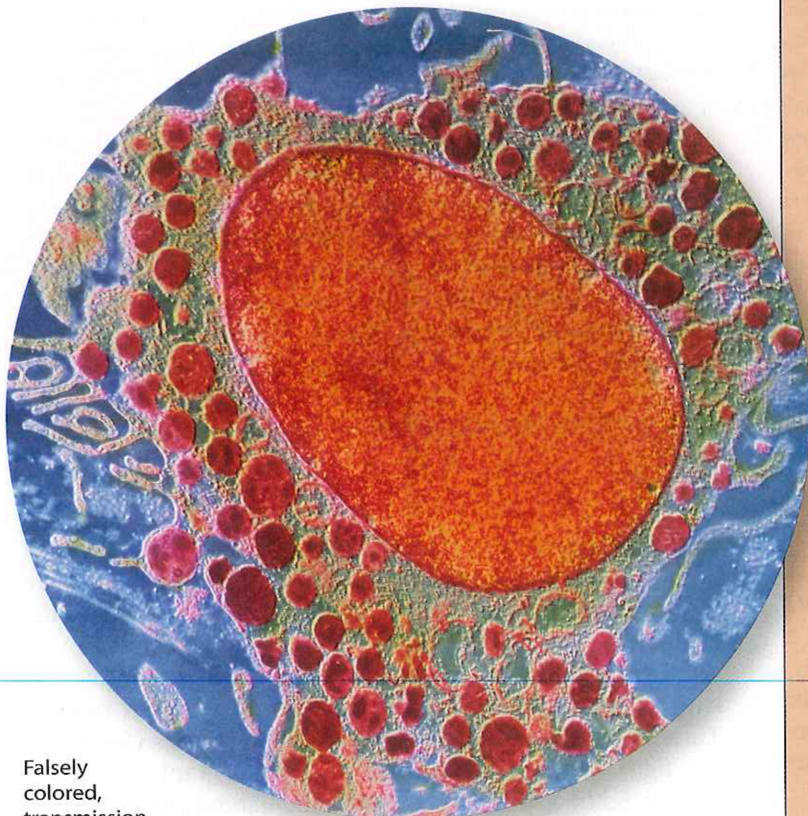
5 Tissues



Falsely colored, transmission electron micrograph (TEM) of a portion of a mast cell. The large, orange oval is the cell's nucleus, and the red granules contain histamine and heparin.

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Module 3: Tissues

Learning Outcomes

After you have studied this chapter, you should be able to:

5.1 Introduction

1 Describe how cells are organized into tissues. (p. 152)
2 Identify the intercellular junctions in tissues. (p. 152)
3 List the four major tissue types in the body. (p. 152)

5.2 Epithelial Tissues

4 Describe the general characteristics and functions of epithelial tissue. (p. 152)
5 Name the types of epithelium and identify an organ in which each is found. (p. 154)
6 Explain how glands are classified. (p. 158)

5.3 Connective Tissues

7 Describe the general characteristics of connective tissue. (p. 161)
8 Compare and contrast the components, cells, fibers, and extracellular matrix (where applicable) in each type of connective tissue. (p. 164)
9 Describe the major functions of each type of connective tissue. (p. 164)

5.4 Types of Membranes

10 Describe and locate each of the four types of membranes. (p. 171)

5.5 Muscle Tissues

11 Distinguish among the three types of muscle tissue. (p. 171)

5.6 Nervous Tissues

12 Describe the general characteristics and functions of nervous tissue. (p. 173)

LEARN PRACTICE ASSESS

Understanding Words

adip-, fat: *adipose* tissue—tissue that stores fat.
chondr-, cartilage: *chondro*cyte—cartilage cell.
-cyt, cell: osteo*cyte*—bone cell.
epi-, upon, after, in addition: *epi*thelial tissue—tissue that covers all free body surfaces.
-glia, glue: neuro*glia*—cells that support neurons; part of nervous tissue.
hist-, web, tissue: *hist*ology—study of composition and function of tissues.
hyal-, resemblance to glass: *hyal*ine cartilage—flexible tissue containing chondrocytes.
inter-, among, between: *inter*calated disc—band between adjacent cardiac muscle cells.
macr-, large: *macr*ophage—large phagocytic cell.
neur-, nerve: *neur*on—nerve cell.
os-, bone: *os*seous tissue—bone tissue.
phag-, to eat: *phag*ocyte—cell that engulfs and destroys foreign particles.
pseud-, false: *pseud*ostratified epithelium—tissue with cells that appear to be in layers, but are not.
squam-, scale: *squam*ous epithelium—tissue with flattened or scalelike cells.
strat-, layer: *strat*ified epithelium—tissue with cells in layers.
stria-, groove: *stria*tions—alternating light and dark cross-markings in skeletal and cardiac muscle cells.

