chapter 5

Tissues

BUILDING A BLOOD VESSEL. Cells aggregate to form tissues, and tissues interact to form organs. Dissecting a complex organ to observe how tissues comprise it is a commonly performed exercise; attempting to build an organ from its component cells and tissues is much more challenging.

The field of tissue engineering uses cells, synthetic materials, or combinations of them to fashion human body parts. Consider the task facing graduate student Nicolas L'Heureux, who recreated a small-diameter human blood vessel as his thesis project. Such a vessel has three layers: an innermost layer of tilelike endothelial cells that secrete anti-clotting agents, a middle layer of smooth muscle and elastic connective tissue, and an outer layer of fibroblasts and the collagen protein they secrete.

Previous attempts at producing a small blood vessel combined natural and synthetic ingredients in various ways, with mixed results. The goal is to keep the inner lining smooth enough to prevent blood clots from forming, but construct outer layers that are strong enough to keep the vessel open under the pressure of circulating blood. The trick, L'Heureux found, was to let the cells do the work—with a little help.

L'Heureux and his co-workers grew fibroblasts and smooth muscle cells in sheets. They then rolled the sheets around tubes through which nutrients circulated in, and cellular wastes circulated out. Then the researchers seeded endothelial cells onto the inner surface, where the cells knit a smooth inner lining. By allowing the fibroblasts to secrete the collagen, rather than supplying the protein directly, the vessels formed in a more natural way and persisted. Blood vessels engineered in this way may eventually be used to treat the thousands of people who need vascular grafts in their legs or new coronary arteries.

Photo:

Recipe for a lab-built small-diameter blood vessel: Seed lining cells onto the inner surfaces of tubes of collagen-secreting cells and smooth muscle. These engineered blood vessels may someday replace damaged vessels in people's legs and hearts.

glutamine-valine. Write DNA and RNA sequences that can specify this chain of amino acids.

6. What effect might changes in the pH of body fluids that accompany illness have on enzymes?
7. Some weight-reduction diets drastically limit intake of carbohydrates but allow foods high in fat and protein. What changes would such a diet cause in the dieter's cellular metabolism? What changes might be noted in this person's urine?

WEB CONNECTIONS

Visit the website for additional study questions and more information about this chapter at:

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Chapter Objectives

After studying this chapter, you should be able to do the following:

5.1 Introduction

1. List the four major tissue types, and provide examples of where each occurs in the body. (p. 92)

5.2 Epithelial Tissues

2. Describe the general characteristics and functions of epithelial tissues. (p. 92)
3. Name the types of epithelium, and identify an organ in which each is found. (p. 92)
4. Explain how glands are classified. (p. 97)

5.3 Connective Tissues

5. List the types of connective tissues within the body. (p. 98)
6. Describe the general cellular components, structures, fibers, and matrix (where applicable) of each type of connective tissue. (p. 100)
7. Describe the major functions of each type of connective tissue. (p. 100)

5.4 Muscle Tissues

8. Distinguish among the three types of muscle tissues. (p. 105)

5.5 Nervous Tissues

9. Describe the general characteristics and functions of nervous tissues. (p. 107)

Aids to Understanding Words

adip- [fat] *adipose* tissue: Tissue that stores fat.
chondr- [cartilage] *chondr*ocyte: Cartilage cell.
-cyt [cell] osteo*cyt*e: Bone cell.
epi- [upon] *epi*thelial tissue: Tissue that covers all free body surfaces.
-glia [glue] neuro*glia*: Cells that bind nervous tissue together.
inter- [between] *inter*calated disc: Band between cardiac muscle cells.
macro- [large] *macro*phage: Large phagocytic cell.
oss- [bone] *oss*eous tissue: Bone tissue.
pseudo- [false] *pseudo*stratified epithelium: Tissue whose cells appear to be in layers, but are not.
squam- [scale] *squam*ous epithelium: Tissue whose cells appear flattened or scalelike.
strat- [layer] *strat*ified epithelium: Tissue whose cells occur in layers.

Key Terms

adipose tissue (ad´ĭ-pōs tish´u)
cartilage (kar´tĭ-lij)
chondrocyte (kon´dro-sīt)
connective tissue (kŏ-nek´tiv tish´u)
epithelial tissue (ep´´ĭ-the´le-al tish´u)
fibroblast (fi´bro-blast)
macrophage (mak´ro-fāj)
muscle tissue (mus´el tish´u)
nervous tissue (ner´vus tish´u)
neuron (nu´ron)
osteocyte (os´te-o-sīt´´)
osteon (os´te-on)

5.1 Introduction

Cells, the basic units of structure and function within the human organism, are organized into groups and layers called **tissues** (tish´uz). Each type of tissue is composed of similar cells specialized to carry on a particular function. The tissues of the human body include four major types: epithelial, connective, muscle, and nervous. Epithelial tissues form protective coverings and function in secretion and absorption. Connective tissues support softer body parts and bind structures together. Muscle tissues produce body movements, and nervous tissues conduct impulses that help control and coordinate body activities. In addition to cells, all tissues contain a nonliving portion called the *matrix,* or intercellular substance. This material varies in composition from tissue to tissue and supports the cells within. Table 5.1 compares the four major tissue types. Throughout this chapter, simplified line drawings (for example, fig. 5.1*A*) are included with each micrograph (for example, fig. 5.1*B*) to emphasize the distinguishing characteristics of the specific tissue.

CHECK YOUR RECALL

1. What is a tissue?
2. List the four major types of tissues.

5.2 Epithelial Tissues

General Characteristics

Epithelial (ep´´i-the´le-al) tissues are widespread throughout the body, covering organs, forming the inner linings of body cavities, and lining hollow organs. This tissue, because it forms linings, always has a free surface—one that is exposed to the outside or to an internal space. The underside of this tissue is anchored to connective tissue by a thin, nonliving layer, called the **basement membrane.**

As a rule, epithelial tissues lack blood vessels. However, nutrients diffuse to epithelium from underlying connective tissues, which have abundant blood vessels.

Epithelial cells readily divide. As a result, injuries heal rapidly as new cells replace lost or damaged ones. Skin cells and cells that line the stomach and intestines are continually damaged and replaced.

Epithelial cells are tightly packed, with little intercellular material between them. Consequently, these cells form effective protective barriers in such structures as the outer layer of the skin and the lining of the mouth. Other epithelial functions include secretion, absorption, excretion, and sensory reception.

Epithelial tissues are classified according to shape and number of layers of cells. Epithelial tissues that are composed of single layers of cells are *simple;* those with two or more layers of cells are *stratified;* those with thin, flattened cells are *squamous;* those with cube-shaped cells are *cuboidal;* and those with elongated cells are *columnar.* In the following descriptions, note that the free surfaces of epithelial cells are modified to reflect their specialized functions.

CHECK YOUR RECALL

1. List the general characteristics of epithelial tissues.
2. Describe the structure of epithelium as it relates to the shape and number of layers of cells.

Simple Squamous Epithelium

Simple squamous (skwa´mus) **epithelium** consists of a single layer of thin, flattened cells. These cells fit tightly together, somewhat like floor tiles, and their nuclei are usually broad and thin (fig. 5.1).

Substances pass rather easily through simple squamous epithelium, which is common at sites of diffusion and filtration. For instance, simple squamous epithelium lines the air sacs (alveoli) of the lungs where oxygen and carbon dioxide are exchanged. It also forms the walls of capillaries, lines the insides of blood and lymph

TABLE 5.1 TISSUES

TYPE	FUNCTION	LOCATION	DISTINGUISHING CHARACTERISTICS
Epithelial	Protection, secretion, absorption, excretion	Cover body surfaces, cover and line internal organs, compose glands	Lack blood vessels, readily divide; cells are tightly packed
Connective	Bind, support, protect, fill spaces, store fat, produce blood cells	Widely distributed throughout body	Mostly have good blood supply; cells are farther apart than cells of epithelia, with matrix in between
Muscle	Movement	Attached to bones, in the walls of hollow internal organs, heart	Contractile
Nervous	Transmit impulses for coordination, regulation, integration, and sensory reception	Brain, spinal cord, nerves	Cells connect to each other and other body parts

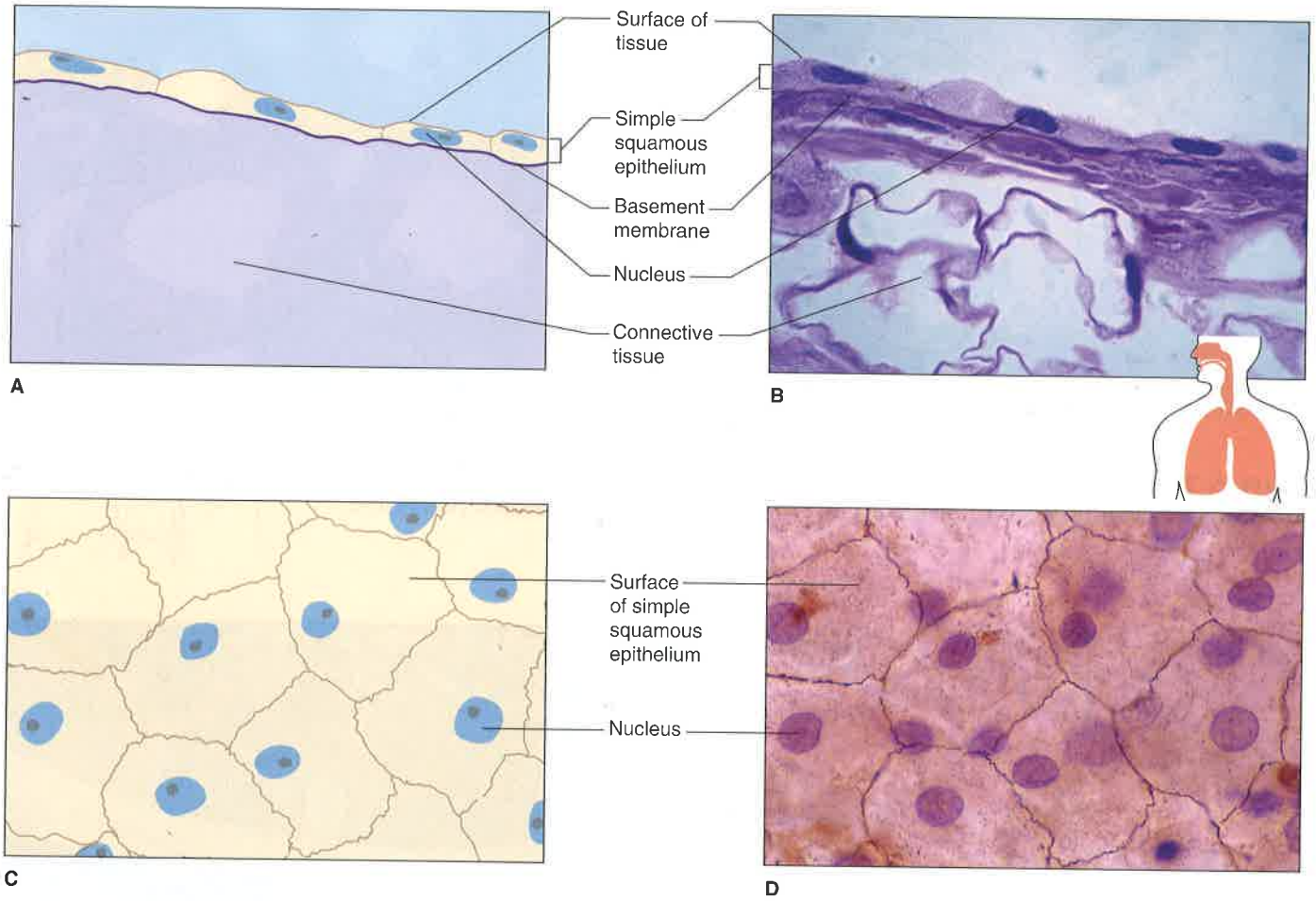

Figure 5.1
Simple squamous epithelium consists of a single layer of tightly packed, flattened cells (670×). (*A*) and (*B*) side view, (*C*) and (*D*) surface view.

vessels, and covers membranes that line body cavities. However, because it is so thin and delicate, simple squamous epithelium is easily damaged.

Simple Cuboidal Epithelium

Simple cuboidal epithelium consists of a single layer of cube-shaped cells. These cells usually have centrally located, spherical nuclei (fig. 5.2).

Simple cuboidal epithelium covers the ovaries and lines most of the kidney tubules and the ducts of certain glands, such as the salivary glands, thyroid gland, pancreas, and liver. In the kidneys, this tissue functions in secretion and absorption; in glands, it secretes glandular products.

Simple Columnar Epithelium

The cells of **simple columnar epithelium** are elongated; that is, they are longer than they are wide. This tissue is composed of a single layer of cells whose nuclei are usually located at about the same level, near the basement membrane (fig. 5.3). The cells of this tissue can be ciliated or nonciliated. *Cilia* extend from the free surfaces of cells and move constantly (see chapter 3, p. 56). In the female reproductive tubes, cilia aid in moving egg cells to the uterus.

Nonciliated simple columnar epithelium lines the uterus and most organs of the digestive tract, including the stomach and the small and large intestines. Because its cells are elongated, this tissue is thick, which enables it to protect underlying tissues. Simple columnar epithelium also secretes digestive fluids and absorbs nutrients from digested food.

