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chapter 4

Principles of Structure and Function

Jenny Hawn has cystic fibrosis, a deadly disease that affects the respiratory system and pancreas. One of the main symptoms of the disease is the production of excess mucus by the cells lining the respiratory tract. Mucus traps bacteria and viruses, resulting in frequent lung infections.

THINKING CRITICALLY

Healthcare costs are skyrocketing. Some critics argue that part of the reason is that our public healthcare dollars are being wasted on procedures such as organ transplants for needy people, which cost taxpayers $200,000 or more each. Such expenditures, they say, are draining dollars that could be invested in preventive medicine, such as prenatal care.

Prenatal care consists of visits to doctors for checkups and advice on nutrition and other matters that are crucial to the development of a healthy fetus. If problems arise, they can be dealt with immediately, not when it's too late and too costly. One organ transplant costs as much as prenatal care for 1,300 to 1,400 pregnant women, assistance that itself could prevent ailments that might even necessitate costly transplant procedures later in life.

Should Americans spend more on preventive medicine (including prenatal care) and less on dramatic life-saving measures, such as organ transplants? Why or why not?

healthnote

4-1 The Truth about Herbal Remedies

A male patient is treated by his physician for a painful infection of the prostate gland, one of the glands that produce a large portion of the semen. The doctor prescribes an antibiotic and advises the patient to take an herbal remedy, saw palmetto, to help prevent prostatic enlargement, a common problem in older men. A young woman suffering from restlessness and minor problems with sleep is advised by a friend to try some valerian root, another type of herbal remedy.

Herbal remedies are derived from roots, bark, seeds, fruit, flowers, leaves, and branches of plants. In China, some herbal remedies even contain animal parts. An estimated 3,000 different medicinal herbs are currently used throughout the world.

Herbal remedies are sold in the United States and in other countries by herbalists and may be mixed on site. More commonly, people get their herbs in pill, capsule, or liquid form from health food stores, grocery stores, large discount stores, or through mail order or online suppliers.

Although herbs have become very popular in the United States in recent years, the Asians have been using them for thousands of years. In China, for instance, the history of herbal remedies dates back 5,000 years. Unbeknownst to many doctors, certain herbs were used routinely in the United States and other developed nations before the advent of modern medicines. In the United States, for instance, Echinacea (ek-eh-NAH-shah) was widely used to treat colds prior to the introduction of sulfa drugs (the first generation of synthetic antibiotics). In Germany, herbal remedies are considered prescription medicines and are covered by health insurance.

Herbal treatments have a long history of use. In addition, the plants they are made from have been the source of a surprisingly large proportion of the prescription and over-the-counter (OTC) drugs in use today. That is, many so-called "modern medicines" contain active ingredients originally extracted from plants. Aspirin, for instance, is derived from the inner bark of willow trees. But are herbal treatments effective?

There is no blanket answer to this question. While research shows that many claims about the effectiveness of numerous common herbal preparations appear to be unfounded, not all are. Echinacea, for instance, does appear to enhance immune system function, and it can be used as a preventative and for treatment of colds and flus. Bilberry, dried blueberries, helps maintain eyesight and improves night vision. It was even used in World War II by members of the Royal Air Force who flew night bombing missions. Valerian root is an effective, nonaddicting sleep aid and mild

Jenny's disease is genetic. Until recently, there was little hope of curing this disease, which claims most of its victims before they reach the age of 20. Today, however, there may be some hope. Geneticists are experimenting with novel ways to repair the genetic defects responsible for excessive mucus production.

To correct this genetic defect, scientists are experimenting with certain cold viruses that infect the cells lining the respiratory tract. Normally, these viruses inject their DNA into the lining cells, causing cold symptoms. Researchers, however, are cutting out the genes of the virus that cause colds and splicing in new genes—ones that could lead to normal mucus production, hopefully creating a lasting cure for this deadly disease. So far, results of studies on small numbers of patients have been promising.

This research is just one of many forms of "body work" scientists are now performing. Other researchers are working at a level slightly higher—that is, at the level of tissues and organs (defined shortly). Some scientists, for instance, are developing genetically engineered pigs whose cells contain human genes. Their hope is that the pig's organs containing human genes could someday be transplanted into people to replace failed livers or kidneys. They even speculate that an organ could be specially made with a person's own genes to prevent tissue rejection. In addition, this organ would be available in a fraction of the time it now takes to find a genetically compatible organ from a suitable donor.

Other researchers are attempting to grow tissues in the laboratory that can be used to repair diseased or damaged organs. For example, researchers successfully implanted a biodegradable material into the walls of urinary bladders of young patients to repair badly damaged organs. This material was populated with cells from the patients' damaged bladders. Five years after the transplant, the bladders were operating as well as traditionally repaired bladders.

Researchers are also surgically removing tendons, heart valves, and other tissues from pigs and using them to replace damaged organs in humans. The tissues are stripped of the pig cells, leaving only an underlying layer of connective tissue. It would then be placed where needed and populated by cells of the human recipient, thus avoiding tissue rejection. The tissues would be able to grow if, for example, the transplant was made in a child.

Health Note 4-1 describes other remarkable medical procedures used to repair or rebuild tissues and organs. This chapter presents some basic information about body structure and function, information you will need to understand the human body and many of the exciting research projects you will hear or read about in the news. This chapter also revisits homeostasis, elaborating on what you've already learned and setting the stage for your study of human organ systems, the subject of much of this text.

relaxant. Saw palmetto appears to be effective in reducing enlargement of the prostate (although a recent study has cast some doubt on this conclusion). Ginger is effective in the treatment of nausea and morning sickness, although it should not be used for an extended time during pregnancy. Garlic lowers serum cholesterol and may have antibacterial properties. Feverfew seems to help prevent migraine headaches. Hawthorn fights hypertension. The list goes on.

The main advantage of herbs, say some proponents, is that they have no side effects and contain no chemicals; they are also purportedly safe and effective. Unfortunately, this claim is far from true. Herbal remedies contain plant chemicals, some of which may have very serious side effects. A number of herbs, for instance, damage the liver, including comfrey—an herb that reportedly promotes bone healing. When taken for long periods, its active chemical ingredient is toxic to the liver.

David Kroll, a pharmacologist from the University of Colorado Health Sciences Center, notes further problems with herbal medicine. First and foremost, he argues that U.S. labeling requirements are inadequate. Herbs are sold as dietary supplements, and as such, no claims about their use are available. Individuals often must rely on advice from sales clerks, friends, or articles they read. Second, very little is known about the long-term effects of the wide variety of herbal remedies or their potential interactions with conventional medicines, although our knowledge is expanding.

Others note that without federal regulations that require strict standards for drug content in various herbal remedies, individuals can't know the exact dose they are receiving. Studies have shown that some herbal remedies have none of the active ingredient or less than the required amounts. In Europe, however, stricter laws require much better controls on product content. Canada has also established standards for the purity and content of herbal remedies.

When given a choice between an over-the-counter remedy and an herbal one, Dr. Kroll recommends the over-the-counter treatment because these products are standardized. Even then, some of these medicines may prove ineffective. Common cough medications, for instance, were recently shown to be ineffective. See **Health Tip 4-1**.

Kroll also notes that treatment with herbal remedies, as with OTC preparations, may delay the diagnosis of more serious conditions. The rule: See a doctor first to be certain that you have what you think you have and buy herbal products that are standardized from reputable companies.

The important lesson in all of this is buyer beware. Study an herb thoroughly before you take it, or better yet, see a qualified physician who practices both traditional and herbal medicine.

4-1 From Cells to Organ Systems

The human body is made up of trillions of cells—perhaps as many as 50 trillion, which is 50,000 million cells. These cells are frequently bound together by extracellular fibers and other extracellular materials, forming **tissues** (from the Latin "to weave"). Extracellular materials may be liquid (as in blood), semisolid (as in cartilage), or solid (as in bone). Tissues, in turn, combine to form organs, discrete structures in the body that carry out specific functions.

KEY CONCEPTS

In the human body, cells of like kind make up tissues; tissues are combined to form organs; organs combine to form organ systems.

Primary Tissues

Four major tissue types are found in humans: (1) epithelial, (2) connective, (3) muscle, and (4) nervous. Table 4-1 lists them. Each tissue consists of two or three subtypes. These tissues exist in all organs, but in varying amounts. The lining of the stomach, for example, consists of a single layer of epithelial (ep-eh-THEEL-ee-ill) cells that protects underlying layers (Figure 4-1).

Just beneath the epithelial lining is a layer of connective tissue. It holds tissues together. Beneath that is a thick sheet of smooth muscle cells, which forms the bulk of the stomach wall. When they contract, these muscles help to mix the contents of the stomach. They also help propel food into the small intestine. Smooth muscle cells are also found in blood vessels supplying the tissues of the stomach. Nerves enter with the blood vessels and control the flow of blood.

KEY CONCEPTS

Four primary tissue types are found in the human body; they are called primary tissues.

TABLE 4-1 The Primary Tissues and Their Subtypes

Epithelial tissue	Connective tissue
Membranous	Connective tissue proper
Glandular	Loose connective tissue
Muscle tissue	Dense connective tissue
Cardiac	Specialized connective tissue
Skeletal	Blood
Smooth	Bone
Nervous tissue	Cartilage
Conductive	
Supportive	

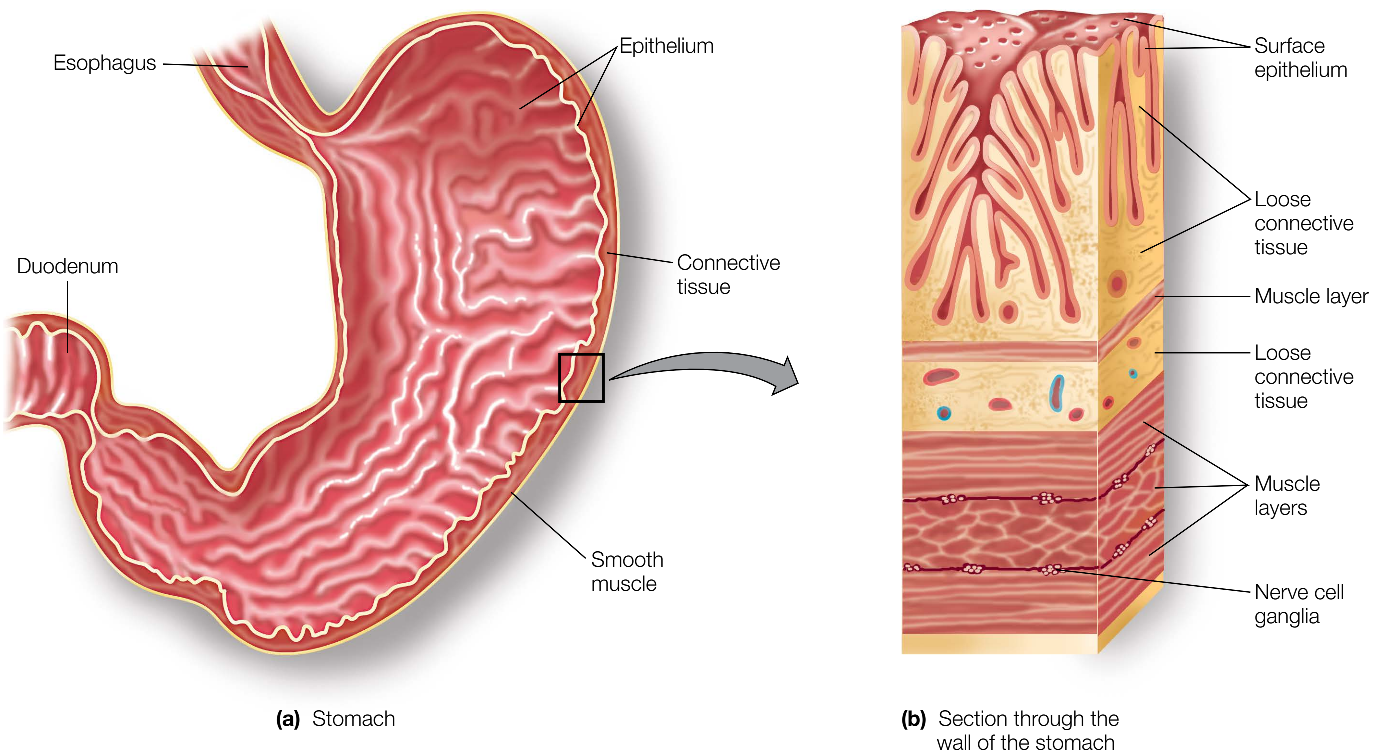


FIGURE 4-1 Human Stomach (a) The stomach, like all organs, contains all four primary tissues. (b) These are shown here in cross section.

Epithelium

Epithelial tissue exists in two basic forms: membranous and glandular. The membranous epithelia consist of sheets of cells tightly packed together, forming the external coverings or internal linings of organs. Membranous epithelia come in a variety of forms, each specialized to protect underlying tissues. To simplify matters, the membranous epithelia are divided into two broad categories: simple epithelia, consisting of single layers of cells, and stratified epithelia, consisting of many layers of cells (Figure 4-2). Epithelial layers are often underlain by a basement membrane, a layer of glycoprotein that fuses with the underlying connective tissue, holding the epithelium in place.

The glandular epithelia consist of clumps of cells that form many of the glands of the body. Epithelial glands arise during embryonic development from tiny "ingrowths" of membranous epithelia, as illustrated in Figure 4-3. Some glands remain connected to the epithelium by hollow ducts and are called **exocrine glands** (EX-oh-crin; glands of external secretion); products of the exocrine glands empty by way of the

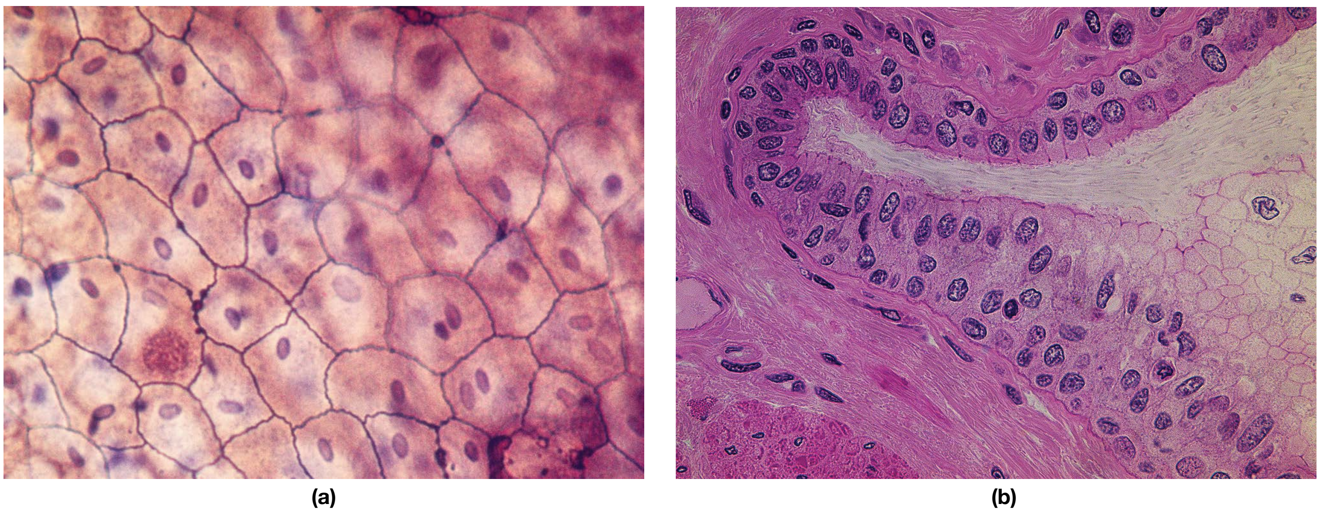


FIGURE 4-2 Membranous Epithelia (a) Single-celled (simple) epithelia and (b) stratified epithelia exist in different parts of the body. (a, © Biophoto Associates/Science Source, Inc.; b, © Donna Beer Stolz, Ph.D., Center for Biologic Imaging, University of Pittsburgh Medical School.)

