, air-transport pathway,* and *diaphragm.* The **lungs** are organs of the body that allow gas exchange to take place between the air and blood. Associated with the lungs is a set of tubes, part of the air-transport pathway, that conducts air from outside the body to the lungs. The single, large-diameter **trachea** is supported by rings of cartilage that prevent its collapse. It branches into two major **bronchi** (singular, *bronchus*), which deliver air to smaller and smaller branches. Bronchi are also supported by cartilage. The smallest tubes, **bronchioles,** contain smooth muscle and are therefore capable of constricting. Finally, the bronchioles deliver air to clusters of tiny sacs, known as **alveoli** (singular, *alveolus*), where the exchange of gases between the air and the blood takes place.

The nose, mouth, and throat are also important parts of the air-transport pathway because they modify the humidity and temperature of the air and clean the air as it passes. The lining of the trachea contains cells with cilia, which beat in one direction to move mucus and foreign materials from the lungs. The foreign matter can then be expelled by swallowing or coughing. Figure 24.6 illustrates the various parts of the respiratory system.

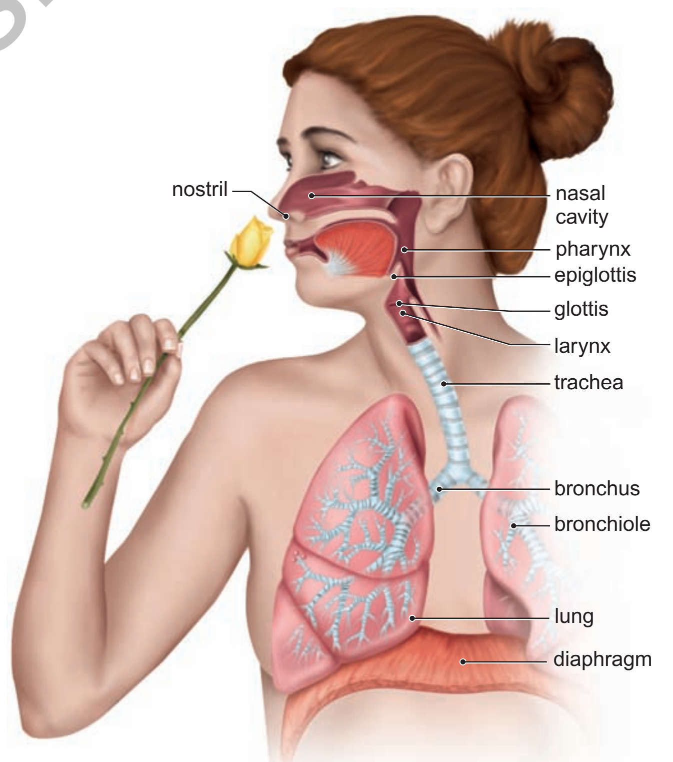


FIGURE 24.6 Respiratory Anatomy
Although gas exchange takes place in the alveoli of the lungs, there are many other important parts of the respiratory system. The nasal cavity cleans, warms, and humidifies the air entering the lungs. The trachea is also important in cleaning the air going to the lungs.

Mechanics of Breathing

Breathing is the process of moving air in and out of the lungs. It is accomplished by the movement of several muscles. The **diaphragm** is a muscular organ that separates the chest cavity, which contains the lungs, from the abdominal cavity. In addition, *intercostal* muscles located between the ribs are involved in breathing. During inhalation, the diaphragm contracts, causing it to move downward and the external intercostal muscles of the chest wall contract, causing the chest wall to move outward and upward. Both of these actions cause the volume of the chest cavity to increase. This results in a lower pressure in the chest cavity compared with the outside air pressure. Thus, air flows from the outside high-pressure area through the trachea, bronchi, and bronchioles to the alveoli. During normal, relaxed breathing, exhalation is accomplished by the chest wall and diaphragm simply relaxing and returning to their normal positions. Muscular contraction is not involved (figure 24.7).

When the body's demand for oxygen increases during exercise, the breathing system responds by exchanging the gases in the lungs more rapidly. This can be accomplished both by increasing the breathing rate and by increasing the volume of air exchanged with each breath. An increase in volume exchanged per breath is accomplished in two ways. First, the muscles of inhalation can contract more forcefully, resulting in a greater change in the volume of the chest cavity. Second, the lungs can be emptied more completely by contracting the muscles of the abdomen, which forces the abdominal contents upward against the diaphragm and compresses the lungs. A set of internal intercostal muscles also helps compress the chest.

Breathing System Regulation

Several mechanisms can cause changes in the rate and depth of breathing, but the primary mechanism is tied to the amount of carbon dioxide present in the blood. Carbon dioxide, a waste product of aerobic cellular respiration, becomes toxic in high quantities because it combines with water to form carbonic acid:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

As mentioned previously, if carbon dioxide cannot be eliminated, the pH of the blood is lowered. Eventually, this can cause death.

Exercising causes an increase in the amount of carbon dioxide in the blood, because the muscles are oxidizing glucose more rapidly. This lowers the blood's pH. Certain brain cells and specialized cells in the aortic arch and carotid arteries are sensitive to changes in blood pH. When these cells sense a lower blood pH, they cause the brain to send nerve impulses more frequently to the diaphragm and intercostal muscles. These muscles contract more rapidly and

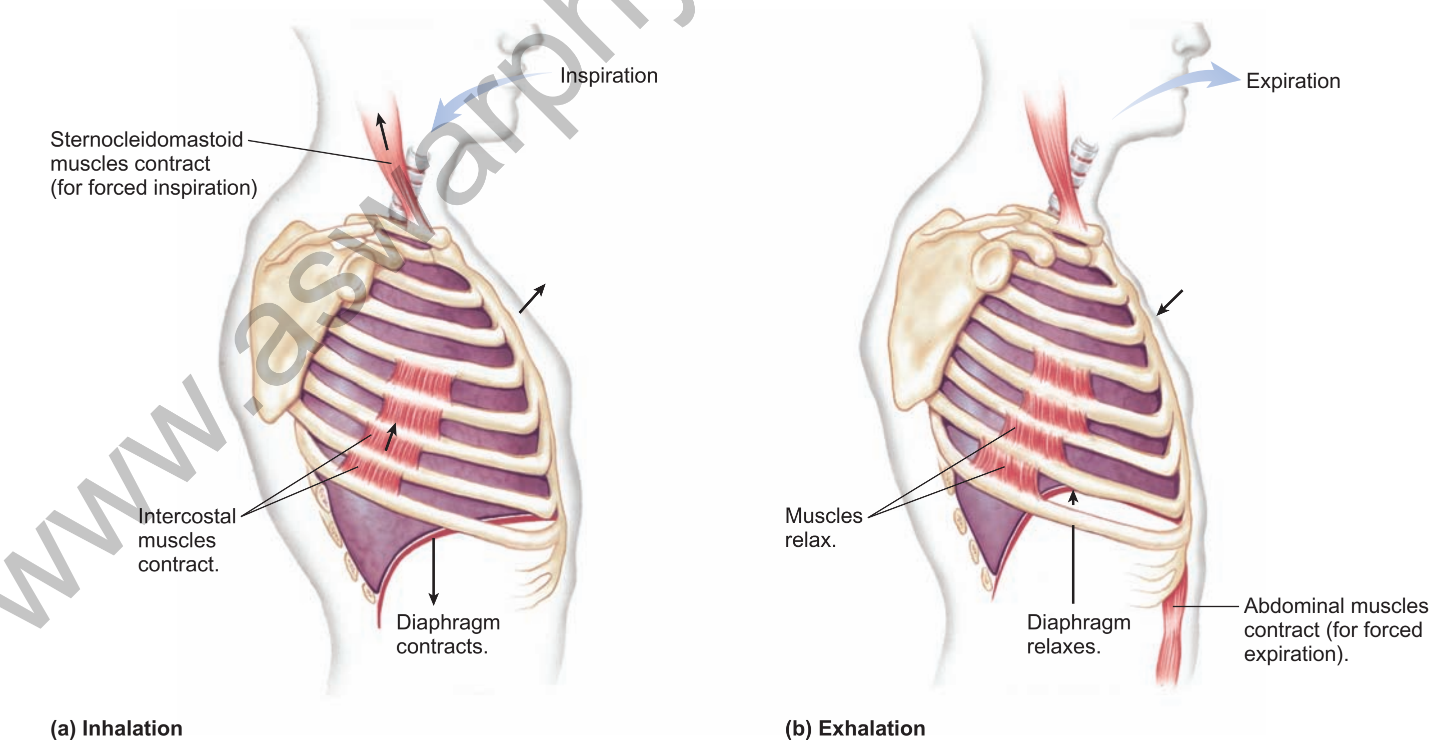


FIGURE 24.7 Breathing Movements
During *(a)* inhalation, the diaphragm and external intercostal muscles between the ribs contract, causing the volume of the chest cavity to increase. During a normal *(b)* exhalation, these muscles relax, and the chest volume returns to normal.

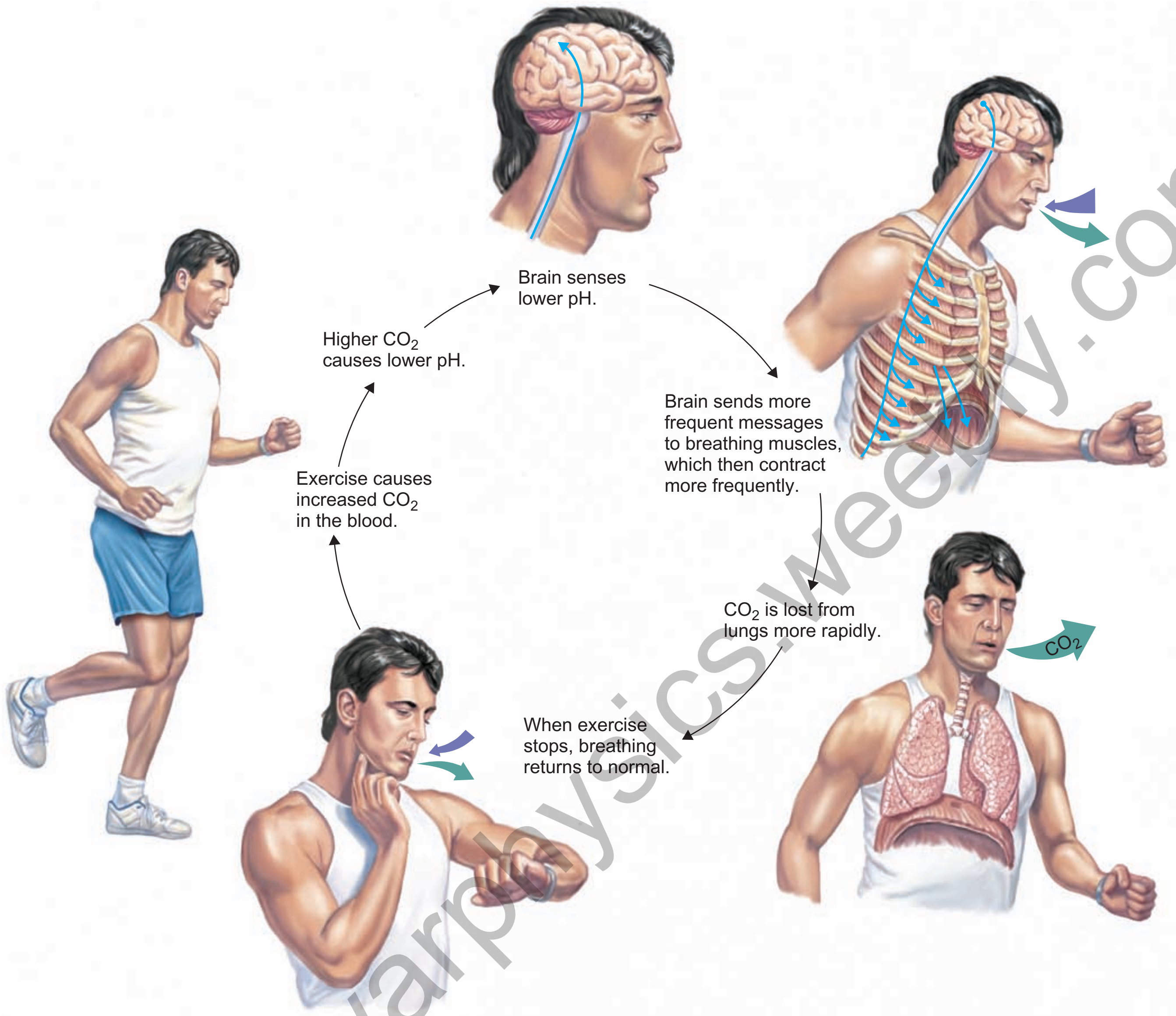


FIGURE 24.8 Control of Breathing Rate
The rate of breathing is controlled by cells in the brain, aorta, and carotid arteries that sense the pH of the blood. When the amount of CO_2 increases, the pH drops (the blood becomes more acidic) and the brain sends more frequent messages to the diaphragm and intercostal muscles, causing the breathing rate to increase. More rapid breathing increases the rate at which CO_2 is lost from the blood; thus, the blood pH rises (it becomes less acidic) and the breathing rate decreases.

more forcefully, resulting in more rapid, deeper breathing. Because more air is being exchanged per minute, carbon dioxide is lost from the lungs more rapidly. When exercise stops, blood pH rises, and breathing eventually returns to normal (figure 24.8).

Lung Function

The lungs allow blood and air to come into close contact with each other. Air flows in and out of the lungs during breathing. The blood flows through capillaries in the lungs and is in close contact with the air in the alveoli of the lungs. For oxygen to enter or carbon dioxide to exit the body, the molecules must pass through a surface. The efficiency of exchange is limited by the surface area available. This problem is solved in the lungs by the large number of tiny sacs, the alveoli. Each alveolus is about 0.25 to 0.5 millimeters across. However, alveoli are so numerous that the total surface area of all these sacs is about 70 square meters—comparable to the floor space of many standard-sized classrooms. The walls of both the capillaries and the alveoli are very thin, and the close association of alveoli and capillaries in the lungs allows the easy diffusion of oxygen and carbon dioxide across these membranes (figure 24.9).

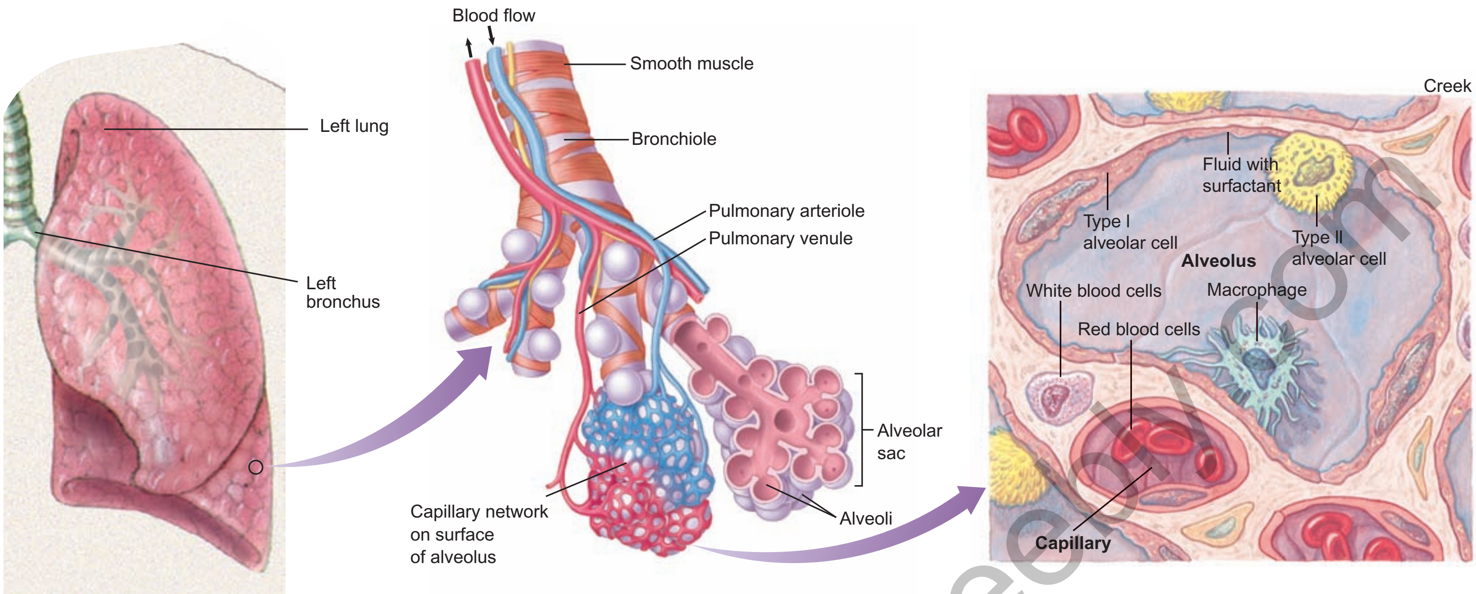


FIGURE 24.9 The Association of Capillaries with Alveoli
The exchange of gases takes place between the air-filled alveolus and the blood-filled capillary. The capillaries form a network around the saclike alveoli. The thin walls of the alveolus and capillary are in direct contact with one another; their combined thickness is usually less than 1 micrometer (a thousandth of a millimeter).

Another factor that increases the efficiency of gas exchange is that both the blood and the air are moving. Because blood is flowing through capillaries in the lungs, the capillaries continually receive new blood that is poor in oxygen and high in carbon dioxide. As blood passes by the alveoli, it is briefly exposed to the gases in the alveoli, where it gains oxygen and loses carbon dioxide. Thus, blood that leaves the lungs is high in oxygen and low in carbon dioxide. Although the movement of air in the lungs is not in one direction, as is the case with blood, the cycle of inhalation and exhalation allows air that is high in carbon dioxide and low in oxygen to exit the body and brings in new air that is rich in oxygen and low in carbon dioxide. This oxygen-rich, bright red blood is then sent to the left side of the heart and pumped throughout the body.

Any factor that interferes with the flow of blood or air or alters the effectiveness of gas exchange in the lungs reduces the efficiency of the organism. A poorly pumping heart sends less blood to the lungs, and the person experiences shortness of breath. Similarly, diseases such as asthma, which cause constriction of the bronchioles, reduce the flow of air into the lungs and inhibit gas exchange.

Any process that reduces the number of alveoli also reduces the efficiency of gas exchange in the lungs. For example, *emphysema* is a progressive disease in which some of the alveoli are lost. As the disease progresses, those afflicted have less and less respiratory surface area and experience greater and greater difficulty getting adequate oxygen, even though they may be breathing more rapidly. Often, emphysema is accompanied by an increase in the amount of connective tissue and the lungs do not stretch as easily, further reducing their ability to exchange gases.

24.4 CONCEPT REVIEW

7. Describe the muscles involved in breathing and explain how they cause air to flow into and out of the lungs.
8. How are CO_2, blood pH, and breathing rate interrelated?
9. How do each of the following affect the efficiency of gas exchange in the lungs: poorly functioning heart, contracted bronchioles, reduced number of alveoli?