Simple columnar cells, specialized for absorption, often have many minute, cylindrical processes extending from their surfaces. These processes, called *microvilli,* increase the surface area of the cell membrane where it is exposed to substances being absorbed.

Typically, specialized, flask-shaped glandular cells are scattered among the columnar cells of simple columnar epithelium. These cells, called *goblet cells,* secrete a protective fluid (*mucus*) onto the free surface of the tissue (fig. 5.3).

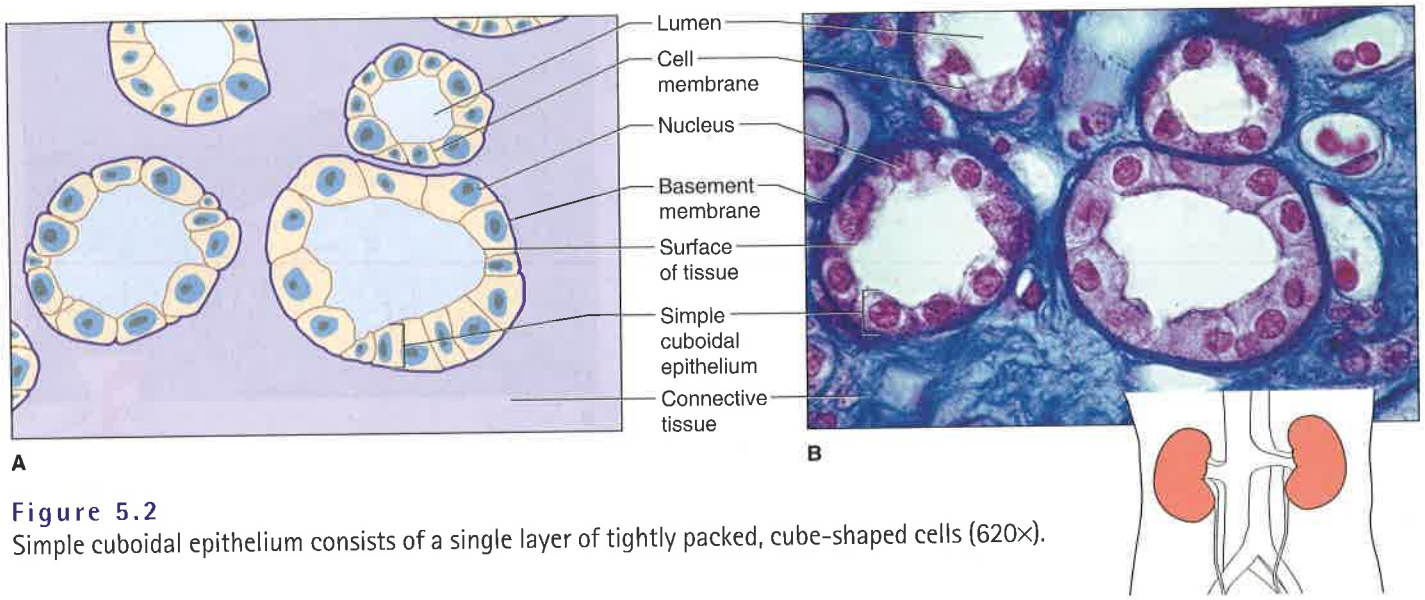

Figure 5.2
Simple cuboidal epithelium consists of a single layer of tightly packed, cube-shaped cells (620×).

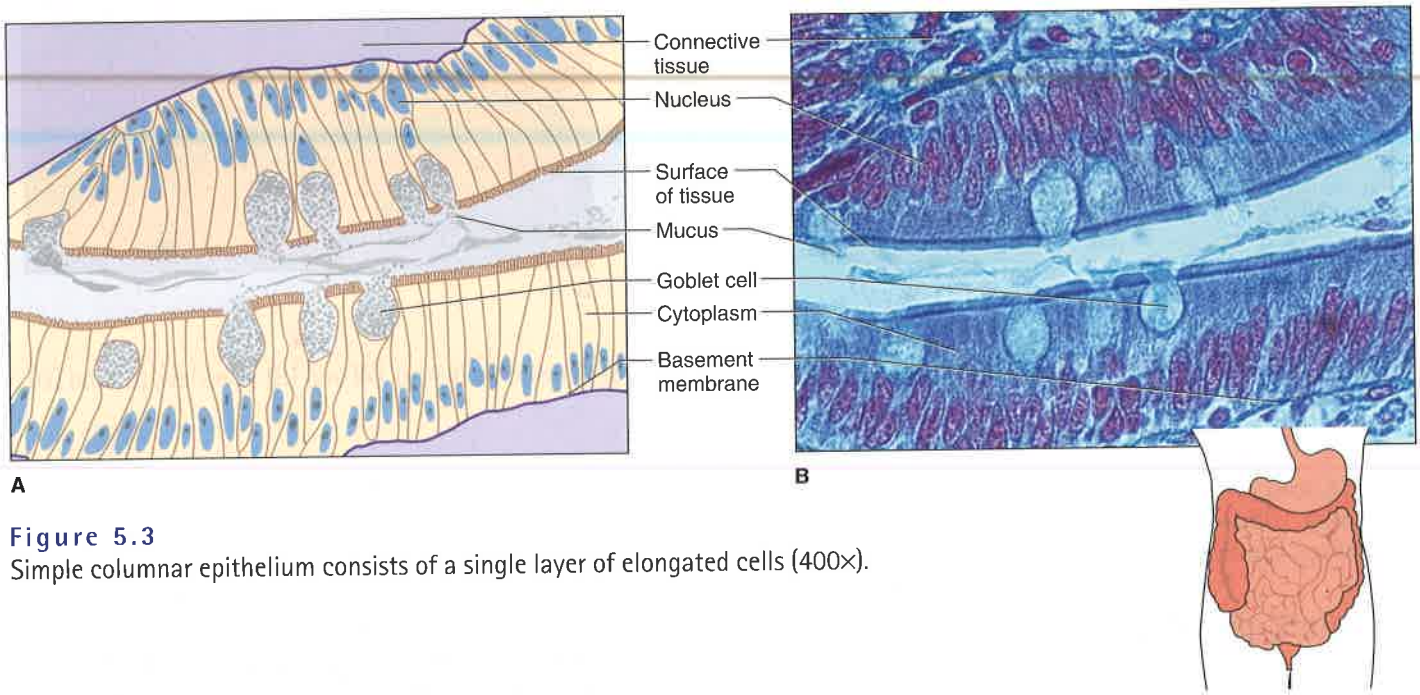

Figure 5.3
Simple columnar epithelium consists of a single layer of elongated cells (400×).

Pseudostratified Columnar Epithelium

The cells of **pseudostratified** (soo´´do-strat´ĭ-fid) **columnar epithelium** appear stratified or layered, but they are not. A layered effect occurs because the cell nuclei are at two or more levels in the row of aligned cells (fig. 5.4).

Pseudostratified columnar epithelial cells commonly have cilia, which extend from the free surfaces of the cells. Goblet cells scattered throughout this tissue secrete mucus, which the cilia sweep away.

Pseudostratified columnar epithelium lines the passages of the respiratory system. Here, the mucus-covered linings are sticky and trap dust and microorganisms that enter with the air. The cilia move the mucus and its captured particles upward and out of the airways.

Stratified Squamous Epithelium

The many cell layers of **stratified squamous epithelium** make this tissue relatively thick. Cells divide in the deeper layers, and newer cells push older ones farther outward, where they become flattened (fig. 5.5).

Stratified squamous epithelium forms the outer layer of the skin (*epidermis*). As skin cells age, they accumulate a protein called *keratin* and then harden and die. This "keratinization" produces a covering of dry, tough, protective material that prevents water and other

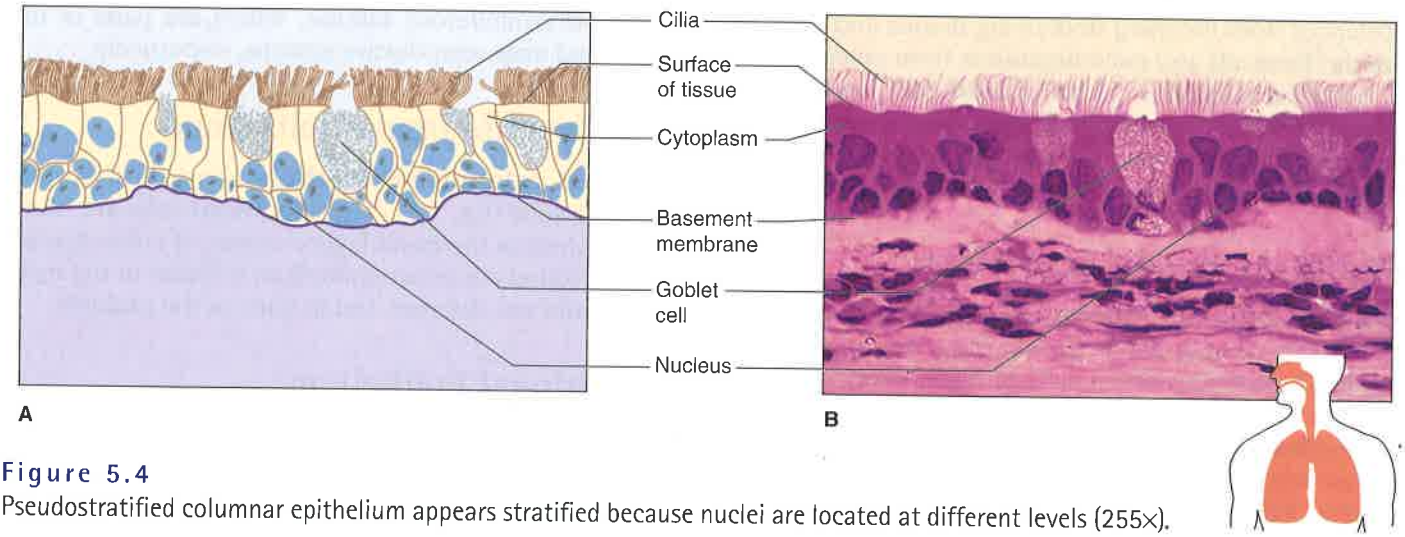

Figure 5.4
Pseudostratified columnar epithelium appears stratified because nuclei are located at different levels (255×).

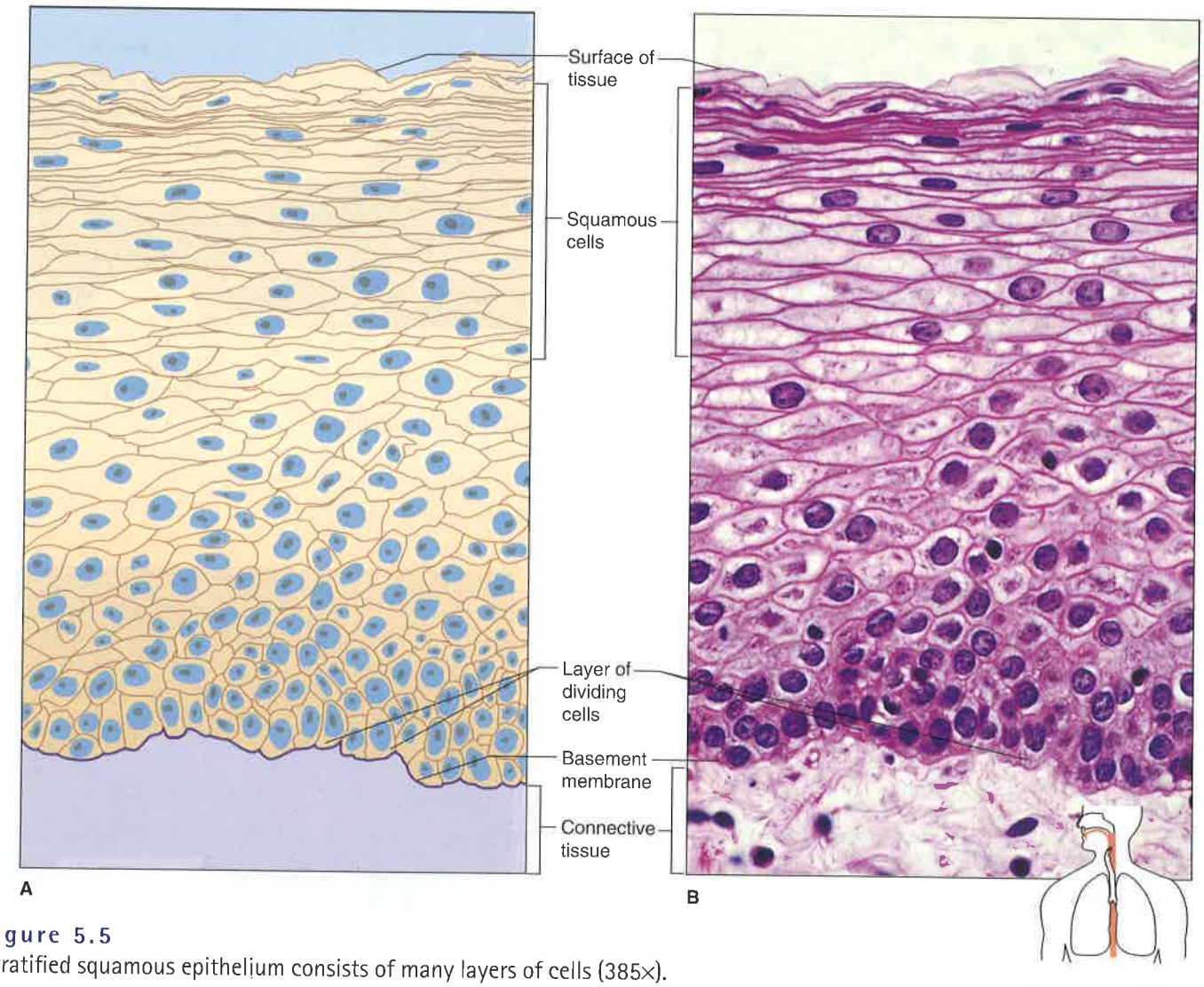

Figure 5.5
Stratified squamous epithelium consists of many layers of cells (385×).

substances from escaping underlying tissues and blocks various chemicals and microorganisms from entering.