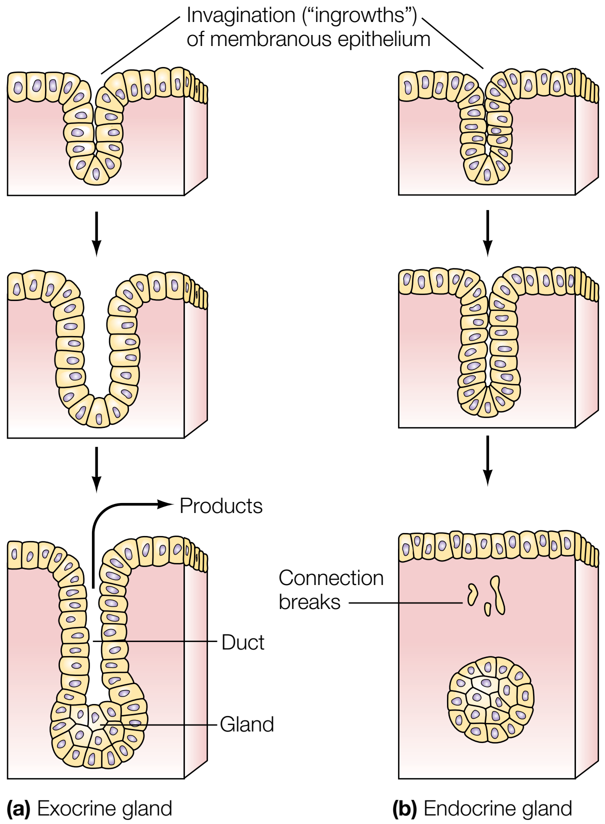


FIGURE 4-3 Formation of Endocrine and Exocrine Glands
(a) Exocrine glands arise from invaginations of membranous epithelia that retain their connection. (Photo © Fred Hossler/Visuals Unlimited.) (b) Endocrine glands lose this connection and thus secrete their products into the bloodstream. (Photo © David M. Philips/Visuals Unlimited.)

ducts (Figure 4-3a). In humans, sweat glands in the skin are exocrine glands. They produce a clear, watery fluid that is released onto the surface of the skin by small ducts. This fluid evaporates from the skin and cools the body. The salivary glands and pancreas are also exocrine glands.

Some glandular epithelial cells break off completely from their embryonic source, as shown in Figure 4-3b, to form endocrine glands (EN-doh-crin; glands of internal secretion). The **endocrine glands** produce hormones that are released into the bloodstream, where they travel to other parts of the body.

KEY CONCEPTS

Epithelium is a primary tissue; it forms linings of organs and during embryological development some types of epithelial tissue forms glands of internal and external secretion.

Health Tip 4-1

Got a cough? You may want to skip the over-the-counter cough medicines. *Why?*

There is no clinical evidence to show that over-the-counter cough medicines actually work. Does anything work?

Yes. Both Benadryl (an antihistamine) and Sudafed (a decongestant) appear to provide relief.

The Marriage of Structure and Function

One of the basic rules of architecture is that form (the structure of a building) often follows function—in other words, architectural design reflects underlying function. This rule also applies to living things. As you study human biology, you will find many examples of this rule.

The membranous epithelia provide a good example of the form-follows-function rule. Consider the outer layer of the human skin, the **epidermis** (ep-eh-DERM-iss). Shown in Figure 4-4a, the epidermis consists of numerous cell layers, known as a **stratified squamous epithelium** (SQUAW-mus). The cells of this epithelium are tightly joined by special connections and flatten toward the surface and die. Together, the thickness of the epidermis, the adhesion of one cell to another, and the dry protective layer of dead cells reduce water loss and protect us from dehydration. They also present a formidable barrier to microorganisms. All of these structural features help maintain homeostasis.

KEY CONCEPTS

In the human body, the structure of cells, tissues, and organs often reflects their function.

Connective Tissue

As the name implies, **connective tissue** is the body's glue. It binds cells and other tissues together and is present in all organs in varying amounts.

The body contains several types of connective tissue, each with specific functions (Figure 4-5). Despite the differences, all connective tissues consist of two basic components: cells and varying amounts of extracellular material. Two types of connective tissue will be discussed here: connective tissue proper and specialized connective tissues—bone, cartilage, and blood.

KEY CONCEPTS

Connective tissues of the body bind cells and various structures together, helping to form tissues organs.

Connective Tissue Proper

Connective tissue proper consists of two types: dense connective tissue and loose connective tissue. The chief difference between them lies in the ratio of cells to extracellular fibers, as shown in Figure 4-5a and b and Figures 4-6a and b.

As the name implies, **dense connective tissue** (DCT) consists primarily of densely packed fibers. The fibers are produced by cells interspersed between the fibers. DCT is found in ligaments and tendons (Figure 4-6b). Ligaments join bones to bones at joints and provide support for joints. Tendons join muscle to bone and aid in body movement.

DCT is also found at other sites, such as the layer of the skin underlying the epidermis, known as the **dermis**. Although this is DCT, the fibers are less regularly arranged than those in ligaments and tendons.

As shown in Figure 4-6b, **loose connective tissue** (LCT) contains cells in a loose network of protein fibers—specifically collagen and elastic fibers. Loose connective tissue forms around blood vessels in the body and in skeletal muscles, where it binds the muscle cells together. It

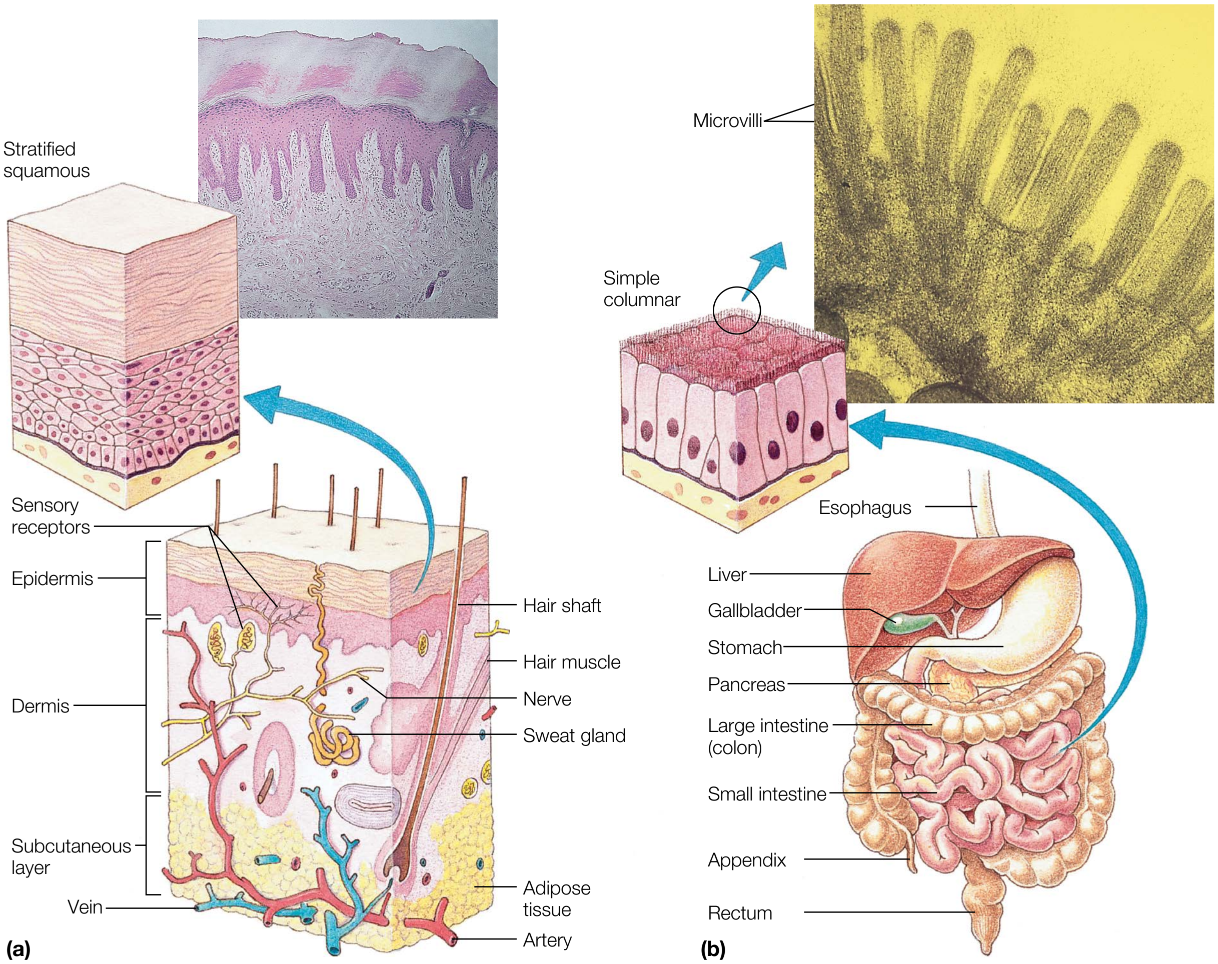


FIGURE 4-4 **Comparison of Two Epithelia with Different Functions** (a) A cross section of the skin showing the stratified squamous epithelium of the epidermis (above), which protects underlying skin from sunlight and desiccation. (b) The simple columnar epithelium of the lining of the small intestine, which is specialized for absorption. The plasma membranes of the cells lining the intestine are thrown into folds (microvilli) that greatly increase the surface area for absorption.

also lies beneath epithelial linings of the intestines and trachea, anchoring them to underlying structures.

The extracellular fibers found in dense and loose connective tissue are produced by a connective tissue cell known as the **fibroblast** (FIE-bro-blast). Fibroblasts also repair tissue damage. When skin is cut or scraped, for example, fibroblasts in the dermis migrate into the injured area. There they begin producing collagen fibers that begin to fill the wound. Skin cells then move in, creating new skin. If the wound is small, the area may be overgrown entirely by the epidermis—so much so that it leaves no scar. In larger wounds, however, the epidermal cells may be unable to cover the entire wound, leaving some of the underlying collagen exposed, which produces a visible scar.

Besides binding tissues together, loose connective tissue houses several cell types that protect us against bacterial and viral infections. One of the most important of these protective cells is the **macrophage** (MACK-row-FAYGE; "big eater"). Macrophages engulf (phagocytize) microorganisms that penetrate the skin and underlying loose connective tissues after an injury. This prevents bacteria from spreading to other parts of the body. Inside the macrophage, microorganisms are destroyed by lysosomes, an enzyme-containing organelle, discussed elsewhere in the text. Macrophages also play a role in immune protection, a topic also discussed elsewhere in the text.

KEY CONCEPTS

Connective tissue proper consists of dense connective tissue like that found in tendons and loose connective tissue like that found beneath the skin.

Adipose Tissue

Some LCT contains fat cells. The **fat cell** is one of the most distinctive of all body cells (Figure 4-5d). Fat cells occur singly or in groups of varying size. Large numbers of fat cells in a given region form a modified type of LCT known as **adipose tissue** (AD-eh-poze), or, less glamorously, fat.

Scientists recognize two types of adipose tissue in the body. In the first, **white fat**, each cell contains a single large and highly conspicuous fat droplet (Figures 4-7a and b).

The other type of fat, **brown fat**, contains numerous small fat globules (Figures 4-7a and b). The cells of brown fat also contain a large number of iron-containing mitochondria, which give it its brownish color. In both types of fat cell, fat globules occupy virtually the entire cell and therefore "press" the cytoplasm and the nucleus to the periphery. Besides containing many smaller fat globules and iron-containing mitochondria, brown fat cells are surrounded by more small blood vessels called

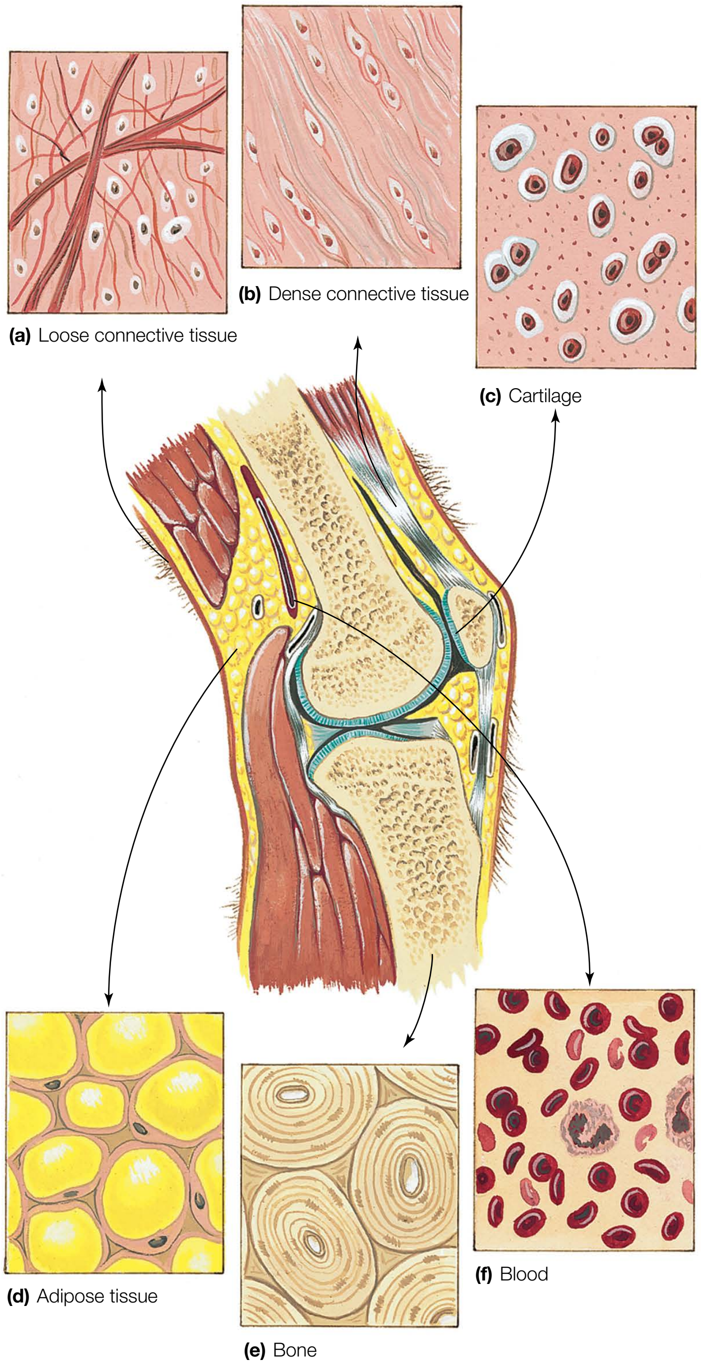


FIGURE 4-5 Connective Tissue Connective tissue consists of many diverse subtypes. (Photo © Photodisc.)

capillaries than are found in white fat. They are there to provide oxygen and nutrients to this more metabolically active fat.