24.5 Obtaining Nutrients: The Digestive System

The **digestive system** is the organ system responsible for the processing and distribution of nutrients; it consists of a muscular tube and glands that secrete digestive juices into the tube. Four kinds of activities are involved in getting nutrients to the cells that need them: mechanical processing, chemical processing,

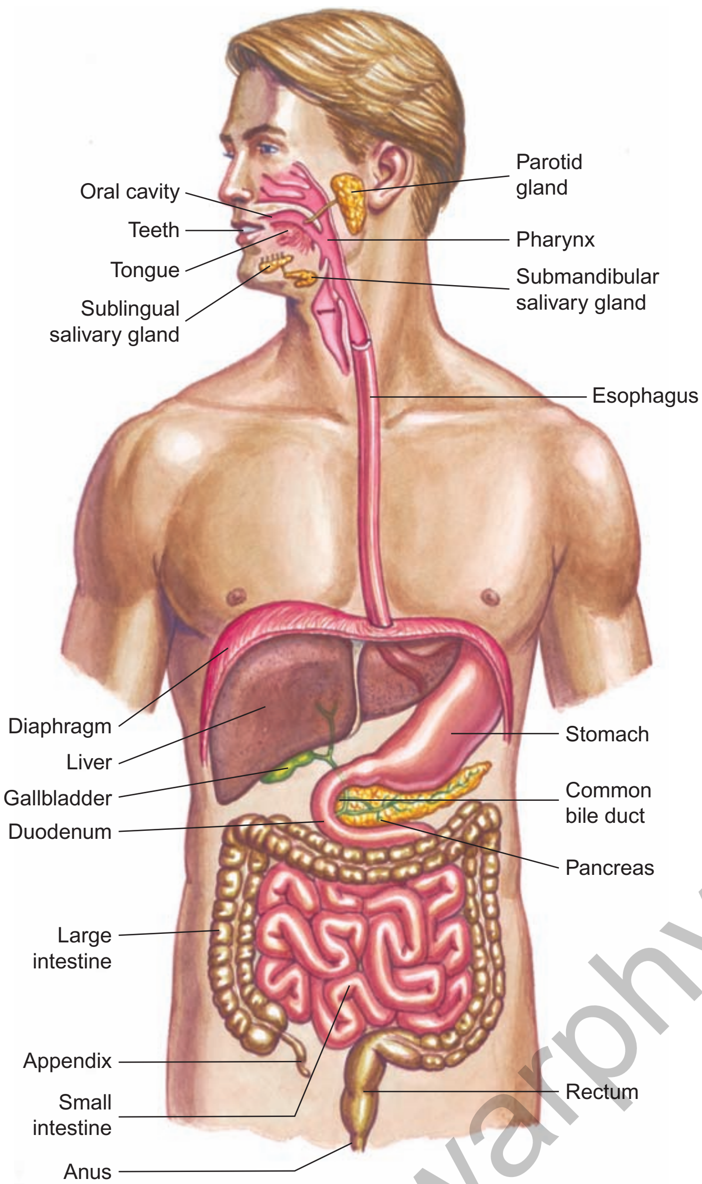


FIGURE 24.10 The Digestive System
The teeth, tongue, and enzymes from the salivary glands modify the food before it is swallowed. The stomach adds acid and enzymes and further changes the food's texture. The food is eventually emptied into the duodenum, where the liver and pancreas add their secretions. The small intestine also adds enzymes and is involved in absorbing nutrients. The large intestine is primarily involved in removing water.

nutrient uptake, and chemical alteration. Figure 24.10 shows the various structures of the digestive system.

Mechanical and Chemical Processing

The purpose of the digestive system is to break down large chunks of food into small molecules, which the circulatory system can distribute to the body's cells. The first step in the digestive process is mechanical processing.

It is important to grind large particles into small pieces by chewing to increase their surface areas and allow for more efficient chemical reactions. It is also important to add water to the food, which further disperses the particles and provides the watery environment needed for these chemical reactions. Materials also must be mixed so that all the molecules that need to interact with one another have a good chance of doing so. The oral cavity and the stomach are the major body regions involved in reducing the size of food particles. The teeth are involved in cutting and grinding food to increase its surface area. The watery mixture that is added to the food in the oral cavity is called *saliva,* and the three pairs of glands that produce saliva are known as **salivary glands.** Saliva contains the enzyme salivary amylase, which begins the chemical breakdown of starch. Saliva also lubricates the oral cavity and helps bind food before swallowing.

In addition to having taste buds that help identify foods and potentially toxic materials, the tongue performs the important service of helping position the food between the teeth and pushing it to the back of the throat for swallowing. The oral cavity is very much like a food processor, in which mixing and grinding take place.

Once the food has been chewed, it is swallowed and passes down the esophagus to the stomach. The process of swallowing involves a complex series of events. First, a ball of food, known as a *bolus,* is formed by the tongue and moved to the back of the oral cavity. There, it stimulates the walls of the throat, also called the **pharynx.** Nerve endings in the lining of the pharynx are stimulated, causing a reflex contraction of the walls of the esophagus, which transports the bolus to the stomach. Because both food and air pass through the pharynx, it is important to prevent food from getting into the lungs. During swallowing, the larynx is pulled upward, causing a flap of tissue, called the *epiglottis,* to cover the opening to the trachea and preventing food from entering the trachea.

In the stomach, additional liquid, called **gastric juice,** is added to the food. Gastric juice contains enzymes and hydrochloric acid. The major enzyme of the stomach is **pepsin,** which initiates the chemical breakdown of protein. The pH of gastric juice is very low, generally around pH 2. Consequently, very few kinds of bacteria or protozoa emerge from the stomach alive. Those that do survive have characteristics that protect them from the gastric juice as they pass through the stomach. The entire mixture is churned by the contractions of the three layers of muscle in the stomach wall. The combined activities of enzymatic breakdown, chemical breakdown by hydrochloric acid, and mechanical processing by muscular movement result in a thoroughly mixed liquid. This liquid eventually leaves the stomach through a valve known as the **pyloric sphincter** and enters the **small intestine** (How Science Works 24.1).

The first part of the small intestine is called the **duodenum.** In addition to producing enzymes, the duodenum secretes several kinds of hormones that regulate the release of food

HOW SCIENCE WORKS 24.1

An Accident and an Opportunity

On the morning of June 6, 1822, on Mackinac Island in northern Lake Huron, a 19-year-old French-Canadian fur trapper named Alexis St. Martin was shot in the stomach by the accidental discharge from a shotgun. The army surgeon at Fort Mackinac, Michigan, Dr. William Beaumont, was called to attend to the wounded man. Part of St. Martin's stomach and body wall had been shot away, and parts of his clothing were embedded in the wound. Although Dr. Beaumont did not expect St. Martin to live, he quickly cleaned the wound, pushed portions of the lung and stomach that were protruding back into the cavity, and dressed the wound. Finding St. Martin alive the next day, Beaumont was surprised and encouraged to do what he could to extend his life. In fact, Dr. Beaumont cared for St. Martin for 2 years. When the wound was completely healed, the stomach had fused to the body wall and a hole allowed Dr. Beaumont to look into the stomach. Fortunately for St. Martin, a flap of tissue from the lining of the stomach closed off the opening, so that what he ate did not leak out.

Dr. Beaumont found that he could look through the opening and observe the activities in the stomach and recognized that this presented an opportunity to study the stomach's function in a way that had not been done before. He gathered gastric juice, had its components identified, introduced food into the hole with a string attached so that he could retrieve the food particles that were partially digested for examination, and observed the effect of emotion on digestion. He discovered many things that were new to science and contrary to the teachings of the time. He recounted many of his observations and experiments in his journal: *"I consider myself but a humble inquirer after truth—a simple experimenter. And if I have been led to conclusions opposite to the opinions of many who have been considered luminaries of physiology, and, in some instances, from all the professors of this science, I hope the claim of sincerity will be conceded to me, when I say that such difference of opinion has been forced upon me by the convictions of experiment, and the fair deductions of reasoning."*

Following are some of his important discoveries.

1. He measured the temperature of the stomach and found that it does not heat up when food is introduced, as was thought at the time: *"But from the result of a great number of experiments and examinations, made with a view to asserting the truth of this opinion, in the empty and full state of the organ, . . . I am convinced that there is no alteration of temperature. . . ."*
2. He found that pure gastric juice contains large amounts of hydrochloric acid. This was contrary to the prevailing opinion that gastric juice was simply water: *"I think I am warranted, from the result of all the experiments, in saying, that the gastric juice, so far from being "inert as water," as some authors assert, is the most general solvent in nature, of alimentary matter—even the hardest bone cannot withstand its action."*

House where Dr. Beaumont treated Alexis St. Martin

3. He observed that gastric juice is not stored in the stomach but, rather, is secreted when food is eaten: *"The gastric juice does not accumulate in the cavity of the stomach, until alimentary matter is received, and excite its vessels to discharge their contents, for the immediate purpose of digestion."*
4. He realized that digestion begins immediately when food enters the stomach. The prevailing opinion of the day was that nothing happened for an hour or more: *"At 2 o'clock P.M.—twenty minutes after having eaten an ordinary dinner of boiled, salted beef, bread, potatoes, and turnips, and drank* [sic] *a gill of water, I took from his stomach, through the artificial opening, a gill of the contents. . . . Digestion had evidently commenced, and was perceptually progressing, at the time."*
5. He discovered that food in the stomach satisfies hunger even though it is not eaten: *"To ascertain whether the sense of hunger would be allayed without food being passed through the oesophagus* [sic], *he fasted from breakfast time, til 4 o'clock, P.M., and became quite hungry. I then put in at the aperture, three and a half drachms of lean, boiled beef. The sense of hunger immediately subsided, and stopped the borborygmus, or croaking noise, caused by the motion of the air in the stomach and intestines, peculiar to him since the wound, and almost always observed when the stomach is empty."*

St. Martin did not take kindly to these probings and twice ran away from Dr. Beaumont's care back to Canada, where he married, had two children, and resumed his former life as a voyager and fur trapper. He did not die until the age of 83, having lived over 60 years with a hole in his stomach.

from the stomach and the release of secretions from the pancreas and liver. The **pancreas** produces a number of digestive enzymes and secretes large amounts of bicarbonate ions, which neutralize the acids that enter from the stomach so that the pH of the duodenum is about pH 8. The liver, a large organ in the upper abdomen, performs several functions, one of which is the secretion of **bile.** When bile leaves the liver, it is stored in the **gallbladder** prior to being released into the duodenum. When bile is released from the gallbladder, it assists mechanical processing by breaking large fat globules into smaller particles, much as soap breaks up fat particles into smaller globules that are suspended in water and washed away. This process is called *emulsification.* Emulsification is important because fats are not soluble in water, yet the reactions of digestion must take place in a water solution.

Along the length of the small intestine, additional watery juices are added until the mixture reaches the **large intestine** or colon. The 1.5-meter-long large intestine is primarily involved in reabsorbing the water that has been added to the food tube when saliva, gastric juice, bile, pancreatic secretions, and intestinal juices are introduced into the digestive system. The large intestine is also home to a variety of bacteria. Most live on food that was not absorbed in the small intestine. Some provide additional benefit by producing vitamins that can be absorbed from the large intestine. A few are capable of causing disease.

Several kinds of enzymes have been mentioned in this section. Each is produced by a specific organ and has a specific function. Chapter 5 introduced the topic of enzymes and how they work. Some enzymes, such as those involved in glycolysis, the Krebs cycle, and protein synthesis, are produced and used inside cells; others, such as the digestive enzymes, are produced by cells and secreted into the digestive tract. Digestive enzymes are simply a class of enzymes; they have the same characteristics as all other enzymes. They are protein molecules that speed up chemical reactions and are sensitive to changes in temperature or pH. The various digestive enzymes, the sites of their production, and their functions are listed in table 24.2.

Nutrient Uptake

Digestion results in a variety of simple organic molecules that are available for absorption from the tube of the gut into the circulatory system. As simple sugars, amino acids, glycerol, and fatty acids move into the circulatory system, surface area again becomes important. The amount of material that can be taken up is limited by the surface area available. There are several ways in which the structure of the intestinal tract provides a large surface area. First, the small intestine is a very long tube; the longer the tube, the greater the internal surface area. In a typical adult human, it is about 6 to 8 meters long. In addition to length, the lining of the small intestine consists of millions of fingerlike projections, called **villi,** which increase the surface area. The cells that make up the villi also have folds in their surface membranes. All of these characteristics increase the surface area available for

TABLE 24.2 Digestive Enzymes and Their Functions

Enzyme	Site of Production	Molecules Altered	Molecules Produced
Salivary amylase	Salivary glands	Starch	Smaller polysaccharides
Pepsin	Stomach lining	Proteins	Peptides
Gastric lipase	Stomach lining	Fats	Fatty acids and glycerol
Chymotrypsin	Pancreas	Polypeptides (long chains of amino acids)	Peptides
Trypsin	Pancreas	Polypeptides	Peptides
Carboxypeptidase	Pancreas	Peptides (several amino acids)	Smaller peptides and amino acids
Pancreatic amylase	Pancreas	Polysaccharides (many sugar molecules attached together)	Disaccharides
Pancreatic lipase	Pancreas	Fats	Fatty acids and glycerol
Nuclease	Pancreas	Nucleic acids	Nucleotides
Aminopeptidase	Intestinal lining	Peptides	Smaller peptides and amino acids
Dipeptidase	Intestinal lining	Dipeptides	Amino acids
Lactase	Intestinal lining	Lactose	Glucose and galactose
Maltase	Intestinal lining	Maltose	Glucose
Sucrase	Intestinal lining	Sucrose	Glucose and fructose
Nuclease	Intestinal lining	Nucleic acids	Nucleotides

the transport of materials from the gut into the circulatory system. Scientists estimate that the cumulative effect of all these features produces a total intestinal surface area of about 250 square meters. That is equivalent to about the area of a basketball court.

The surface area by itself would be of little value if it were not for the intimate contact of the circulatory system with the intestinal lining. Each villus contains several capillaries and a branch of the lymphatic system called a **lacteal.** The close association between the intestinal surface and the circulatory and lymphatic systems allows for the efficient uptake of nutrients from the cavity of the gut into the circulatory system (figure 24.11).

Several processes are involved in the transport of materials from the small intestine to the circulatory system. Some molecules, such as water and many ions, simply diffuse through the wall of the small intestine into the circulatory system. Other materials, such as amino acids and simple sugars, are assisted across the membrane by carrier molecules. Fatty acids and glycerol are absorbed into the intestinal lining cells, where they are resynthesized into fats and enter lacteals in the villi. Because the lacteals are part of the lymphatic system, which eventually empties its contents into the circulatory system, fats also are transported by the blood. They just reach the blood by a different route.

Chemical Alteration: The Role of the Liver

When the blood leaves the small intestine, it flows directly to the liver through the **hepatic portal vein.** Portal veins are blood vessels that collect blood from capillaries in one part of the body and deliver it to a second set of capillaries in another part of the body without passing through the heart. Thus, *hepatic portal veins* collect nutrient-rich blood from the small intestine and deliver it directly to the liver. As the blood flows through the liver, enzymes in the liver cells modify many of the molecules and particles that enter them. One of the functions of the liver is to filter any foreign organisms from the blood that might have entered through the intestinal cells.

The liver also detoxifies many dangerous molecules that might have entered with the food. Many foods contain toxic substances that could be harmful if not destroyed by the liver. Ethyl alcohol is one obvious example. Many plants contain various kinds of toxic molecules that are present in small quantities and could accumulate to dangerous levels if the liver did not perform its role of detoxification.

In addition, the liver is responsible for modifying nutrient molecules. The liver collects glucose molecules and synthesizes glycogen, which can be stored in the liver for later use. When glucose is in short supply, the liver can convert some of

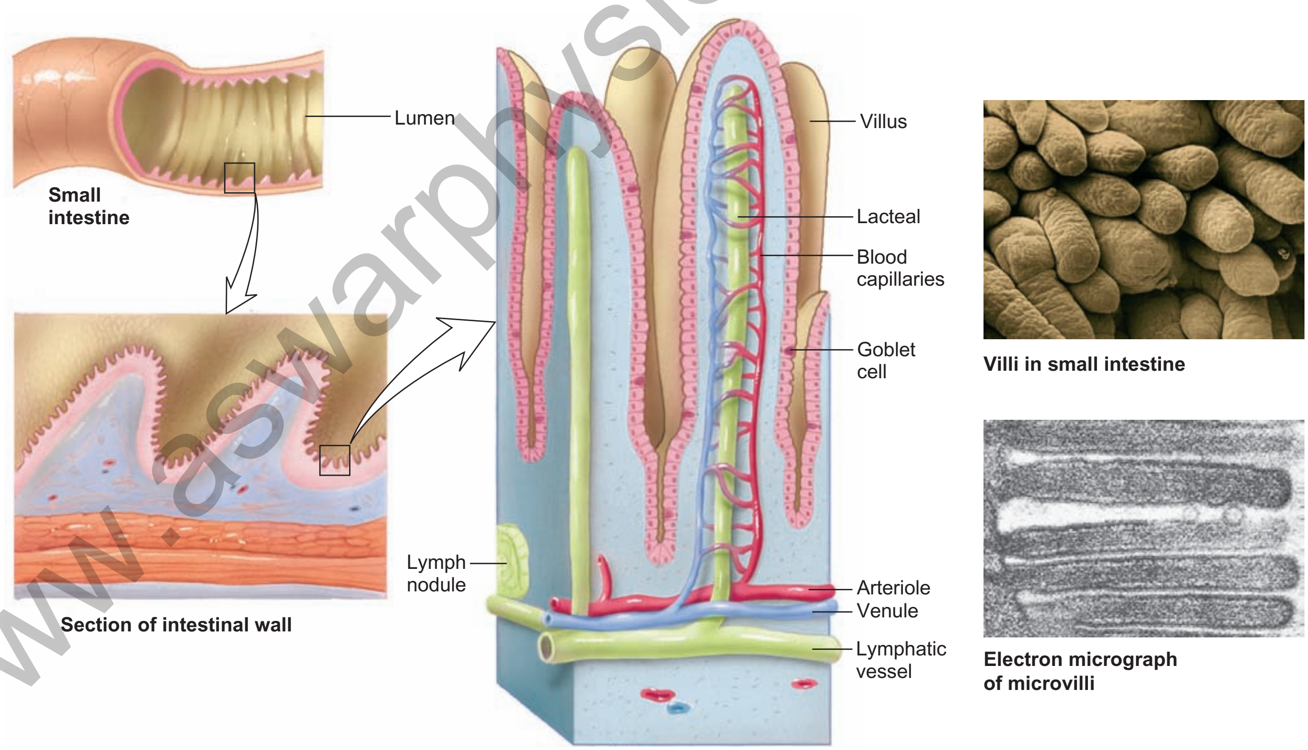


FIGURE 24.11 The Exchange Surface of the Intestinal Tract
The surface area of the intestinal lining is increased by the many fingerlike projections known as villi. Within each villus are capillaries and lacteals. Most kinds of materials enter the capillaries, but most fat-soluble substances enter the lacteals, part of the lymphatic system, giving them a milky appearance. Because the lymphatic system empties into the circulatory system, fat-soluble materials also eventually enter the circulatory system. The close relationship between the vessels and the epithelial lining of the villi allows for the efficient exchange of materials from the intestinal cavity to the circulatory system.

its stored glycogen back into glucose. Although amino acids are not stored, the liver can change the relative numbers of various amino acids circulating in the blood. It can remove the amino group from one kind of amino acid and attach it to a different carbon skeleton, generating a different amino acid. The liver can also take the amino group off amino acids, so that what remains of the amino acid can be used in aerobic cellular respiration. The toxic amino groups are then converted to urea by the liver. Urea is secreted back into the bloodstream for disposal in urine.

24.5 CONCEPT REVIEW

10. Describe three ways in which the digestive system increases its ability to absorb nutrients.
11. List three functions of the liver.
12. Name five digestive enzymes and describe their functions.
13. What is the role of bile, saliva, enzymes, and hydrochloric acid in digestion?
14. How is fat absorption different from the absorption of carbohydrate and protein?

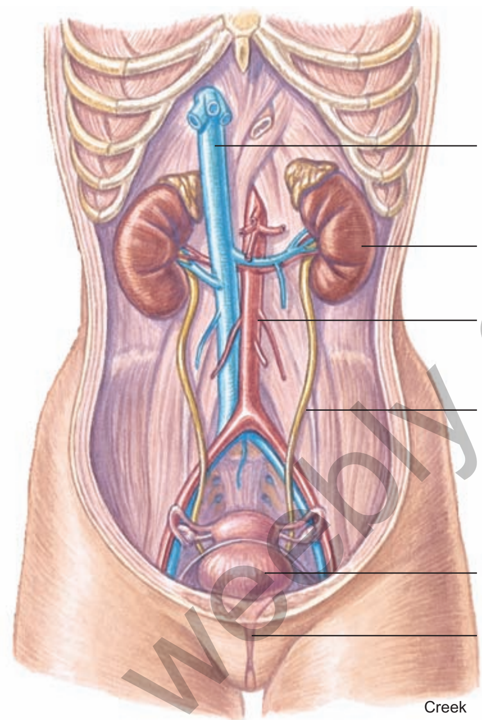


FIGURE 24.12 The Excretory System
The primary organs involved in removing materials from the blood are the kidneys. The urine produced by the kidneys is transported by the ureters to the urinary bladder. From the bladder, the urine is emptied to the outside of the body by way of the urethra.

24.6 Waste Disposal: The Excretory System

The **excretory system** is the organ system responsible for the processing and elimination of metabolic waste products; it consists of the kidneys, ureters, urinary bladder, and urethra (figure 24.12). Because cells modify molecules during metabolic processes, harmful waste products are constantly being formed. Urea is a common waste; many other toxic materials must be eliminated as well. Among these are large numbers of hydrogen ions produced by metabolism. This excess of hydrogen ions must be removed from the bloodstream. Other molecules, such as water and salts, may be consumed in excessive amounts and must also be removed.