Stratified squamous epithelium also lines the mouth, throat, vagina, and anal canal. In these parts, the tissue is not keratinized; it stays soft and moist, and the cells on its free surfaces remain alive.

Stratified Cuboidal Epithelium

Stratified cuboidal epithelium consists of two or three layers of cuboidal cells that form the lining of a lumen. The layering of the cells provides more protection than the single layer affords (fig. 5.6).

Stratified cuboidal epithelium lines the larger ducts of the mammary glands, sweat glands, salivary glands, and pancreas. It also forms the lining of developing ovarian follicles and seminiferous tubules, which are parts of the female and male reproductive systems, respectively.

Stratified Columnar Epithelium

Stratified columnar epithelium consists of several layers of cells (fig. 5.7). The superficial cells are elongated, whereas the basal layers consist of cube-shaped cells. Stratified columnar epithelium is found in the male urethra and vas deferens and in parts of the pharynx.

Transitional Epithelium

Transitional epithelium is specialized to change in response to increased tension. It forms the inner lining of the urinary bladder and lines the ureters and part of

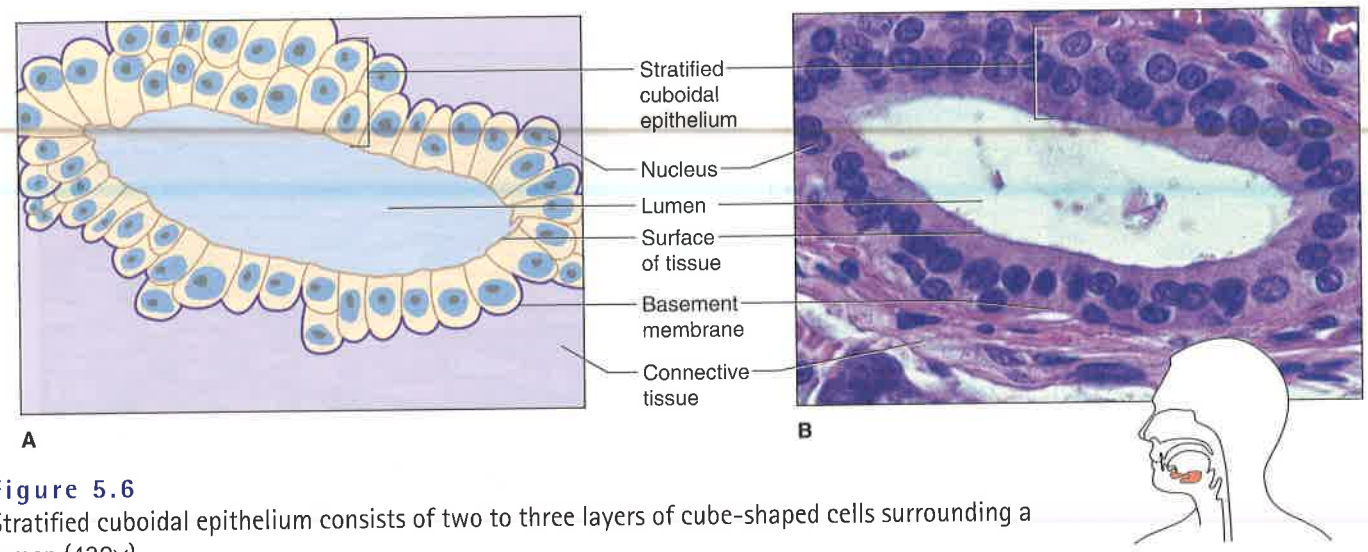

Figure 5.6
Stratified cuboidal epithelium consists of two to three layers of cube-shaped cells surrounding a lumen (430×).

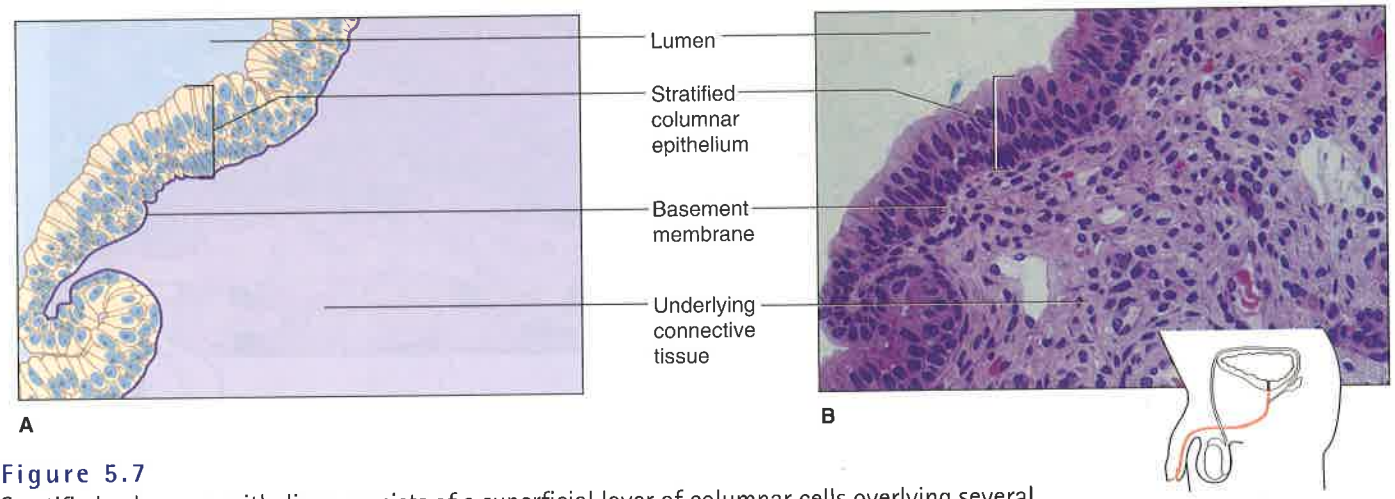

Figure 5.7
Stratified columnar epithelium consists of a superficial layer of columnar cells overlying several layers of cuboidal cells (220×).

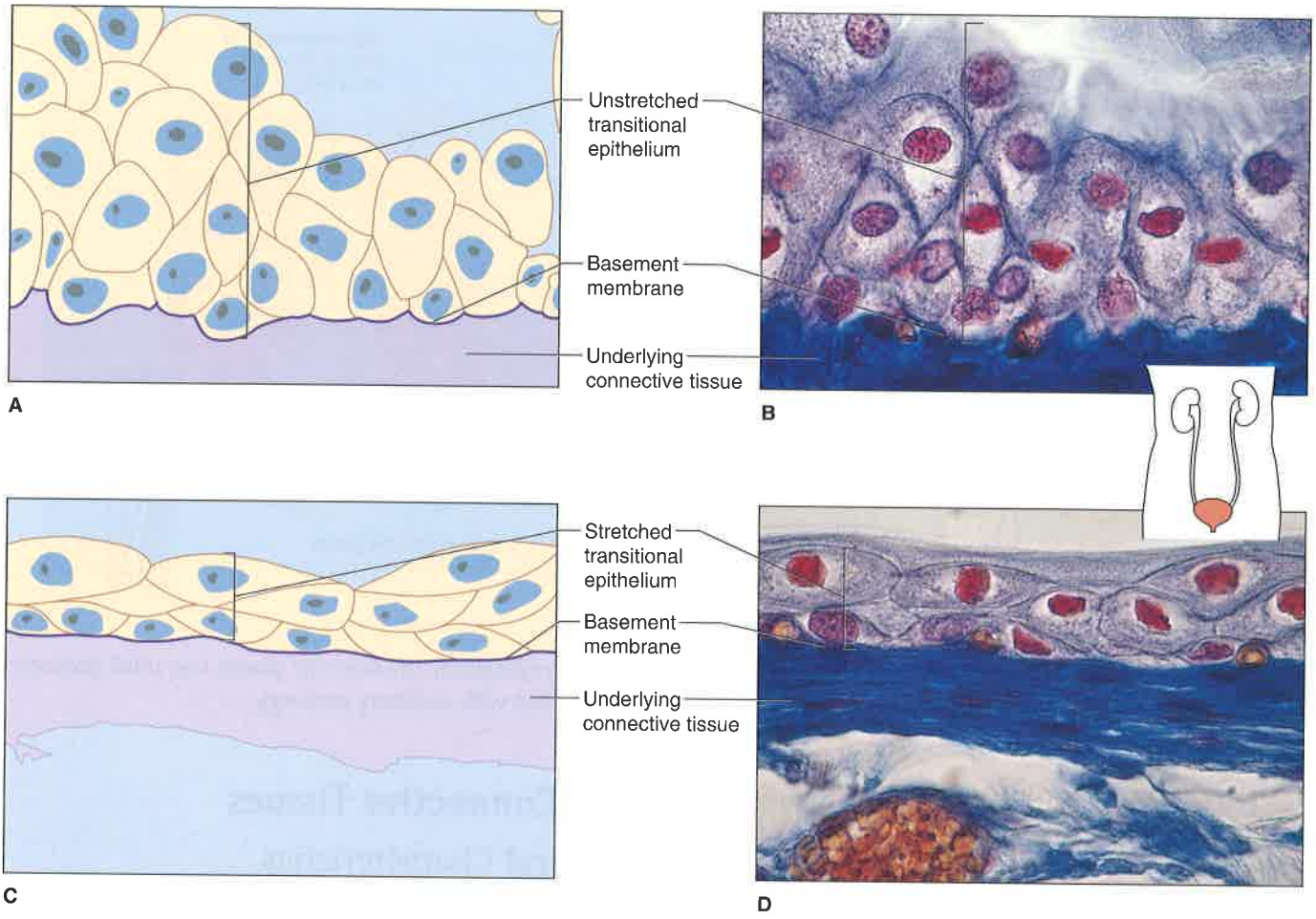

Figure 5.8
Transitional epithelium. (*A* and *B*) When the organ wall contracts, transitional epithelium is unstretched and consists of many layers (675×). (*C* and *D*) When the organ is distended, the tissue stretches and appears thinner (675×).

the urethra. When the walls of one of these organs contract, the tissue consists of several layers of cuboidal cells; however, when the organ is distended, the tissue stretches, and the physical relationships among the cells change (fig. 5.8). In addition to providing an expandable lining, transitional epithelium forms a barrier that helps prevent the contents of the urinary tract from diffusing back into the internal environment.

Up to 90% of all human cancers are *carcinomas*, which are growths that originate in epithelium. Most carcinomas begin on surfaces that contact the external environment, such as skin, linings of the airways in the respiratory tract, or linings of the stomach or intestine in the digestive tract. This observation suggests that the more common cancer-causing agents may not penetrate tissues very deeply.

Glandular Epithelium

Glandular epithelium is composed of cells that are specialized to produce and secrete substances into ducts or into body fluids. Such cells are usually found within columnar and cuboidal epithelia, and one or more of these cells constitute a *gland*. Glands that secrete their products into ducts that open onto some internal or external surface are called **exocrine glands.** Glands that secrete their products into tissue fluid or blood are called **endocrine glands.** (Endocrine glands are discussed in chapter 11.)