White fat is widely distributed throughout the body. It serves as an important storage depot for triglycerides, a type of lipid, which are used as an energy source by the body. Fatty deposits also provide insulation for humans, many other mammals, and some birds, especially those that live in aquatic environments where heat loss can be substantial. Some fat deposits help cushion organs like the kidney, helping to protect them from physical damage. White fat cells also produce a hormone, known as *leptin*. As you will learn elsewhere in the text, leptin helps regulate hunger—in fact, it is a naturally occurring hunger suppressant that normally keeps us from overeating.

Brown fat is found in newborns. In fact, it is quite abundant in newborns and for good reason—it helps them combat cold temperatures. It is found along the back, along the upper part of the spine, and in the shoulders. How?

Brown fat is extremely metabolically active. It produces a substantial amount of heat. This is helpful to newborns because they are not yet capable of shivering when cold or taking other measures to stay warm like donning clothing or covering themselves with blankets. How does the brown fat cell produce so much heat?

Enzymes in the cell's mitochondria break glucose down, capturing energy locked in the covalent bonds. They store the energy in ATP molecules for later use. Because this process is not 100% efficient, waste heat is generated. It's what produces our body temperature. In brown fat cells, however, the mitochondria make proportionately less ATP and proportionately more heat—a lot more heat.

For many years, scientists thought that brown fat was found only in newborn infants. Recent studies have debunked this belief, showing that brown fat is also found in adults, although it is restricted to the neck and large blood vessels of the chest.

For humans, fatty deposits often become unsightly. To rid the body of these deposits, nutritionists advise exercise and reduced food intake. Some individuals opt for a surgical measure called *liposuction* (LIE-poh-suck-shun; Figure 4-8). In this procedure, a small incision is made in the skin through which surgeons insert a device they use to suck out unwanted fat deposits under the skin in various locations such as the buttocks and abdomen. The fat cells extracted from one region can even be transferred to other regions, such as the breast and lips, to resculpt the human body. Liposuction is a relatively safe technique but, like most surgery, not free from risk.

KEY CONCEPTS

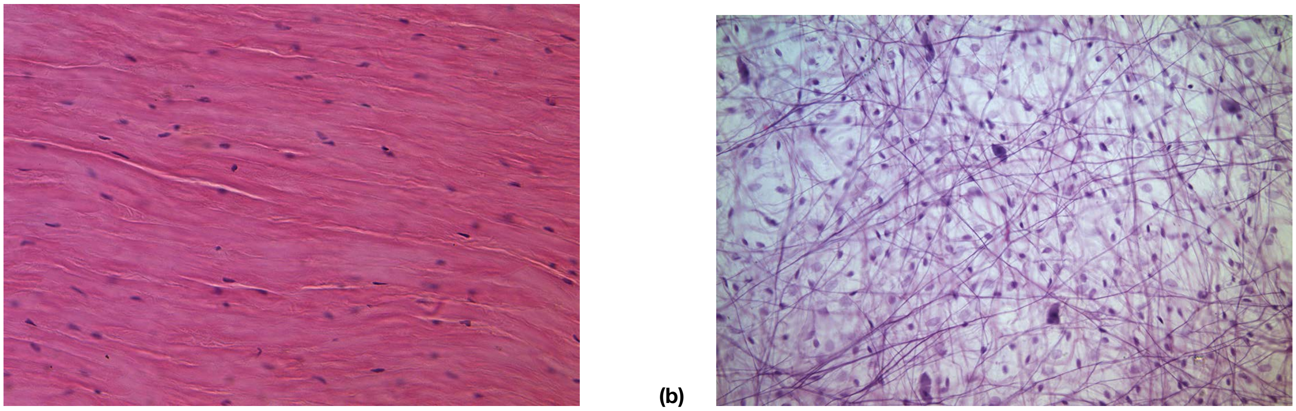
The human body contains two types of adipose tissue or fat: white and brown; they differ significantly in their function.

Health Tip 4-2

To lose or maintain weight, eat a salad with low-fat dressing before lunch and dinner. Then reduce portion sizes of your main course.

Why?

Salads fill you up, yet contain few calories. This strategy will not only help you lose weight, it will provide the valuable vitamins, minerals, fiber, and other nutrients your body needs to maintain your health.



(a) (b)

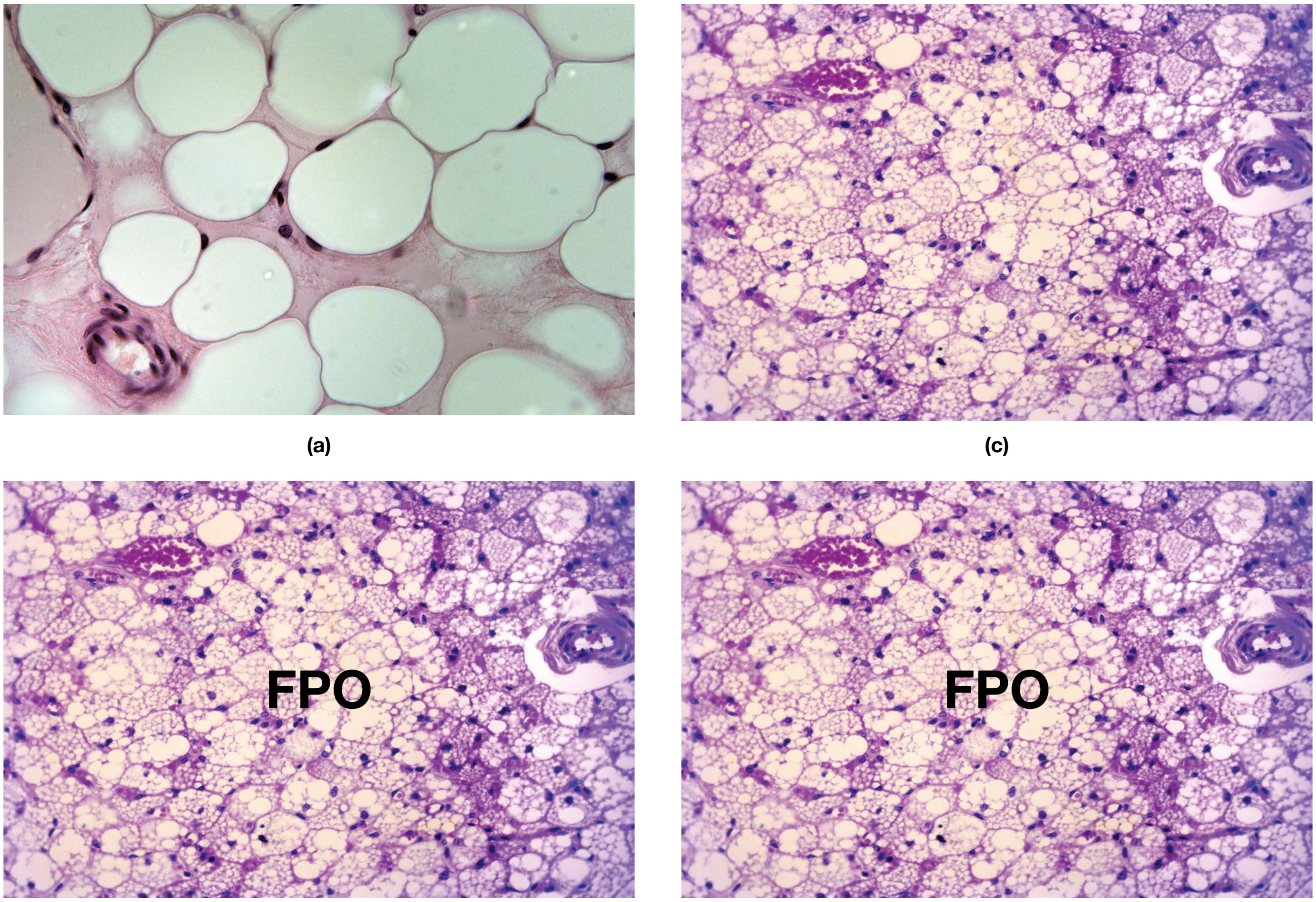
FIGURE 4-6 **Connective Tissue as Seen through the Light Microscope** (a) Dense connective tissue. (b) Loose connective tissue. (a and b © Donna Beer Stolz, Ph.D., Center for Biologic Imaging, University of Pittsburgh Medical School.)

Specialized Connective Tissue

The body contains three types of specialized connective tissue: cartilage, bone, and blood.

Cartilage. **Cartilage** consists of cells embedded in an abundant and rather impenetrable extracellular material, the *matrix* (Figure 4-9). Surrounding virtually all types of cartilage is a layer of dense, irregularly packed connective tissue. This layer contains capillaries that supply nutrients to cartilage cells through diffusion. No blood vessels penetrate the cartilage itself. Because cartilage cells are nourished by diffusion from capillaries, damaged cartilage heals very slowly. Therefore, joint injuries that involve the cartilage often take years to repair or may not heal at all.

Three types of cartilage are found in humans: hyaline, elastic, and fibrocartilage. The most prevalent type is



(a) (c) (b) (d)

FIGURE 4-7 (a) Light micrograph of white fat. (© Donna Beer Stolz, Ph.D., Center for Biologic Imaging, University of Pittsburgh Medical School.) (b) Electron micrograph of white fat. (Credit line to come when image arrives.) (c) Light micrograph of brown fat. (© Biophoto Associates/Science Source.) (d) Electron micrograph of brown fat. (Credit line to come when image arrives.)

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FIGURE 4-8 **Liposuction** During liposuction surgery, the physician aspirates fat from deposits lying beneath the skin, helping to reduce unsightly accumulations. (© Girish Menon/ShutterStock, Inc.)

hyaline cartilage (HIGH-ah-lynn; Figure 4-9a). Hyaline cartilage contains numerous collagen fibers, which appear white to the naked eye. Found on the ends of many bones in joints, hyaline cartilage in such locations greatly reduces friction, so bones can move over one another with ease. Hyaline cartilage also makes up the bulk of the nose and is found in the larynx (voice box) and the trachea or wind pipe. The ends of the ribs join to the sternum (breastbone) via hyaline cartilage. In embryonic development, the first skeleton is made of hyaline cartilage. It is later converted to bone.

Elastic cartilage contains many wavy elastic fibers, which give it flexibility (Figure 4-9b). Elastic cartilage is therefore found in regions where support and flexibility are required—for example, in the ears.

Fibrocartilage is a rare form of cartilage. It contains strong collagen fibers and is found in areas that must withstand tension and pressure (Figure 4-9c). Fibrocartilage is found in the shock absorbers, that is, the **intervertebral disks**

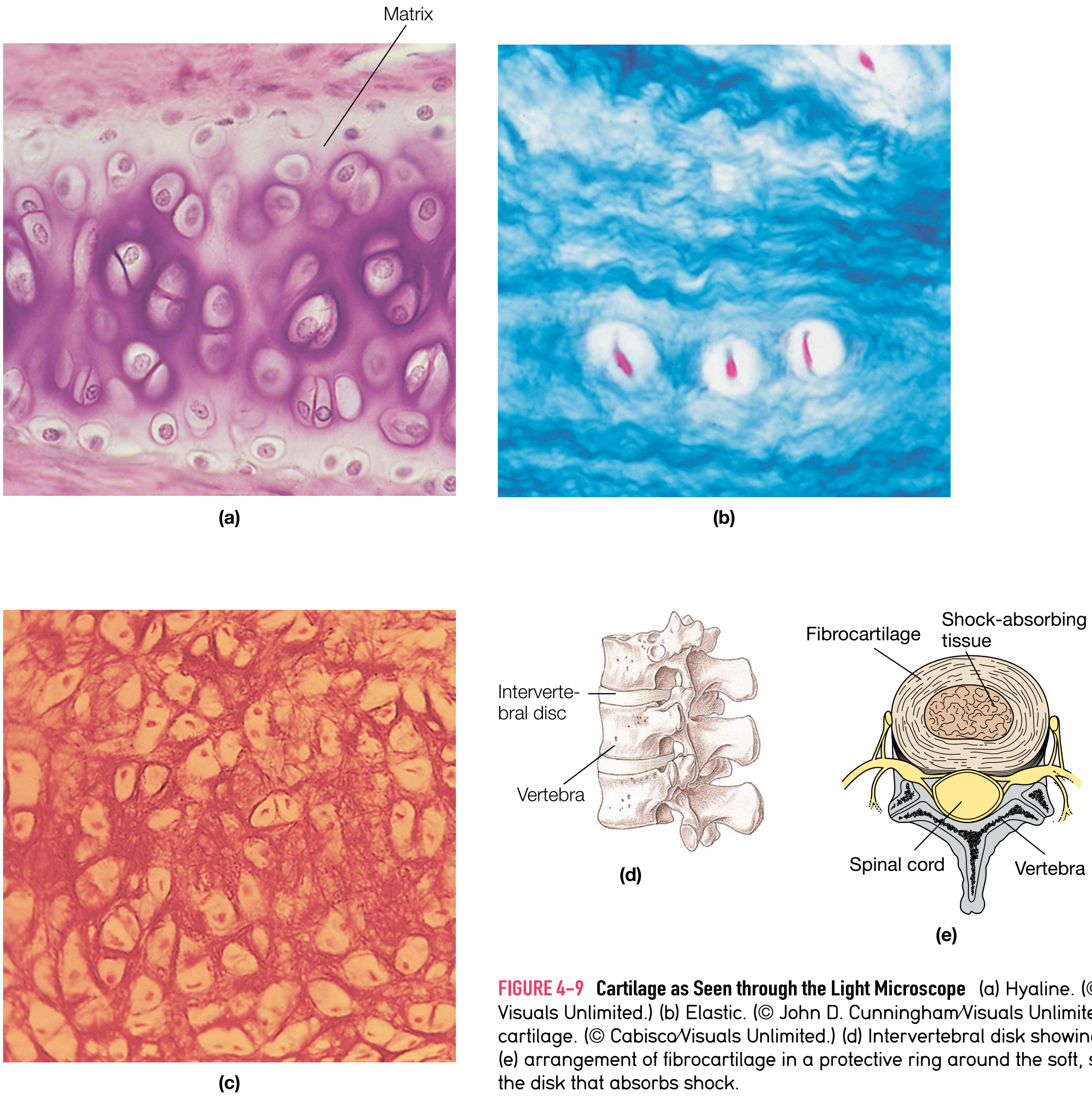

FIGURE 4-9 **Cartilage as Seen through the Light Microscope** (a) Hyaline. (© Fred Hossler/Visuals Unlimited.) (b) Elastic. (© John D. Cunningham/Visuals Unlimited.) (c) Fibrocartilage. (© Cabisco/Visuals Unlimited.) (d) Intervertebral disk showing location and (e) arrangement of fibrocartilage in a protective ring around the soft, spongy part of the disk that absorbs shock.