Kidney Structure

The **kidneys** are the primary organs involved in regulating the level of toxic or unnecessary molecules in the body. The kidneys consist of about 2.4 million tiny units called **nephrons.** At one end of a nephron is a cup-shaped structure called a **Bowman's capsule,** which surrounds a knot of capillaries known as a **glomerulus** (figure 24.13). In addition to Bowman's capsule, a nephron consists of three distinctly different regions: the **proximal convoluted tubule,** the **loop of Henle,** and the **distal convoluted tubule.** The distal convoluted tubule of a nephron is connected to a collecting duct, which transports fluid to the ureters and ultimately to the urinary bladder, where it is stored until it can be eliminated through the urethra.

Kidney Function

As in the other systems discussed in this chapter, the excretory system involves a close connection between the circulatory system and a surface. In this case, the large surface is provided by the walls of the millions of nephrons, which are surrounded by capillaries. Three major activities occur at these surfaces: filtration, reabsorption, and secretion. The glomerulus presents a large surface for the filtering of material from the blood to Bowman's capsule. Blood that enters the glomerulus is under pressure from the muscular contraction of the heart. The capillaries of the glomerulus are quite porous and provide a large surface area for the movement of water and small dissolved molecules from the blood into Bowman's capsule. Normally, only the smaller molecules, such as glucose, amino acids, and ions, are able to pass through the glomerulus into the Bowman's capsule at the end of the nephron. The various kinds of blood cells and larger molecules, such as proteins like albumin, do not pass out of the blood into the nephron. (The chronic presence of albumin in the urine is an indicator of kidney damage or disease.) This physical filtration process allows many kinds of molecules to leave the blood and enter the nephron. The volume of material filtered in this way through the approximately 2.4 million nephrons of the kidneys is about 7.5 liters per hour. Because the entire blood supply is about 5 to 6 liters, there must be a method for recovering much of this fluid.

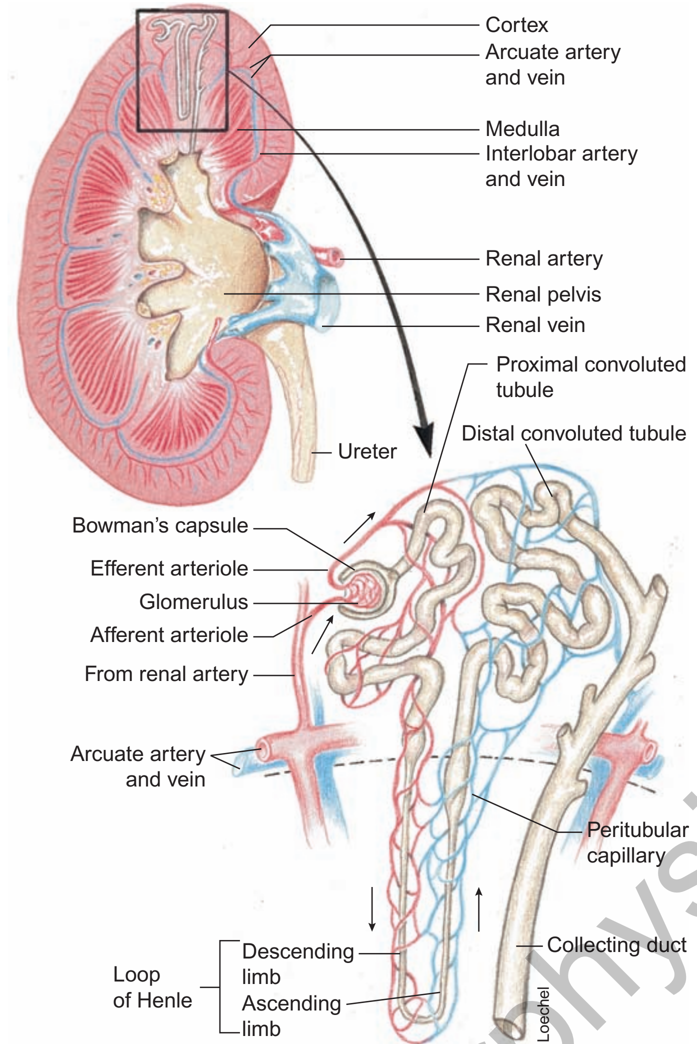


FIGURE 24.13 The Structure of the Nephron
The nephron and the closely associated blood vessels create a system that allows for the passage of materials from the circulatory system to the nephron by way of the glomerulus and Bowman's capsule. Materials are added to and removed from the fluid in the nephron via the tubular portions of the nephron and their associated capillaries.

Surrounding the various portions of the nephron are capillaries that passively accept or release molecules on the basis of diffusion gradients. The walls of the nephron are made of cells that actively assist in the transport of materials. Some molecules are reabsorbed from the nephron and picked up by the capillaries that surround them, whereas other molecules are actively secreted into the nephron from the capillaries. Each portion of the nephron has cells with specific secretory abilities.

The proximal convoluted tubule is primarily responsible for reabsorbing valuable materials from the fluid moving through it. Molecules such as glucose, amino acids, and sodium ions are actively transported across the membrane of the proximal convoluted tubule and returned to the blood. In addition, water moves across the membrane because it follows the absorbed molecules and diffuses to the area where water molecules are less common. By the time the fluid has reached the end of the proximal convoluted tubule, about 65% of the fluid has been reabsorbed into the capillaries surrounding this region.

The next portion of the tubule, the loop of Henle, is primarily involved in removing additional water from the nephron. Although the details of the mechanism are complicated, the principles are rather simple. The cells of the ascending loop of Henle actively transport sodium ions from the nephron into the space between nephrons where sodium ions accumulate in the fluid that surrounds the loop of Henle. The collecting ducts pass through this region as they carry urine to the ureters. Because the area these collecting ducts pass through is high in sodium ions, water within the collecting ducts diffuses from the ducts and is picked up by surrounding capillaries. However, the ability of water to pass through the wall of the collecting duct is regulated by hormones. Thus, it is possible to control water loss from the body by regulating the amount of water lost from the collecting ducts. For example, if you drank a liter of water or some other liquid, the excess water would not be allowed to leave the collecting duct (it would stay in the collecting duct) and would exit the body as part of the urine. However, if you were dehydrated, most of the water passing through the collecting ducts would be reabsorbed, and very little urine would be produced. The primary hormone involved in regulating water loss is the antidiuretic hormone (ADH). When the body has excess water, cells in the hypothalamus of the brain respond and send a signal to the pituitary, and only a small amount of ADH is released and water is lost in the urine. When you are dehydrated, the same brain cells cause more ADH to be released and water leaves the collecting duct and is returned to the blood.

The distal convoluted tubule is primarily involved in fine-tuning the amounts of various kinds of molecules that are lost in the urine. Hydrogen ions (H^+), sodium ions (Na^+), chloride ions (Cl^-), potassium ions (K^+), and ammonium ions (NH_4^+) are regulated in this way. Some molecules that pass through the nephron are relatively unaffected by the various activities going on in the kidneys. One of these is urea, which is filtered through the glomerulus into Bowman's capsule. As it passes through the nephron, much of it stays in the tubule and is eliminated in the urine. Many other kinds of molecules, such as minor metabolic waste products and some drugs, are also treated in this manner. Figure 24.14 summarizes the major functions of the various portions of the kidney tubule system.

24.6 CONCEPT REVIEW

15. What are the functions of the glomerulus, proximal convoluted tubule, loop of Henle, and distal convoluted tubule?
16. Describe how the kidneys regulate the amount of water in the body.

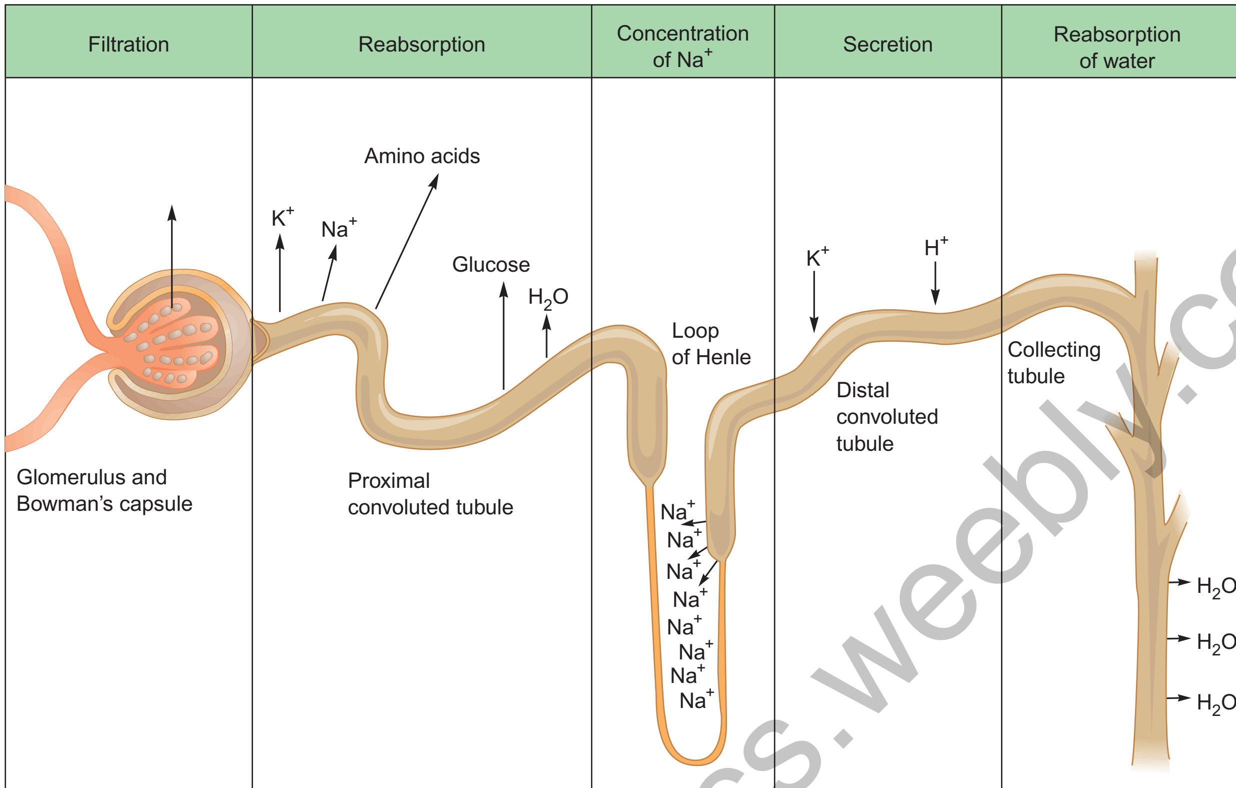


FIGURE 24.14 Specific Functions of the Nephron
Each portion of the nephron has specific functions. The glomerulus and Bowman's capsule accomplish the filtration of fluid from the bloodstream into the nephron. The proximal convoluted tubule reabsorbs most of the material filtered. The loop of Henle concentrates Na^+ so that water will move from the collecting tubule. The distal convoluted tubule regulates pH and ion concentration by differential secretion of K^+ and H^+ and other ions.

Summary

The body's systems must be integrated in such a way that the internal environment stays relatively constant. This chapter surveys five systems of the body—the cardiovascular, lymphatic, respiratory, digestive, and excretory systems—and describes how they are integrated. All of these systems are involved in the exchange of materials across membranes.

The cardiovascular system consists of a pump, the heart, and blood vessels that distribute the blood to all parts of the body. The blood is a carrier fluid that transports molecules and heat. The exchange of materials between the blood and body cells takes place through the walls of the capillaries. Because the flow of blood can be regulated by the contraction of arterioles, blood can be sent to different parts of the body at different times. Hemoglobin in red blood cells is very important in the transport of oxygen. Carbonic anhydrase is an enzyme in red blood cells that converts carbon dioxide into bicarbonate ions, which can be easily carried by the blood.

The lymphatic system is a collection of thin-walled tubes (lymph vessels) that branch throughout the body and lymph organs. The lymphatic system moves fat from the intestinal tract to the bloodstream through lacteals, transports excess tissue fluid back to the cardiovascular system, and defends against harmful agents, such as bacteria and viruses. The lymph organs include the lymph nodes, tonsils, spleen, thymus gland, and red bone marrow.

The respiratory system consists of the lungs and the associated tubes that allow air to enter and leave the lungs. The diaphragm and muscles of the chest wall are important in the process of breathing. In the lungs, alveoli provide a large surface area in association with capillaries, which allows for the rapid exchange of oxygen and carbon dioxide.

The digestive system disassembles food molecules. This involves several processes: grinding by the teeth and stomach, the emulsification of fats by bile from the liver, the addition of water to dissolve molecules, and enzymatic action to break complex molecules into simpler molecules for absorption. The small intestine provides a large surface area for the absorption of nutrients, because it is long and its wall contains many tiny projections that increase surface area. Once absorbed, the materials are carried to the liver, where molecules can be modified. The large intestine is primarily involved in reabsorption of water.

The excretory system is a filtering system of the body. The kidneys consist of nephrons, into which the circulatory system filters fluid. Most of this fluid is useful and is reclaimed by the cells that make up the walls of these tubules. Materials that are present in excess and those that are harmful are allowed to escape. Some molecules may be secreted into the tubules before being eliminated from the body.

Key Terms

*Use the interactive flash cards on the **Concepts in Biology, 14/e** website to help you learn the meaning of these terms.*

alveoli 542
aorta 538
arteries 534
arterioles 539
atria 537
atrioventricular valves 538
bile 548
blood 534
Bowman's capsule 550
breathing 543
bronchi 542
bronchioles 542
capillaries 534
cardiovascular system 534
diaphragm 543
diastolic blood pressure 539
digestive system 545
distal convoluted tubule 550
duodenum 546
excretory system 550
formed elements 534
gallbladder 548
gastric juice 546
glomerulus 550
heart 534
hemoglobin 534
hepatic portal vein 549
kidneys 550
lacteal 549
large intestine 548
loop of Henle 550
lungs 542
lymph 541
lymph nodes 542
lymphatic system 541
nephrons 550
pancreas 548
pepsin 546
pharynx 546
plasma 534
platelets 536
proximal convoluted tubule 550
pulmonary artery 538
pulmonary circulation 538
pyloric sphincter 546
red blood cells (rbcs) 534
respiratory system 542
salivary glands 546
semilunar valves 538
small intestine 546
systemic circulation 538
systolic blood pressure 539
tissue fluid 537
trachea 542
veins 534
ventricles 537
villi 548
white blood cells (wbcs) 536

Basic Review

1. The vessels that carry blood away from the heart are
   a. veins.
   b. arteries.
   c. capillaries.
   d. lacteals.
2. Which of the following is not a formed element?
   a. rbc
   b. wbc
   c. platelets
   d. plasma
3. _____ is the liquid that baths the body's cells and contains the same chemicals as plasma but smaller amounts of albumin.
4. Which of the following is not a function of the lymphatic system?
   a. It moves fat from the intestinal tract to the bloodstream.
   b. It transports excess tissue fluid back to the cardiovascular system.
   c. It defends against harmful agents, such as bacteria and viruses.
   d. It carries oxygen to cells deep in the body.
5. The stomach
   a. produces hydrochloric acid.
   b. begins digestion of protein.
   c. continues the mechanical breakdown of food begun in the mouth.
   d. All of the above are correct.
6. Saliva contains the enzyme _____, which begins the chemical breakdown of starch.
   a. salivary amylase
   b. pepsin
   c. trypsin
   d. pylorase
7. In the respiratory system, the small sacs in the lungs where gas exchange takes place are called
   a. nephrons.
   b. alveoli.
   c. nodes.
   d. platelets.

8. The lining of the small intestine consists of millions of fingerlike projections, called
   a. nodes.
   b. alveoli.
   c. villi.
   d. glomeruli.
9. The proximal convoluted tubule is primarily involved in
   a. secreting harmful materials into the nephron.
   b. reabsorbing useful materials from the nephron.
   c. removing hydrogen ions from the urine.
   d. None of the above is correct.
10. About 200 billion _____ are formed each day and are important in blood clotting.
   a. nephrons
   b. lacteals
   c. platelets
   d. formed elements
11. The primary waste products released in the urine are _____ and _____.
12. The flow of blood back to the heart through veins is assisted by valves and _____.
13. Breathing rate is primarily determined by the level of the chemical _____ in the blood.
14. Capillaries are intimately associated with the _____ of the lungs, the _____ of the kidneys, and the _____ of the small intestine.
15. The right ventricle pumps blood to the _____.

Answers
1. b 2. d 3. Tissue fluid 4. d 5. d 6. a 7. b 8. c 9. b 10. c 11. urea; hydrogen ions 12. contractions of the body's muscles 13. carbon dioxide 14. alveoli, nephrons, villi 15. lungs

Thinking Critically

Mechanically Assisted Life
It is possible to keep a human being alive even if the heart, lungs, kidneys, and digestive tract are not functioning by using heart-lung machines in conjunction with kidney dialysis and intravenous feeding. This implies that the basic physical principles involved in the functioning of these systems is well understood because the natural functions can be duplicated with mechanical devices. However, these machines are expensive and require considerable maintenance. Should society be spending money to develop smaller, more efficient mechanisms that could be used to replace diseased or damaged hearts, lungs, and kidneys?

CHAPTER 25

Nutrition

Food and Diet

CHAPTER OUTLINE

Energy Drinks—Hype or Help?

Check the ingredient list.

Energy drinks are marketed to appeal to young people. They claim to provide energy for physical activity. What are the facts?

Many energy drinks do contain various kinds of sugar that are a source of Calories. The amount of sugar is generally similar to that in soft drinks. Some energy drinks are sugar-free.

The primary ingredients in all energy drinks are substances that stimulate the nervous system. Caffeine is usually shown as an ingredient and is typically in an amount equivalent to that found in a cup of coffee, although some brands have higher amounts. Two herbal ingredients commonly found in energy drinks are also known to be stimulants—guarana and yerba maté. Because they are herbal products, it is not required that companies provide detailed information about their quantities and effects. Both of these ingredients are extracts of South American plants. So, energy drinks containing guarana or yerba maté have additional stimulants that have effects similar to caffeine.

Taurine is another ingredient commonly found in energy drinks. It is naturally produced by the body and is a major ingredient of liver bile. It is present in meat and fish. Although it is often called an amino acid, it is not. However, it is produced in the body from the amino acid cysteine. It appears to have a variety of effects in the body but it is unclear if additional quantities have any beneficial effect. Its presence in energy drinks is probably related to some evidence that it improves the endurance of muscles. Its name is also of interest. It was first isolated from the bile of an ox, so it was given the name *taurine* after Taurus the bull. It appears that high doses are not harmful.

So, it appears that the primary effect of these drinks is to stimulate the nervous system so that people are more alert. They are not sources of energy in the metabolic sense.

- **What is the nutritional content of an energy drink?**
- **What role does caffeine play in metabolism?**
- **Should marketers of energy drinks be required to prove their claims?**

Background Check

Concepts you should understand in order to get the most out of this chapter:

- The basic principles of chemistry (chapter 2)
- The basic principles of organic chemistry (chapter 3)
- How enzymes work in processing energy and matter (chapter 5)
- The structure and function of the digestive system (chapter 24)

25.1 Living Things as Chemical Factories: Matter and Energy Manipulators

Organisms maintain themselves by constantly processing molecules to obtain energy and building blocks for new living material. Autotrophs can manufacture organic molecules from inorganic molecules, but heterotrophs must consume organic molecules to get what they need. **Nutrients** are all the molecules required to support living things. Some nutrients are elements, such as calcium, iron, and potassium; others are organic molecules, such as carbohydrates, proteins, fats, and vitamins. All heterotrophs obtain the nutrients they need from food, and each kind of heterotroph has particular nutritional requirements. This chapter examines the nutritional requirements of humans.

Diet and Nutrition Defined

The word *nutrition* is used in two contexts. First, **nutrition** is the branch of science that seeks to understand food, its nutrients, how the body uses nutrients, and how inappropriate combinations or quantities of nutrients lead to ill health. The word *nutrition* also refers to all the processes by which we take in food and use it, including *ingestion, digestion, absorption,* and *assimilation*. **Ingestion** is the process of taking food into the body through eating. **Digestion** is the breakdown of complex food molecules to simpler molecules. **Absorption** is the movement of simple molecules from the digestive system to the circulatory system for dispersal throughout the body. **Assimilation** is the modification and incorporation of absorbed molecules into the structure of the organism.