Exocrine glands are classified according to the ways these glands secrete their products (fig. 5.9). Glands that release watery, protein-rich fluids by exocytosis are called **merocrine** (mer´o-krin) **glands.** Glands that lose small portions of their glandular cell bodies during secretion are called **apocrine** (ap´o-krin) **glands. Holocrine** (ho´lo-krin) **glands** are those in which the

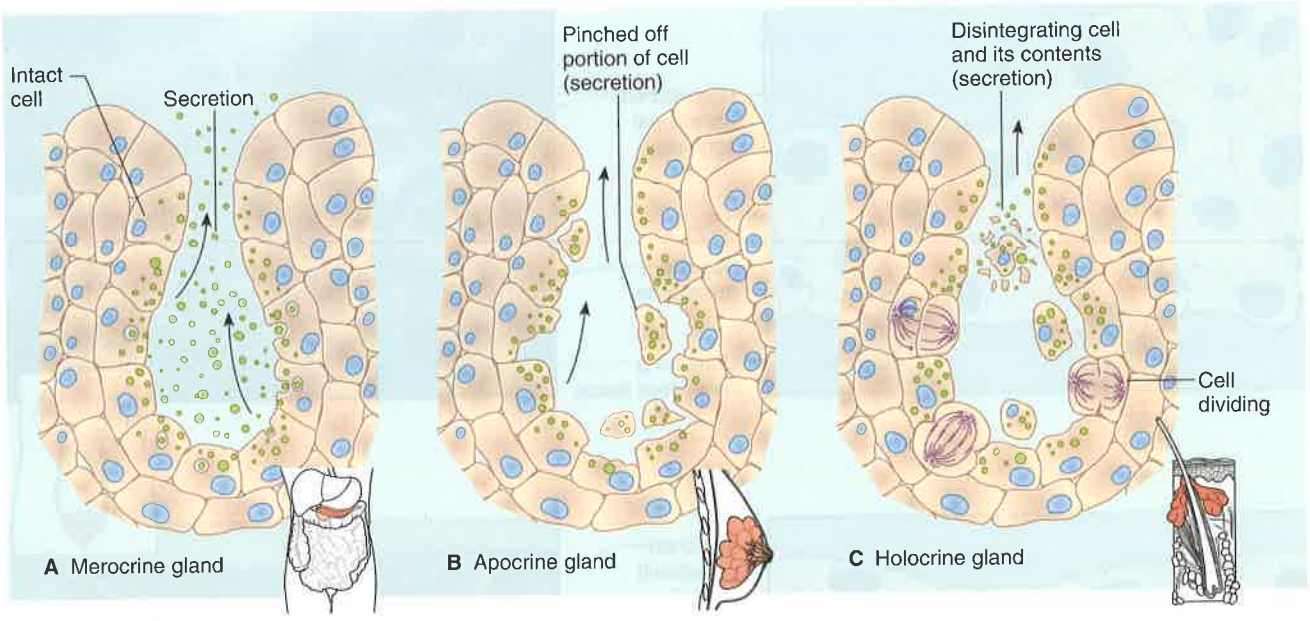

Figure 5.9
Glandular secretions. (*A*) Merocrine glands release secretions without losing cytoplasm. (*B*) Apocrine glands lose small portions of their cell bodies during secretion. (*C*) Holocrine glands release entire cells filled with secretory products.

entire cell lyses during secretion. Table 5.2 summarizes these glands and their secretions.

Most exocrine secretory cells are merocrine, and they can be further subdivided as either *serous cells* or *mucous cells*. The secretion of serous cells is typically watery, has a high concentration of enzymes, and is called *serous fluid*. Serous cells are common in the linings of the body cavities. Mucous cells secrete a thicker fluid called *mucus*. This substance is rich in the glycoprotein *mucin* and is abundantly secreted from the inner linings of the digestive and respiratory systems. Table 5.3 summarizes the characteristics of the different types of epithelial tissues.

CHECK YOUR RECALL

1. Describe the special functions of each type of epithelium.
2. Distinguish between exocrine glands and endocrine glands.
3. Explain how exocrine glands are classified.
4. Distinguish between a serous cell and a mucous cell.

5.3 Connective Tissues

General Characteristics

Connective (kŏ-nek´tiv) **tissues** bind structures, provide support and protection, serve as frameworks, fill spaces, store fat, produce blood cells, protect against infections, and help repair tissue damage. Connective tissue cells are farther apart than epithelial cells, and they have an abundance of intercellular material, or **matrix** (ma´triks), between them. This matrix consists of *fibers* and a *ground substance* whose consistency varies from fluid to semisolid to solid.

Connective tissue cells can usually divide. These tissues have varying degrees of vascularity, but in most cases, they have good blood supplies and are well nourished. Some connective tissues, such as bone and cartilage, are quite rigid. Loose connective tissue (areolar), adipose tissue, and dense connective tissue are more flexible.

TABLE 5.2 TYPES OF GLANDULAR SECRETIONS

TYPE OF GLAND	DESCRIPTION OF SECRETION	EXAMPLE
Merocrine glands	A fluid product released through the cell membrane by exocytosis	Salivary glands, pancreatic glands, sweat glands of the skin
Apocrine glands	Cellular product and portions of the free ends of glandular cells pinched off during secretion	Mammary glands, ceruminous glands lining the external ear canal
Holocrine glands	Entire cells filled with secretory products disintegrate	Sebaceous glands of the skin

TABLE 5.3

EPITHELIAL TISSUES

TYPE	FUNCTION	LOCATION
Simple squamous epithelium	Filtration, diffusion, osmosis; covers surface	Air sacs of the lungs, walls of capillaries, linings of blood and lymph vessels
Simple cuboidal epithelium	Secretion, absorption	Surface of ovaries, linings of kidney tubules, and linings of ducts of certain glands
Simple columnar epithelium	Absorption, secretion, protection	Linings of uterus, stomach, and intestine
Pseudostratified columnar epithelium	Protection, secretion, movement of mucus	Linings of respiratory passages
Stratified squamous epithelium	Protection	Outer layer of skin, linings of oral cavity, throat, vagina, and anal canal
Stratified cuboidal epithelium	Protection	Linings of larger ducts of mammary glands, sweat glands, salivary glands, and pancreas
Stratified columnar epithelium	Protection, secretion	Vas deferens, part of the male urethra, parts of the pharynx
Transitional epithelium	Distensibility, protection	Inner lining of urinary bladder and linings of ureters and part of urethra
Glandular epithelium	Secretion	Salivary glands, sweat glands, endocrine glands

Major Cell Types

Connective tissues contain a variety of cell types. Some of them are called *fixed cells* because they are usually present in stable numbers. These include fibroblasts and mast cells. Other cells, such as macrophages, are *wandering cells*. They appear in tissues temporarily, usually in response to an injury or infection.

Fibroblasts (fi´bro-blastz) are the most common type of fixed cell in connective tissue. These large, star-shaped cells produce fibers by secreting proteins into the matrix of connective tissues (fig. 5.10).

Macrophages (mak´ro-fājez), or histiocytes, originate as white blood cells (see chapter 14, p. 374) and are almost as numerous as fibroblasts in some connective tissues. They are specialized to carry on phagocytosis. Macrophages can move about and function as scavenger and defensive cells that clear foreign particles from tissues (fig. 5.11).

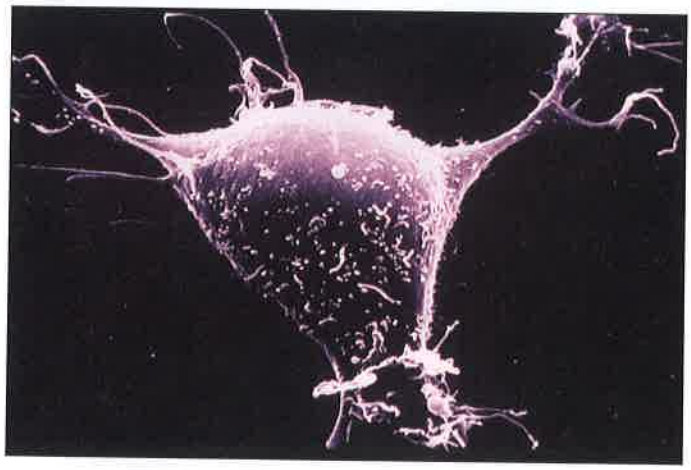

Figure 5.10
Scanning electron micrograph of a fibroblast (3,800×).

Mast cells are large and widely distributed in connective tissues. They are usually located near blood vessels (fig. 5.12). Mast cells release heparin, which prevents blood clotting, and histamine, which promotes some of the reactions associated with inflammation and allergies (see chapter 14, pp. 374 and 382).

Connective Tissue Fibers

Fibroblasts produce three types of connective tissue fibers: collagenous fibers, elastic fibers, and reticular fibers. Of these, collagenous and elastic fibers are the most abundant (fig. 5.13).

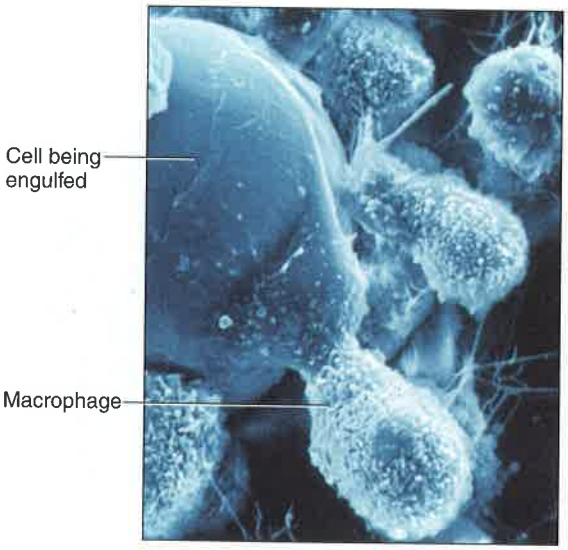

Figure 5.11
Macrophages are scavenger cells common in connective tissues. This scanning electron micrograph shows a number of macrophages engulfing a larger cell (3,300×).

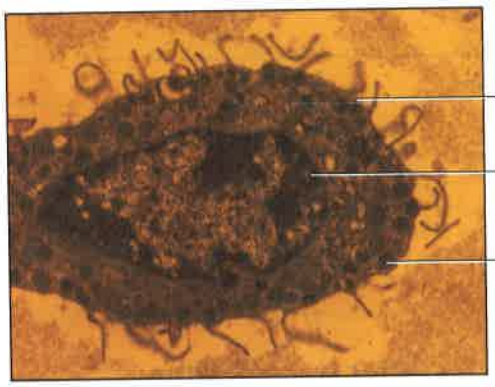

Figure 5.12
Transmission electron micrograph of a mast cell (5,000×).

When skin is exposed to prolonged and intense sunlight, connective tissue fibers lose elasticity, and the skin stiffens and becomes leathery. In time, the skin may sag and wrinkle. Collagen injections may temporarily smooth out wrinkles. However, collagen applied as a cream to the skin does not combat wrinkles because collagen molecules are far too large to actually penetrate the skin.

Collagenous (kol-laj´ĕ-nus) **fibers** are thick threads of the protein *collagen*. Collagenous fibers are grouped in long, parallel bundles, and they are flexible but only slightly elastic. More importantly, they have great tensile strength—that is, they resist considerable pulling force. Thus, collagenous fibers are important components of body parts that hold structures together, such as **ligaments** (which connect bones to bones) and **tendons** (which connect muscles to bones).

Tissue containing abundant collagenous fibers is called *dense connective tissue*. Such tissue appears white, and for this reason, collagenous fibers are sometimes called *white fibers*.

Elastic fibers are composed of a protein called *elastin*. These thin fibers branch, forming complex networks. Elastic fibers are weaker than collagenous fibers, but they stretch easily and can resume their original lengths and shapes. Elastic fibers are common in body parts that are frequently stretched, such as the vocal cords. They are sometimes called *yellow fibers* because tissues well supplied with them appear yellowish.

Reticular fibers are very thin collagenous fibers. They are highly branched and form delicate supporting networks in a variety of tissues.

Categories of Connective Tissue

Connective tissue is broken down into two categories. *Connective tissue proper* includes loose connective tissue, adipose tissue, and dense connective tissue. The *specialized connective tissues* include cartilage, bone, and blood.

Loose Connective Tissue

Loose connective tissue, or **areolar** (ah-re´o-lar) **tissue,** forms delicate, thin membranes throughout the body. The cells of this tissue, mainly fibroblasts, are located some distance apart and are separated by a gel-like matrix containing many collagenous and elastic fibers that fibroblasts secrete (fig. 5.13).

Loose connective tissue binds the skin to the underlying organs and fills spaces between muscles. It lies beneath most layers of epithelium, where its many blood vessels nourish nearby epithelial cells.

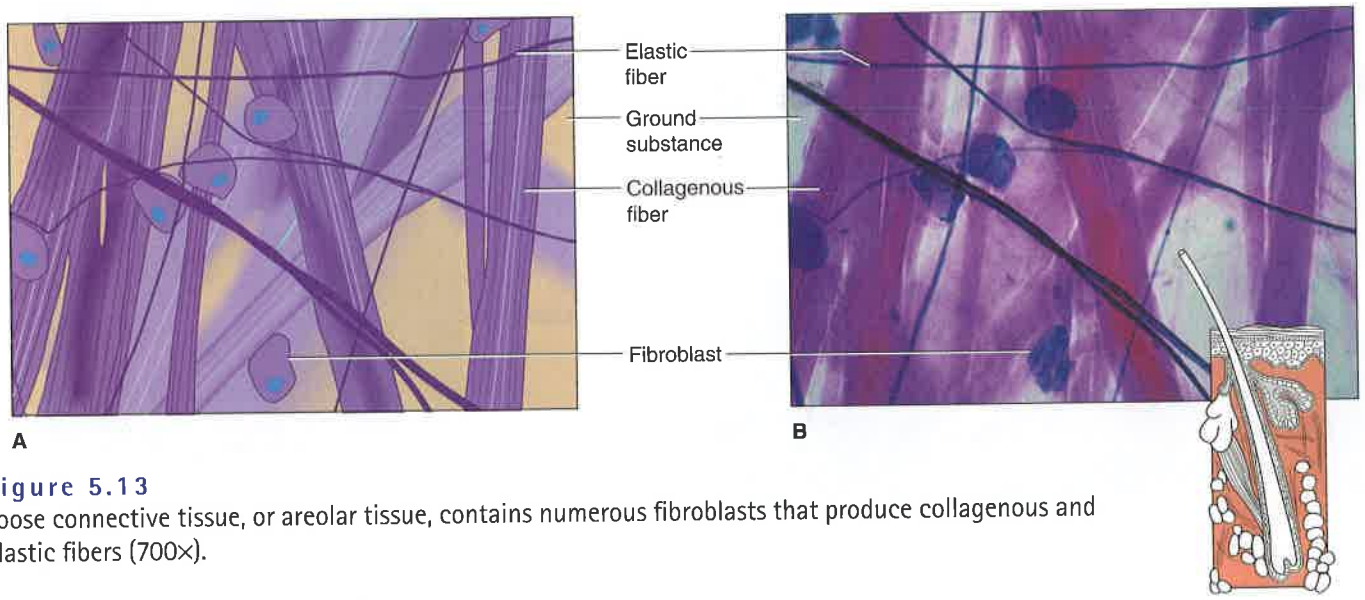

Figure 5.13
Loose connective tissue, or areolar tissue, contains numerous fibroblasts that produce collagenous and elastic fibers (700×).