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(a) (b)

FIGURE 4-10 **Protecting Your Back** Bend your knees as the man in (a) is doing, not your back, when you're lifting. (b) With your back straight, stand up and lift with your legs. (a and b, © Jones & Bartlett Learning, LLC.)

(in-ter-VER-tah-braul), which lie between the bones of the spine, the vertebrae (Figure 4-9d). An intervertebral disk consists of a soft, cushiony central region that absorbs shock. Fibrocartilage forms a ring around the central portion of the disk, holding it in place (Figure 4-9e).

The fibrocartilage ring may weaken and tear, especially in overweight individuals. This causes the central part of the disk to bulge outward, pressing against nearby nerves. This condition is referred to as a *slipped* or *herniated disk* and usually occurs in the neck or lower back, resulting in a significant amount of pain in the neck, back, or one or both legs, depending on the location of the damaged disk.

This problem can be corrected by surgery, although physical therapy is often the first plan of attack. Lasers are also being used to remove herniated disks. In some cases, the entire disk is removed and the vertebrae are fused. You can reduce your chances of "slipping" a disk in the first place by watching your weight, keeping in shape, sitting upright (not slouching) in a chair, and lifting heavy objects carefully (Figure 4-10).

Bone. **Bone** is a form of specialized connective tissue that provides internal support as well as protection to internal organs such as the brain. Bone also plays an important role in maintaining blood calcium levels and is, therefore, a homeostatic organ. Calcium is required for many body functions, including muscle contraction and normal nerve functioning.

Like all connective tissues, bone consists of cells embedded in an abundant extracellular matrix (Figure 4-11b). Bone matrix consists primarily of collagen fibers (which give bone its strength and resiliency), interspersed with numerous needlelike salt crystals containing calcium, phosphate, and hydroxide ions. They give bone its hardness.

Two types of bone tissue are found in the body: compact bone and spongy bone (Figure 4-11a). **Compact bone** is, as its name implies, dense and hard. As illustrated in Figure 4-11b, the cells in compact bone are located in concentric rings of calcified matrix. These cells surround a central canal through which the blood vessels and nerves pass. Each bone cell, or *osteocyte*, has numerous processes that course through tiny canals in the bony matrix, known as *canaliculi* (CAN-al-ICK-u-LIE; literally "little canals"). The canaliculi provide a route for nutrients and wastes to flow to and from the bone cells.

Inside most bones of the body is a tissue known as spongy bone. **Spongy bone** consists of an irregular network of calcified collagen plates (spicules). As shown in Figure 4-11c, on the surface of the plates are numerous osteoblasts (OSS-tee-oh-BLASTS). **Osteoblasts** are a type of bone cell that produces the collagen, which later becomes calcified. Once these cells are surrounded by calcified matrix, they are referred to as **osteocytes**.

Spongy bone also contains large cells known as **osteoclasts** (Figure 4-11c and d). These cells digest bony matrix, releasing calcium, when blood calcium levels fall. They also help to resculpt bones internally to help meet changing forces that occur as a person's activity levels change.

Blood. **Blood** is another specialized form of connective tissue—although some biologists prefer to consider it a separate tissue type called *vascular tissue*. Blood consists of formed elements and a large amount of extracellular material. The formed elements of blood consist of the red and white blood cells and the platelets. The formed elements are responsible for 45% of the blood volume. The extracellular material is a fluid known as **plasma**. It makes up the remaining 55%.

Red blood cells transport oxygen and small amounts of carbon dioxide to and from the lungs and body tissues. **White blood cells** rid the body of foreign organisms such as viruses and bacteria that can cause infections. **Platelets** are fragments of large cells (megakaryocytes) located in the red bone marrow, the principal site of blood cell formation. Platelets play a key role in blood clotting.

KEY CONCEPTS

Specialized connective tissue performs specific functions vital to homeostasis.

Muscle Tissue

Muscle tissue is found in virtually every organ in the body. Muscle gets its name from the Latin word for "mouse" (*mus*). Early observers likened the contracting muscle of the biceps to a mouse moving under a carpet.

Muscle is an excitable tissue. When stimulated, it contracts, producing mechanical force. Muscle cells working in large numbers can create enormous forces. Muscles of the jaw, for instance, create a pressure of 200 pounds per square inch, forceful enough to snap off a finger. (Don't try this at home.) Muscle also moves body parts, propels food along the digestive tract, and expels the fetus from the uterus during birth. Heart muscle contracts and pumps blood through the 50,000 miles of blood vessels in the human body. Acting in smaller numbers, muscle cells are responsible for intricate movements, such as those required to play the violin or move the eyes.

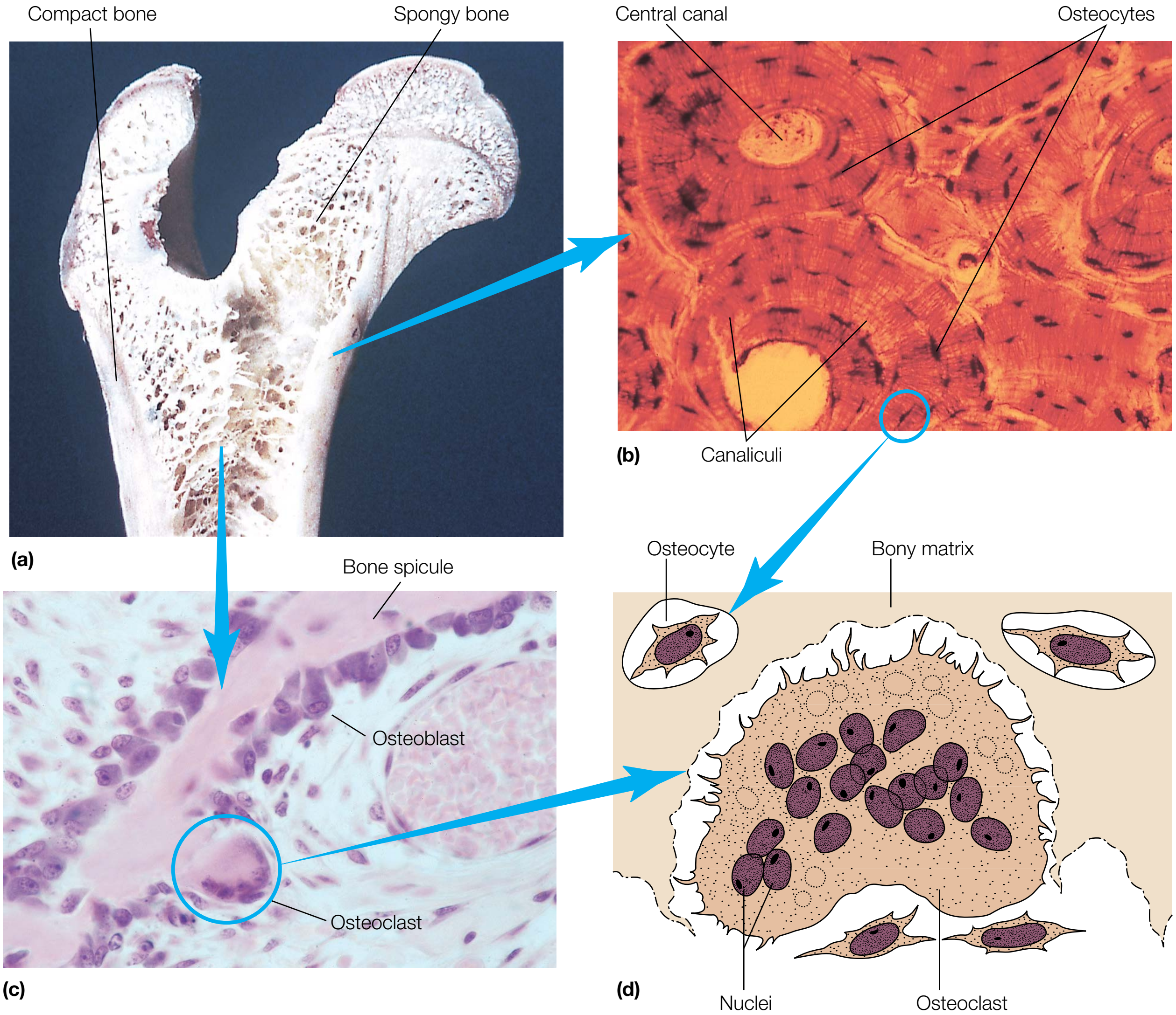


FIGURE 4-11 Bone (a) Compact and spongy bone, shown in a section of the humerus. (© R. Calentine/Visuals Unlimited.) (b) Light micrograph of compact bone. (© John D. Cunningham/Visuals Unlimited.) (c) Photomicrograph of spongy bone, showing osteoblasts and osteoclasts. (© R. Kessel/Visuals Unlimited.) (d) Osteoclast digesting surface of bony spicule.

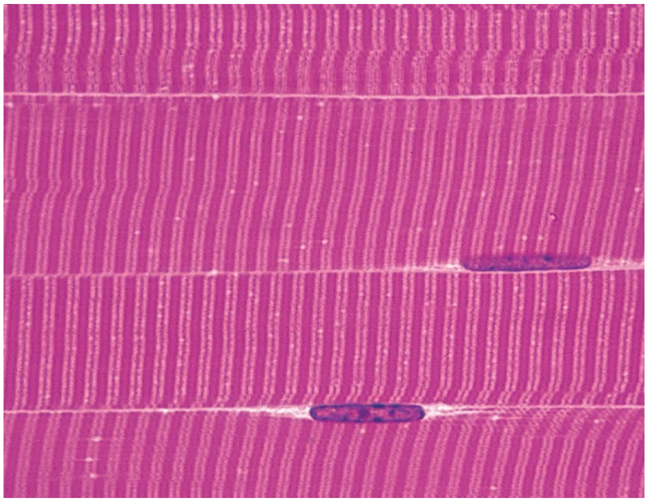
Three types of muscle tissue are found in humans: skeletal, cardiac, and smooth. The cells in each type of muscle tissue contain two contractile protein filaments, actin and myosin. These very same fibers were first encountered in your study of the microfilamentous network lying beneath the plasma membrane of cells. This layer of fibers plays a key role in cell division. When stimulated, actin and myosin filaments of muscle cells slide over one another, shortening and causing contraction.

Skeletal Muscle. The majority of the body's muscle is called **skeletal muscle**—so named because it is frequently attached to the skeleton. When skeletal muscle contracts, it causes body parts (arms and legs, for instance) to move. Most skeletal muscle in the body is under voluntary, or conscious, control. Signals from the brain cause the muscle to contract. A notable exception is the skeletal muscle of the upper esophagus, which contracts automatically during swallowing. (The initial act of swallowing is voluntary—pushing the food to the back of the oral cavity—but from that point on, the action is involuntary.)

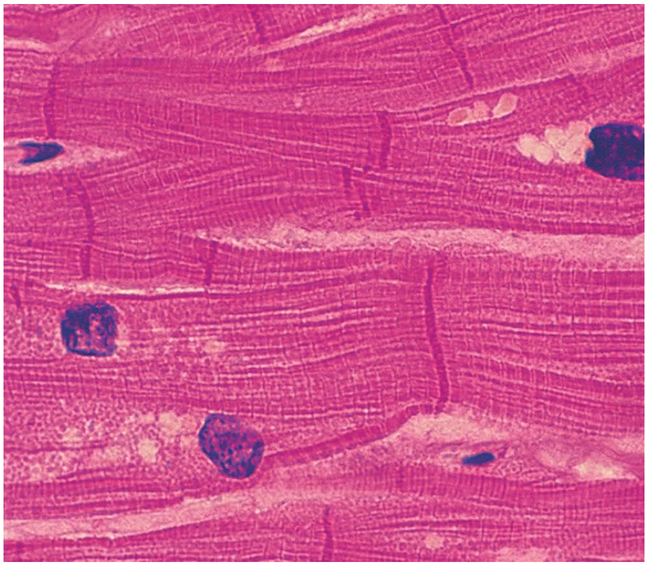
Skeletal muscle cells are long cylinders formed during embryonic development by the fusion of many embryonic muscle cells. Because of this, skeletal muscle cells are usually referred to as *muscle fibers*. Each muscle fiber contains many nuclei (Figure 4-12a). Because of the dense array of contractile fibers in the cytoplasm of the muscle fiber, the nuclei become pressed against the plasma membrane. As a result, muscle fibers cannot divide, and damaged muscle cells cannot be replaced.

Skeletal muscle fibers appear banded, or striated, when viewed under the light microscope (Figure 4-12a). The striations result from the unique arrangement of actin and myosin filaments inside muscle cells.

Cardiac Muscle. Like skeletal muscle, **cardiac muscle** is banded (Figure 4-12b). Unlike skeletal muscle, cardiac muscle is involuntary; that is, it contracts without conscious control. Found only in the walls of the heart, each cardiac muscle cell contains a single nucleus. Cardiac muscle cells also branch and interconnect freely, and individual cells are tightly connected



(a)



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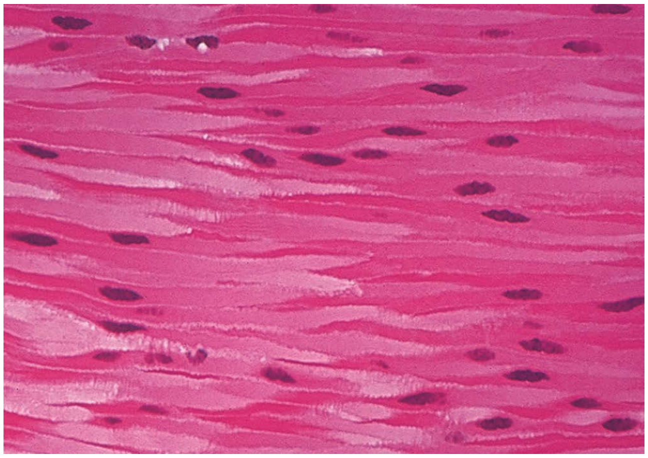


(c)

FIGURE 4-12 Three Types of Muscle as Seen through the Light Microscope
(a) Skeletal (398x). (© Ed Reschke/Visuals Unlimited.) (b) Cardiac (974x). (© Ed Reschke/Visuals Unlimited.) (c) Smooth (398x). (© M. I. Walker/Science Source, Inc.)

to one another. This adaptation helps maintain the structural integrity of the heart, an organ subject to incredible strain as it pumps blood through the body day and night. The points of connection also provide pathways for electrical impulses to travel from cell to cell, allowing the muscle of the heart chambers to contract uniformly when stimulated.