Many of the nutrients that enter living cells undergo chemical changes before they are incorporated into the body. These interconversion processes are ultimately under the control of the cell's genetic material. It is DNA that codes the information necessary to manufacture the enzymes required to extract energy from chemical bonds and to convert raw materials (nutrients) into the structure (anatomy) of the organism.

Diet is the food and drink consumed by a person from day to day. It must contain the minimal nutrients necessary to manufacture and maintain the body's structure (e.g., the bones, skin, tendon, muscle) and regulatory molecules (enzymes and hormones) and to supply the energy (ATP) needed to run the body's machinery. If the diet is deficient in nutrients, or if a person's body cannot process nutrients efficiently, a dietary deficiency and ill health may result. A good understanding of nutrition can promote good health; it requires an understanding of the energy and nutrient content in various foods (figure 25.1).

Energy Content of Food

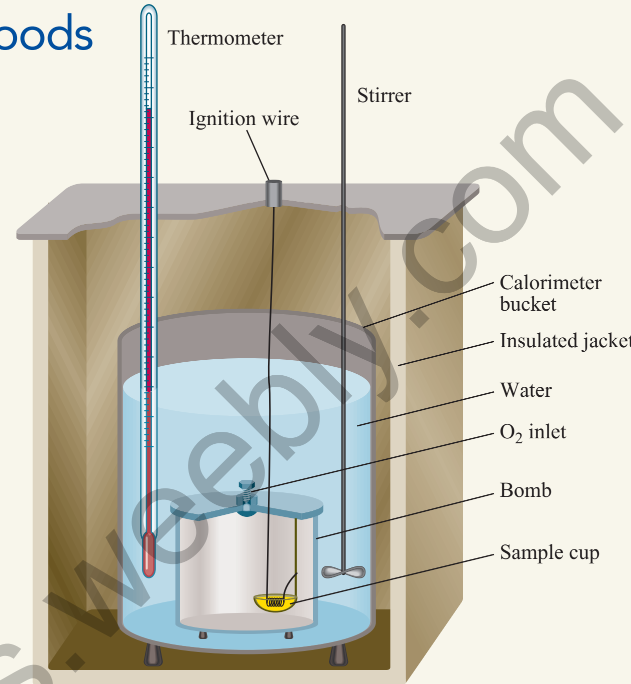
The *kilocalorie (kcal)* is the unit used to measure the amount of energy in foods. One **kilocalorie** is the amount of energy needed to raise the temperature of 1 *kilogram* of water 1°C. Remember that the prefix *kilo-* means "1,000 times" the value listed. Therefore, a kilocalorie is 1,000 times more heat energy than a *calorie*. A **calorie** is the amount of heat energy

FIGURE 25.1 Diet
Your diet is what you eat on a daily basis.

HOW SCIENCE WORKS 25.1

Measuring the Caloric Value of Foods

A bomb calorimeter is an instrument used to determine the energy content of food. This is done by determining how much heat a given amount of food produces when it is burned. To operate the instrument, a small food sample is formed into a pellet and sealed inside a strong container called a bomb. The bomb is filled with oxygen under 30 atmospheres of pressure and is then placed in a surrounding jacket filled with water. The sample is electrically ignited. As it reacts with the oxygen (burns), the food sample in the bomb produces heat that is transferred to the water in the jacket that surrounds the bomb. The increase in temperature of the water is recorded. A kilocalorie (Calorie) is the amount of heat energy needed to increase the temperature of 1 kilogram of water 1°C. Therefore, if 1 gram of food results in a water temperature increase of 4°C for each kilogram of water, that food has 4 kilocalories (Calories).



needed to raise the temperature of 1 *gram* of water 1°C. Although the energy unit for nutrition is a kilocalorie, it is usually called a Calorie with a capital C. This is unfortunate because it is easy to confuse a dietary Calorie, which is really a kilocalorie, with a calorie. Most books on nutrition and dieting use the term Calorie to refer to *food calories* (How Science Works 25.1).

25.1 CONCEPT REVIEW

1. What is a nutrient?
2. What is the difference between digestion and assimilation?
3. How is the energy content of food measured?

25.2 The Kinds of Nutrients and Their Function

Nutritionists have divided nutrients into six major classes: carbohydrates, lipids, proteins, vitamins, minerals, and water. Chapters 2 and 3 presented the chemical makeup of these types of molecules, and chapter 6 explored the nature of cellular respiration. A look at each of these classes of nutrients from a nutritionist's point of view should reveal how the human body works and how its nutritional needs can be met.

Carbohydrates

From a nutritional point of view, there are three kinds of carbohydrates that are significant: sugars, starch, and fiber. The basic building blocks of carbohydrates are simple sugars (monosaccharides) such as glucose, fructose, and galactose. Two simple sugars can be combined to form double sugars (disaccharides) such as lactose, maltose, and sucrose. Both mono- and disaccharides are commonly called sugar. In plants, large numbers of glucose molecules can be joined to form a polysaccharide called *starch*. The function of starch in the plant is to store food. However, animals can use this energy-storage molecule for energy as well. Starch is a primary source of Calories for humans (figure 25.2).

Functions of Carbohydrates

The primary function of sugars and starch in the diet is as a source of energy. During digestion, starch and disaccharides are broken down to simple sugars that are absorbed from the gut and used by cells during respiration. There are 4 Calories (kilocalories) in a gram of carbohydrate. In addition to serving as a source of energy, most sugars (glucose, fructose, lactose, sucrose, maltose) taste sweet and stimulate the appetite. Simple sugars are also used as building blocks in the manufacture of molecules such as nucleic acids.

Dietary fiber consists of cellulose and several other complex carbohydrates that are indigestible. Dietary fiber has several nutritional functions. It slows the absorption of

FIGURE 25.2 Carbohydrates
The primary source of carbohydrates is seeds of plants such as wheat, oats, rice, and beans and things made from the seeds. For most of the people of the world, carbohydrate in the form of starch is the primary item in their diet.

sugars, which helps to regulate the level of glucose in the blood. This is particularly important for diabetics. Dietary fiber also reduces the absorption of cholesterol from the intestine and thus can have the beneficial effect of lowering cholesterol in the blood, which reduces the incidence of heart disease. It provides bulk to the contents of the intestine and stimulates peristalsis (rhythmic contractions) in the intestinal tract. It also tends to retain water in the intestine, reducing the incidence of constipation.

Carbohydrate Quality

Food sources that contain carbohydrates are not all the same. Flour is made from seeds such as wheat, corn, rye, rice, buckwheat, and millet that are ground up. Many kinds of foods are constructed from refined flour, which is essentially pure starch. Whole-grain flour contains many other parts of the seeds and has much more fiber and other nutrients than contained in refined flours. Foods that consist primarily of refined flours and sugars (candy bars, soft drinks, white bread, cakes, etc.) are high in Calories but low in other important nutrients. Therefore, these foods sources are often said to have "empty Calories"—they provide Calories but little other nutritional value. The latest nutritional recommendations encourage people to reduce their consumption of refined flours and sugars and increase their consumption of whole grain products.

How the Body Manages Carbohydrates

When we consume carbohydrates, we cannot use them immediately to provide energy for our cells. Our bodies store this energy in two ways. We can store small amounts as glycogen in muscles and the liver for later use. Glycogen consists of glucose molecules hooked together but in a different way from that of starch. Glycogen is sometimes called animal starch. The body can only store small amounts of carbohydrate as glycogen. Therefore, carbohydrates should be a daily part of the diet. If we consume much more carbohydrate than we need, the excess is converted to fat and stored in fat tissue.

A diet deficient in carbohydrates results in fats being oxidized and converted to ATP. In situations in which carbohydrates are absent, most of the fats are metabolized to *keto acids*. Large numbers of keto acids may be produced in extreme cases of fasting, resulting in a potentially dangerous change in the body's pH. If a person does not have stored fat to metabolize, a carbohydrate deficiency will result in use of the body's proteins as a source of energy. This is usually only encountered in starvation, extreme cases of fasting, or eating disorders. In extreme cases, this can be fatal, because the oxidation of protein results in an increase in toxic, nitrogen-containing compounds.

Lipids

The class of nutrients technically known as *lipids* is often called *fats*. This may lead to some confusion, because fats are only one of three subclasses of lipids. Each subclass of lipids—phospholipids, steroids, and true fats—plays an important role in human nutrition.

Phospholipids are the major molecules in membrane structures (endoplasmic reticulum, plasma membrane, Golgi, etc.) of cells. Although various kinds of phospholipids are sold as dietary supplements, they are unnecessary because all food composed of cells contains phospholipids.

Many steroids are hormones that help regulate a variety of body processes. With the exception of vitamin D, it is not necessary to include steroids as a part of the diet. Cholesterol is a steroid, manufactured in the body and commonly found in foods of animal origin. Excess consumption of cholesterol causes health problems in some people.

The *true fats* (also called *triglycerides*) are composed of a glycerol molecule attached to three fatty acids.

Functions of Fats

Fats are the primary long-term, energy-storage molecules in animals and plants. Therefore, they are an excellent source of energy. They release 9 Calories of energy per gram compared to 4 Calories per gram for carbohydrate or protein. A teaspoon holds about 5 grams of a fat like olive oil.

In addition to serving as sources of energy in the diet and energy-storage molecules in the body, fats have several other important functions. Some vitamins, such as A, D, E, and K, do not dissolve in water but dissolve in fat and, therefore, require fat in the gut for their absorption. A layer of fat under the skin is a valuable insulator against internal heat loss. The layer of fat under the skin and that which surrounds organs is also an excellent shock absorber. Fat deposits in the back of the eyes serve as cushions when the head suffers a severe blow. During starvation, these deposits are lost, and the eyes become deep-set in the eye sockets, giving the person a ghostly appearance.

The pleasant taste and "mouth feel" of many foods is the result of fats. Their ingestion provides a full feeling after a meal because they tend to remain in the stomach so that it empties later than if fat were not present.

Kinds of Fats Important in Nutrition

Fats consist of the molecule of glycerol with three fatty acids attached. Several kinds of fats are commonly discussed with respect to nutrition (figure 25.3). *Saturated fats* have fatty acid portions that do not have any double bonds between carbons. They are generally of animal origin and are solids at room temperature. *Unsaturated fats* have double bonds between carbons in the fatty acid portion of the molecule. They are called oils because they are liquids at room temperature. They are generally of plant origin. *Polyunsaturated fats* have several double bonds in the fatty acid portion of the molecule. *Trans fats* are created when unsaturated fats are chemically altered (hydrogenated) to make them more solid. Although they are still unsaturated, they have fewer double bonds and have a slightly different structure from the fats normally produced by organisms. Trans fats cause an increase in the amount of "bad" lipids in the blood.

Some fats contain the **essential fatty acids,** linoleic acid and linolenic acid, which cannot be synthesized by the human body and, therefore, must be a part of the diet. The body requires these essential fatty acids for normal growth, blood clotting, and healthy skin. Most diets that incorporate a variety of foods, including meats and vegetable oils, have enough of these essential fatty acids. A diet high in linoleic acid has also been shown to help reduce the amount of cholesterol in the blood. Because of negative health effects associated with saturated fats and trans fats in the diet, people are encouraged to reduce their total consumption of fats and to substitute unsaturated fats for saturated and trans fats.

How the Body Manages Fat

Body fat is produced when food consumption is higher than the amount needed for daily energy needs. This stored energy source can be called upon when a person does not consume enough Calories to meet daily energy demands. Early in the history of our species this was vitally important because obtaining food was often irregular. Periods of food scarcity were common and stored fat was important for survival. However, today food is abundantly available for most of us and often exceeds our daily needs. Thus, what once was an important mechanism for survival has become a problem of obesity for many people.

Saturated Fats

Unsaturated Fats

FIGURE 25.3 Saturated and Unsaturated Fats
Animal fats are saturated. Dairy products, meats, and foods cooked in animal fats are high in saturated fats. Plant fats are usually oils and are unsaturated fats.

Proteins

Proteins are composed of amino acids linked together; however, not all proteins contain the same amino acids.

Functions of Proteins

Proteins are involved in a great number of structures and activities in the body. Cell membranes contain protein along with phospholipids. Structures like muscles, tendons, ligaments, skin, and connective tissues all have proteins as an important constituent. Many proteins are involved in regulating particular activities of the body. Enzymes control metabolism. Antibodies protect from disease. Hormones communicate. Many other proteins are involved in sending and receiving signals between cells. Proteins also provide a last-ditch source of energy during starvation when carbohydrate and fat reserves are used up. Thus, it is accurate to say that it is the proteins of an organism that determine its structure, metabolic abilities, and capacity to regulate and coordinate the various activities of the body.

Because proteins are so important, many people have a misconception about the amount of protein necessary in the diet. The amount is actually quite small (about 50 grams/day) and can be obtained easily. A hamburger, a half chicken breast, or a fish sandwich contains the daily amount of protein needed by most people.

Kinds of Proteins

From a nutritional point of view, proteins can be divided into two groups: *complete proteins* and *incomplete proteins*. **Complete proteins** contain all the amino acids required by the body and necessary for good health. Proteins derived from animal sources—meat, poultry, fish, eggs, milk—are complete proteins (figure 25.4). **Incomplete proteins** lack certain amino acids that the body must have to build essential proteins. Most plant proteins are deficient in one or more of the essential amino acids. For example, the amino acid lysine is absent or in very low quantities in wheat, rice, and corn and the amino acid tryptophan is limited in beans. However, eating a combination of beans and rice or corn and beans provides the equivalent of a complete protein.

The human body can manufacture some amino acids but is unable to manufacture others. Those the body cannot manufacture are called **essential amino acids** (table 25.1). Without adequate amounts of these essential amino acids in the diet, a person may develop a protein-deficiency disease.

In many parts of the world, people live on diets that provide the Calories they need from carbohydrates and fats but are low in complete protein. In part, this is because carbohydrates and fats are inexpensive to grow and process, in comparison with proteins. One protein-deficiency disease is **kwashiorkor;** its symptoms are easily seen (figure 25.5). A person with this deficiency has a distended belly, slow growth, and slow movement and is emotionally depressed. If the disease is caught in time, brain damage can be prevented and death averted. This requires a change in diet, including expensive protein, such as poultry, fish, beef, shrimp, or milk. As the world food problem increases, these expensive foods will be in even shorter supply and will become more and more costly.

FIGURE 25.4 Sources of Proteins
The muscle tissue of animals, eggs, and milk products are good sources of complete protein. Beans are also a good protein source but are an incomplete protein since they are low in the amino acid tryptophan.

TABLE 25.1 Sources of Essential Amino Acids

Essential Amino Acids	Comments
Threonine	In most sources of protein
Isoleucine	In most sources of protein
Methionine	In most sources of protein
Valine	In most sources of protein
Phenylalanine	In most sources of protein
Leucine	In most sources of protein
Tryptophan	**Deficient in legumes**
Lysine	**Deficient in grains**
Arginine	Essential in infants only; in most sources of protein
Histidine	Essential in infants only; present in human and cow's milk and infant formula

FIGURE 25.5 Kwashiorkor
This starving child shows the symptoms of kwashiorkor, a protein-deficiency disease. If this child were treated with adequate protein containing all the amino acids, the symptoms could be reduced.

How the Body Manages Protein

Unlike carbohydrates and fats, proteins cannot be stored for later use. Because they are not stored and because they have many important functions, adequate amounts of protein must be present in the daily diet. However, a high-protein diet is not necessary. Only small amounts of protein—20 to 30 grams—are metabolized and lost from the body each day and must be replaced. A diet containing 50 grams of protein would easily cover this loss. Any protein in excess of that needed to rebuild lost molecules is metabolized to provide the body with energy.

Protein that makes up the structure of the body is protected from being metabolized to provide energy for cells. The mechanisms that protect protein are called **protein-sparing** mechanisms. During fasting or starvation, several kinds of metabolic adjustments allow the body to continue functioning without an input of food. Many of the body's cells can use fat as their primary source of energy, thus protecting the more valuable protein. The breakdown of fats results in the production of compounds called *ketones*. Some of these ketones are released in the breath and can be detected as the odor of acetone. Acetone is an odor you would associate with fingernail polish. People who are fasting, anorexic, or diabetic or have other metabolic problems often have this "ketone breath."

However, red blood cells and nervous tissue must have glucose, which can be supplied by the breakdown of glycogen stored in muscles and the liver. However, after a day or two of fasting, glycogen stores are depleted and glucose is unavailable from glycogen. Only at this point does the body begin to convert some of the amino acids from structural protein into glucose to supply these blood cells and nerve cells. During the early stages of starvation, the amount of fat in the body steadily decreases, but the amount of protein drops only slightly—20 to 30 grams per day (figure 25.6).

Although fat can supply energy for many cells during fasting or starvation, the fat cannot completely protect the proteins if there are no carbohydrates in the diet. With prolonged

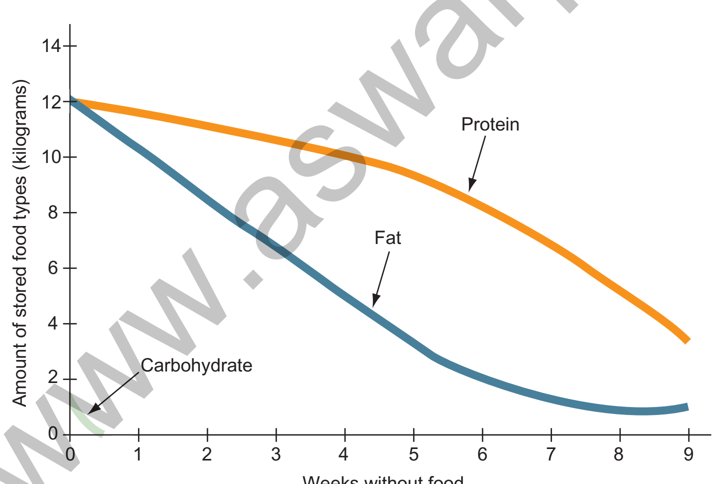


FIGURE 25.6 Protein-Sparing Mechanisms
The body uses various metabolic mechanisms to protect proteins during fasting or starvation. Notice that carbohydrate stores (glycogen) are depleted quickly and that fat stores fall much faster than protein. Protein-sparing mechanisms enable the body to protect essential enzymes and other proteins.

starvation, the fat stores are eventually depleted and structural proteins (as much as 125 grams per day) are used for all the body's energy needs. When starvation reaches this point, it is usually fatal. People who are chronically undernourished do not have the protective effect of fat and experience the effects of starvation much more quickly than those who have stored fat. Children are particularly at risk, because they also need nutrients as building blocks for growth.

Vitamins

Vitamins are organic molecules needed in small amounts to maintain essential metabolic activities. Like essential amino acids and essential fatty acids, vitamins cannot be manufactured by the body. Table 25.2 lists vitamins for which there are recommended daily intakes.

Functions of Vitamins

Vitamins are involved as participants in many metabolic reactions. Some vitamins are actually incorporated into the structure of enzymes. Such vitamins are called *coenzymes*. For example, the B-complex vitamin niacin helps enzymes involved in aerobic cellular respiration. Several vitamins are antioxidants that protect cells. During normal metabolic processes, compounds called *free radicals* are produced. Free radicals are extremely reactive and can combine with and alter the structure of important molecules in the cell. Some of the vitamins (in particular, vitamins A, C, and E) combine with free radicals and neutralize their effects.

Kinds of Vitamins

From a nutritional point of view there are two kinds of vitamins: water-soluble vitamins and fat-soluble vitamins. The water-soluble vitamins are vitamin C and the various kinds of B vitamins. The fat-soluble vitamins are A, D, E, and K. Vitamin D deserves some special comment. Although vitamin D is found in certain foods, it is also formed when the ultraviolet light in sunshine strikes a cholesterol molecule in the skin, converting cholesterol to vitamin D. This means that vitamin D is not really a vitamin at all. It came to be known as a vitamin because of the mistaken idea that it was acquired only through food, rather than being formed in the skin on exposure to sunshine. It would be more correct to call vitamin D a hormone, but most people do not.

How Vitamins Are Managed in the Body

The water-soluble vitamins are not stored in the body and thus must be obtained in the diet on a daily basis because they are lost in the urine. Excess fat-soluble vitamins are stored in the liver and can be released for use when needed. Therefore, it is not necessary to have these vitamins in the diet every day.