Adipose Tissue

Adipose (ad′ĭ-pōs) **tissue,** or fat, is a specialized form of loose connective tissue that develops when certain cells (adipocytes) store fat in droplets within their cytoplasm and enlarge (fig. 5.14). When such cells are so numerous that they crowd other cell types, they form adipose tissue. Adipose tissue lies beneath the skin, in spaces between muscles, around the kidneys, behind the eyeballs, in certain abdominal membranes, on the surface of the heart, and around certain joints.

Adipose tissue cushions joints and some organs, such as the kidneys. It also insulates beneath the skin, and it stores energy in fat molecules.

The average adult has between 40 and 50 billion fat cells.

Overeating and lack of exercise can increase the size of adipose cells, leading to becoming overweight or obese. During periods of fasting, however, fat supplies energy, and adipocytes lose fat, shrink, and become more like fibroblasts.

Dense Connective Tissue

Dense connective tissue consists of many closely packed, thick, collagenous fibers and a fine network of elastic fibers. It has relatively few cells, most of which are fibroblasts (fig. 5.15).

Collagenous fibers of dense connective tissue are very strong, enabling the tissue to withstand pulling forces. Dense connective tissue often binds body parts together as parts of tendons and ligaments. This type of tissue is also in the protective white layer of the eyeball

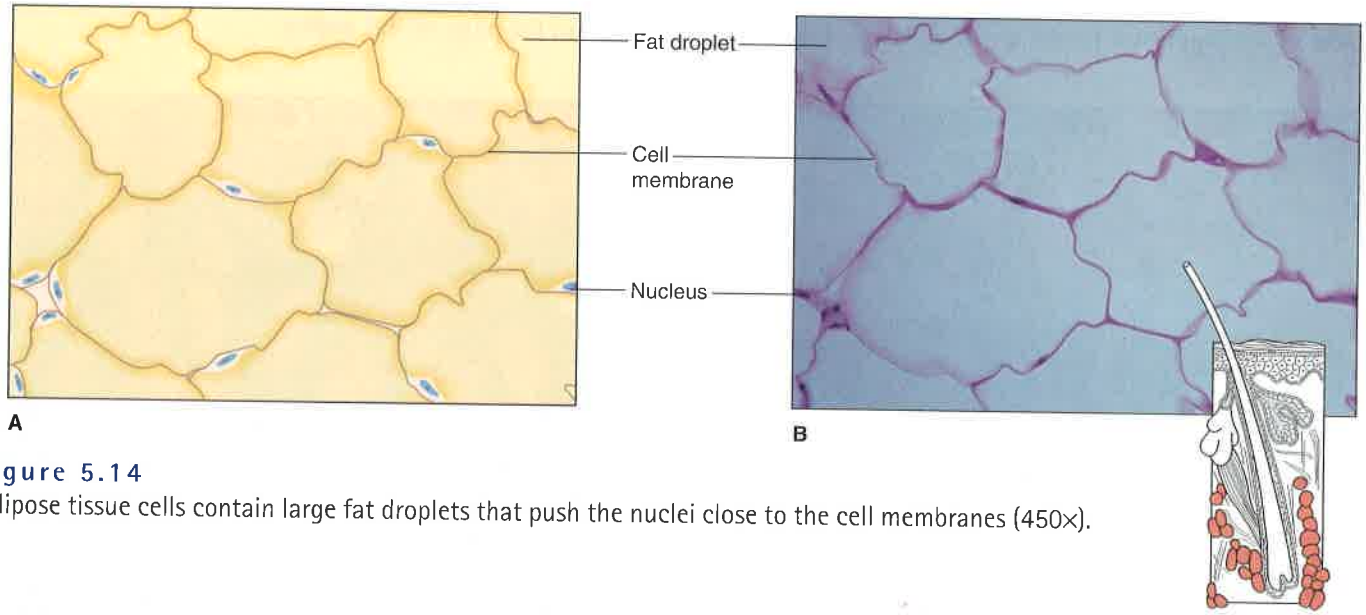

Figure 5.14
Adipose tissue cells contain large fat droplets that push the nuclei close to the cell membranes (450×).

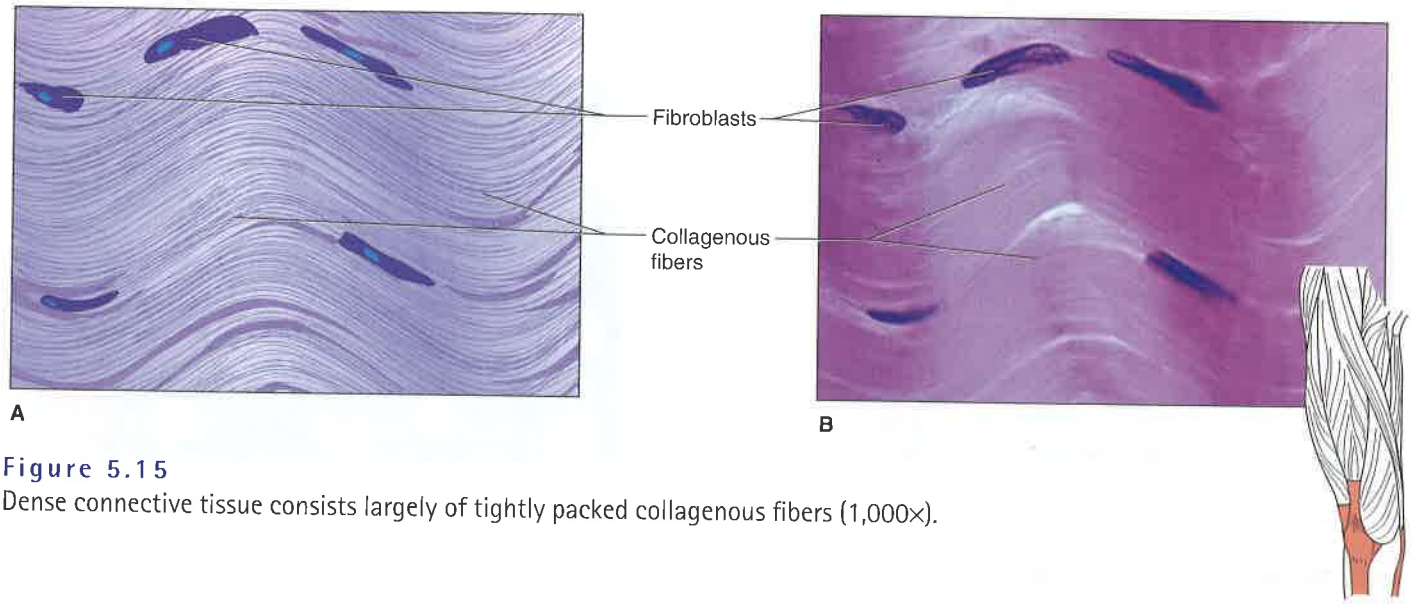

Figure 5.15
Dense connective tissue consists largely of tightly packed collagenous fibers (1,000×).

and in the deeper skin layers. The blood supply to dense connective tissue is poor, slowing tissue repair.

CHECK YOUR RECALL

1. What are the general characteristics of connective tissues?
2. What are the characteristics of collagen and elastin?
3. What feature distinguishes adipose tissue from other connective tissues?
4. Explain the difference between loose connective tissue and dense connective tissue.

Cartilage

Cartilage (kar´ti-lij) is a rigid connective tissue. It provides support, frameworks, and attachments; protects underlying tissues; and forms structural models for many developing bones.

Cartilage matrix is abundant and is largely composed of collagenous fibers embedded in a gel-like ground substance. Cartilage cells, or **chondrocytes** (kon´dro-sītz), occupy small chambers called *lacunae* and thus lie completely within the matrix (fig. 5.16).

A cartilaginous structure is enclosed in a covering of connective tissue called the *perichondrium*. The perichondrium contains blood vessels that provide cartilage cells with nutrients by diffusion. The lack of a direct blood supply to cartilage tissue is why torn cartilage heals slowly and why chondrocytes do not divide frequently.

Different types of intercellular material (matrix) distinguish three types of cartilage. **Hyaline cartilage,** the most common type, has very fine collagenous fibers in its matrix and looks somewhat like white glass (fig. 5.16). It is found on the ends of bones in many joints, in the soft part of the nose, and in the supporting rings of the respiratory passages. Hyaline cartilage is also important in the growth of most bones (see chapter 7, p. 130).

Elastic cartilage contains a dense network of elastic fibers and thus is more flexible than hyaline cartilage (fig. 5.17). It provides the framework for the external ears and for parts of the larynx.

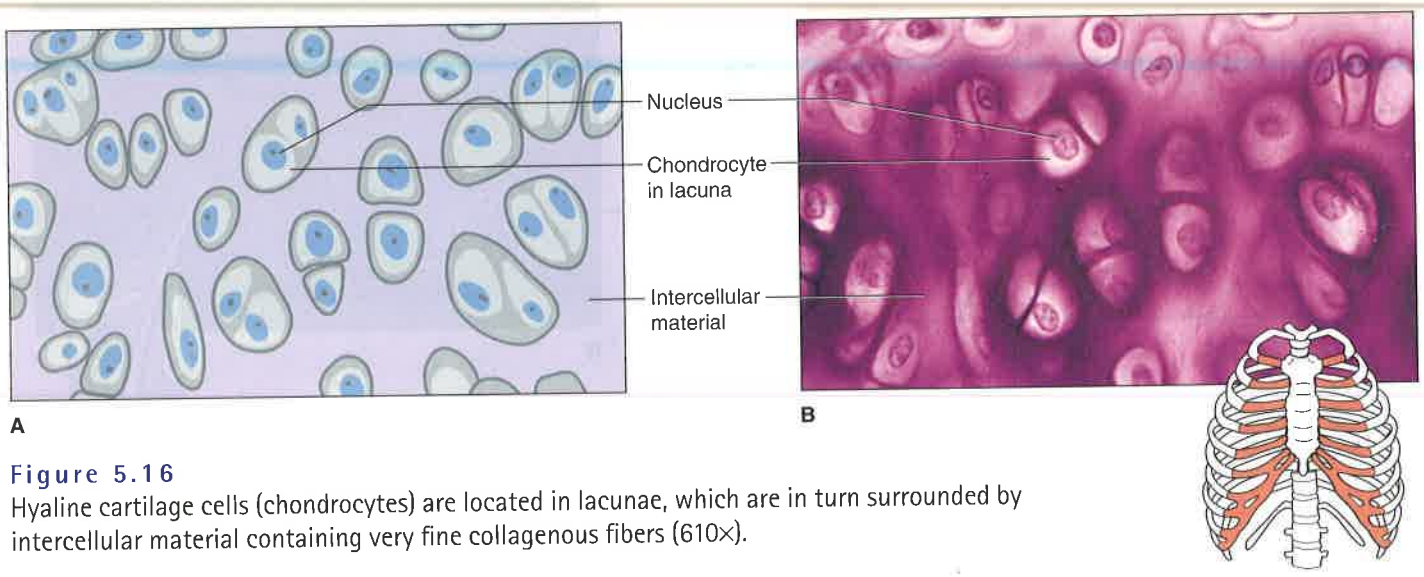

Figure 5.16
Hyaline cartilage cells (chondrocytes) are located in lacunae, which are in turn surrounded by intercellular material containing very fine collagenous fibers (610×).