Smooth Muscle. **Smooth muscle**, so named because it lacks visible striations, is involuntary. Actin and myosin filaments are present in smooth muscle cells but are not arranged in an organized fashion like those found in other types (Figure 4-12c). Smooth muscle cells typically occur in large groups, specifically bands or sheets—for example, in the walls of hollow organs such as the intestine, stomach, and uterus (see Figure 4-1).

Smooth muscle cells in the wall of the stomach churn the food, mixing the stomach contents, and force tiny spurts of liquefied food into the small intestine. Smooth muscle contractions also propel the food along the intestinal tract. Smooth muscle cells may also occur in small groups, for example, in small rings that surround tiny blood vessels. When these cells contract, they reduce the supply of blood to tissues. Smooth muscle cells may also occur in the connective tissue of certain organs such as the prostate gland of boys and men. They help propel fluid from this gland during ejaculation.

KEY CONCEPTS

Muscle consists of highly specialized cells that contract when stimulated. Three types of muscle tissue are found in the body: cardiac, skeletal, and smooth.

Nervous Tissue

Last but not least of the primary tissues is **nervous tissue**. It consists of two types of cells: conducting cells or neurons and nonconductive cells or neuroglia (literally, nerve glue). Together, the neurons and the neuroglial cells form the brain, spinal cord, and nerves, described elsewhere in the text.

The conducting cells or **neurons** are sometimes modified to respond to specific stimuli, such as pain or temperature. Stimulation results in nerve impulses, which the neuron transmits from one region of the body to another.

The nonconductive cells of the nervous system are called **neuroglia** and were long thought to be merely a kind of nervous system connective tissue. They are by far the most prominent type of cell in the brain and spinal cord, outnumbering nerve cells by about nine to one. Although nonconducting cells provide physical support for nerve cells, we now know that they also perform other functions. One type of neuroglial cell, for instance, engulfs bacteria, helping reduce brain infections. Another type of neuroglial cell transports nutrients from blood vessels to neurons. This cell also produces a hormone that stimulates regrowth of nerve cells. Researchers hope that one day this hormone can be used to treat diseases of the nervous system resulting from the degeneration of neurons, such as Parkinson's disease. The hormone-producing cells also guard against toxins by creating a barrier to many potentially harmful substances. Although neuroglial cells have long been considered nonconductive, new research suggests that they communicate with each other as well as with nerve cells.

Neurons. At least three distinct types of neurons are found in the body. Despite obvious structural differences, they share several common features. We will study these similarities by looking at one of the most common (and complex) nerve cells, the **multipolar neuron**, shown in Figures 4-13a and b.

The multipolar neuron contains a prominent cell body to which are attached several short, highly branched processes, known as *dendrites* (DEN-drites). (It is the presence of these processes that gives this neuron its name, multipolar.) The

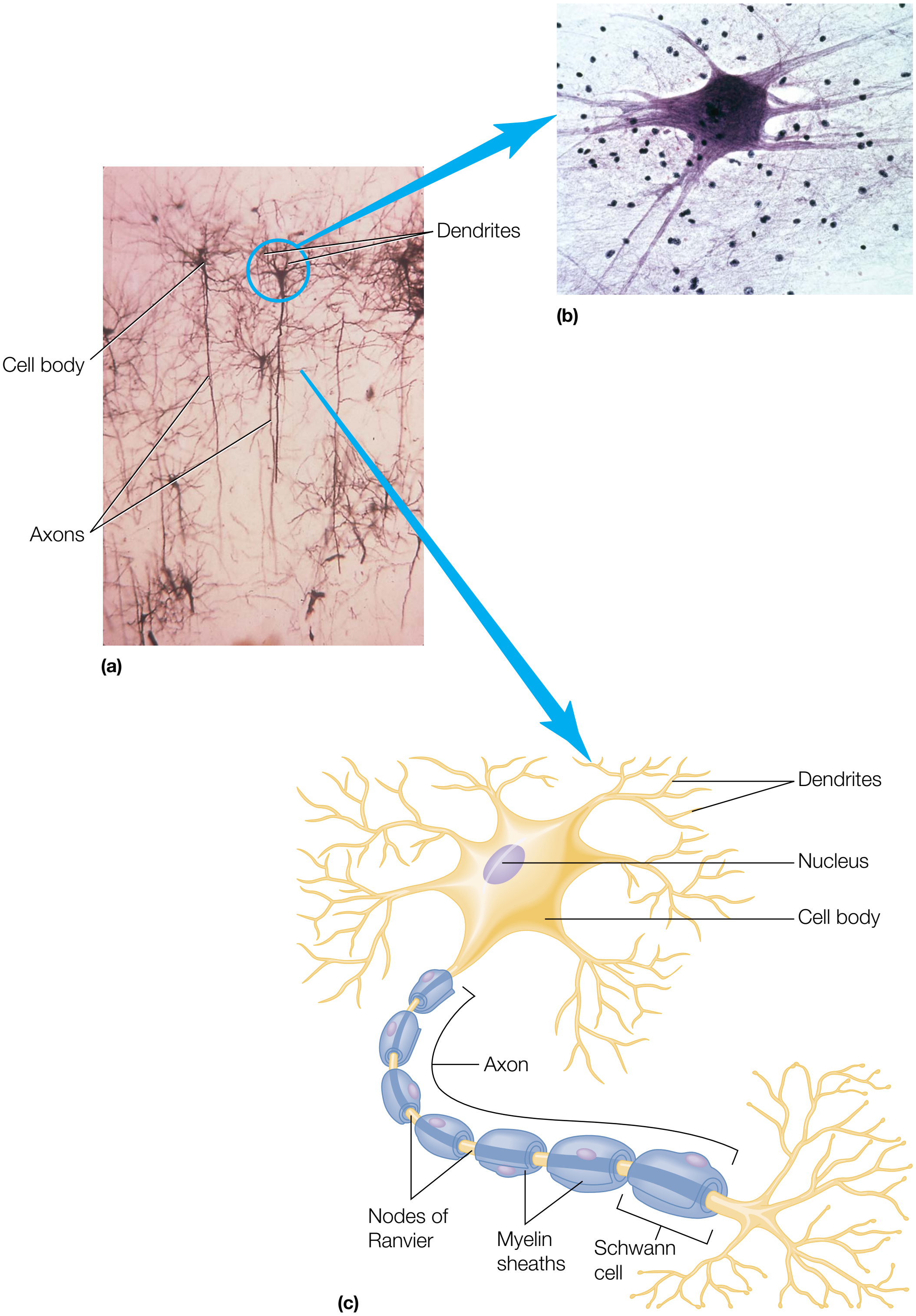


FIGURE 4-13 **Multipolar Neurons** (a) Attached to the cell body of the multipolar neuron are many highly branched dendrites (b), which deliver impulses to the cell body. (a, © John D. Cunningham/Visuals Unlimited; b, © Manfred Kage/Science Source.) (c) Multipolar neurons have one long, unbranching fiber called the axon, which transmits impulses away from the cell body.

dendrites receive impulses from receptors (discussed next) or other neurons and transmit them to the cell body. Also attached to the cell body of the multipolar neuron is a large, fairly thick process, known as the *axon* (AXE-on). It transports bioelectric impulses away from the nerve cell body.

Nervous tissue plays an important role in body function. It monitors internal and external conditions through various sensors called *receptors*. Nerve cells use this information to bring about internal changes that ensure our survival and well-being. Input from various sensors is fed into the brain and spinal cord via nerves. Incoming information is then compiled and appropriate responses are mounted. Some may be automatic responses, ones we're not consciously aware of. Others involve conscious responses. Both conscious and unconscious responses help maintain homeostasis.

KEY CONCEPTS

Nervous tissues consists of highly specialized cells called neurons that are capable of conducting bioelectric impulses from part of the body to another vital to control many body functions.

Organs and Organ Systems

Cells in your body contain organelles ("little organs") that carry out many of its functions in isolation from the biochemically active cytoplasm. As pointed out elsewhere in the text, compartmentalization such as this is an important evolutionary adaptation. Compartmentalization also occurs in organisms in their internal organs.

Organs are discrete structures that have evolved to perform specific functions, such as digestion, enzyme production, and hormone production. Most organs, however, do not function alone. Instead, they are part of groups of co-operative organs, called **organ systems**. The brain, spinal cord, and nerves are all organs that belong to an organ system known as the nervous system.

As you will see, components of an organ system are sometimes physically connected—as in the digestive system (Figure 4-14a). In other cases, they are dispersed throughout the body—as in the endocrine system (Figure 4-14b). In addition, some organs belong to more than one system. The pancreas, for example, produces digestive enzymes used to break down food in the small intestine. The pancreas is

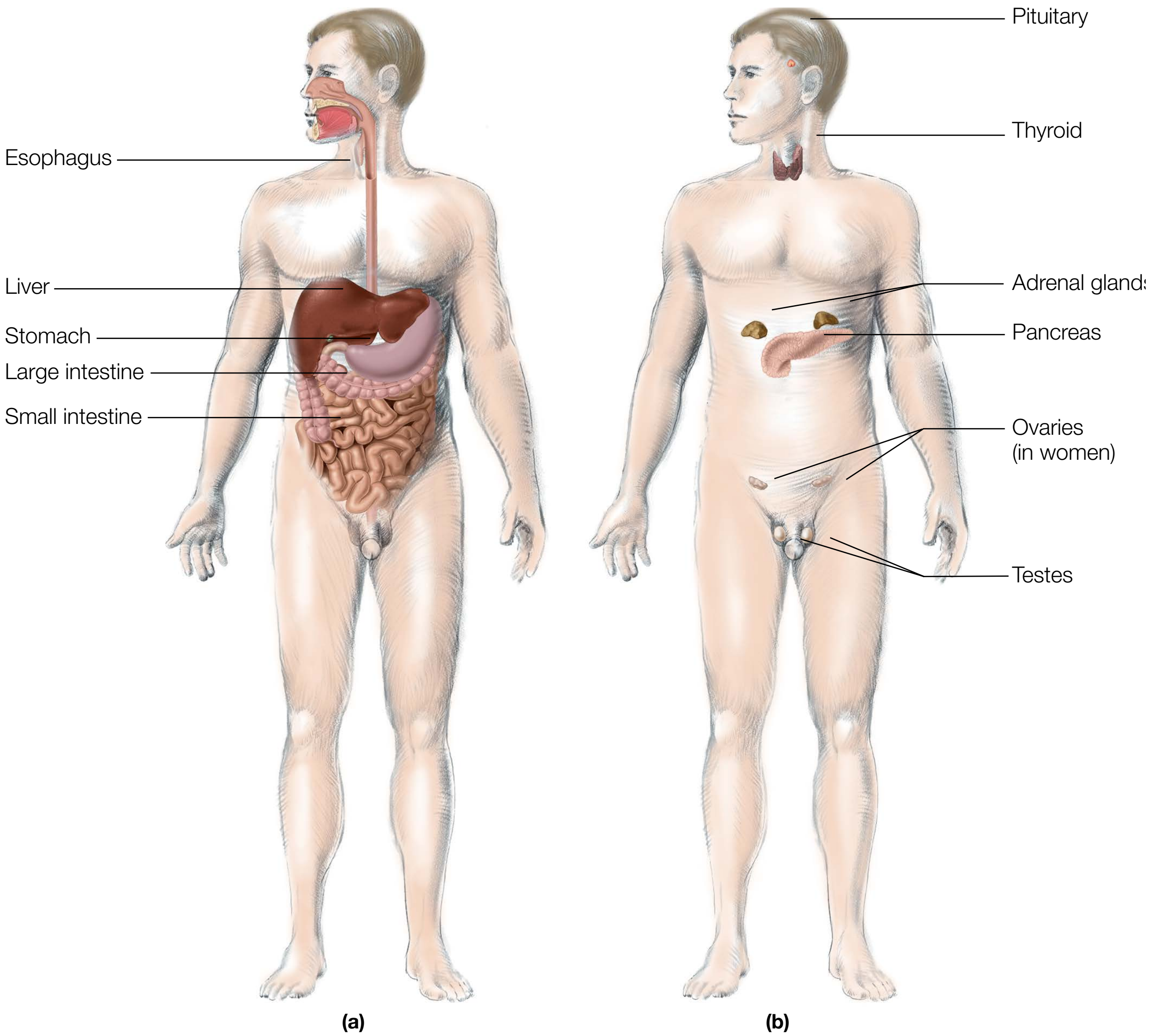


FIGURE 4-14 Comparison of the Endocrine and Digestive Systems (a) The digestive system. (b) The endocrine system.

therefore part of the digestive system. However, some cells of the pancreas produce hormones that are released into the bloodstream where they circulate to body tissues to help control blood glucose levels. Thus, the pancreas also belongs to the endocrine system.

Many of the chapters in this text describe the organ systems of the human body and the functions they perform, paying special attention to their role in homeostasis. Figure 4-15 summarizes the functions of each organ system and lists the role each plays. You may want to take a moment to read the descriptions in the boxes describing the organ systems before proceeding.

KEY CONCEPTS

Organs are structures that evolved to perform very specific functions like digestion and respiration; organs are part of organ systems consisting of numerous organs that function together to carry out their functions.

4-2 Principles of Homeostasis

Organ systems perform many functions, virtually all of which are involved in **homeostasis**. Defined as a state of relative internal constancy, homeostasis occurs on a variety of levels—in cells, tissues, organs, organ systems, organisms, and even the environment. Homeostatic systems at all levels of biological organization have several common features.

KEY CONCEPTS

The organs of the body perform a multitude of functions, all essential for maintaining homeostasis.

Negative Feedback

Most of the processes you will be studying in this course are controlled by a process biologists refer to as feedback mechanisms. The most common type is called **negative feedback**. To understand how negative feedback systems work, consider a familiar example, the heating system of a house. It contains many of the features present in biological feedback mechanisms (Figure 4-16a).

In the winter, the heating system of a house maintains a constant internal temperature, even though the outside temperature fluctuates considerably. Heat lost through ceilings, walls, and windows is replaced by heat generated from the combustion of natural gas or oil in the furnace (Figure 4-16a).