Because many vitamins are inexpensive and their functions are poorly understood, many advocate large doses (megadoses) of vitamins to prevent a wide range of diseases. Often,

TABLE 25.2 Sources and Functions of Vitamins

Name	Recommended Daily Intake for Young Adults: Women	Men	Physiological Value	Readily Available Sources	Other Information
Water-Soluble Vitamins					
Vitamin B_1 (thiamin)	1.1 mg/d	1.2 mg/d	Maintains nerves and heart; involved in carbohydrate metabolism	Whole grains, legumes, pork	Larger amounts needed during pregnancy and lactation
Vitamin B_2 (riboflavin)	1.1 mg/d	1.3 mg/d	Important in aerobic respiration reactions; maintains skin and mucous membranes	Whole grains, dairy products, green vegetables; liver	
Vitamin B_3 (niacin)	14 mg/d	16 mg/d	Important in aerobic respiration reactions	Whole grains, meat	
Vitamin B_6 (pyridoxine pyridoxol, pyridoxamine)	1.3 mg/d	1.3 mg/d	Builds red blood cells; maintains nervous system	Whole grains, milk, meat, legumes, nuts, leafy green vegetables	Large doses cause pain and numbness in the extremities
Vitamin B_{12} (cobalamin)	2.4 μg/d	2.4 μg/d	Protein and fat metabolism; forms red blood cells; maintains nervous system	Animal foods only—dairy products, meat, poultry, seafood	Stored in the liver; vegetarians must consume yeast or cereals with B_{12} added
Vitamin C	75 mg/d	90 mg/d	Antioxidant; maintains connective tissue	Many fruits and vegetables; leafy green vegetables, tomatoes, potatoes	
Folate (folic acid)	400 μg/d	400 μg/d	Coenzyme in metabolism; production of red blood cells	Most foods, fortified cereals, beans	Adequate amounts needed in pregnancy; low levels associated with neural tube defects
Choline (lecithin)	425 mg/d	550 mg/d	Component of cell membranes; component of acetylcholine—a neurotransmitter	All foods	Only important in people unable to consume food normally
Fat-Soluble Vitamins					
Vitamin A	700 μg/d	900 μg/d	Antioxidant; important in vision; maintains skin and intestinal lining	Orange, red, and leafy green vegetables, liver	Stored in liver; children have little stored; blindness results from lack of vitamin
Vitamin D	5 μg/d	5 μg/d	Needed to absorb calcium from gut; necessary for strong bones and teeth	Vitamin D fortified milk; exposure of skin to sunlight	Toxic in high concentrations
Vitamin E	15 mg/d	15 mg/d	Antioxidant; protects cell membranes	Whole grains, nuts, vegetables, vegetable oils	Only two cases of deficiency ever identified
Vitamin K	90 μg/d	120 μg/d	Blood clotting	Leafy green vegetables	Recommended for newborns

the benefits advertised are based on fragmentary evidence and lack a clearly defined mechanism of action. The consumption of high doses of vitamins is unwise, because megadoses of many vitamins are toxic. For example, fat-soluble vitamins, such as vitamins A and D, are stored in body fat and the liver and can reach such high levels that ill health results. Excess vitamin A causes joint pain, hair loss, and jaundice. Excess vitamin D results in calcium deposits in the kidneys, high

HOW SCIENCE WORKS 25.2

Preventing Scurvy

Scurvy is a nutritional disease caused by a lack of vitamin C in the diet. Vitamin C is essential to the formation of collagen, a fiberlike protein important in most tissues. The symptoms of scurvy include the poor healing of wounds; fragile blood vessels, resulting in bleeding; a lack of bone growth; and a loosening of the teeth.

Scurvy is not common today; however, in the past, many people on long sea voyages developed scurvy because their diets lacked fresh fruits and vegetables. This was such a common problem that the disease was often called sea scurvy. Excerpts from a letter by a Dr. Harness to the First Lord of the Admiralty of the British navy describe the practice of using lemons to prevent scurvy on British ships: *"During the blockade of Toulon in the summer of 1793, many of the ships' companies were afflicted with symptoms of scurvy; . . . I was induced to propose . . . the sending a vessel into port for the express purpose of obtaining lemons for the fleet; . . . and the good effects of its use were so evident . . . that an order was soon obtained from the commander in chief, that no ship under his lordship's command should leave port without being previously furnished with an ample supply of lemons. And to this circumstance becoming generally known may the use of lemon juice, the effectual means of subduing scurvy, while at sea, be traced."*

A common term applied to British seamen during this time was *limey*.

amounts of calcium in the blood, and bone pain. High doses of some of the water-soluble vitamins also have toxic effects: Vitamin B_6 (pyridoxine) in high concentrations causes symptoms related to the nervous system, such as unsteady gait and numbness in the hands. However, inexpensive multivitamins that provide 100% of the recommended daily allowance can prevent or correct deficiencies caused by a poor diet without the danger of toxic consequences. Most people do not need vitamin supplements *if they eat a well-balanced diet* (How Science Works 25.2).

The lack of a particular vitamin in the diet can result in a **vitamin-deficiency disease.** Vitamin-deficiency diseases that show recognizable symptoms are extremely rare, except in countries with extreme food emergencies. Since vitamin A is necessary for vision, vitamin A deficiency is a leading cause of preventable blindness in children in developing countries. Night blindness is another manifestation of a lack of vitamin A.

Minerals

Minerals are elements found in nature that cannot be synthesized by the body. Table 25.3 lists the sources and functions of several common minerals. Because minerals are elements, they cannot be broken down or destroyed by metabolism or cooking. They commonly occur in many foods and in water.

Functions of Minerals

Minerals retain their characteristics whether they are in foods or in the body, and each plays a different role in metabolism. Minerals can function as regulators, activators, transmitters, and controllers of various enzymatic reactions. For example, sodium (Na^+) and potassium ions (K^+) are involved in maintaining the polarity of cell membranes and are important in the transmission of nerve impulses, whereas magnesium ions (Mg^{++}) facilitate energy release during reactions involving ATP. Without iron, not enough hemoglobin would be formed to transport oxygen, a condition called *anemia*, and a lack of calcium may result in *osteoporosis*. **Osteoporosis** is a calcium-deficiency disease in older adults that is tied to diet. Persons with this disease lose bone mass; their bones become more brittle and subject to fracture. The body needs calcium to maintain bone, so many adults take calcium supplements. However, calcium alone does not prevent osteoporosis. Bone strength is directly related to the amount of stress placed on the bone. Therefore, exercise is extremely important to assure that calcium will be incorporated into bones and improve their strength. Folic acid and other B vitamins may also help in preventing osteoporosis. Many minerals are important in the diet. In addition to those just mentioned, we need chlorine, cobalt, copper, iodine, phosphorus, sulfur, and zinc to remain healthy. With few exceptions, adequate amounts of minerals are obtained in a normal diet. Calcium and iron supplements may be necessary, however, particularly in women.

How the Body Manages Minerals

Many minerals such as sodium, potassium, and chloride are balanced by having excess amounts excreted in the urine. Minerals such as calcium and phosphorus are part of the structure of bone. These sources can be mobilized if the diet is low in these minerals, with the consequence of weakened bones. Pregnant and nursing mothers need to supplement their calcium intake to prevent bone loss. The body stores some iron bound to the protein ferritin in the liver, bone marrow, and spleen.

TABLE 25.3 Sources and Functions of Minerals

Name	Recommended Daily Intake for Young Adults: Women	Recommended Daily Intake for Young Adults: Men	Physiological Value	Readily Available Sources	Other Information
Sodium	Less than 1,500 mg/d	Less than 1,500 mg/d	Maintains cell membrane ionic balance; osmotic balance	Present in most foods, table salt	Most people get much more than needed; high levels associated with high blood pressure; people should restrict their intake to less than 1,500 mg/d
Potassium	4,700 mg/d	4,700 mg/d	Maintains cell membrane ionic balance	Banana, legumes, potato skins, tomato	Low amounts lead to acute nervous system, muscular system, and cardiac problems
Calcium	1,000 mg/d	1,000 mg/d	Builds bones and teeth; blood clotting; muscle contraction	Dairy products, leafy green vegetables	Children need 1,300 mg/d to support bone growth; vitamin D needed for calcium absorption
Iron	18 mg/d	8 mg/d	Necessary to make hemoglobin	Meats, leafy green vegetables, seafood, legumes	Because of menstruation women need more than men; pregnant women need twice the normal dose
Phosphorus	700 mg/d	700 mg/d	Maintains acid/base balance; enzyme cofactor; component of bones and teeth	All foods	Most people get more than needed; children need 1,250 mg/d to support bone growth
Magnesium	310 mg/d	400 mg/d	Coenzyme; necessary for bone mineralization; muscle and nerve function	Leafy green vegetables, whole grains, legumes	Found in chlorophyll
Selenium	55 µg/d	55 µg/d	Involved in many enzymatic reactions	Meat, grains, seafood	Toxic in high doses
Zinc	8 mg/d	11 mg/d	Involved in many enzymatic reactions; wound healing; fetal development	Whole grains, beans, meat, fish, poultry	Toxic in high doses
Copper	900 µg/d	900 µg/d	Involved in many enzymatic reactions; involved in iron metabolism	Liver, poultry, shellfish, legumes, whole grains	Toxic in high doses

Water

Water is crucial to all life and plays many essential roles. Humans can survive weeks without food but would die in a matter of days without water. It is known as the universal solvent, because so many types of molecules are soluble in it. The human body is about 65% water. Even dense bone tissue consists of 33% water. All the chemical reactions in living things take place in water. It is the primary component of blood, lymph, and body tissue fluids. Inorganic and organic nutrients and waste molecules are also dissolved in water.

Dissolved inorganic ions, such as sodium (Na^+), potassium (K^+), and chloride (Cl^-), are electrolytes because they form a solution capable of conducting electricity. The concentration of these ions in the body's water must be regulated to prevent electrolyte imbalances.

Excesses of many types of waste are eliminated from the body dissolved in water; that is, they are excreted from the kidneys as urine or in small amounts from the lungs or skin through evaporation. In a similar manner, the evaporation of water from the skin cools the body. Water molecules are also essential reactants in all the various hydrolytic reactions of metabolism. Without it, the breakdown of molecules such as starch, proteins, and lipids would be impossible. With all these important roles played by water, it's no wonder that nutritionists recommend that we drink the equivalent of at least eight glasses each day. This amount of water can be obtained from tap water, soft drinks, juices, and numerous food items, such as lettuce, cucumbers, tomatoes, and applesauce.

25.2 CONCEPT REVIEW

4. Why are some nutrients referred to as *essential*? Name them.
5. List the six main classes of nutrients as described by nutritionists. Describe the chemical nature of each and give one function of each class of nutrient.

25.3 Dietary Reference Intakes

The U.S. Department of Agriculture (USDA) regularly publishes updated guidelines for maintaining good nutritional health. The current guidelines, the **Dietary Reference Intakes,** provide information on the amounts of certain nutrients various members of the public should receive. These daily guidelines are very detailed. There are different guidelines for children, men, and women by age group. There are also specific guidelines for pregnant and nursing mothers. There are also guidelines about the maximum amount of certain nutrients that people should get.

Dietary Reference Intakes are used when preparing product labels. By law, labels must list ingredients from the greatest to the least in quantity. In addition to carbohydrates, fats, proteins, and fiber, about 25 vitamins and minerals have Dietary Reference Intakes. Table 25.4 gives examples of some of the more common nutrients and their reference amounts for young adults.

25.3 CONCEPT REVIEW

6. How much of each of the following nutrients should you get each day: iron, calcium, protein, and fiber?

25.4 The Food Guide Pyramid

Using Dietary Reference Intakes and product labels or counting Calories is a complicated way to plan a diet. Planning a diet around basic food groups is generally easier. The USDA's **Food Guide Pyramid** is a tool for planning a nutritious diet (figure 25.7). The basic philosophy of the Food Guide Pyramid is to provide simple, understandable recommendations that, when followed, will provide adequate amounts of the different kinds of nutrients. Furthermore, it is designed to limit the consumption of nutrients that can be harmful to health to acceptable levels. It also provides guidelines about exercise. The color and width of the bands refers to food groups and servings at one of many Calorie levels based on age, sex, and activity level. Go to www.pyramid.gov. Select MyPyramid Plan, type in your age, sex, height, weight, and typical physical activity to get a dietary plan that is designed for your specific needs.

Grains

Grains include vitamin-enriched or whole-grain cereals and products such as breads, bagels, buns, crackers, dry and cooked cereals, pancakes, pasta, and tortillas. Most of the items in this group are dry and seldom need refrigeration. Whole-grain foods contain many more nutrients (particularly vitamins and dietary fiber) than do products made with refined flours. Refined flours are made from grains but have had the outer hulls removed. What remains after the hull is removed is essentially starch. Half of the foods consumed from this group should be whole-grain products. National studies show that nearly 100 percent of the United States population consumes more refined grains than recommended.

Cereal group

The Food Guide Pyramid recommends that women consume 6 oz a day and men consume 8 oz a day of foods made from grains. One oz is equal to about one slice of bread or half a bagel. Grains should provide most of the energy (Calories) in the diet. Furthermore, they provide energy in the form of complex carbohydrates, such as starch, which is the main ingredient in most grain products. These foods help satisfy the appetite, and many are very low in fat. They also provide fiber, which assists in the proper functioning of the digestive tract. Foods high in fiber are also a source of several vitamins and minerals.

Significant nutritional components of grains are complex carbohydrate (starch), dietary fiber, several B vitamins, vitamin E, and the minerals iron and magnesium.

Fruits

The separation of plant foods into fruits and vegetables is sometimes confusing. Is a tomato a vegetable or a fruit? The confusion arises from the fact that the term *vegetable* is not scientifically precise but for nutritional purposes

TABLE 25.4 Dietary Reference Intakes for Some Common Nutrients

Nutrient	Women, 19–30 Years Old	Men, 19–30 Years Old	Maximum, Persons 19–30 Years Old	Value of Nutrient
Carbohydrates	130 g/day (45–65% of Calories)	130 g/day (45–65% of Calories)	No maximum set but refined sugars should not exceed 25% of total Calories	A source of energy
Proteins	46 g/day (10–35% of Calories)	56 g/day (10–35% of Calories)	No maximum but high-protein diets stress kidneys	Proteins are structural components of all cells; there are 10 essential amino acids that must be obtained in the diet
Fats	20–35% of Calories	20–35% of Calories	Up to 35% of total Calories	Energy source and building blocks for many molecules needed
Saturated and *trans* fatty acids	As low as possible	As low as possible	Less than 10% of Calories	
Linoleic acid	12 g/day	17 g/day	No maximum set	Essential fatty acid needed for enzyme function and maintenance of epithelial cells
Linolenic acid	1.1 g/day	1.6 g/day	No maximum set	Essential fatty acid needed to reduce coronary heart disease
Cholesterol	As low as possible	As low as possible	Less than 300 mg/day	None needed, because the liver makes cholesterol
Water	2.7 liters/day	3.7 liters/day	No maximum set	
Total fiber	28 g/day	34 g/day	No maximum set	Improve gut function
Calcium	1 g/day	1 g/day	2.5 g/day	Needed for the structure of bones and many other functions
Iron	18 g/day	8 g/day	45 g/day	Needed to build the hemoglobin of red blood cells
Sodium	1.5 g/day	1.5 g/day	2.3 g/day (most people exceed this limit)	Needed for normal cell function
Vitamin A	700 μg/day	900 μg/day	3,000 μg/day	Maintains skin and intestinal lining
Vitamin C	75 mg/day	90 mg/day	2,000 mg/day	Maintains connective tissue and skin
Vitamin D	5 μg/day	5 μg/day	50 μg/day	Needed to absorb calcium for bones

generally means a plant material that is not sweet and is eaten during the main part of a meal. *Fruit*, on the other hand, is a botanical term for the structure produced from the female part of the flower that contains the seeds. Although botanically green beans, peas, and corn are all fruits, nutritionally speaking they are placed in the vegetable category, because they are generally eaten during the main part of a meal. From a nutritional point of view, fruits include such sweet plant products as melons, berries, apples, oranges, and bananas. The Food Guide Pyramid recommends 1 to 2 cups of fruit per day, depending on age. Only about 25 percent of the U. S. population consumes the minimum recommended amount of fruit. However, because fruits tend to be high in natural sugars, the consumption of large

Exercise Guidelines
What is included?
Activity above normal daily activities
Daily recommendation:
Minimum: 30 minutes of moderate exercise/day
What is moderate exercising?
Brisk walking ($3\frac{1}{2}$ miles/hour)
Hiking
Golf/walking
Gardening/yardwork
Bicycling (less than 10 miles/hour)
Other important factors
More than 30 minutes/day provides additional health benefits.

Grains
What is included?
Products made from grains—rice, wheat, corn, oats
Daily recommendation:
Young adult males: 8 oz
Young adult females: 6 oz
What is an oz?
$\frac{1}{2}$ cup of cooked cereal, rice, or pasta
1 cup dry cereal
1 tortilla, pancake, slice of bread
$\frac{1}{2}$ bagel, English muffin
Other important factors
Half of intake should be from whole grains.

Vegetables
What is included?
Fresh or cooked, vegetables, vegetable juice, dry beans and peas
Daily recommendation:
Young adult males: 3 cups
Young adult females: $2\frac{1}{2}$ cups
What is a cup?
1 cup of raw or cooked vegetables
1 cup of vegetable juice
2 cups of raw leafy green vegetables
Other important factors
On a weekly basis, you should eat some
Dark green, leafy vegetables
Orange vegetables
Starchy vegetables—corn, potatoes
Dry beans or peas
Other vegetables

Fruits
What is included?
Fresh, cooked, or dried fruit or fruit juice
Daily recommendation:
Young adult males: 2 cups
Young adult females: 2 cups
What is a cup?
1 cup of fruit or 100% fruit juice
$\frac{1}{2}$ cup of dried fruit
Other important factors
Fruit drinks are not fruit juice.

Oils
What is included?
Vegetable oils; oils from nuts and fish
Daily recommendation:
Young adult males: 7 teaspoons
Young adult females: 6 teaspoons
Other important factors
Most people get much more fat and oil in their diet than recommended.
Avoid saturated fats, which are solid and trans fat.
Palm kernel oil and coconut oil are high in saturated fats.

Meat and Beans
What is included?
Meat, poultry, fish, shellfish
Dry beans, and peas
Nuts, and seeds
Eggs
Daily recommendation:
Young adult males: $6\frac{1}{2}$ oz
Young adult females: $5\frac{1}{2}$ oz
What is an oz?
1 oz of meat, poultry, fish
$\frac{1}{2}$ oz of nuts or seeds
$\frac{1}{4}$ cup of dry beans or peas
1 egg
Other important factors
Most people exceed these daily recommendations.
Eat a variety of products from this group.
Meats are often high in saturated fats.
Some fish and nuts have essential fatty acids.

Milk
What is included?
Milk, cheese, yogurt, ice cream, frozen yogurt
Daily recommendation:
Young adult males: 3 cups
Young adult females: 3 cups
What is a cup?
1 cup of milk or yogurt
$1\frac{1}{2}$ oz cheese
2 cups of cottage cheese
$1\frac{1}{2}$ cups of ice cream
Other important factors
Choose no-fat or low-fat milk products whenever possible.

U.S. Department of Agriculture
Center for Nutrition Policy and Promotion
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CNPP-15

FIGURE 25.7 **The Food Guide Pyramid**
The Food Guide Pyramid suggests that we eat certain amounts of five food groups while decreasing our intake of fats and sugars. This guide simplifies menu planning and helps us ensure that we get all the recommended amounts of basic nutrients. In order to be healthy, exercising on a regular basis is also essential.


Fruits group

amounts of fruits can add a significant number of Calories to the diet. In addition to cellulose in the cell walls, fruits contain many other kinds of indigestible complex carbohydrates that are important as dietary fiber.

Significant nutritional components of fruits are carbohydrate (sugars), dietary fiber, water, minerals such a potassium, and vitamin C.

Vegetables

Vegetables include nonsweet plant materials, such as broccoli, carrots, cabbage, corn, green beans, tomatoes, potatoes, lettuce, and spinach. The Food Guide Pyramid suggests 4 1/2 cups be eaten from this group each day for those who need 2,000 calories to maintain their weight and health. A cup is considered 1 cup of raw, leafy vegetables or 1/2 cup of other types. There is increasing evidence that cabbage, broccoli, and cauliflower can provide some protection from certain types of cancers. This is a good reason to include these foods in your diet. National studies indicate that most Americans do not consume at least the minimum recommended quantities of vegetables for their age and sex.