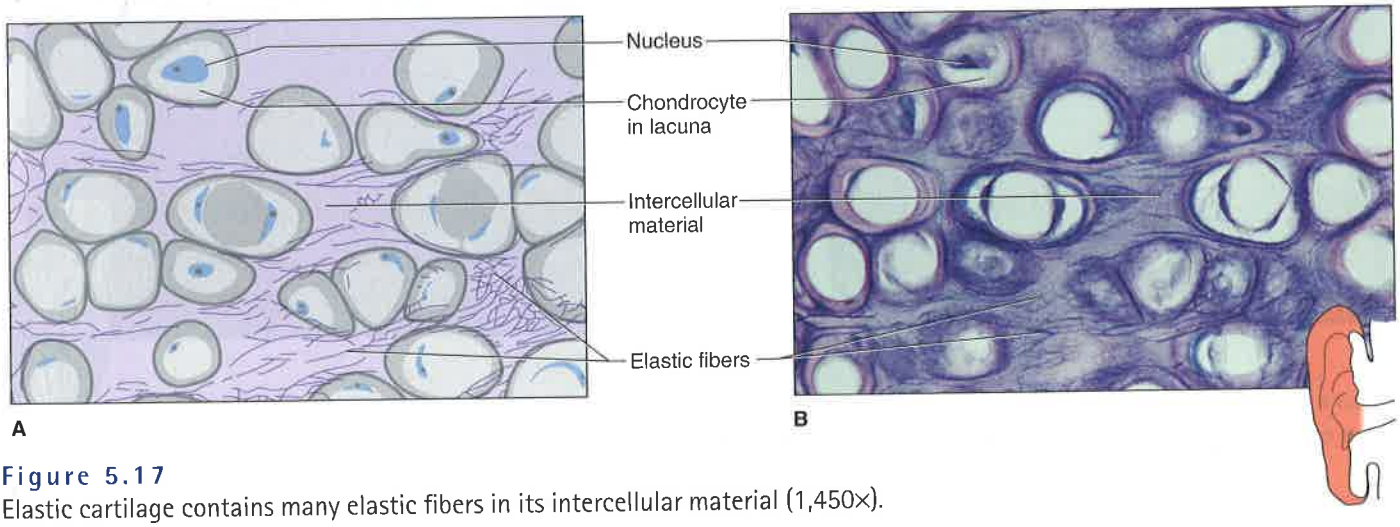

Figure 5.17
Elastic cartilage contains many elastic fibers in its intercellular material (1,450×).

Between ages 30 and 70, a nose may lengthen and widen by as much as half an inch, and the ears may lengthen by a quarter inch due to the fact that cartilage is one of the few tissues that continues to grow as we age.

Fibrocartilage, a very tough tissue, contains many collagenous fibers (fig. 5.18). It is a shock absorber for structures that are subjected to pressure. For example, fibrocartilage forms pads (intervertebral discs) between the individual bones (vertebrae) of the spinal column. It also cushions bones in the knees and in the pelvic girdle.

Bone

Bone is the most rigid connective tissue. Its hardness is largely due to mineral salts, such as calcium phosphate and calcium carbonate, between cells. This matrix also contains abundant collagen fibers, which are flexible and reinforce the mineral components of bone.

Bone internally supports body structures. It protects vital parts in the cranial and thoracic cavities, and is an attachment for muscles. Bone also contains red marrow, which forms blood cells, and it stores and releases inorganic chemicals such as calcium and phosphorus.

Bone matrix is deposited in thin layers called *lamellae,* which form concentric patterns around tiny longitudinal tubes called *central canals,* or Haversian canals (fig. 5.19). Bone cells, or **osteocytes** (os´te-o-sītz), are located in lacunae, which are rather evenly spaced between the lamellae. Consequently, osteocytes too form concentric circles.

In a bone, the osteocytes and layers of intercellular material, which are concentrically clustered around a central canal, form a cylinder-shaped unit called an **osteon** (os´te-on), or Haversian system. Many osteons cemented together form the substance of bone.

Each central canal contains a blood vessel, which places every bone cell near a nutrient supply. In addition, bone cells have many cytoplasmic processes that extend outward and pass through very small tubes in the matrix called *canaliculi.* These cellular processes connect with the membranes of nearby cells. As a result, materials can move rapidly between blood vessels and bone cells. Thus, in spite of its inert appearance, bone is a very active tissue that heals much more rapidly than does injured cartilage. (The microscopic structure of bone is described in more detail in chapter 7, p. 129.)

Blood

Blood transports a variety of materials between interior body cells and those that exchange substances with the external environment. In this way, blood helps maintain stable internal environmental conditions. Blood is composed of *formed elements* suspended in a fluid matrix called *blood plasma.* The formed elements include *red blood cells, white blood cells,* and cell fragments called *platelets* (fig. 5.20). Most blood cells form in red marrow within the hollow parts of certain long bones. Chapter 12 describes blood in detail. Table 5.4 lists the characteristics of the connective tissues.

CHECK YOUR RECALL

1. Describe the general characteristics of cartilage.
2. Explain why injured bone heals more rapidly than injured cartilage.
3. What are the major components of blood?

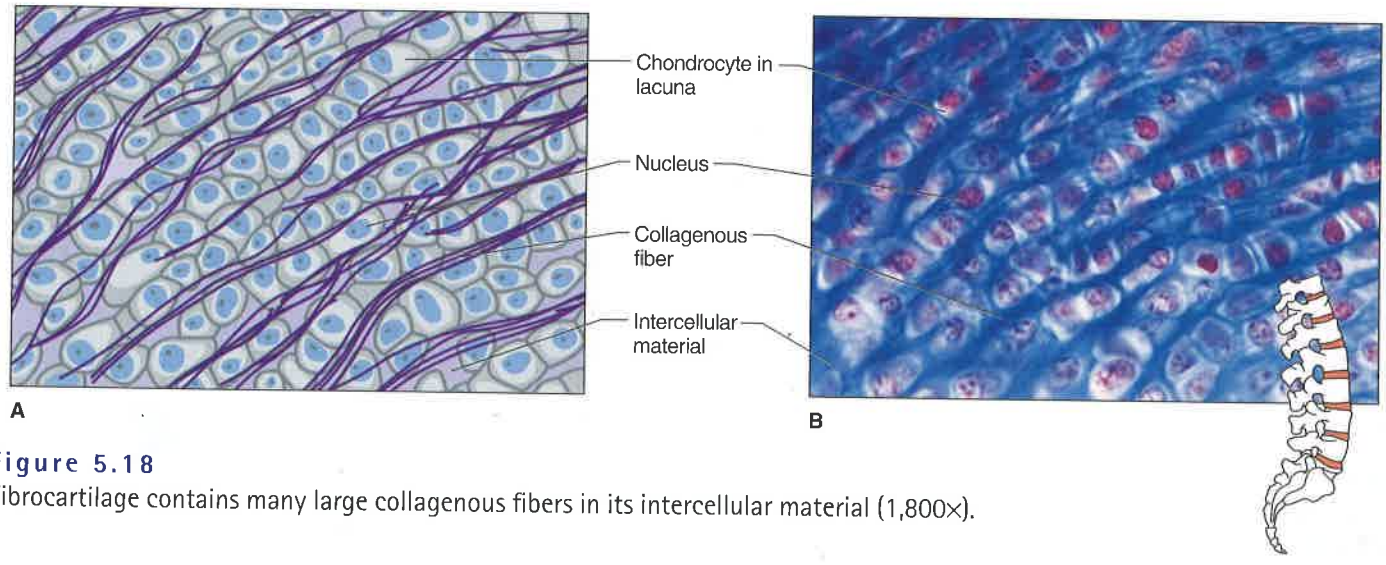

Figure 5.18
Fibrocartilage contains many large collagenous fibers in its intercellular material (1,800×).

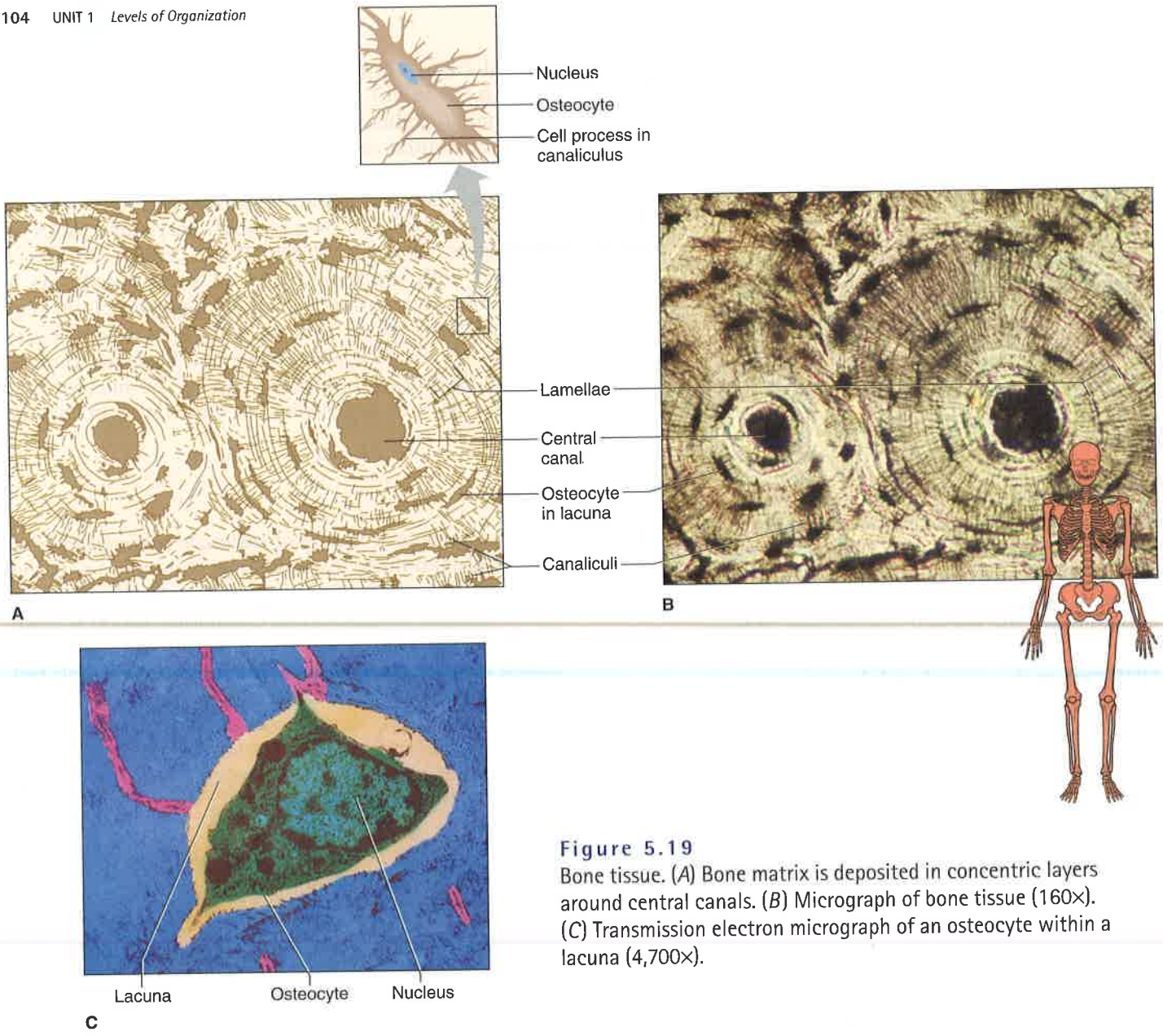

Figure 5.19
Bone tissue. (*A*) Bone matrix is deposited in concentric layers around central canals. (*B*) Micrograph of bone tissue (160×). (*C*) Transmission electron micrograph of an osteocyte within a lacuna (4,700×).

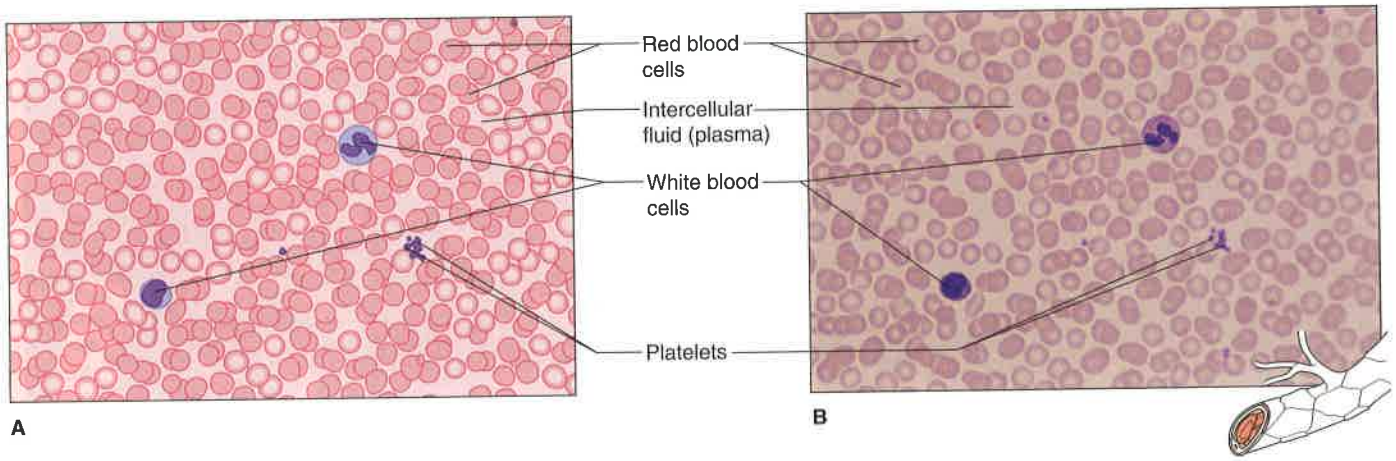

Figure 5.20
Blood tissue consists of red blood cells, white blood cells, and platelets suspended in an intercellular fluid (425×).