The furnace is controlled by a thermostat. It monitors room temperature. When indoor temperature falls below the setting, the thermostat sends a signal to the furnace, turning it on. Heat from the furnace is then distributed through the house, raising the room temperature. When the room temperature reaches the desired setting, the thermostat shuts the furnace off. Like all negative feedback mechanisms, the product of the system (heat) "feeds back" on the process, shutting it down.

A graph of a hypothetical house temperature is shown in Figure 4-16b and illustrates another important principle of homeostasis: Homeostatic systems do not maintain absolute constancy. Rather, they maintain conditions (such as body temperature) within a given range.

All homeostatic mechanisms in humans operate in a similar fashion, maintaining conditions within a narrow range around an operating point. The operating point is akin to the setting on a thermostat. As you will see in later chapters, our bodies maintain fairly constant levels of a great many chemical components, including hormones, nutrients, wastes, and ions. We also maintain physical conditions such as body temperature, blood pressure, blood flow, and others. Most of this is done subconsciously and automatically.

KEY CONCEPTS

Homeostatic mechanisms in the body are controlled primarily by negative feedback loops.

Sensors and Effectors

Biological homeostatic mechanisms contain **sensors** that detect change and **effectors** that correct conditions. In your home, the thermostat is the sensor and the furnace is the effector.

The human body contains many sensors. For example, the skin contains nerve cell endings that detect outside temperature. When temperatures change, they send signals to the brain, alerting it to outside conditions. The brain then sends signals to the body to adjust for temperature, for example, to generate more heat internally if it is too cold. The options for generating more heat are many.

One of the main sources of heat in the human body is the breakdown (catabolism) of glucose and other molecules. For example, cells of the body break down glucose to make ATP. During this process, heat is given off. Each cell, then, is a tiny furnace whose heat radiates outward and is distributed throughout the body by the blood. Unlike the furnace in your home, the cellular "furnaces" cannot be turned up very quickly. They respond much more slowly than a furnace and are part of a delayed response to low temperature. As winter progresses, metabolism increases and the body produces more heat.

In order to respond to sudden changes in outside temperature, the body must rely on more rapid mechanisms. If you walked outdoors on a cold winter night dressed only in a light sweater and blue jeans, for example, receptors in your skin would sense the cold and send signals to the brain. The brain, in turn, would send signals to blood vessels in the skin, causing them to constrict, reducing the flow of blood in the skin. The restriction of blood flow through the skin reduces heat loss. If it is cold enough outside, the brain may also send signals to the muscles, causing them to undergo rhythmic contractions, known as *shivering*. Shivering burns additional glucose, releasing additional heat. Many voluntary actions may also be "ordered" by the brain to reduce heat loss or generate more heat. For example, you might turn around

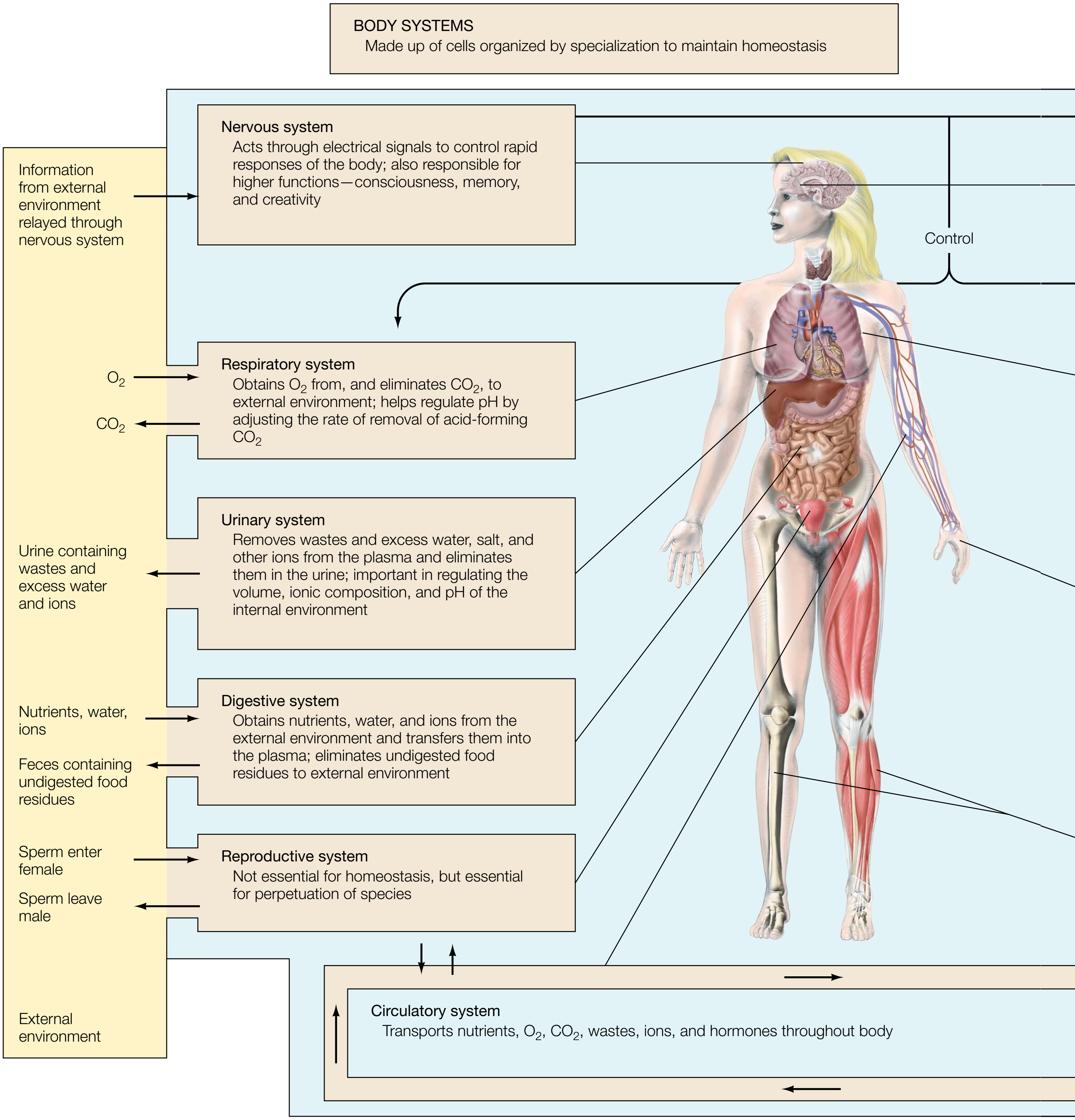
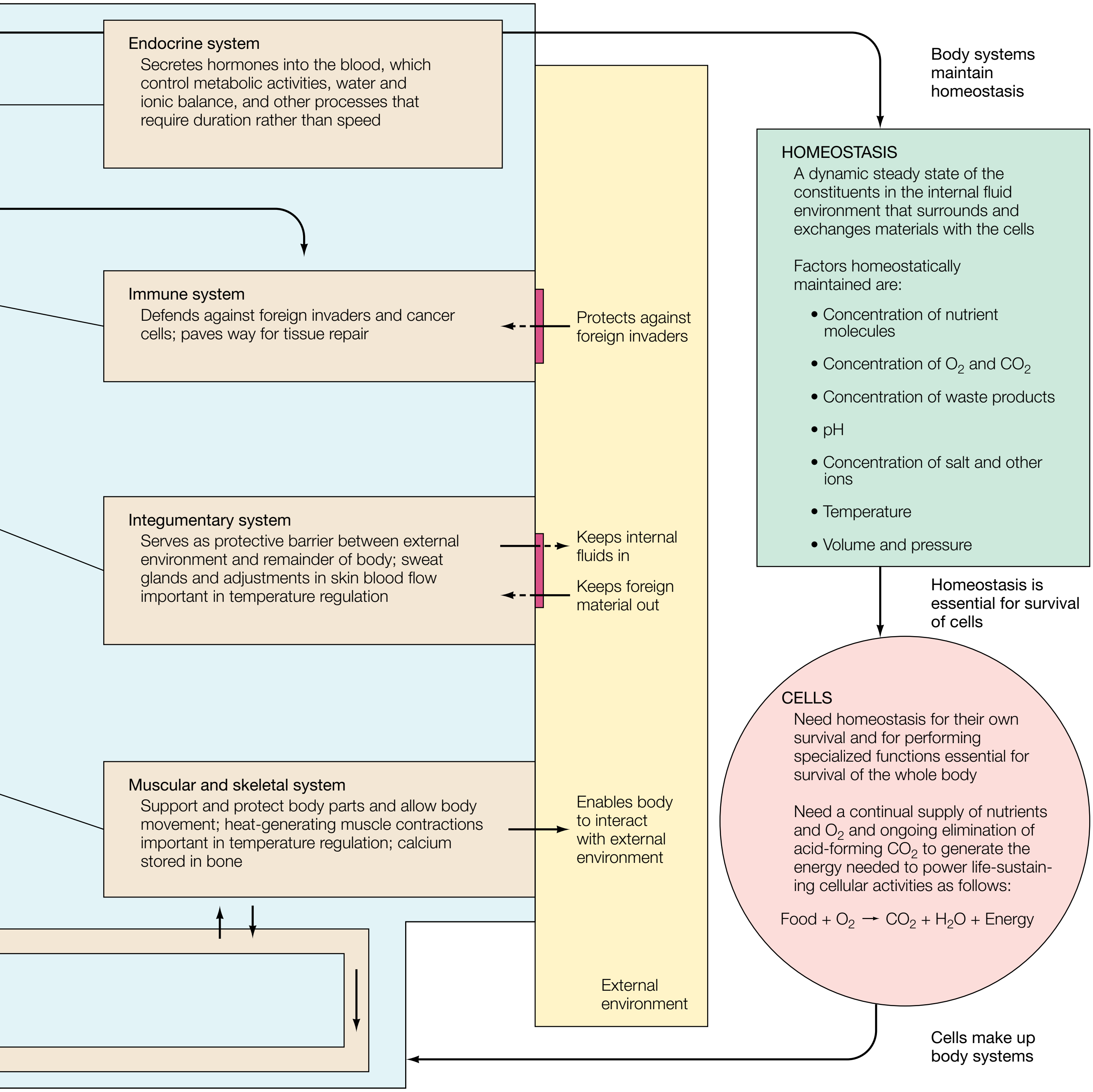


FIGURE 4-15 **Role of the Body Systems in Maintaining Homeostasis**


Endocrine system
Secretes hormones into the blood, which control metabolic activities, water and ionic balance, and other processes that require duration rather than speed
Body systems maintain homeostasis
HOMEOSTASIS
A dynamic steady state of the constituents in the internal fluid environment that surrounds and exchanges materials with the cells
Factors homeostatically maintained are:
• Concentration of nutrient molecules
• Concentration of O_2 and CO_2
• Concentration of waste products
• pH
• Concentration of salt and other ions
• Temperature
• Volume and pressure
Immune system
Defends against foreign invaders and cancer cells; paves way for tissue repair
Protects against foreign invaders
Integumentary system
Serves as protective barrier between external environment and remainder of body; sweat glands and adjustments in skin blood flow important in temperature regulation
Keeps internal fluids in
Keeps foreign material out
Homeostasis is essential for survival of cells
CELLS
Need homeostasis for their own survival and for performing specialized functions essential for survival of the whole body
Need a continual supply of nutrients and O_2 and ongoing elimination of acid-forming CO_2 to generate the energy needed to power life-sustaining cellular activities as follows:
Food + O_2 → CO_2 + H_2O + Energy
Muscular and skeletal system
Support and protect body parts and allow body movement; heat-generating muscle contractions important in temperature regulation; calcium stored in bone
Enables body to interact with external environment
External environment
Cells make up body systems

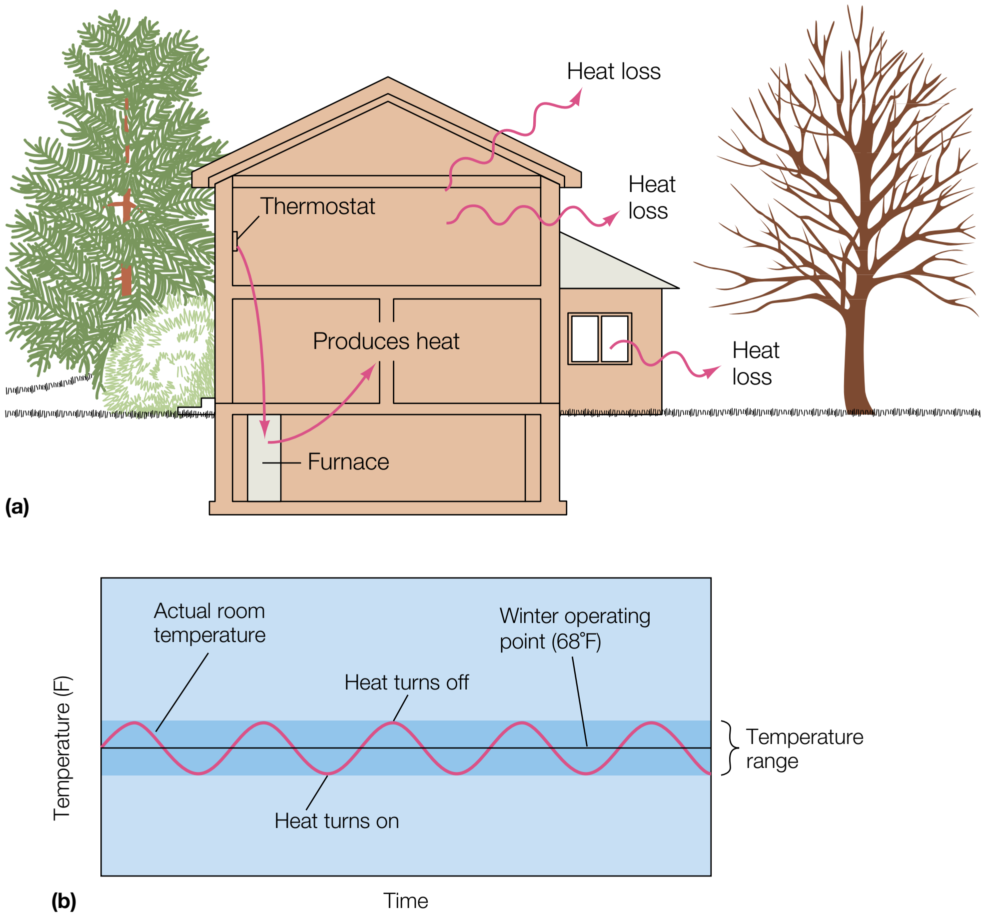


FIGURE 4-16 **Homeostasis in Our Homes** (a) Heat is maintained in a house by a furnace, which compensates for heat loss. The thermostat monitors the internal temperature and switches the furnace on and off in response to temperature changes. (b) A hypothetical temperature graph showing temperature fluctuation around the operating point.

and go back inside at least to grab a coat and hat. In humans, conscious acts are often crucial components of homeostasis.