Vegetables group

Vegetables are the primary source of many vitamins. Because different vegetables contain different kinds and amounts of vitamins, you should include many different kinds in your diet. In particular you should include some from each of the following kinds: leafy, dark green vegetables (lettuce, kale, "greens," spinach, chard, etc.); orange vegetables (carrots, squash, sweet potatoes, pumpkin, yams, etc.); dry beans or peas; starchy vegetables (potatoes, green peas, lima beans, corn, etc.); other kinds of vegetables (cucumbers, celery, tomatoes, green beans, turnips, cabbage, egg plant, etc.). Vegetables—particularly those that are eaten raw—provide dietary fiber, which assists in the proper functioning of the digestive tract.

Significant nutritional components of vegetables are carbohydrate; fiber; several B vitamins; vitamins A, C, E, and K; and the minerals potassium, iron, and magnesium.

Milk

All of the cheeses, ice cream, yogurt, and milk are in this group. Two to 3 cups, depending on age, are recommended each day. One and one-half ounces of hard cheese is equivalent to a cup. Product labels state the appropriate serving size of individual items. Vitamin D–fortified dairy products are the primary dietary source of vitamin D. Remember that many cheeses contain large amounts of cholesterol and fat per serving. Low-fat dairy products are now recommended in the pyramid and are becoming increasingly common as manufacturers seek to match their products with the public's desire for less fat in the diet.

Dairy group

Significant nutritional components of milk are protein, carbohydrate, fat, several B vitamins, vitamin D, and the minerals calcium and potassium. Some milk has vitamin A added.

Meat and Beans

This group contains most of the things we eat as a source of protein—for example, beef, chicken, fish, nuts, beans, peas, tofu, and eggs. Recall that daily protein intake is essential, because protein is not stored in the body, as are fats and carbohydrates, and that the body cannot manufacture the 10 essential amino acids, so they must be included in the diet. Animal proteins are complete proteins. The Food Guide Pyramid recommends 5.5–6.5 oz of protein per day for young adults. This means that one small hamburger meets about half of your daily needs. Most people eat many times what they need.


Meat group

Because many sources of protein also contain significant amounts of fat, and health recommendations suggest reducing our fat intake, more attention is being paid to the quantity of the protein-rich foods in the diet. Beans (except for the oil-rich soybean) are excellent sources of protein without unwanted fat. Food selection and preparation are also important in reducing fat consumption. Selecting foods that have less fat, broiling rather than frying, and removing the fat before cooking all reduce fat in the diet. For example, most of the fat in chicken and turkey is attached to the skin, so removing the skin removes most of the fat.

Since the body cannot store protein, any protein consumed above what is needed to replace lost proteins is metabolized to provide energy. Eating excessive amounts of protein, however, can stress the kidneys by causing higher concentrations of calcium in the urine, can increase the demand for water to remove toxic keto acids produced from the breakdown of amino acids, and can lead to weight gain because of the intake of fat normally associated with many sources of protein.

Vegetarians must pay particular attention to acquiring adequate sources of protein, because they have eliminated a major source from their diet. They can get all the essential amino acids if they eat proper combinations of plant materials. Although nuts and soybeans are high in protein, they should not be consumed in large quantities because they are also high in fats.

Significant nutritional components of this food group are protein, fat, several B vitamins, vitamin E from seeds and nuts, and the minerals iron, zinc, and magnesium. Fish in the diet provides essential fatty acids.

Oils

The oils group includes canola, corn, olive, and sunflower oils, which are used in cooking. Some oils, such as olive, sesame, and walnut, are used to flavor foods. Small amounts of oils are important in the diet, because certain essential fatty acids cannot be manufactured by the body and must be obtained in the diet. However, because oils are fats, they have a high Caloric content. Most oils are high in monounsaturated or polyunsaturated fats and low in saturated fats. Plant oils do not contain cholesterol. Mayonnaise, some salad dressings, and soft margarine are almost entirely made of oils.

Oils group

The Food Guide Pyramid recommends that for an adult, total fat intake should be between 20 and 35% of total Calories consumed daily. Most fats should be polyunsaturated and monounsaturated fatty acids, from fish, nuts, and vegetable oils. For most people this is equivalent to about 6 to 7 teaspoons of oil per day. Other recommendations are that saturated fats, trans fats, and cholesterol be as low as possible. Saturated fats come from animals and include butter, beef fat (suet), chicken fat, and pork fat (lard). Saturated fats and cholesterol are associated with the consumption of animal products, so choosing lean meats and cooking to remove fat are important for reducing total fat consumption. Unsaturated fats can be made into saturated fats by adding hydrogen (hydrogenated). When this occurs, an oil (unsaturated fat) is converted to a saturated fat. When oils are hydrogenated some of the fats are converted to trans fats. Margarine and shortening are examples of hydrogenated oils.

A few plant oils, such as coconut and palm oil, are high in saturated fats and have health effects similar to those of saturated fats from animal sources.

Significant nutritional components of oils are Calories, essential fatty acids, and vitamin E.

Exercise

Since over 65 percent of adult Americans are overweight and over 30 percent are obese, exercise is important to improving health. Therefore, exercise is included in the Food Guide Pyramid. Although it is not directly related to nutrition, the amount of exercise people get affects the number of Calories they can consume on a daily basis without gaining weight. Exercise has other health benefits as well. The pyramid recommends at least 30 minutes of moderate exercise per day; longer periods and more vigorous exercise have additional health benefits (Outlooks 25.1). Moderate exercise is that which elevates the heart rate significantly. Activities such as doing household chores or walking while shopping do not elevate heart rate and, therefore, do not count as moderate exercise. Moderate physical activities include walking briskly (about 3½ miles per hour), hiking, doing gardening/yard work, dancing, golf (walking and carrying clubs), bicycling (less than 10 miles per hour), and weight training (general light workout).

The Food Guide Pyramid includes a discussion of discretionary Calories. A basic plan for any nutritional program should be to match the Calories consumed with the Calories expended and thus maintain a desirable weight. People with very active lifestyles expend more Calories and, therefore, need to consume more Calories. These Calories can come from any of the food groups simply by eating more. Extremely active persons need to add concentrated sources of carbohydrates and fats to their diet. However, these fats should still be unsaturated fats. Table 25.5 lists the Calories required for persons involved in various activities.

25.4 CONCEPT REVIEW

7. Name the six basic food groups and give two examples of each.
8. Why has exercise been included in the Food Guide Pyramid?

25.5 Determining Energy Needs

Significant energy expenditure is required for muscular activity. However, even when the body is at rest, energy is required to maintain breathing, heart rate, and other normal body functions. The **basal metabolic rate (BMR)** is the rate at which the body uses energy when it is at rest. The basal metabolic rate of most people requires more energy than their voluntary muscular activity. Much of this energy is used to keep the body temperature constant. A true measurement of basal metabolic rate requires a measurement of oxygen used over a specific period under controlled conditions.

OUTLOOKS 25.1

Exercise: More than Just Maintaining Your Weight

The Food Guide Pyramid recommends 30 minutes of moderate exercise above normal daily activities. This might be a brisk walk at 3.5 miles/hour, golfing, bicycling (10 miles/hour), and hiking. Workouts such as weight lifting—or riding a cart while golfing—do not fall into this category. In addition to planned exercise, there are other ways to be active—such as taking the stairs instead of the elevator or escalator, parking at the far end of the lot when shopping, walking to the corner store instead of driving, or cutting the grass with a push mower instead of a riding mower.

When most people talk about exercise, they often focus on weight control. However, research in many diverse areas has revealed benefits that influence many aspects of a person's health. In addition to helping control weight, exercise:

- Increases the strength of muscles and general muscle tone
- Reduces the likelihood of injuries because of improved strength and balance
- Improves self-esteem and feelings of well-being
- Reduces feelings of depression and anxiety
- Helps control diabetes
- Strengthens heart muscle
- Improves cardiovascular health
- Lowers serum cholesterol
- Lowers blood pressure
- Improves sex life
- Strengthens bones and joints; bones respond to the stress placed on them by exercise by adding bone mass
- Improves flexibility
- Increases efficiency of the respiratory system
- Increases the efficiency of aerobic respiration in mitochondria
- Heightens the immune response to better protect against infection
- Increases endorphins in the brain to reduce pain threshold and increase pleasure sensation

TABLE 25.5 Typical Energy Requirements for Common Activities

Light Activities (120–150 Calories/hr)	Light to Moderate Activities (150–300 Calories/hr)	Moderate Activities (300–400 Calories/hr)	Heavy Activities (420–600 Calories/hr)
Dressing	Sweeping floors	Pulling weeds	Chopping wood
Typing	Painting	Walking behind a lawnmower	Shoveling snow
Slow walking	Walking 2–3 mi/hr	Walking 3.5–4 mi/hr on a level surface	Walking or jogging 5 mi/hr
Standing	Bowling	Golf (no cart)	Walking up hills
Studying	Store clerking	Doubles tennis	Cross-country skiing
Sitting activities	Canoeing 2.5–3 mi/hr	Canoeing 4 mi/hr	Swimming
	Bicycling on a level surface at 5.5 mi/hr	Volleyball	Bicycling 11–12 mi/hr or up and down hills

Several factors affect an individual's basal metabolic rate, including age, gender, height, weight, and fundamental differences in metabolism. Basal metabolic rates decline throughout life. Children have high basal metabolic rates and elderly people have low basal metabolic rates. In general, men have higher metabolic rates than women. The larger a person, the higher his or her metabolic rate. With all of these factors taken into account, most young adults fall into the range of 1,200 to 2,200 Calories per day for a basal metabolic rate.

Because few of us rest 24 hours a day, we normally require more than the energy needed for basal metabolism. One of these requirements is **specific dynamic action (SDA),** the amount of energy needed to process the food we eat. It is equal to approximately 10% of the total daily Caloric intake.

In addition to basal metabolic rate and specific dynamic action, the activity level of a person determines the number of Calories needed. This is known as voluntary muscular activity. A good general indicator of the number of Calories needed above

TABLE 25.6 Additional Calories as Determined by Occupation

Occupation	Calories Needed per Day Above Basal Metabolic Rate*
Sedentary (student)	500–700
Light work (businessperson)	750–1,200
Moderate work (laborer)	1,250–1,500
Heavy work (professional athlete)	1,550–5,000 and up

*These are general figures and will vary from person to person, depending on the specific activities performed in the job.

basal metabolic rate is the type of occupation a person has (table 25.6). Because most adults are relatively sedentary, they would receive adequate amounts of energy if women consumed 2,200 Calories and men consumed 2,900 Calories per day.

25.5 CONCEPT REVIEW

9. Define the terms *basal metabolic rate, specific dynamic action,* and *voluntary muscular activity.*

25.6 Eating Disorders

The three most common health problems related to diet and patterns of food consumption are obesity, bulimia, and anorexia nervosa. All three disorders involve behaviors that lead to ill health. The causes of these behaviors are complex and often involve a strong psychological component. Metabolic imbalances may also contribute to the development of these disorders, particularly obesity. Culture has a strong influence on our perceptions of ourselves and influences our behavior. Some studies have shown that there is a tendency for members of a family to develop the same kinds of eating disorders. Therefore, it has been suggested that genetic factors influence the risk of developing eating disorders. On the other hand, members of the same family also are likely to develop patterns of eating related to culture and other factors. Eating disorders are often associated with psychological depression.

Obesity

Obesity is the condition of being overweight to the extent that a person's health, quality of life, and life span are adversely affected (figure 25.8). Obesity occurs when people consistently take in more food energy than is necessary to meet their daily requirements. About 30% of the U.S. population is considered to be obese, based on their having a body mass index above 30 kg/m^2. An obese person has a significantly increased risk for many diseases. In general, the higher the body mass index, the more significant the risk.

FIGURE 25.8 Obesity
Obesity is a serious health problem for about 30% of North Americans.

Determining Body Mass Index (BMI)

Body mass index (BMI) is a measure of body weight compared with height. BMI is calculated by determining a person's weight (without clothing) in kilograms and their barefoot height in meters. The BMI is the weight in kilograms divided by height in meters squared:

$$\text{BMI} = \frac{\text{weight in kilograms}}{(\text{height in meters})^2}$$

(Appendix 1 of this book gives conversions to the metric system of measurements.) For example, a person with a height of 5 feet 6 inches (1.68 meters) who weighs 165 pounds (75 kilograms) has a body mass index of 26.6 kg/m^2:

$$\text{BMI} = \frac{\text{kg}}{\text{m}^2} = \frac{75\text{ kg}}{(1.68\text{ m})^2} = \frac{75\text{ kg}}{2.82\text{ m}^2} = 26.6\text{ kg/m}^2$$

A person with a body mass index of less than 18.5 kg/m^2 is considered to be underweight. A body mass index between 18.5 and 25 kg/m^2 is considered a healthy weight; between 25 and 30 kg/m^2 overweight; and over 30 kg/m^2 is considered obese. Figure 25.9 allows you to determine what weight category you are in.

Contributing Causes to Obesity

While all obese people have an imbalance between their food intake and their energy expenditure, the reasons for this imbalance are complex and varied. It appears that for most people, the imbalance is related to culture and lifestyle, although for some there are underlying biological reasons as well.

1. *Cultural Influences* Our culture encourages food consumption. Social occasions and business meetings frequently involve eating. It is clear that these and other cultural factors have much to do with the incidence of

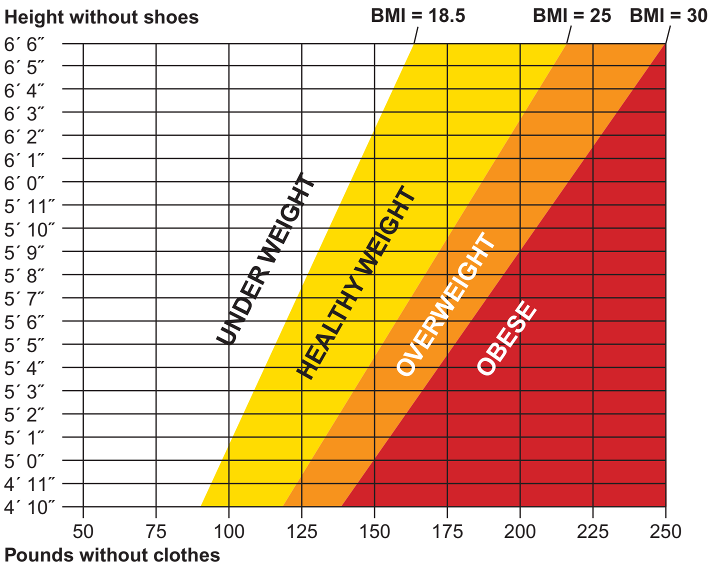


FIGURE 25.9 **Body Mass Index**
This graph allows you to determine which body mass index category you fall into.

obesity. For example, obesity rates have increased over time, which strongly suggests that most cases of obesity are due to changes in lifestyle, not inherent biological factors. Furthermore, immigrants from countries with low rates of obesity show increased rates of obesity when they integrate into the American culture.

Snack foods are an important cultural influence. Snack foods typically have high amounts of sugars and fats. Consumption of these foods at other than meal times increases the total number of Calories consumed during the day. Furthermore, many of these foods are said to provide "empty Calories"—Calories are provided by sugar or fat but there is little or no other nutritional benefit (protein, vitamins, minerals, or fiber).

Restaurants play a role. Less than half the meals consumed in the United States are prepared in the home. This means that the consumer has reduced choices in the kind of food available, no control over the way foods are prepared, and little control over serving size. Meals prepared in restaurants and fast-food outlets emphasize meat and minimize the fruit, vegetable, and cereal portions, in direct contradiction to the Food Guide Pyramid. The methods of preparation also typically involve cooking with oils and serving with dressings or fat-containing condiments. In addition, portion sizes are generally much larger than recommended. Furthermore, restaurants and other food preparers have increased the size of portions significantly over the past 50 years. For example, in the 1950s, a fast-food serving of French fries was 2.4 ounces. Today, that size is still available, but it is the small size, and medium and large sizes contain two to three times the quantity of the small size.

An inactive lifestyle contributes to the incidence of obesity. Often, exercise is all that is needed to control a weight problem. In addition to increasing metabolism during the exercise itself, exercise tends to raise the basal metabolic rate for a period of time following exercise.

2. *Psychological Factors* Overeating is associated with a variety of psychological factors. Eating is a pleasurable activity and, as with all pleasurable activities, it is sometimes difficult to determine when to stop. Conversely, overeating also is often associated with depression.
3. *Genetic and Metabolic Differences* Recent discoveries of genes in mice suggest that there are genetic components that contribute to obesity. In one study, mice without a crucial gene gained an extraordinary amount of weight. There may be similar genes in humans. It is also clear that some people have much lower metabolic rates than most of the population and, therefore, need much less food than is typical. Still other obese individuals have a chemical imbalance of the nervous system that prevents them from feeling "full" until they have eaten an excessive amount of food. This imbalance prevents the brain from turning off the desire to eat. Research into the nature and action of this brain chemical indicates that, if obese people lacking this chemical receive it in pill form, they can feel "full" even when their food intake is decreased by 25% (Outlooks 25.2).

Dealing with Obesity

Weight control is a matter of balancing the Calories ingested with the Calories expended by normal daily activities and exercise. The Food Guide Pyramid is clearly designed to provide information that will aid people in maintaining an appropriate weight.

Medical advice is important in dealing with obesity. Although it is likely that most cases of obesity do not involve underlying medical causes, it is wise to rule out that possibility before beginning a program to deal with obesity. Health practitioners are changing their view of obesity from one of blaming the obese person for lack of self-control to one of treating the condition as a chronic disease that requires a varied approach to control. For most people, dietary counseling and increased exercise are all that is needed, but some need psychological counseling, drug therapy, or surgery. Regardless, controlling obesity can be very difficult because it requires basic changes in a person's eating habits, lifestyle, and value system.

Diet plans provide many different approaches to managing one's diet to maintain an appropriate weight. Not all of these plans are the same, and not all are suitable to a particular situation. Some of these are based on solid nutritional and biological research while others are not. If a diet plan is to be valuable in promoting good health, it must satisfy a person's needs in several ways. It must provide Calories and the nutrients important to good health. It should also contain readily available foods from all the basic food groups, and it should provide enough variety to prevent the person from becoming bored. In the final analysis, it should change how he or she eats.

OUTLOOKS 25.2

The Genetic Basis of Obesity

Advances have been made in identifying the genetic and biochemical factors that regulate body weight. While not yet fully understood, a person's ability to regulate food intake and control body weight is at least partly controlled by the actions of several genes.

The molecules produced by these genes are messengers that control the flow of information between the stomach and nerve cells in a portion of the brain called the *hypothalamus*. This flow of information controls the appetite—whether one is hungry or not depends on how these cells are stimulated. Several molecules are involved in this control:

1. *Leptin* is a hormone produced by white fat tissue; it is the product of the *ob* gene (formerly called the "*ob*esity" gene). Leptin acts on nerve cells in the brain to regulate food intake. The *absence* of leptin causes severe obesity; the presence of leptin suppresses the appetite center of the brain. As a person's weight increases, the additional fat cells increase the production of leptin. In animals, the increase in leptin signals the brain to send signals that cause the animal to eat less and the body to do more. In humans, however, this does not appear to be the case, because many obese people have high levels of leptin and no suppression of appetite.
2. *Neuropeptide Y (NPY)* is a small protein that increases appetite. Leptin's appetite-suppressing effects may be due to the fact that leptin can inhibit NPY.
3. *Alpha-melanocyte-stimulating hormone (α-MSH)*, which also increases production of the brown pigmentation of the skin, suppresses the appetite by acting on the hypothalamus. Leptin is believed to stimulate the production of α-MSH, which suppresses the appetite.
4. *Melanin-concentrating hormone (MCH)* is another neuropeptide. High levels of MCH in the brain increase food consumption and low levels decrease food consumption. Some believe that the smell of food may stimulate the production of MCH and enhance appetite. The gene for MCH is significantly more active in the brains of the obese.
5. *Ghrelin* is a growth hormone peptide secreted by the stomach. It has the opposite effect of leptin—it appears to be a powerful appetite stimulant.

Fad diets promise large, rapid weight loss but, in fact, may result only in temporary water loss. They may encourage eating and drinking foods that are diuretics, which increase the amount of urine produced and thus increase water loss. Or they may encourage exercise or other activities that cause people to lose water through sweating. Or they may simply encourage people to eat less for a period of time, which results in a temporary weight loss because there is less food in the gut.

Exercise should be a part of any program dealing with obesity. The health risks associated with being overweight or obese can be lessened by increasing one's *fitness*. **Fitness** is a measure of how efficiently a person can function both physically and mentally. A person with a BMI of 30 kg/m^2 may be more fit than someone with a BMI of 23 kg/m^2 if he or she is involved in a regular program of physical and mental exercise. As fitness increases, so does metabolism, strength, mental acuity, and coordination. The use of body mass index to assess healthy weights is based on the assumption that excess weight is the result of fat tissue. In most cases this is true. However, since muscle is more dense than fat, very muscular people may have a high BMI and fall into the overweight or obese category when, in fact, they may not be.