TABLE 5.4

CONNECTIVE TISSUES

TYPE	FUNCTION	LOCATION
Loose connective tissue	Binds organs together, holds tissue fluids	Beneath skin, between muscles, beneath epithelial tissues
Adipose tissue	Protects, insulates, stores fat	Beneath skin, around kidneys, behind eyeballs, on surface of heart
Dense connective tissue	Binds organs together	Tendons, ligaments, deeper layers of skin
Hyaline cartilage	Supports, protects, provides framework	Nose, ends of bones, rings in the walls of respiratory passages
Elastic cartilage	Supports, protects, provides flexible framework	Framework of external ear and parts of larynx
Fibrocartilage	Supports, protects, absorbs shock	Between bony parts of spinal column, parts of pelvic girdle and knee
Bone	Supports, protects, provides framework	Bones of skeleton
Blood	Transports substances, helps maintain stable internal environment	Throughout body within a closed system of blood vessels and heart chambers

5.4 Muscle Tissues

General Characteristics

Muscle (mus´el) **tissues** are contractile; that is, their elongated cells, or *muscle fibers,* can shorten. As they contract, muscle fibers pull at their attached ends, and this action moves body parts. The three types of muscle tissue—skeletal, smooth, and cardiac—are discussed in chapter 8.

Approximately 40% of the body is skeletal muscle, and almost another 10% is smooth and cardiac muscle.

Skeletal Muscle Tissue

Skeletal muscle tissue is found in muscles that attach to bones and are controlled by conscious effort. For this reason, it is often called *voluntary* muscle tissue. The long, threadlike cells of skeletal muscle have alternating light and dark cross-markings called *striations.* Each cell has many nuclei just beneath its cell membrane (fig. 5.21). A nerve impulse can stimulate the muscle fiber to contract and then relax.

The muscles containing skeletal muscle tissue move the head, trunk, and limbs. They enable us to make facial expressions, write, talk, sing, chew, swallow, and breathe.

Smooth Muscle Tissue

Smooth muscle tissue is called smooth because its cells do not have striations. Smooth muscle cells are shorter than those of skeletal muscle and are spindle-shaped, each with a single, centrally located nucleus (fig. 5.22). This tissue comprises the walls of hollow internal organs, such as the stomach, intestine, urinary bladder, uterus, and blood vessels. Unlike skeletal muscle, smooth muscle usually cannot be stimulated to

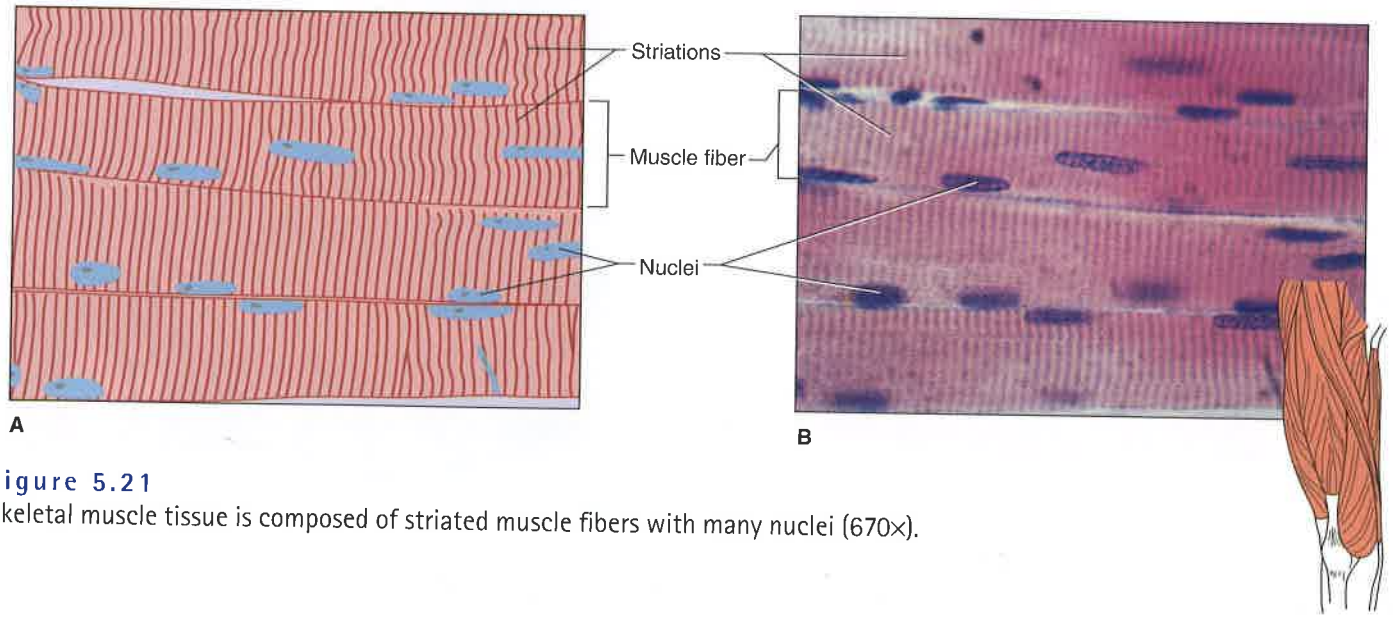

Figure 5.21
Skeletal muscle tissue is composed of striated muscle fibers with many nuclei (670×).

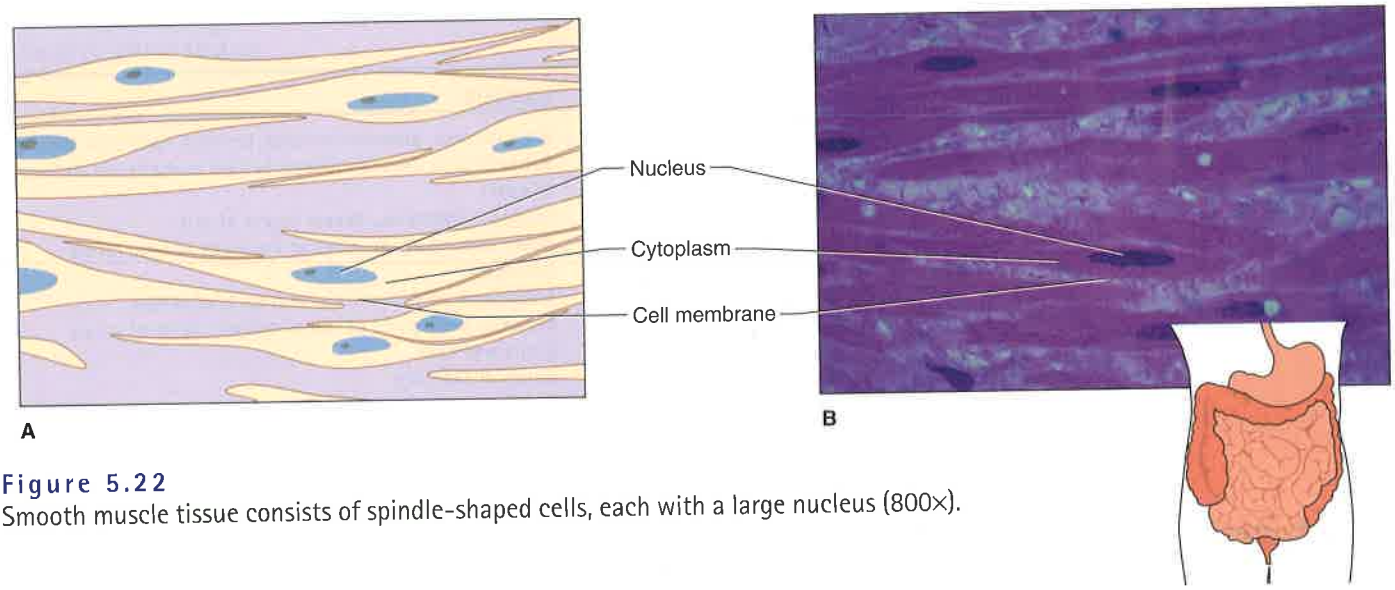

Figure 5.22
Smooth muscle tissue consists of spindle-shaped cells, each with a large nucleus (800×).

contract by conscious efforts. Thus, its actions are *involuntary*. For example, smooth muscle tissue moves food through the digestive tract, constricts blood vessels, and empties the urinary bladder.

Cardiac Muscle Tissue

Cardiac muscle tissue is only in the heart. Its cells, which are striated, are joined end-to-end. The resulting muscle fibers are branched and connected in complex networks. Each cell within a cardiac muscle fiber has a single nucleus (fig. 5.23). Where it touches another cell is a specialized intercellular junction called an *intercalated disc*, discussed further in chapter 8, p. 184.

Cardiac muscle, like smooth muscle, is controlled involuntarily. This tissue makes up the bulk of the heart and pumps blood through the heart chambers and into blood vessels.

CHECK YOUR RECALL

1. List the general characteristics of muscle tissues.
2. Distinguish among skeletal, smooth, and cardiac muscle tissues.

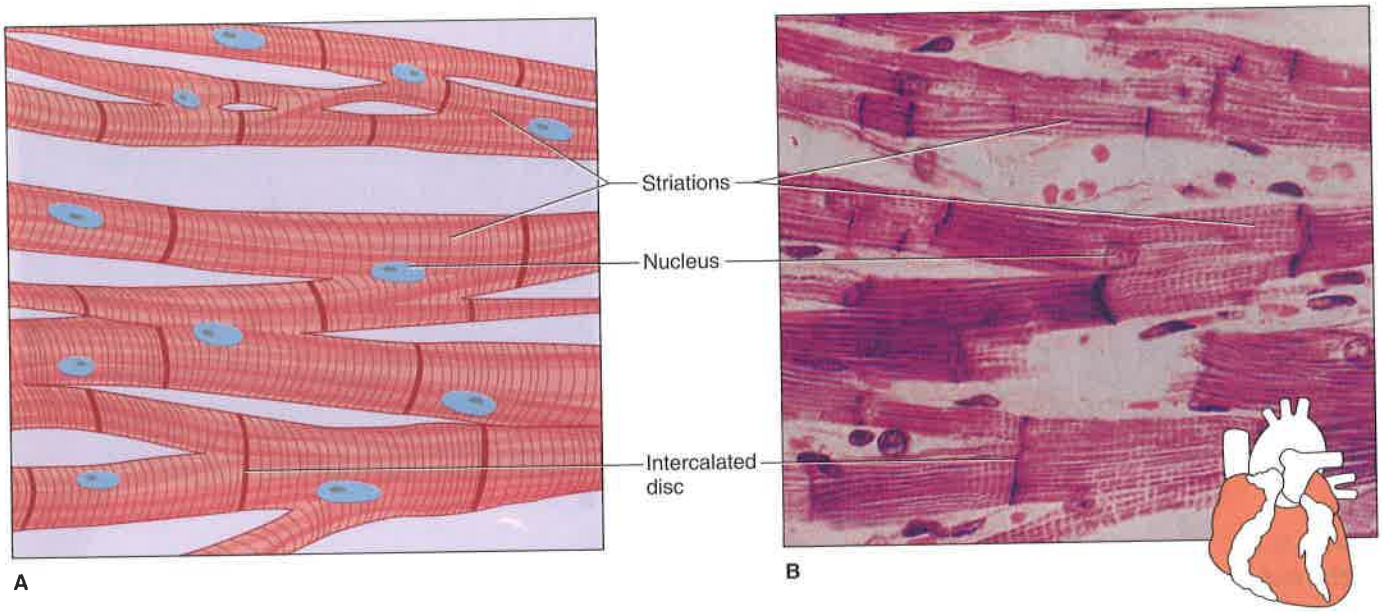

Figure 5.23
Cardiac muscle fibers are branched and interconnected, with a single nucleus each (360×).

The cells of different tissues vary greatly in their abilities to divide. Cells that divide continuously include the epithelial cells of the skin and inner lining of the digestive tract and the connective tissue cells that form blood cells in red bone marrow. However, skeletal and cardiac muscle cells and nerve cells do not usually divide at all after differentiating.

Fibroblasts respond rapidly to injuries by increasing in number and fiber production. They are often the principal agents of repair in tissues that have limited abilities to regenerate. For instance, cardiac muscle tissue typically degenerates in the regions damaged by a heart attack. Fibroblasts then, over time, knit connective tissue that replaces the damaged cardiac muscle. A scar is formed.

TABLE 5.5 MUSCLE AND NERVOUS TISSUES

TYPE	FUNCTION	LOCATION
Skeletal muscle tissue (striated)	Voluntary movements of skeletal parts	Muscles usually attached to bones
Smooth muscle tissue (lacks striations)	Involuntary movements of internal organs	Walls of hollow internal organs
Cardiac muscle tissue (striated)	Heart movements	Heart muscle
Nervous tissue	Sensory reception and conduction of nerve impulses	Brain, spinal cord, and peripheral nerves

5.5 Nervous Tissues

Nervous (ner´vus) **tissues** are found in the brain, spinal cord, and peripheral nerves. The basic cells are called **neurons** (nu´ronz), or nerve cells (fig. 5.24). Neurons sense certain types of changes in their surroundings. They respond by transmitting nerve impulses along cytoplasmic extensions (cellular processes) to other neurons or to muscles or glands. Because neurons communicate with each other and with muscle and gland cells, they can coordinate, regulate, and integrate many body functions.

In addition to neurons, nervous tissue includes **neuroglial cells** (nu-rog´le-ahl selz) or supporting cells, shown in figure 5.24. These cells support and bind the components of nervous tissue, carry on phagocytosis, and help supply nutrients to neurons by connecting them to blood vessels. Nervous tissue is discussed in chapter 9. Table 5.5 summarizes the general characteristics of muscle and nervous tissues.