KEY CONCEPTS

All homeostatic systems require sensors and effectors. Sensors are specialized structures that detect change and effectors are the glands and organs of the body that help make adjustments for those changes.

Upsetting Homeostasis

Homeostasis can be thrown out of balance by many factors. On a hot day, for example, water escapes our bodies very rapidly through perspiration. Although perspiration helps cool us down, if water loss is severe, it can be quite damaging. Severe water loss leads to dehydration, which may upset homeostasis—so much so that death may occur. Going without water for a prolonged period (approximately 3 days) can kill a human being.

Just as changes in the output of a substance—for example, perspiration—drastically alter homeostasis, so do changes in input. Excess salt intake, for example, can result in high blood pressure in some people that can lead to other problems like stroke, kidney disease, and hardening of the arteries. Whatever the cause, imbalances in homeostasis can have dramatic impacts on human health.

KEY CONCEPTS

Homeostasis can be altered by changing inputs or outputs.

Control of Homeostasis

Correcting imbalances to maintain homeostasis requires numerous reflexes—automatic responses. Reflexes occur without conscious control. Two types of reflexes exist: nervous system and hormonal.

At any one time, the brain and spinal cord receive thousands of signals from receptors in the body. These signals alert the nervous system to internal and external conditions. The brain and spinal cord then send out signals to effectors, after integrating (making sense of) the various inputs they have received. The main effectors are the muscles and glands of the body. These are nervous system reflexes.

Hormonal reflexes also help us respond to changes. Hormones are chemical substances produced by the endocrine glands. Released into the blood, hormones travel to distant sites, where they effect change. Hormones don't just pour out of endocrine glands in a constant stream, however. They are released only when needed and usually as part of a chemical reflex essential for maintaining homeostasis.

Nervous and endocrine feedback mechanisms generally occur over considerable distances. Nervous system responses

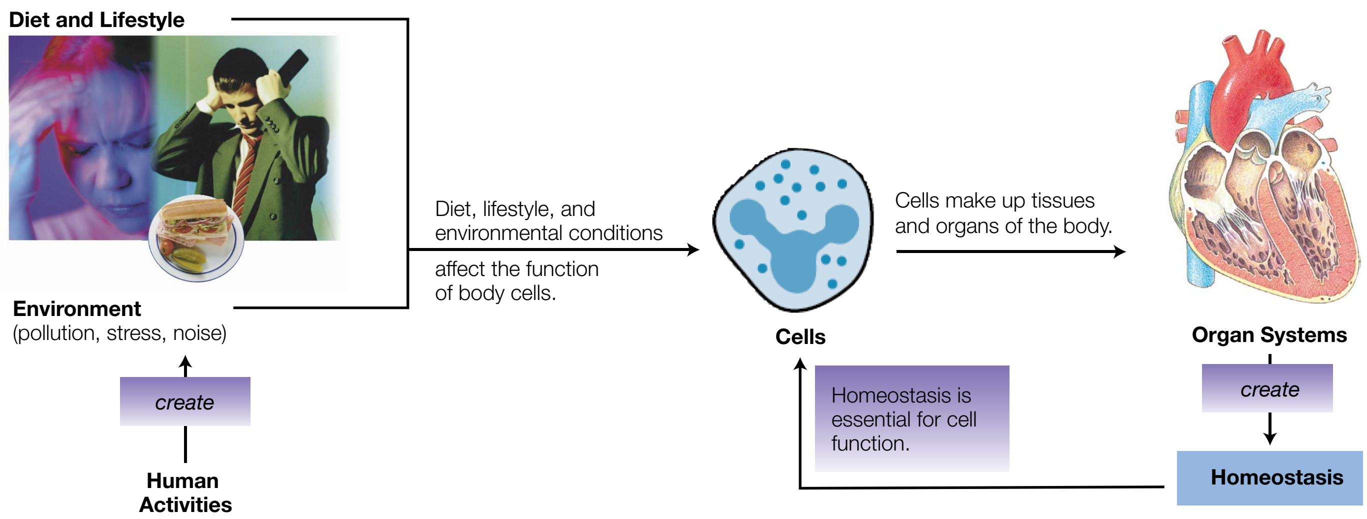


FIGURE 4-17 **Human Health Is Dependent on Maintaining Homeostasis** Homeostasis, however, is affected by the condition of our environment. Stress, pollution, noise, and other environmental factors upset the function of cells and body systems, thus upsetting homeostasis and human health. As a result, human health is dependent on a healthy environment. (Left photo © Nick Rowe/Photodisc/Getty Images; right photo © Jonnie Miles/Photodisc/Getty Images.)

tend to occur more quickly, however, as the responses are elicited by nerve impulses traveling along nerves at a high rate of speed, as opposed to hormones that must circulate in the bloodstream to reach their effectors.

The body also possesses chemical feedback mechanisms that operate over very short distances. They usually involve chemicals called **paracrines** (PEAR-ah-crins). Produced by individual cells, paracrines diffuse to neighboring cells, where they elicit an effect. One example is epidermal growth factor (EGF), a paracrine produced by skin cells. It is released when skin cells are damaged or lost. EGF stimulates cell division in remaining cells, helping to fix the wound and thus provides a degree of local control.

One of the best-known paracrines is a group of chemical substances known as *prostaglandins* (PROSS-tah-GLAND-ins). Prostaglandins comprise a rather large group of molecules with diverse functions. Some stimulate blood clotting; others stimulate smooth muscle contraction.

KEY CONCEPTS

The nervous and endocrine systems control virtually all homeostatic processes in the body.

The Link between Health and Homeostasis

This book emphasizes a theme that is important to all of us—notably, that human health is dependent on homeostasis within the cells, tissues, and organs of the body. Homeostasis, in turn, requires a healthy social, psychological, and physical environment and freedom from disease-causing organisms. The health of the physical environment, our air and water, for instance, is also dependent in part on properly functioning homeostatic systems in nature. These systems evolved to help maintain conditions conducive to life. Unfortunately, they can be damaged by human activities like burning coal in coal-fired power plants, which release a number of harmful chemical pollutants.

The relationship between homeostasis and health is summarized in Figure 4-17. Take a moment to study this diagram. Notice that the organ systems in your body (right side of diagram) help to maintain homeostasis. That's vital for proper cell function. Cells, of course, make up the tissues and organs of the body. Cells also contain homeostatic mechanisms that are vital to their own function as well as to the overall economy of the organism.

On the left side of the diagram, you see that environmental factors, such as pollution and disease organisms, affect the function of cells and body systems in ways that can upset the body's internal balance, thus altering human health. Stress and other factors can also affect homeostasis, detracting from our health. Figure 4-15 also summarizes some key points about homeostasis that you may want to review when studying this material. For a discussion of herbal remedies that help restore health, see Health Note 4-1.

KEY CONCEPTS

Human health is dependent on the proper functioning of homeostatic mechanisms of the body.

4-3 Biological Rhythms

The previous discussion may give the impression that homeostasis establishes an unwavering stability. In truth, some key bodily processes undergo rhythmic change.

Understanding Biological Rhythms

Body temperature, for instance, varies during a 24-hour period by as much as 0.5°C. Blood pressure may change by as much as

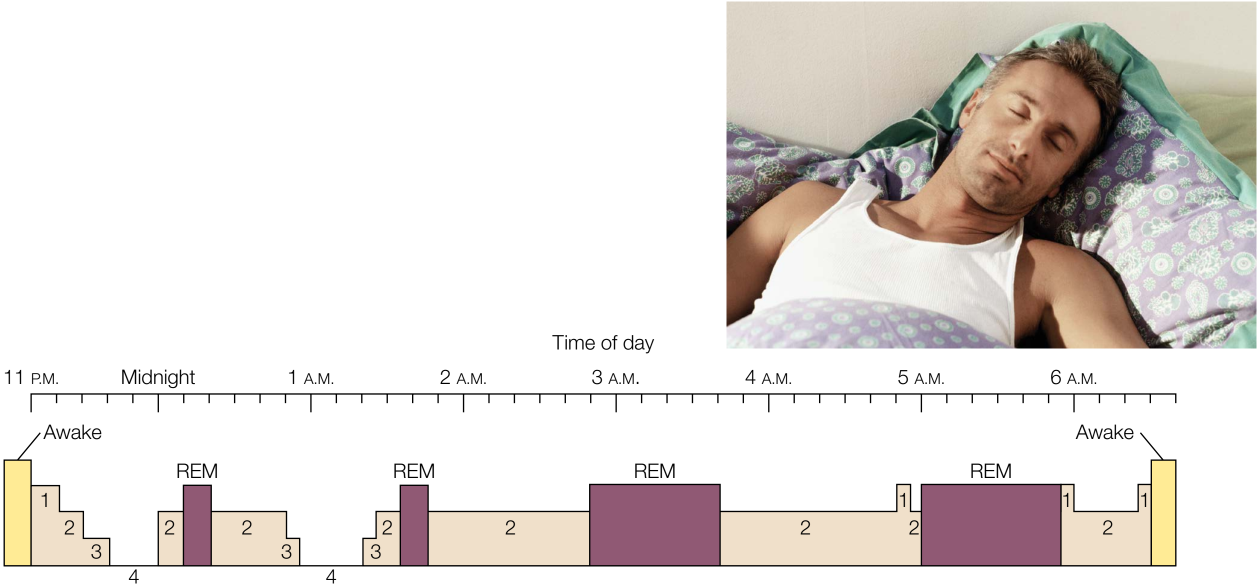


FIGURE 4-18 Stages of Sleep Numbers indicate the stages of sleep: the higher the number, the deeper the sleep. Note that around midnight sleep is deepest. As morning approaches, a person's sleep is lighter, and REM sleep, or dream sleep, occurs in longer increments. (Photo © Photos.com.)

20%, and the number of white blood cells, which fight infection, can vary by 50% during the day. Alertness also varies considerably. About 1:00 PM each day, for instance, most people go through a slump. For most of us, activity and alertness peak early in the evening, making this an excellent time to study. Daily cycles, such as these, are called **circadian rhythms** (sir-KADE-ee-an; "about a day"). These also are referred to as **biological rhythms** or **biorhythms**. Circadian rhythms are natural cycles in body function linked to the 24-hour day-night cycle.

Many hormones follow daily rhythmic cycles. The male sex hormone testosterone, for example, follows a 24-hour cycle. The highest levels occur in the night, particularly during dream sleep, also known as REM sleep. Dream sleep occurs primarily in the early morning hours—the later the hour, the longer the periods of dream sleep (Figure 4-18).

Not all cycles occur over 24 hours, however. Some can be much longer. The menstrual cycle, for instance, is a recurring series of events in the reproductive functions of women that lasts, on average, 28 days. During the menstrual cycle, levels of the female sex hormone estrogen undergo dramatic but predictable shifts.

The important point is that although many chemical substances are held within a fairly narrow range by homeostatic mechanisms, others fluctuate widely in normal cycles. These cycles are part of the body's dynamic balance.

KEY CONCEPTS

Many processes in the body fluctuate slightly during the day or over longer periods; these natural fluctuations are called biological rhythms.

Control of Biological Rhythms

Research suggests that the brain controls many internal rhythms. One region in particular, the suprachiasmatic nucleus (SUE-pra-ki-as-MAT-tick), is thought to play a major role in coordinating several key rhythms.

The suprachiasmatic nucleus (SCN) is a clump of nerve cells located at the base of the brain in a region called the *hypothalamus*. The SCN is believed to regulate other control centers. As a result, the suprachiasmatic nucleus is often referred to as the *master clock* or, more commonly, the *biological clock*. Like the automatic timer of a sprinkler system, the SCN ticks off the minutes, faithfully imposing its control on the body, turning body functions on and off.

Ultimate control of the SCN is thought to reside in a gland in the brain known as the *pineal gland* (PIE-knee-al). It secretes a hormone thought to keep the suprachiasmatic nucleus in sync with the 24-hour day-night cycle. The release of this hormone is controlled by light. Scientists have recently found that the biological clock responds differently to different colors of light. Their work shows that the biological clock (presumably via the pineal gland) is particularly responsive to blue light. Physicians are even using blue light to treat patients who suffer from depression during the winter, when days are shorter and often gloomy. This condition is known as *seasonal-affective disorder* (SAD). In one study, a 45-minute exposure to blue light each morning reduced SAD in 60% of all patients.

Exposure to blue light perks up drowsy people, too, so some businesses in Europe are installing lights whose color can be adjusted. In the morning, when workers first arrive, the lighting is automatically set to provide more blue light. Some experts are suggesting that schools install blue lighting to increase student alertness and performance. Interestingly, however, the problem of drowsy students may be better addressed by making changes in activity at home. Some studies suggest that exposure of teens to blue light from computer screens and television late at night may be throwing off their sleep patterns. By artificially stimulating students at night, this light makes it harder for them to get to sleep . . . so they arrive at school in a state of near slumber. To prevent this, some researchers suggest that students wear yellow-orange glasses that filter out blue light at night and thus help them get to bed on time.

The study of biological rhythms has yielded some important information and insights. One practical application is a better understanding of jet lag—that drowsy, uncomfortable feeling people get from the disruption of sleeping patterns caused by long-distance airplane travel. Jet lag occurs when the body's biological clock becomes out of sync with the day-night cycle of a traveler's new surroundings. A businesswoman who travels from Los Angeles to New York, for instance, may be wide awake at 10:00 PM New York time because her body is still on Los Angeles time—3 hours earlier. If she normally goes to bed at 10:00 PM, she may not feel tired until 1:00 AM in New York. When the alarm goes off at 6:00 AM, our weary traveler crawls out of bed exhausted, because as far as her body is concerned, it is 3:00 AM Los Angeles time. Making matters worse, she may not have fallen asleep until 1:00 AM.

To avoid the discomfort associated with travel, sleep researchers suggest that you abide by your internal clock, following "home time" when in a new time zone, or, barring that, try to reset your biological clock before you get there. You can do this by going to bed an hour or two earlier when you are traveling from west to east. Do just the opposite for east-to-west travel. Insomnia is another disruption of sleeping patterns. More on this topic is in Health Note 4-2.

Research on body rhythms has also shown that people respond to drugs differently at different times of the day and night. Certain drugs that combat high blood pressure, for instance, are more effective if taken at night than in the morning. By administering drugs at the body's most receptive times, physicians may be able to reduce the doses, thereby lowering toxic side effects and fighting diseases more effectively.

KEY CONCEPTS

The brain controls many natural body rhythms.

4-4 Health and Homeostasis

Human health is dependent on maintaining homeostasis, but homeostasis can be upset by many factors. Even stress created by an unhealthy environment can upset our internal balance and our health. The work environment can be a particularly stressful place for many reasons. Difficult bosses, noise, exposure to dangerous equipment, heavy workloads, grouchy coworkers, and shiftwork all contribute to stress that upset homeostasis and damage our health.