An exercise program can involve organized exercise in sports or fitness programs. It can also include simple lifestyle changes, such as walking up stairs rather than taking an elevator, parking at the back of the parking lot so you walk farther, riding a bike for short errands, and walking down the hall to someone's office rather than using the phone or e-mail.

Many people who initiate exercise plans as a way of reducing weight are frustrated because they initially gain weight rather than lose it. This is because a given volume of muscle weighs more than fat. Typically, they are "out of shape" and have low muscle mass. If they gain a pound of muscle at the same time they lose a pound of fat, they do not lose weight. However, if the fitness program continues, they will eventually stop increasing muscle mass and will lose weight. Even so, weight as muscle is more healthy than weight as fat.

Bulimia

Bulimia ("hunger of an ox") is a disease condition in which the person engages in a cycle of eating binges followed by fasting or purging the body of the food by inducing vomiting or using laxatives (figure 25.10). The following are behaviors typically shown by bulimics:

- Excessive preoccupation with body image
- Excessive preoccupation with exercise
- Going to the bathroom after meals (to vomit)
- Hiding the fact that they are eating
- The use of laxatives or diuretics
- Irregular eating habits

Many bulimics also use diuretics, which cause the body to lose water, resulting in the loss of weight. A bulimic person may induce vomiting physically or by using nonprescription drugs. Case studies have shown that some bulimics take 40 to 60 laxatives a day to rid themselves of food. For some, the laxatives become addictive.

Bulimics are usually of normal body weight or are overweight. Although women are more likely than men to become bulimic, there has been an increasing number of men with this disorder. The cause is thought to be psychological, stemming from depression or other psychological problems.

The binge-purge cycle and the associated use of diuretics and laxatives result in a variety of symptoms that can be deadly. It is often called the silent killer because it is difficult to detect. The following is a list of the major health problems observed in many bulimics:

- Excessive water loss
- Diminished blood volume
- Extreme mineral deficiencies
- Kidney malfunction
- Increased heart rate
- Loss of rhythmic heartbeat
- Lethargy
- Diarrhea
- Severe stomach cramps
- Damage to teeth and gums
- Loss of body proteins
- Migraine headaches
- Fainting spells

Anorexia Nervosa

Anorexia nervosa (figure 25.11) is a nutritional deficiency disease characterized by severe, prolonged weight loss as a result of a voluntary severe restriction in food intake. It is most common among adolescent and preadolescent women. An anorexic person's fear of becoming overweight is so intense that, even though weight loss occurs, it does not lessen the fear of obesity, and the person continues to diet, even refusing to maintain the optimum body weight for his or her age, sex, and height. Persons who have this disorder have a distorted perception of their bodies. They see themselves as fat when, in fact, they are starving to death. Society's preoccupation with body image, particularly

FIGURE 25.10 Bulimia
Persons with bulimia go on eating binges followed by fasting or activities to get rid of food such as inducing vomiting, using laxatives, or using diuretics.

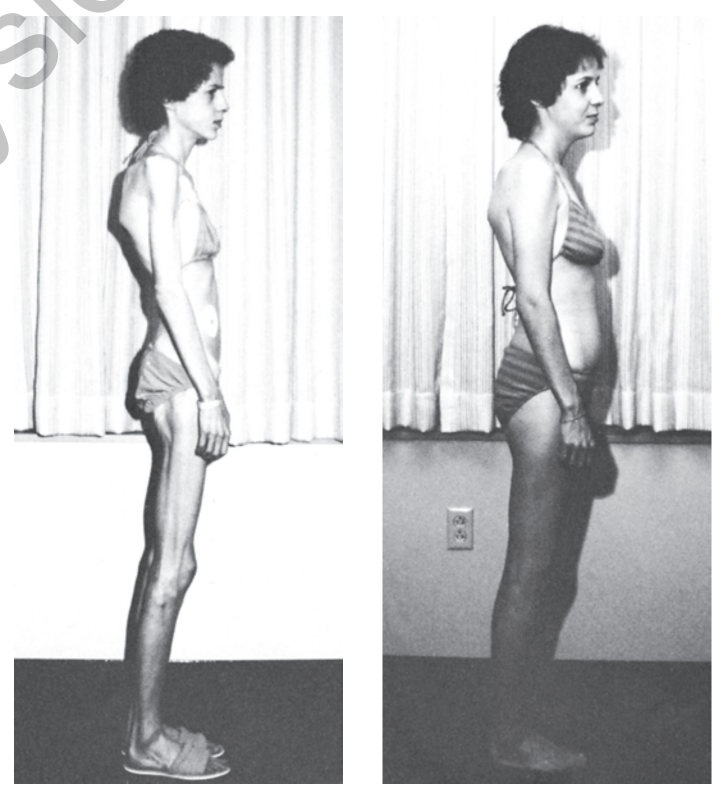


FIGURE 25.11 Anorexia Nervosa
Anorexia nervosa is a psychological eating disorder afflicting many Americans. These photographs were taken of an individual before and after treatment. Restoring a person with this disorder requires both medical and psychological efforts.

OUTLOOKS 25.3

Muscle Dysmorphia

A cousin to anorexia, *muscle dysmorphia* is an obsession with being muscular. Commonly called "big-orexia," it has been an under-diagnosed condition because, for men, being big is acceptable. Their muscles may be sculptured and bulging, yet no amount of persuasion can convince them their body is big enough. Those with this condition feel they are the objects of hate, resentment, fear, and loathing, and therefore must continue to "bulk up." To accomplish this, they exercise to the extreme and take anabolic steroids. Long-term use of these steroids, whether injectable or tablet form, can result in damage to the liver, heart, and muscles; raised cholesterol levels; mood swings; acne; enlarged breasts; and "'roid-rage." The common misconception about these steroids is that, when properly taken, they are safe. They are not.

among young people, may contribute to the incidence of this disease. Outlooks 25.3 describes an additional example of a problem with distorted body image. The following are some of the symptoms of anorexia nervosa:

- Thin, dry, brittle hair
- Degradation of fingernails
- Constipation
- Amenorrhea (lack of menstrual periods)
- Decreased heart rate
- Loss of body proteins
- Weaker than normal heartbeat
- Calcium deficiency
- Osteoporosis
- Hypothermia (low body temperature)
- Hypotension (low blood pressure)
- Increased skin pigmentation
- Reduction in the size of the uterus
- Inflammatory bowel disease
- Slowed reflexes
- Fainting
- Weakened muscles

25.6 CONCEPT REVIEW

10. What is BMI? How is it calculated?
11. What are the three primary eating disorders?
12. What is the role of leptin in controlling appetite?

25.7 Nutrition Through the Life Cycle

Nutritional needs vary throughout life and are related to many factors, including age, sex, reproductive status, and level of physical activity. Infants, children, adolescents, adults, and the elderly all require essentially the same types of nutrients but have special nutritional needs related to their stage of life, requiring slight adjustments in the kinds and amounts of nutrients they consume.

Infancy

A person's total energy requirements per kilogram are highest during the first 12 months of life: 100 Calories per kilogram of body weight per day; 50% of this energy is required for an infant's basal metabolic rate. Infants triple their weight and increase their length by 50% during their first year; this is their so-called first growth spurt. Because they are growing so rapidly, they require food that contains adequate proteins, vitamins, minerals, and water. They also need food that is high in Calories. For many reasons, the food that most easily meets these needs is human breast milk (table 25.7). Even with breast milk's many nutrients, many physicians strongly recommend multivitamin supplements as part of an infant's diet.

Studies have shown that kids under the age of 2 are "self regulating" when it comes to food intake. They eat only the amount they need. However, as they enter childhood, other factors begin to affect diet and they are likely to follow the eating patterns of their family.

Childhood

As infants reach childhood, their dietary needs change. The rate of growth generally slows between 1 year of age and puberty, and girls increase in height and weight slightly faster than boys.

First growth spurt

TABLE 25.7 Comparison of Human Breast Milk and Cow's Milk*

Nutrient	Human Milk	Cow's Milk (whole milk)
Energy (Calories/1,000 grams)	690	660
Protein (grams per liter)	9	35
Fat (grams per liter)	40	38
Lactose (grams per liter)	68	49
Vitamins		
A (international units)	1,898	1,025
C (micrograms)	44	17
D (activity units)	40	14
E (international units)	3.2	0.4
K (micrograms)	34	170
Thiamin (B_1) (micrograms)	150	370
Riboflavin (B_2) (micrograms)	380	1,700
Niacin (B_3) (milligrams)	1.7	0.9
Pyridoxine (B_6) (micrograms)	130	460
Cobalamin (B_{12}) (micrograms)	0.5	4
Folic acid (micrograms)	41–84.66	2.9–68
Minerals (All in Milligrams)		
Calcium	241–340	1,200
Phosphorus	150	920
Sodium	160	560
Potassium	530	1,570
Iron	0.3–0.56	0.5
Iodine	200	80

*All milks are not alike. Each milk is unique to the species that produces it for its young, and each infant has its own growth rate. Humans have one of the slowest infant growth rates, and human milk contains the least amount of protein. Because cow's milk is so different, many pediatricians recommend that human infants be fed either human breast milk or formulas developed to be comparable to breast milk during the first 12 months of life. The use of cow's milk is discouraged. This table lists the relative amounts of the nutrients in human breast milk and cow's milk.

During childhood, the body becomes leaner and the bones elongate; the brain reaches 100% of its adult size between the ages of 6 and 10. To meet children's growth and energy needs adequately, protein intake should be high enough to take care of the development of new tissues. Minerals, such as calcium, zinc, and iron, as well as vitamins, are necessary to support growth and prevent anemia. Many parents continue to give their children multivitamin supplements, but this should be done only after a careful evaluation of their children's diets. Three groups of children are at risk for vitamin deficiency and should receive such supplements:

1. Children from deprived families and those suffering from neglect or abuse
2. Children who have anorexia nervosa or poor eating habits or who are obese
3. Children who are strict vegetarians

During childhood, eating habits are very erratic and often cause parental concern. Children often limit their intake of milk, meat, and vegetables while increasing their intake of sweets. To get around these problems, parents can provide calcium by serving cheeses, yogurt, and soups as alternatives to milk. Meats can be made more acceptable if they are in easy-to-chew, bite-sized pieces, and vegetables might be more readily accepted if smaller portions are offered on a more frequent basis. Steering children away from high-fat foods (e.g., french fries, potato chips) and sugar (e.g., cookies, soft drinks) by offering healthy alternatives can lower their risk for potential health problems. For example, sweets in the form of fruits can help reduce dental caries (*carrion* = rotten). Parents can better meet the dietary needs of children by making food available on a more frequent basis, such as every 3 to 4 hours. Obesity is an increasing problem among children. Parents sometimes encourage this by insisting that children eat everything served to them. Before the age of 2, most children automatically regulate the food they eat to an appropriate amount. After that age, parents should be concerned about both the kinds and the amounts of food children eat.

Adolescence

The nutrition of an adolescent is extremely important because, during this period, the body changes from nonreproductive to reproductive. Puberty is usually considered to last between 5 and 7 years. Before puberty, males and females have similar proportions of body fat and muscle. Both body fat and muscle make up between 15% and 19% of the body's weight. Lean body mass, primarily muscle, is about equal in males and females. During puberty, female body fat increases to about 23%, and in males it decreases to about 12%. Males double their muscle mass in comparison with females. The changes in body form that take place during puberty constitute the second growth spurt. Because of their more rapid rate of growth and unique growth patterns, males require more of certain nutrients than females (protein, vitamin A, magnesium, and zinc). During adolescence, youngsters gain as much as 20% of their adult height and 50% of their adult weight, and many body organs double in size. Nutritionists have taken these growth patterns and spurts into account by establishing Dietary Reference Intakes for males and females 10 to 20 years old, including requirements at the peaks of growth spurts. Dietary Reference Intakes at the peak of the growth spurt are much higher than they are for adults and children.

Adulthood

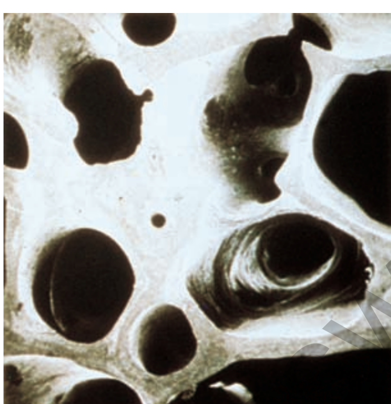
People who have completed the changes associated with adolescence are considered to have entered adulthood. During adulthood, the body enters a plateau phase, and diet and nutrition focus on maintenance and disease prevention. Nutrients are used primarily for tissue replacement and repair, and changes such as weight loss occur slowly. Because the BMR slows, as does physical activity, the need for food energy decreases from about 2,900 Calories in average young adult males (ages 20 to 40) to about 2,300 for elderly men. For women, the corresponding numbers decrease from 2,200 to 1,900 Calories. Protein intake for most U.S. citizens is usually in excess of the recommended amount. The Dietary Reference Intakes standard for protein is about 56 grams for men and 46 grams for women each day. About 25–50% should come from animal foods to ensure intake of the essential amino acids. The rest should be from plant-protein foods, such as whole grains, legumes, nuts, and vegetables.

Old Age

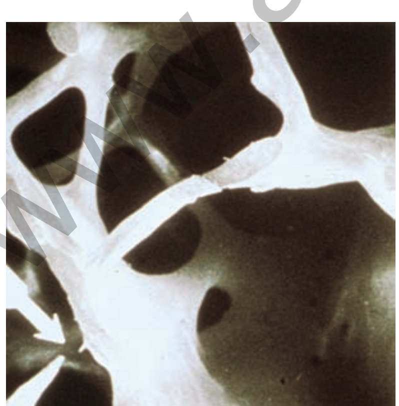
As people move into their sixties and seventies, the digestion and absorption of all nutrients through the intestinal tract slows down. The number of cells undergoing mitosis is reduced, resulting in an overall loss in the number of body cells. With age, complex organs, such as the kidneys and brain, function less efficiently, and protein synthesis becomes inefficient. With regard to nutrition, energy requirements for the elderly decrease as the BMR slows, physical activity decreases, and eating habits change.

The change in eating habits is significant, because it can result in dietary deficiencies. For example, linoleic acid, an essential fatty acid, may fall below required levels as an older person reduces the amount of food he or she eats. The same is true for some vitamins and minerals. Therefore, it may be necessary to supplement the diet daily with 1 tablespoon of vegetable oil. Vitamin E, multiple vitamins, or a mineral supplement may also be necessary. The loss of body protein means that people must be certain to meet their daily Dietary Reference Intakes for protein and participate in regular exercise to prevent muscle loss. As with all stages of the life cycle, regular exercise is important in maintaining a healthy, efficiently functioning body.

The two minerals that demand special attention are calcium and iron, especially for women. A daily intake of 1,200 milligrams of calcium should prevent calcium loss from bones (figure 25.12), and a daily intake of 15 milligrams of iron should allow adequate amounts of hemoglobin to be manufactured to prevent anemia in women over 50 and men over 60. In order to reduce the risk for chronic



(a) Normal bone



(b) Osteoporosis

(c) Bone breaks occur with osteoporosis

FIGURE 25.12 Osteoporosis *(a)* Healthy bone and *(b)* a section of bone from a person with osteoporosis. This calcium-deficiency disease results in a change in the density of the bones as a result of the loss of bone mass. Bones that have undergone this change look "lacy" or like Swiss cheese, with larger than normal holes. *(c)* A few risk factors associated with this disease are being female and fair-skinned; having a sedentary lifestyle; using alcohol, caffeine, and tobacco; and having reached menopause.

diseases such as heart attack and stroke, adults should eat a balanced diet, participate in regular exercise programs, control their weight, avoid tobacco and alcohol, and practice stress management.

Pregnancy and Lactation

The period of pregnancy and milk production (lactation) requires that special attention be paid to the diet to ensure proper fetal development, a safe delivery, and a healthy milk supply. Studies have shown that an inadequate supply of essential nutrients can result in infertility, spontaneous abortion, and abnormal fetal development.

The daily amount of essential nutrients must be increased, as should Caloric intake. Calories must be increased by 300 per day to meet the needs of an increased BMR; the development of the uterus, breasts, and placenta; and the work required for fetal growth. Some of these Calories can be obtained by drinking milk, which simultaneously supplies the calcium needed for fetal bone development. Women who cannot tolerate milk should consume supplementary sources of calcium. In addition, their protein intake should be at least 71 grams per day; however, as mentioned earlier, most people in developed countries consume much more than this per day. Two essential nutrients, folic acid and iron, should be obtained through prenatal supplements, because they are essential to cell division and the development of the fetal blood supply.

The mother's nutritional status affects the developing baby in several ways (figure 25.13). If she is under 15 years of age or has had three or more pregnancies in a 2-year period, her nutritional stores are inadequate to support a successful pregnancy. The use of drugs, such as alcohol, caffeine, nicotine, and "hard" drugs (e.g., heroin), can result in decreased nutrient exchange between the mother and fetus. In particular, heavy smoking can result in low birth weight, and alcohol abuse is responsible for *fetal alcohol syndrome (FAS)*. Children with FAS may show the characteristics such as: small size for their age, facial abnormalities, poor coordination, hyperactive behavior; learning disabilities; developmental disabilities (e.g., speech and language delays); mental retardation or low IQ.

FIGURE 25.13 Diet Is Important During Pregnancy
During pregnancy diet is extremely important. Whatever the mother eats can influence the development of the embryo. A healthy diet assures that the embryo will get the nutrients it needs. The use of drugs and alcohol during pregnancy can have severe effects on the developing embryo.

25.7 CONCEPT REVIEW

13. During which phase of the life cycle is a person's demand for Calories per unit of body weight the highest?
14. What changes need to be made to the diet of the elderly?
15. What changes should be made in the diet of pregnant and nursing mothers?

25.8 Nutrition for Fitness and Sports

Many people are very interested in the value of fitness and sports to a healthy lifestyle. Along with this, an interest has developed in the role nutrition plays in providing fuel for activities, controlling weight, and building muscle. The cellular respiration process described in chapter 6 is the source of the energy needed to take a leisurely walk or run a marathon. However, the specific molecules used to get energy depend on the length of the period of exercise, whether or not one warms up before exercise, and how much effort one exerts during exercise. The molecules respired by muscle cells to produce ATP may be glucose, fatty acids, or amino acids. Glucose is stored as glycogen in the muscles, liver, and some other organs. Fatty acids are stored as triglycerides in fat cells. Amino acids are found in small amounts in the blood. Which molecules are respired depends on the duration and intensity of exercise. Glucose from glycogen and fatty acids from triglycerides are typically the primary fuels. Amino acids provide 10% or less of a person's energy needs, even in highly trained athletes.

Conditioning includes many interrelated body adjustments in addition to energy considerations. Training increases the strength of muscles, including the heart, and increases the efficiency of their operation. Practicing a movement allows for the development of a smooth action, which is more energy-efficient than a poorly trained motion. As the body is conditioned, the number of mitochondria per cell increases, the Krebs cycle and the ETS run more efficiently, the number of capillaries increases, fats are respired more efficiently and for longer periods, and weight control becomes easier.

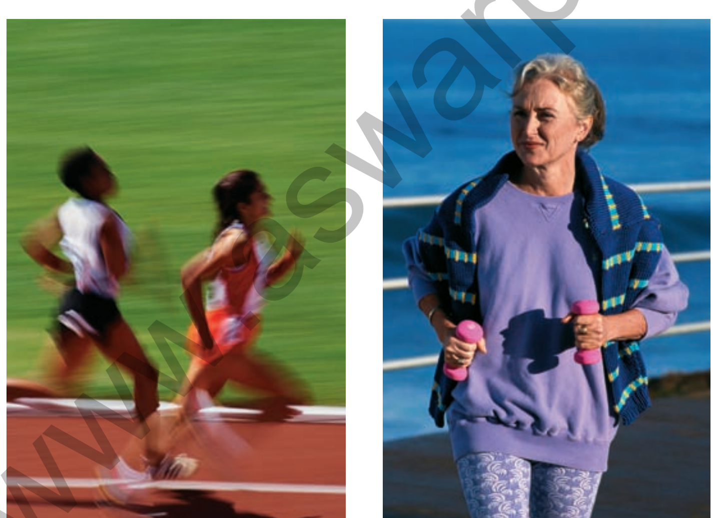
Anaerobic and Aerobic Exercise

Anaerobic exercise involves bouts of exercise that are so intense that the muscles cannot get oxygen as fast as they need it; therefore, they must rely on the anaerobic respiration of glucose to provide the energy needed. Activities such as weight-lifting or running short sprints are almost entirely anaerobic. During anaerobic respiration lactic acid builds up in muscles. The lactic acid is eventually transferred to the blood and delivered to the liver where it is metabolized. Following a bout of anaerobic exercise, one breathes rapidly for a period until the lactic acid is metabolized.