A New View of Cell Specialization—Proteomics

A tissue atlas displays groups of cells stained and viewed with the aid of a microscope. It's easy to tell skeletal muscle from adipose tissue from blood. A new way to look at tissues is to profile the proteins that their cells manufacture. These proteins are responsible for cell specializations and arise from the expression of subsets of the genome. Such an approach is called *proteomics*. A skeletal muscle cell, for example, transcribes messenger RNA molecules from genes that encode contractile proteins, whereas an adipose cell yields mRNAs whose protein products enable the cell to store massive amounts of fat. All cells also transcribe many mRNA molecules whose encoded proteins make life at the cellular level possible.

In the mid 1990s, technology was developed to display the genes expressed in particular cell types. The tool is a DNA microarray (also known as a gene chip). It is a square of glass or plastic smaller than a postage stamp to which thousands of small pieces of DNA of known sequence are bound, in a grid pattern, so that the position of each entrant is known. Then mRNAs are extracted from a cell or tissue sample, copied into DNA "probes," and labeled with a fluorescent dye. The grid positions where the probes bind fluoresce, which a laser scanner detects and converts into an image. The intensity of the fluorescence reveals the abundance of the mRNAs present. Probes representing two cell sources can be linked to different fluorescent tags so that their gene expression patterns can be directly compared—such as a healthy and cancerous version of the same cell type. A microarray can scan for activity in all genes or be customized to paint molecular portraits of specific functions, such as secretion or contractility.

Researchers are compiling DNA microarray patterns for the 260⁺ types of normal differentiated cells in a human body. A statistical analysis called hierarchy clustering groups cells by similarities in gene expression. The results generally agree with traditional histology (the study of tissues) from microscopy, but sometimes reveal new proteins in specific cell types. Although DNA microarrays can fill in molecular details that cannot be seen under a microscope, a pair of discerning human eyes will always be necessary to see the bigger picture of how cells assemble into tissues. ■

5.1 INTRODUCTION

In all complex organisms, cells are organized into **tissues** (tish′uz), which are layers or groups of similar cells with a common function. Some cells, such as blood cells, are separated from each other in fluid-filled spaces or intercellular (in″ter-sell′u-lar) spaces. Many other cell types, however, are tightly packed, with structures called **intercellular junctions** that connect their cell membranes.

In one type of intercellular junction, called a *tight junction*, the membranes of adjacent cells converge and fuse. The area of fusion surrounds the cell like a belt, and the junction closes the space between the cells. Tight junctions typically join cells that form sheetlike layers, such as those that line the inside of the digestive tract. The linings of tiny blood vessels in the brain consist of cells held tightly together (From Science to Technology 5.1).

Another type of intercellular junction, called a *desmosome*, rivets or "spot welds" skin cells, enabling them to form a reinforced structural unit. The cell membranes of certain other cells, such as those in heart muscle and muscle of the digestive tract, are interconnected by tubular channels called *gap junctions*. These channels link the cytoplasm of adjacent cells and allow ions, nutrients (such as sugars, amino acids, and nucleotides), and other small molecules to move between them (fig. 5.1). Table 5.1 summarizes intercellular junctions.

Tissues can be distinguished from each other by variations in cell size, shape, organization, and function. The study of tissues, **histology**, will assist understanding in later discussions of the physiology of organs and organ systems. The tissues of the human body include four major types: *epithelial*, *connective*, *muscle*, and *nervous*. These tissues associate, assemble, and interact to form organs that have specialized functions. Table 5.2 compares the four major tissue types.

This chapter examines epithelial and connective tissues in detail, and introduces muscle and nervous tissues. Throughout this chapter, simplified line drawings (for example, fig. 5.2*a*) are included with each micrograph (for example, fig. 5.2*b*) to emphasize the distinguishing characteristics of the specific tissue, as well as a locator icon (an example of where in the body that particular tissue is found). Chapter 9 discusses muscle tissue in more detail, and chapters 10, 11, and 12 examine nervous tissue.

PRACTICE

1. What is a tissue?
2. What are the different types of intercellular junctions?
3. List the four major types of tissue.

5.2 EPITHELIAL TISSUES APIR

General Characteristics

Epithelial (ep″ĭ-the′le-al) **tissues** are found throughout the body. Epithelium covers the body surface and organs, forms the inner lining of body cavities, and lines hollow organs. It always has a *free (apical) surface* exposed to the outside or internally to an open space. A thin, nonliving layer called the **basement membrane** anchors epithelium to underlying connective tissue.

5.1 FROM SCIENCE TO TECHNOLOGY

Nanotechnology Meets the Blood-Brain Barrier

Nanotechnology is helping drug developers to circumvent a problem in drug delivery based on an anatomical impediment—the close attachments of the cells that form tiny blood vessels in the brain. Like a tight line of police officers keeping out a crowd, the blood-brain barrier is a 400-mile network of capillaries in the brain whose cells are firmly attached by overlapping tight junctions. These cells also lack the scattered vesicles and windowlike clefts in other capillaries. In addition, star-shaped brain cells called astrocytes wrap around the barrier.