Variable work schedules are particularly troublesome. Dr. Richard Restak, a neurologist and author, notes that the "usual rhythms of wakefulness and sleep . . . seem to exert a stabilizing effect on our physical and psychological health." The greatest disrupter of our natural circadian rhythms, he says, is the variable work schedule.

Today, one out of every four working men and one out of every six working women are on a variable work schedule, alternating frequently between day and night shifts. Why? In many industries, factories are kept running 24 hours a day to make optimal use of equipment and buildings. Workers must be on the job day and night. As a result, more restaurants and stores are finding it profitable to be open 24 hours a day, and more healthcare workers must be on duty at night to care for accident victims.

Workers on alternating shifts suffer from a higher incidence of ulcers, insomnia, irritability, depression, and tension than workers on regular shifts. These are all signs that homeostasis is upset. Making matters worse, tired, irritable workers whose judgment is impaired by fatigue pose a threat not only to themselves but also to society. Why?

Humans typically sleep at night and are awake during the day. Make a person work at night when he or she normally sleeps, say sleep experts, and you can expect more accidents and lower productivity. The two most significant accidents at nuclear power plants (Chernobyl in the former Soviet Union and Three Mile Island in the United States) were, many experts believe, caused in part by sleepy workers who missed important signals or made serious errors in judgment because they were working late at night, a time unsuitable for clear thinking. Many experts believe that plane crashes, auto accidents, and acts of medical malpractice can also be traced to judgment errors made by individuals who were working against their natural body rhythms.

Thanks to studies of biological rhythms, researchers are finding ways to reset the body's clock. These efforts could lessen the problems shift workers face and improve safety and productivity.

KEY CONCEPTS

The body's natural rhythms can be disrupted by shift work and by changing time zones.

Health Tip 4-3

To improve your chances of a good night's sleep, the National Sleep Foundation recommends regular exercise.

Why?

Exercise helps decrease stress and strengthens muscles that can reduce aches and pains that disturb sleep, especially as we get older. It also improves balance in old age. If you exercise late in the day, be sure to complete your exercise a couple of hours before bedtime.

healthnote

4–2 Wide Awake at 3 AM: Causes and Cures of Insomnia

It's Thursday evening. The final exam in your human biology course is tomorrow. Forty percent of your grade depends on your score. You've studied hard, but it's well past midnight and you can't get to sleep. It's happened before and you know your ability to think during the test, which is scheduled to start at 8:00 AM, will be impaired. That puts more pressure on you, making it more difficult to sleep.

This frustrating problem, which affects almost everyone at some time in life, is just one of several sleep disorders that physicians call *insomnia* (in-SOM-knee-ah). Another common complaint of insomniacs is waking up in the middle of the night and not being able to fall asleep again for several hours, if at all. In other instances, individuals find that they wake up too early; still others complain of sleeping through the night but waking up feeling groggy and unrefreshed.

Insomnia is best defined as a condition of inadequate or poor quality sleep. That is, you don't get enough sleep or you sleep poorly. It's a problem that affects many people. In a recent study in Canada, for example, two of every five people surveyed said they had trouble sleeping at least once a week. Insomnia affects both men and women but is more common in women and the elderly.

Insomnia may be transient (short term), intermittent (on and off), or chronic (persistent). Short-term and intermittent insomnia are generally of less concern than chronic insomnia, which can last for years. Chronic insomniacs complain of tiredness, a lack of energy, difficulty concentrating, and irritability. Insomnia can make people more susceptible to common illnesses, such as colds.

What causes insomnia? Perhaps the most common cause of insomnia is a change in one's daily routine. Starting a new semester, sleeping in a strange environment, moving into a new home, and anxiety over job interviews or tests are some possible causes. But these are generally short-lived stimuli.

Chronic insomnia is often related to more serious problems. Certain diseases that cause pain and nausea, for example, may affect sleep. Chronic anxiety, for example, caused by a project at work that may take 5 months to complete, with many deadlines along the way, can keep one from falling asleep.

Another very common cause of chronic insomnia is depression. Depression usually manifests itself in the wide-awake-at-3:00-AM syndrome. A person who is depressed may fall asleep without trouble but may wake up every morning at 2:00 or 3:00 AM and may stay awake for a few hours or through the entire night. Depression comes in a variety of shapes and sizes, too—and can last for many years. Insomnia can also be caused by alcohol and caffeine consumption.

What can be done to treat chronic insomnia? If you have a medical problem, treatment of that problem can be helpful. If you are feeling anxious all of the time, the stress-relieving techniques described elsewhere in the text can be helpful, including psychological help. Depression can be treated by psychotherapy, which helps eliminate sources of the problem. Antidepressant drugs are often prescribed for insomniacs, although it may take a few weeks for symptoms of depression to begin to subside. Unfortunately, some antidepressants such as Prozac and Paxil can cause sleeplessness in about one-third of the patients.

Besides these important steps, experts recommend the following dos and don'ts for dealing with insomnia.

- Go to bed and get up at the same time each day.
- Maintain a comfortable temperature in your bedroom—not too hot or too cold.
- Sleep in a quiet, darkened room.
- Exercise regularly during the week to relieve stress. Exercise no later than the early afternoon.
- Engage in quiet tasks such as reading or listening to music in the hour or two before bedtime.
- Try a light bedtime snack with protein just before going to bed.
- Avoid caffeine, which is found in coffees, teas, and caffeinated sodas, especially late in the day.
- Don't use alcohol to stimulate sleep.
- If you can't fall asleep within 30 minutes, get out of bed, engage in some relaxing activity, and then go to bed when you feel tired.
- If you need a nap, take one early in the day, before 3:00 PM.

Finally, insomnia can be treated by over-the-counter sleeping pills such as Tylenol PM or Advil PM. They're supposedly safe and nonaddictive. Prescription medicines can also be taken. One popular prescription is Ambien. Ambien is used to treat short-term insomnia. It is usually not taken for more than 2 weeks because it can worsen insomnia. Several newer medications have also been introduced in recent years.

Another effective treatment is melatonin. Melatonin is a naturally produced hormone that comes from a small gland in the brain, the pineal gland. Melatonin comes in tablets and can be purchased in health food stores or health food sections of grocery stores or other outlets.

SUMMARY

From Cells to Organ Systems

1. The basic structural unit of all organisms is the cell. In humans, cells and extracellular material form tissues, and tissues, in turn, combine to form organs. Organs combine to form organ systems. The human body is made up of ten organ systems.
2. Four basic tissues are found in the bodies of most multicellular animals such as humans: epithelial, connective, muscle, and nervous. Organs contain all four primary tissues in varying proportions.
3. Epithelial tissues consist of two types: membranous epithelia, which form the coverings or linings of organs, and glandular epithelia, which form exocrine (glands of external secretion) and endocrine glands (glands of internal secretion).
4. Connective tissues bind other tissues together, provide protection, and support body structures. All connective tissues consist of cells and extracellular fibers.
5. Two types of connective tissue are found in the body: connective tissue proper (dense and loose connective tissue) and specialized connective tissue (cartilage, bone, and blood).
6. Cartilage consists of specialized cells embedded in a matrix of extracellular fibers and other extracellular material.
7. Bone is a dynamic tissue that provides internal support, protects organs such as the brain, and helps regulate blood calcium levels.
8. Bone consists of bone cells (osteocytes) and a calcified cartilage matrix. Two types of bone tissue exist: spongy and compact.
9. Blood consists of numerous blood cells and platelets and an extracellular fluid, called plasma.
10. Muscle is an excitable tissue that contracts when stimulated. Three types of muscle tissue are found in the human body: skeletal, cardiac, and smooth muscle.
11. Skeletal muscle is under voluntary control, for the most part, and forms the muscles that attach to bones. Cardiac muscle is located in the heart and is involuntary. Smooth muscle is involuntary and forms sheets of varying thickness in the walls of organs and blood vessels.
12. Nervous tissue consists of two types of cells: conducting and nonconducting (supportive). The conducting cells, called neurons, transmit impulses from one region of the body to another. The nonconducting cells are a type of nervous system connective tissue but also play many other important roles.

Principles of Homeostasis

13. The nervous and endocrine systems coordinate the functions of organ systems, helping the body maintain homeostasis.
14. Homeostatic systems do not maintain absolute constancy and can be upset by alterations in input or output. Imbalances can seriously affect an individual's health.
15. Homeostatic mechanisms are reflexes, occurring without conscious control. They operate by negative feedback through the nervous and endocrine systems.

Biological Rhythms

16. Many physiological processes undergo definite rhythmic changes. These natural rhythms may take place over a 24-hour period or over much longer or shorter periods.
17. The brain controls many biological cycles. A clump of nerve cells (the suprachiasmatic nucleus) is thought to play a major role in coordinating these cycles.

Health and Homeostasis

18. The physical, social, and psychological environments we live in greatly affect homeostasis and our health.
19. One of the greatest disrupter of our homeostasis is the variable work schedule, which is surprisingly common among industrialized nations.
20. Workers on alternating shifts suffer from a higher incidence of ulcers, insomnia, irritability, depression, and tension—all indications of homeostasis that's out of whack—than workers on regular shifts. Making matters worse, tired, irritable workers whose judgment is impaired by fatigue pose a threat not only to themselves, but also to society.
21. Researchers are finding ways to reset the biological clock, which could lessen the problems shift workers face.

THINKING CRITICALLY ANALYSIS

This Analysis corresponds to the Thinking Critically scenario that was presented at the beginning of this chapter.

Many of us feel tremendous sympathy for the needy. Are you one of them? Why or why not?

Those who do feel sympathy often want to help in any way they can, even if it means spending hundreds of thousands of dollars on an organ transplant.

That said, most of us recognize that there are limits to the amount of money that is available for public health. We must prioritize our spending. Do you agree or disagree?

After you have given your opinion on this matter, put yourself in the position of a needy parent whose child needs a kidney transplant to survive. How does this perspective affect your position on this issue? What lessons can be learned from this (your) self-examination?

KEY TERMS AND CONCEPTS

Adipose tissue, p. 76
Biological rhythms, p. 90
Biorhythms, p. 90
Blood, p. 80
Bone, p. 80
Brown fat, p. 76
Cardiac muscle, p. 81
Cartilage, p. 78
Circadian rhythms, p. 90
Compact bone, p. 80
Connective tissue, p. 75
Connective tissue proper, p. 75
Dense connective tissue, p. 75
Dermis, p. 75
Effector, p. 85
Elastic cartilage, p. 79
Endocrine gland, p. 75
Epidermis, p. 75
Exocrine gland, p. 74
Fat cells, p. 76
Fibroblast, p. 76
Fibrocartilage, p. 79
Homeostasis, p. 85
Hyaline cartilage, p. 79

Intervertebral disk, p. 79
Loose connective tissue, p. 75
Macrophage, p. 76
Multipolar neuron, p. 83
Muscle tissue, p. 80
Negative feedback, p. 85
Nervous tissue, p. 82
Neuroglia, p. 82
Neuron, p. 82
Organ, p. 84
Organ system, p. 84
Osteoblasts, p. 80
Osteoclasts, p. 80
Osteocytes, p. 76
Paracrines, p. 89
Plasma, p. 80
Platelets, p. 80
Red blood cells, p. 80
Sensor, p. 85
Skeletal muscle, p. 81
Smooth muscle, p. 82
Spongy bone, p. 80
Stratified squamous epithelium, p. 75
Tissue, p. 73
White blood cells, p. 80
White fat, p. 76

CONCEPT REVIEW

1. Define the following terms: tissues, extracellular material, organs, and organ systems. pp. 73–85.
2. List the four basic tissue types and their subtypes. p. 73.
3. Discuss some biological examples showing how structure reflects function. p. 75.
4. Describe the two broad types of connective tissue and how they function. pp. 75–80.
5. Why do cartilage injuries repair so slowly or not at all? Bone is repaired much more easily than cartilage. Why? pp. 78–80.
6. In what way is bone part of a homeostatic system? What bone cells play a part in homeostasis? p. 80.
7. Describe skeletal muscle. What is a muscle fiber? Why do muscle fibers appear banded? What are the contractile proteins found in muscle? Are they found in all types of muscle, or just skeletal muscle? p. 81.
8. Define nervous tissue. What types of cells are found in nervous tissue? pp. 82–84.
9. What is a neuron? Describe its parts? What does each part do? pp. 82–83.
10. What is an organ system? List some examples. pp. 84–85.
11. Define homeostasis, and describe the major principles of homeostasis presented in this chapter. Use an example to illustrate your points. pp. 85–87.
12. Why do all homeostatic systems require sensors and effectors? p. 85.
13. Make a list of homeostatically controlled body functions, p. 85.
14. What are biorhythms? Are biological rhythms an exception to the principle of homeostasis? pp. 89–90.
15. Describe the biological clock. Where is it located? How does shift work upset the biological clock? How can these problems be lessened? pp. 90–91.
16. Why might time of day affect the effectiveness of a medicine you take? p. 91.

SELF-QUIZ: TESTING YOUR KNOWLEDGE

1. The internal and external linings of organs are a type of tissue known as ________. p. 74.
2. A simple epithelium consists of ___ layer(s) of cells. p. 74.
3. A ______________ epithelium consists of multiple layers of cells. p. 74.
4. Endocrine glands are made from ______________ epithelium during embryonic development. p. 75.
5. Ligaments and tendons are made up of ____________ connective tissue. p. 75.
6. The cell responsible for making fibers in connective tissue is known as the _______. p. 75.
7. Accumulations of fat cells in the body are known as _____________ tissue. p. 76.
8. _____ is poorly supplied with blood and therefore does not heal readily after injury. p. 78.
9. The most common type of cartilage is known as _____________ cartilage. p. 79.
10. Bone cells or _______________ are formed when osteoblasts become surrounded by bony matrix. p. 80.
11. The _____________________ is a type of bone cell that digests bone, releasing calcium into the bloodstream. p. 80.
12. ___________ muscle is the type of muscle that is under voluntary control and is responsible for moving body parts like the arms and legs. p. 81.
13. Many organs like the stomach and uterus contain thick sheets of involuntary muscle known as _____________ muscle. p. 82.
14. The nerve cell or ____________ is a conducting cell found in the nervous system. p. 82.
15. The nonconducting cells in the nervous system are known collectively as _______. p. 82.
16. A collection of organs that function together is called a(n) _______________. p. 84.
17. Homeostatic mechanisms in the body are typically controlled by ___________ feedback. p. 85.
18. All homeostatic mechanisms rely on ______ to detect changes and _________ to respond to them. p. 85.
19. A biological rhythm lasting 24 hours is known as a _____________ rhythm. p. 90.
20. Control of daily body rhythms is believed to be housed primarily in the _________________ gland. p. 90.

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