Aerobic exercise occurs when the level of exertion allows the heart and lungs to keep up with the oxygen needs of the muscles (figure 25.14).

Metabolic Changes During Aerobic Exercise

Most exercise programs encourage participants to do warm-up activities before beginning strenuous exercise. These activities serve several purposes. A primary function is to increase heart rate, which has several benefits. Blood is pumped more rapidly, resulting in more blood reaching the muscles. In addition, the capillaries in the muscles dilate so that more blood is able to flow through muscles. Finally, the warm-up exercise actually increases the temperature of the muscles, which makes them less stiff and also reduces the viscosity ("thickness") of the blood. All of these actions are important because they increase the flow of blood to muscles and allow the blood to supply oxygen efficiently to the muscles and increase the speed and power of muscular contraction. These activities also lead to an increased speed of nerve conduction and provide a psychological benefit to the athlete. Finally, the warm-up activities begin a metabolic shift toward breaking down glycogen in muscle to provide the energy for muscular activity.



Anaerobic Exercise Aerobic Exercise

FIGURE 25.14 Anaerobic and Aerobic Exercise
Sprinters are involved in anaerobic exercise—the runners cannot get enough oxygen to their muscles during the short race. Exercise walkers and joggers are involved in aerobic exercise—they are exercising at a rate that allows oxygen to get to muscles as fast as it is used up.

The body goes through several metabolic changes during aerobic exercise. For a short time at the beginning of exercise, anaerobic respiration provides the energy muscles need. As exercise continues, the body shifts to aerobic respiration as the circulatory system and respiratory system make adjustments to be able to supply oxygen to the muscles as fast as it is used. This metabolic shift is often experienced as a "second wind." The athlete experiences a period of "shortness of breath" at the beginning of exercise that disappears with the switch to aerobic respiration. This is particularly true if he or she did no warm-up activities.

There are shifts even after the body has switched to aerobic exercise. Initially the energy supplied to muscles comes from glycogen stored in the muscles. As the period of activity increases, there is another metabolic shift in which fats (triglycerides) begin to be metabolized. Fatty acids released into the blood from fat cells begin to be used to provide some of the energy. (A small amount of protein is also metabolized, particularly if the exercise is of long duration.) At this point both glycogen and fats are being used to supply energy. The balance between glycogen and fat metabolism shifts toward fat metabolism the longer the exercise continues. This is why moderate, longer periods of exercise are most beneficial in weight loss. Eventually, if the exercise continues for long enough, the body's store of glycogen is exhausted and the athlete experiences a debilitating fatigue known as "hitting the wall." This occurs because glucose is not available in high enough quantities.

After a period of exercise it is recommended that people engage in cool-down activities that allow the body to return slowly to a resting state. These activities generally involve 5 to 10 minutes of jogging or walking accompanied by stretching exercises. This allows lactic acid and other metabolic waste products to be removed from muscles and metabolized or eliminated. The muscles involved in exercise had been receiving large amounts of blood, so they also need to return to a resting state. This involves reducing blood flow to the muscles and actually using the muscle contractions of the cool-down activities to squeeze veins to assist in the return of blood from the muscles. There is also a metabolic shift back to one that is less demanding of glycogen.

Diet and Exercise

Diet is an important adjunct to any exercise program. During exercise a primary concern is to take in adequate amounts of water. Water is important for two reasons: (1) Evaporation of water is a primary mechanism for preventing overheating of the body during exercise; and (2) loss of water during exercise also causes the viscosity of the blood to increase and makes the heart work harder to pump the "thicker" blood. A water loss of only 5% of body weight can decrease muscular activity by as much as 30%. Drinking tap water is the best way for most casual athletes to replace the water they lose. Sports drinks that contain salts

OUTLOOKS 25.4

Myths or Misunderstandings About Diet and Nutrition

Myth or Misunderstanding	Scientific Basis
1. Exercise burns calories.	1. Calories are not molecules, so they cannot be burned in the physical sense, but we do oxidize (burn) the fuels (carbohydrates, fats, and proteins) to provide the energy (measured in Calories) needed to perform various activities.
2. Active people who are increasing their fitness need more protein.	2. The amount of protein needed is very small—about 50 grams. Most people get many times the amount of protein required from their normal diet.
3. Vitamins supply energy.	3. Most vitamins assist enzymes in bringing about chemical reactions, some of which may be energy yielding, but they are not sources of energy.
4. Large amounts of protein are needed to build muscle.	4. A person can build only a few grams of new muscle per day. Therefore, consuming large amounts of protein will not increase the rate of muscle growth.
5. Large quantities (megadoses) of vitamins will fight disease, build strength, and increase the lifespan.	5. Quantities of vitamins that greatly exceed recommendations have not been shown to be beneficial. Large doses of some vitamins (e.g., vitamins A, D, and B_3) are toxic.
6. Protein supplements are more quickly absorbed than dietary protein and can build muscle faster.	6. There is adequate protein in nearly all diets. The supplements may be absorbed faster, but that does not mean that they are incorporated into muscle mass faster.
7. Vitamins prevent cancer, heart disease, and other health problems.	7. Vitamins are important to health. However, it is a gross oversimplification to suggest that the consumption of excess amounts of specific vitamins will prevent certain diseases. Many factors contribute to the causes of disease.

(electrolytes) and glucose may be helpful to those who lose a great deal of water during hot weather or prolonged exercise. The general rule is to replace the water you lose.

Individuals who are engaged in long bouts of exercise, such as long-distance running or cycling, need to take in additional Calories in the form of glucose. Because they are using up larger amounts of glycogen in their muscles, providing glucose during exercise can help them prolong their exercise. Some serious athletes practice *carbohydrate loading*. This practice involves consuming meals with large amounts of carbohydrates in the days before a competition. It has been demonstrated that when carbohydrate loading is coupled with training for endurance events, the amount of glycogen stored in the liver increases, allowing, the athlete to go longer before running out of glycogen.

Carbohydrates

The need for protein in an athlete's diet has also been investigated. An increase in dietary protein does not automatically increase strength, endurance, or speed. In fact, most Americans eat the 10% additional protein that athletes require as a part of their normal diets. The body uses the additional protein for many things, including muscle growth; however, increasing protein intake does not automatically increase muscle size. Only when there is a need is the protein used to increase muscle mass. Exercise provides that need. The body will build the muscle it needs to meet the demands placed on it. Vitamins and minerals operate in much the same way. No supplements should be required as long as the diet is balanced and complex (Outlooks 25.4 and 25.5).

25.8 CONCEPT REVIEW

16. How do anaerobic and aerobic exercise differ?
17. Describe what metabolic changes take place during prolonged exercise.
18. What is *carbohydrate loading?*
19. Describe the importance of water, carbohydrate, and protein in the diet of a typical healthy active person.

OUTLOOKS 25.5

Nutritional Health Products and Health Claims

Drug stores, supermarkets, health-food stores, and websites sell a wide variety of products that are not drugs but claim to provide benefits to health. Drugs must be proven to work as described and be safe. Nutritional health products are considered to be foods and manufacturers are not required to prove they function as described. There are three common categories of these products.

Dietary supplements are materials that are consumed by mouth that the manufacturer claims have beneficial health effects. These materials can be vitamins, minerals, plant materials, amino acids, enzymes, hormones, tissues, extracts of tissues, or a metabolite (any substance involved in metabolism). Manufacturers of dietary supplements are not allowed to make *specific* health claims ("Vitamin A prevents blindness.") but are allowed to make three general kinds of claims:

1. Health claims ("Improves immune system function." or "Consumption of folate may reduce birth defects.")
2. Structure/function claims ("Promotes bone and joint health." or "Calcium builds strong bones.")

   If the manufacturer makes a structure/function claim, it must provide the following disclaimer on the label. *This statement has not been evaluated by the FDA. This product is not intended to diagnose. treat, cure, or prevent any disease.*
3. Nutrient content claims ("High in fiber." or "Excellent source of lycopene.")

   Manufacturers do not need permission to produce and sell their products, but must determine for themselves that the product is not harmful and that the claims they make are not false or misleading. They do not need to provide any government agency with proof of their claims.

Probiotics are live microorganisms thought to be beneficial to health when consumed. There are suggestions that these microorganisms may inhibit harmful microbes, and thus relieve several kinds of intestinal problems (diarrhea, colitis). Probiotics are typically consumed in fermented foods such as yogurt, sauerkraut, pickled vegetables, or in capsules as dietary supplements. A common use of certain lactic acid bacteria is to alleviate symptoms of lactose intolerance.

Prebiotics are nondigestible food substances that are thought to support the growth of "good" bacteria in the gut. The most commonly described prebiotic is dietary fiber. Soluble fiber is thought to be best for the growth of beneficial bacteria.

Summary

To maintain good health, people must ingest nutrient molecules that can enter the cells and function in the metabolic processes. The proper quantity and quality of nutrients are essential to good health. Nutritionists have classified nutrients into six groups: carbohydrates, proteins, lipids, minerals, vitamins, and water. Energy for metabolic processes can be obtained from carbohydrates, lipids, and proteins and is measured in Calories. An important measure of the amount of energy required to sustain a human at rest is the basal metabolic rate. To meet this and all additional requirements, the U.S. Department of Agriculture (USDA) has established the Dietary Reference Intakes, recommended dietary allowances for each nutrient. The USDA publishes the Food Guide Pyramid, which places foods into the following categories: grains, fruits, vegetables, milk, oils, and meat and beans. It also provides recommendations about exercise. The goal of the Food Guide Pyramid is to provide easily understood guidelines that will help people develop a healthy diet and lifestyle.

Should there be metabolic or psychological problems associated with a person's normal metabolism, a variety of disorders can occur, including obesity, anorexia nervosa, and bulimia. As people move through the life cycle, their nutritional needs change, requiring a reexamination of their eating habits to maintain good health. Exercise is an important part of a healthy lifestyle. A person's diet may need to be adjusted to support the level of exercise he or she maintains. For most people, the most important nutritional need associated with exercise is water to replace that lost through sweating. Serious athletes often require diets that contain higher numbers of Calories, particularly in the form of carbohydrates.

Key Terms

*Use the interactive flash cards on the **Concepts in Biology, 14/e** website to help you learn the meaning of these terms.*

absorption 556
aerobic exercise 579
anaerobic exercise 579
anorexia nervosa 574
assimilation 556
basal metabolic rate (BMR) 569
body mass index (BMI) 571
bulimia 573
calorie 556
complete proteins 559
diet 556
dietary fiber 557
Dietary Reference Intakes 565
digestion 556
essential amino acids 560
essential fatty acids 559
fitness 573
Food Guide Pyramid 565
incomplete proteins 559

Basic Review

1. _____ is the modification and incorporation of absorbed molecules into the structure of an organism.
   a. Nutrition
   b. Assimilation
   c. Dieting
   d. Absorption
2. The rate at which the body uses energy when at rest is called its
   a. basal metabolic rate.
   b. basal metabolic index.
   c. specific dynamic action.
   d. work.
3. A body mass index between 25 and 30 kg/m^2 indicates that a person is
   a. within a normal range.
   b. obese.
   c. overweight.
   d. extremely active.
4. Some complex carbohydrates are a source of _____, which slows the absorption of nutrients and stimulate peristalsis (rhythmic contractions) in the intestinal tract.
   a. fiber
   b. vitamins
   c. minerals
   d. lipids
5. Linoleic acid and linolenic acid are called _____ because they cannot be synthesized by the human body and, therefore, must be a part of the diet.
   a. amino acids
   b. fatty acids
   c. essential fatty acids
   d. B-complex vitamins
6. Inorganic elements, found throughout nature, that cannot be synthesized by the body are called
   a. vitamins.
   b. essential amino acids.
   c. electrolytes.
   d. minerals.
7. When proteins are conserved and carbohydrates and fats are oxidized first as a source of ATP energy, the body is involved in
   a. protein-sparing.
   b. specific dynamic action.
   c. absorption.
   d. dieting.
8. Information on the amounts of certain nutrients various members of the public should receive is contained in
   a. the Food Guide Pyramid.
   b. the Protein-Sparing Guide.
   c. kwashiorkor.
   d. the Dietary Reference Intakes.
9. A person with _____ has a cycle of eating binges followed by purging of the body of the food by inducing vomiting or using laxatives.
   a. bulimia
   b. anorexia nervosa
   c. obesity
   d. kwashiorkor
10. The use of alcohol during pregnancy can result in decreased nutrient exchange between the mother and fetus, as well as other developmental abnormalities called
    a. osteoporosis.
    b. fetal alcohol syndrome (FAS).
    c. bulimia.
    d. fetal deficiency disease.
11. Eating large amounts of protein is required to build large muscles. (T/F)
12. Which of the following categories of people would be affected the most by a shortage of protein in their diet?
    a. athletes
    b. children
    c. people in old age
    d. adult men
13. Items in the grain food group are important because they supply
    a. carbohydrates.
    b. vitamins.
    c. fiber.
    d. All of the above are correct.
14. Which food group provides protein, calcium, and vitamin D in the diet?
    a. meat and beans
    b. fruit
    c. vegetables
    d. milk
15. For most persons who exercise, the most important nutrient is
    a. carbohydrates.
    b. protein.
    c. fats.
    d. water.

Answers
1. b 2. a 3. c 4. a 5. c 6. d 7. a 8. d 9. a 10. b
11. F 12. b 13. d 14. d 15. d

Thinking Critically

Getting Ready for Exercise
Imagine that you're a 21-year-old woman who has never been involved in any kind of sport, but suddenly you have become interested in playing rugby, a very demanding contact sport. If you are to play well with only minor injuries, you must get into condition. Describe the changes you should make in your daily diet and exercise program to prepare for this new experience.

CHAPTER 26

The Body's Control Mechanisms and Immunity

Court Finds No Link Between Vaccination and Autism

Measles/Mumps/Rubella vaccination important for public health.

CHAPTER OUTLINE

Autism is a disorder of the brain that results in a variety of abnormal behavior patterns. General symptoms include difficulty in participating in social situations, repetitive behaviors, late development of language skills, and preoccupation with certain topics. The disorder may also range from severe to mild and affects about 1 in 150 births. It is clear that genes are involved in the development of autism, but it is also strongly suspected that there are environmental factors that trigger its development.

Because parents and their physicians often recognize autism's symptoms when the children are going through their initial immunizations for childhood diseases, many people have associated the onset of autism with vaccines. This has led to a significant number of people wanting to exclude their children from immunizations, particularly the measles, mumps, and rubella (MMR) vaccine.

However, avoiding immunization also has significant risk. About 1 in 100 children infected with measles develops blindness, 5 in 100 develop ear infections, and 1 in 1000 develops encephalitis. Rubella also has serious consequences. Pregnant women who develop rubella in the first trimester of their pregnancy have about an 85% chance of having a child with a significant birth defect.

In 2008 a special federal appeals court ruled that, based on scientific evidence, there was no link between the MMR vaccine and autism. This legal decision cleared the way for stronger requirements for the vaccination of children. However, some people still will be unconvinced, and avoid having their children vaccinated.

- **What is a vaccine?**
- **How do vaccines work to prevent disease?**
- **Should vaccinations for childhood infectious diseases be mandatory?**

Background Check

Concepts you should understand in order to get the most out of this chapter:
- The various types of chemical reactions (chapter 2)
- The structure of eukaryotic cells (chapter 4)
- How cellular processes are controlled by enzymes (chapter 5)

26.1 Coordination in Multicellular Animals

A large, multicellular organism, which consists of many kinds of systems, must have a way of integrating various functions so that it can survive. Its systems must be coordinated to maintain a reasonably constant internal environment. Recall from chapter 1 that **homeostasis** is the maintenance of a constant internal environment as a result of monitoring and modifying the functioning of various systems. Homeostatic mechanisms are involved in maintaining blood pressure, body temperature, body fluid levels, and blood pH. When we run up a hill, our leg and arm muscles move in a coordinated way to provide power. They burn fuel (glucose) for energy and produce carbon dioxide and lactic acid as waste products, which tend to lower the pH of the blood. The heart beats faster to provide oxygen and nutrients to the muscles, we breathe faster to supply the muscles with oxygen and get rid of carbon dioxide, and the blood vessels in the muscles dilate to allow more blood to flow to them. Running generates excess heat. As a result, more blood flows to the skin to get rid of the heat, and sweat glands begin to secrete fluid, thus cooling the skin. All these automatic internal adjustments help the body maintain a constant level of oxygen, carbon dioxide, and glucose in the blood; constant pH; and constant body temperature.

One common homeostatic mechanism is **negative-feedback inhibition,** a mechanism in which an increase in the output of a reaction causes a decrease in the stimulus, which eventually causes a decrease in the output (figure 26.1a). A common negative-feedback inhibition mechanism is a household heating system. The thermostat is set to a particular temperature. When the temperature in the room drops too low, the thermostat sends a message (stimulus) to the furnace to produce heat, and the temperature in the room rises. As the temperature rises to the set point, it eventually causes the thermostat to send a message that turns the furnace off.

Negative-feedback systems work in your body in a similar manner. Various body functions have set points, such as body temperature, blood pH, and blood osmotic pressure. When the body drifts from the set point, messenger molecules move throughout the body and provide a stimulus to cause a response that will correct the change from the set point. When a response causes a change that brings the body back to the set point, a message is sent back to a control center telling it to stop producing the stimulus. For example, your

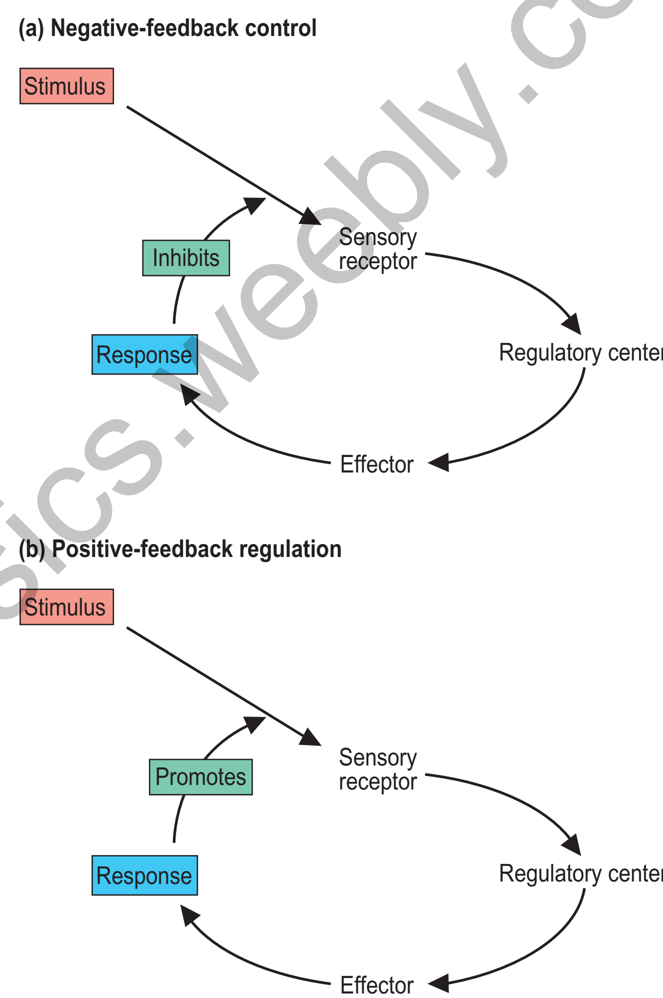


FIGURE 26.1 Negative- and Positive-Feedback Control
(a) Negative-feedback control occurs when the response to a stimulus inhibits the stimulus, thus reducing the response.
(b) Positive-feedback happens when a response to a stimulus causes an increase in the stimulus which further increases the response.

body seeks to maintain a constant level of glucose in the blood. After you eat a meal, the level of glucose begins to rise, which is the stimulus for the pancreas to release the hormone insulin. The insulin causes cells of the muscles and liver to remove glucose from the blood and store it as glycogen. As the glucose is removed from the blood, the pancreas is no longer stimulated to release insulin and removal of glucose