CHECK YOUR RECALL

1. Describe the general characteristics of nervous tissues.
2. Distinguish between neurons and neuroglial cells.

Clinical Connection

Canavan disease is an inherited illness that illustrates what can happen when communication between the cells of a tissue fails. A child with Canavan disease lags in acquiring developmental skills, such as sitting and standing. Vision worsens, and the child does not make eye contact or react much to the surroundings. He or she may have seizures, require tube feeding, and muscle control may be so poor that the head cannot even be held erect. The child usually dies before adolescence.

The cause of Canavan disease is disruption of the interaction between certain neurons in the brain and

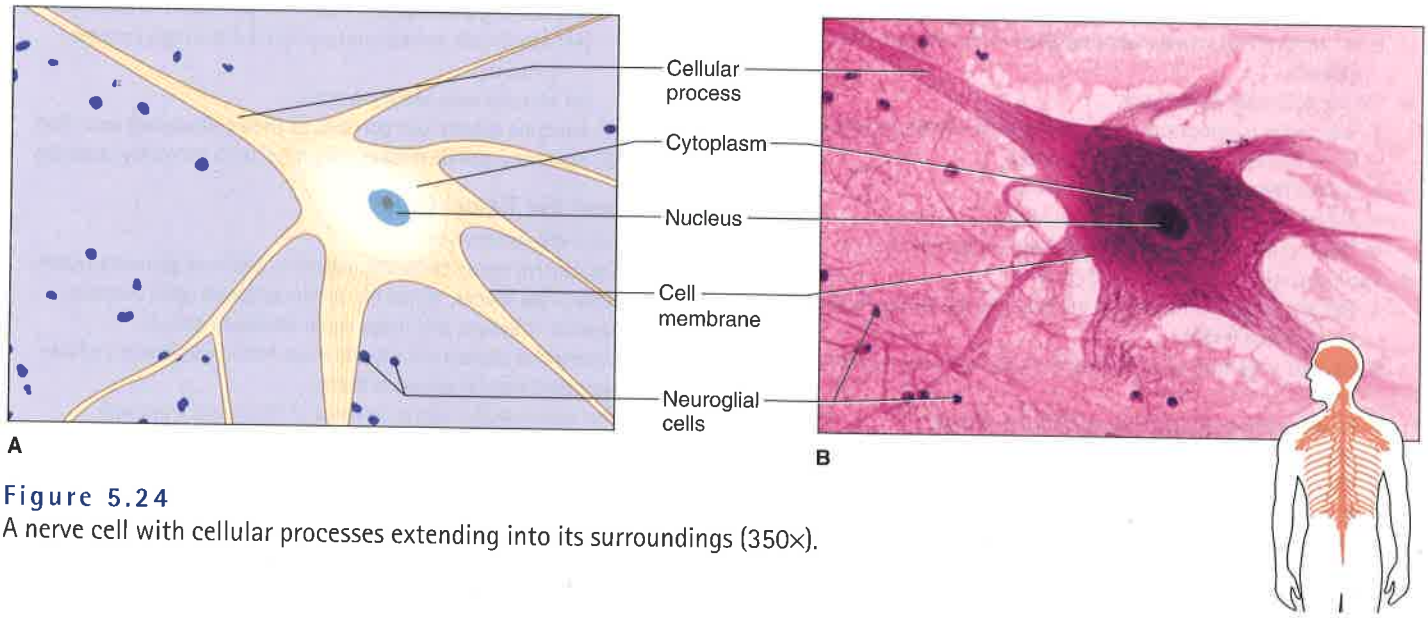

Figure 5.24
A nerve cell with cellular processes extending into its surroundings (350×).

the neighboring neuroglial cells, that produce the fatty myelin that coats the neurons and makes nerve impulse transmission fast enough for the brain to function. Specifically, the neurons release N-acetylaspartate (NAA), which is broken down into harmless compounds by an enzyme, aspartoacylase, that the neuroglia produce. Canavan disease is aspartoacylase deficiency. NAA builds up, which eventually destroys the neuroglia. Without sufficient myelin, the neurons cease to function, and symptoms begin.

Canavan disease has no conventional treatment. However, experimental gene therapy delivers the healthy gene for aspartoacylase into neurons, enabling them to secrete their own enzyme, which in turn stimulates the neuroglial cells to make myelin. Although the gene therapy is invasive—delivered through holes bored into the skull—and must be repeated every few years, it appears to work. Three months after treatment, the first recipient, 18-month-old Lindsay Karlin, looked around, moved, and vocalized, when previously she could barely open her eyes and did not interact with anyone. "It was as though she had awakened," wrote her mother. A magnetic resonance image of Lindsay's brain showed that myelination of neurons had begun in regions where it had vanished.

SUMMARY OUTLINE

5.1 Introduction (p. 92)

Tissues are groups of cells with specialized structural and functional roles. Intercellular materials, varying from solid to liquid, separate cells. The four major types of human tissue are epithelial tissues, connective tissues, muscle tissues, and nervous tissues.

5.2 Epithelial Tissues (p. 92)

1. General characteristics
   a. Epithelial tissue covers all free body surfaces and is the major tissue of glands.
   b. Epithelium is anchored to connective tissue by a basement membrane, lacks blood vessels, contains little intercellular material (matrix), and is replaced continuously.
   c. It functions in protection, secretion, absorption, and excretion.
   d. Epithelial tissues are classified according to shape and number of layers of cells.
2. Simple squamous epithelium
   a. This tissue consists of a single layer of thin, flattened cells.
   b. It functions in gas exchange in the lungs and lines the blood and lymph vessels and various body cavities.
3. Simple cuboidal epithelium
   a. This tissue consists of a single layer of cube-shaped cells.
   b. It carries on secretion and absorption in the kidneys and various glands.
4. Simple columnar epithelium
   a. This tissue is composed of elongated cells whose nuclei are located near the basement membrane.
   b. It lines the uterus and digestive tract.
   c. Absorbing cells often possess microvilli.
   d. This tissue contains goblet cells that secrete mucus.
5. Pseudostratified columnar epithelium
   a. This tissue appears stratified because the nuclei are located at two or more levels.
   b. Its cells may have cilia that move mucus over the surface of the tissue.
   c. It lines passageways of the respiratory system.
6. Stratified squamous epithelium
   a. This tissue is composed of many layers of cells.
   b. It protects underlying cells.
   c. It covers the skin and lines the mouth, throat, vagina, and anal canal.
7. Stratified cuboidal epithelium
   a. This tissue is composed of two or three layers of cube-shaped cells.
   b. It lines the larger ducts of the mammary glands, sweat glands, salivary glands, and pancreas.
   c. It functions in protection.
8. Stratified columnar epithelium
   a. The top layer of cells in this tissue contains elongated columns. Cube-shaped cells make up the bottom layers.
   b. It is in the vas deferens, parts of the male urethra, and parts of the pharynx.
   c. This tissue protects and secretes.
9. Transitional epithelium
   a. This tissue is specialized to become distended.
   b. It is in the walls of various organs of the urinary tract.
10. Glandular epithelium
    a. Glandular epithelium is composed of cells that are specialized to secrete substances.
    b. A gland consists of one or more cells.
       (1) Exocrine glands secrete into ducts.
       (2) Endocrine glands secrete into tissue fluid or blood.
    c. Exocrine glands are classified according to composition of their secretions.
       (1) Merocrine glands secrete fluid without loss of cytoplasm.
          (a) Serous cells secrete watery fluid with a high enzyme content.
          (b) Mucous cells secrete mucus.
       (2) Apocrine glands lose portions of their cells during secretion.
       (3) Holocrine glands release cells filled with secretory products.

5.3 Connective Tissues (p. 98)

1. General characteristics
   a. Connective tissue connects, supports, protects, provides frameworks, fills spaces, stores fat, produces blood cells, protects against infection, and helps repair damaged tissues.
   b. Connective tissue cells usually have considerable intercellular material (matrix) between them.
   c. This intercellular matrix consists of fibers and a ground substance.
   d. Major cell types
      (1) Fibroblasts produce collagenous and elastic fibers.
      (2) Macrophages are phagocytes.
      (3) Mast cells may release heparin and histamine, and usually are near blood vessels.

e. Connective tissue fibers
(1) Collagenous fibers are composed of collagen and have great tensile strength.
(2) Elastic fibers are composed of microfibrils embedded in elastin and are very elastic.
(3) Reticular fibers are very fine, collagenous fibers.

2. Categories of connective tissue
a. Connective tissue proper includes loose connective tissue, adipose tissue, and dense connective tissue.
b. Specialized connective tissue includes cartilage, bone, and blood.
3. Loose connective tissue
a. This tissue forms thin membranes between organs and binds them.
b. It is beneath the skin and between muscles.
4. Adipose tissue
a. This tissue is a specialized form of connective tissue that stores fat.
b. It is found beneath the skin, in certain abdominal membranes, and around the kidneys, heart, and various joints.
5. Dense connective tissue
a. This tissue is largely composed of strong, collagenous fibers.
b. It is found in the tendons, ligaments, white portions of the eyes, and the deep layer of the skin.
6. Cartilage
a. Cartilage provides a supportive framework for various structures.
b. Its intercellular material is composed of fibers and a gel-like ground substance.
c. Cartilaginous structures are enclosed in a perichondrium.
d. Cartilage lacks a direct blood supply and is slow to heal.
e. Major types are hyaline cartilage, elastic cartilage, and fibrocartilage.
7. Bone
a. The intercellular matrix of bone contains mineral salts and collagen.
b. Its cells are usually organized in concentric circles around central canals. Canaliculi connect them.
c. Bone is an active tissue that heals rapidly.
8. Blood
a. Blood transports substances and helps maintain a stable internal environment.
b. Blood is composed of red cells, white cells, and platelets suspended in plasma.
c. Blood cells develop in red marrow in the hollow parts of long bones.

5.4 Muscle Tissues (p. 105)

1. General characteristics
a. Muscle tissues contract, moving structures that are attached to them.
b. Three types are skeletal, smooth, and cardiac muscle tissues.
2. Skeletal muscle tissue
a. Muscles containing this tissue usually are attached to bones and controlled by conscious effort.
b. Cells, or muscle fibers, are long and threadlike.
c. Muscle fibers contract when stimulated by nerve impulses, then immediately relax.
3. Smooth muscle tissue
a. This tissue is in the walls of hollow internal organs.
b. Usually it is involuntarily controlled.
4. Cardiac muscle tissue
a. This tissue is found only in the heart.
b. Cells are joined by intercalated discs and form branched networks.

5.5 Nervous Tissues (p. 107)

1. Nervous tissue is in the brain, spinal cord, and peripheral nerves.
2. Neurons (nerve cells)
a. Neurons sense changes and respond by transmitting nerve impulses to other neurons or to muscles or glands.
b. They coordinate, regulate, and integrate body activities.
3. Supporting cells
a. Some of these cells bind and support nervous tissue.
b. Others carry on phagocytosis.
c. Still others connect neurons to blood vessels.

REVIEW EXERCISES

1. Define *tissue.* (p. 92)
2. Name the four major types of tissues in the human body. (p. 92)
3. Describe the general characteristics of epithelial tissues. (p. 92)
4. Explain how the structure of simple squamous epithelium provides its function. (p. 92)
5. Name an organ in which each of the following tissues is found, and give the function of each tissue. (p. 92)
a. Simple squamous epithelium
b. Simple cuboidal epithelium
c. Simple columnar epithelium
d. Pseudostratified columnar epithelium
e. Stratified squamous epithelium
f. Stratified cuboidal epithelium
g. Stratified columnar epithelium
h. Transitional epithelium
i. Glandular epithelium
6. Define *gland.* (p. 97)
7. Distinguish between an exocrine gland and an endocrine gland. (p. 97)
8. Explain how glandular secretions differ. (p. 97)
9. Define *mucus.* (p. 97)
10. Describe the general characteristics of connective tissues. (p. 98)
11. Define *matrix.* (p. 98)
12. Describe three major types of connective tissue cells. (p. 99)
13. Distinguish between collagen and elastin. (p. 100)
14. Explain the relationship between loose connective tissue and adipose tissue. (p. 101)
15. Define *dense connective tissue.* (p. 101)
16. Explain why injured dense connective tissue and cartilage are usually slow to heal. (p. 102)
17. Name the types of cartilage, and describe their differences and similarities. (p. 102)
18. Describe how bone cells are organized in bone tissue. (p. 103)
19. Describe the composition of blood. (p. 103)
20. Describe the general characteristics of muscle tissues. (p. 105)
21. Distinguish among skeletal, smooth, and cardiac muscle tissues. (p. 105)
22. Describe the general characteristics of nervous tissues. (p. 107)
23. Distinguish between neurons and neuroglial cells. (p. 107)

CRITICAL THINKING

1. Tissue engineering combines living cells with synthetic materials to create functional substitutes for human tissues. What components would you use to engineer replacement (*a*) skin, (*b*) blood, (*c*) bone, and (*d*) muscle?
2. Collagen and elastin are added to many beauty products. What type of tissue are they normally part of?
3. Joints such as the elbow, shoulder, and knee contain considerable amounts of cartilage and dense connective tissue. How does this explain the fact that joint injuries are often very slow to heal?
4. Cancer-causing agents (carcinogens) usually act on cells that are dividing. Which of the four tissues would carcinogens most influence? Least influence?

WEB CONNECTIONS

Visit the website for additional study questions and more information about this chapter at:

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