The blood-brain barrier shields brain tissue from toxins and biochemical fluctuations that could be overwhelming. It also allows selective drug delivery. Certain antihistamines, for example, do not cause drowsiness because they cannot breach the barrier. But this protection has a trade-off—the brain cannot take up many therapeutic drugs that must penetrate to be effective.

For decades researchers have attempted to deliver drugs across the barrier by tagging compounds to substances that can cross, and injecting substances that temporarily relax the tight junctions. More recently, researchers have applied nanotechnology to the problem of circumventing the blood-brain barrier. Nanotechnology is the application of structures smaller than 100 billionths of a meter (100 nanometers) in at least one dimension.

Nanoparticles that can cross the blood-brain barrier are made of combinations of oils and polymers, with a neutral or slightly negative charge (positively charged particles are toxic). In one application, anesthetics or chemotherapeutics are loaded into fatty bubbles (liposomes) that are in turn placed in nanoparticles. This delivery system masks the part of the drug that cannot cross the barrier and slows release of the drug, which diminishes side effects.

In another application, insulin is delivered in inhaled nanoparticles 10 to 50 nanometers in diameter. Originally developed to provide insulin to people with diabetes instead of injecting it, clinical trials are showing that nanoparticle delivery of insulin is also helpful in maintaining memory in people who have mild cognitive impairment or Alzheimer disease. ■

Cancer cells secrete a substance that dissolves basement membranes, enabling the cells to invade tissue layers. Cancer cells also produce fewer adhesion proteins, or none at all, which allows them to spread into surrounding tissue.

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, so injuries heal rapidly as new cells replace lost or damaged ones. For example, skin cells and the cells that line the stomach and intestines are continually damaged and replaced.

Epithelial cells are tightly packed. In many places, desmosomes attach epithelial cells, forming protective barriers in such structures as the outer layer of the skin and the inner lining of the mouth. Other epithelial functions include secretion, absorption, and excretion.

Epithelial tissues are classified according to cell shape and the number of cell layers. Epithelial tissues composed of thin, flattened cells are *squamous;* those with cubelike cells are *cuboidal;* and those with elongated cells are *columnar.* Epithelium composed of a single layer of cells is *simple* and with two or more layers of cells, *stratified.* In the following descriptions, modifications of the free surfaces of epithelial cells reflect their specialized functions.

PRACTICE

4 List the general characteristics of epithelial tissue.
5 Explain how epithelial tissues are classified.

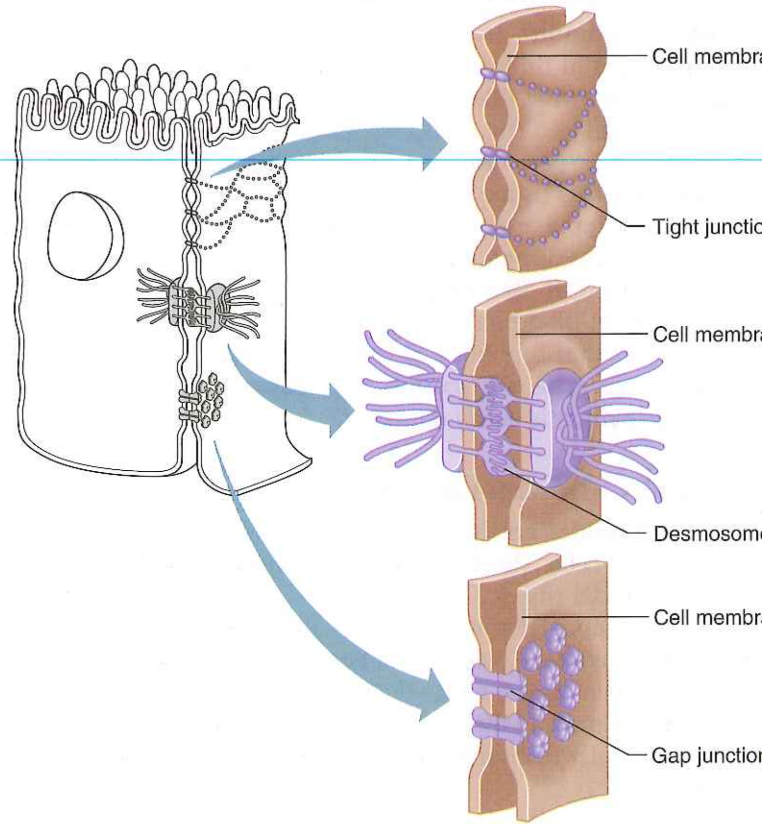


FIGURE 5.1 Intercellular junctions. Tight junctions fuse cell membranes, desmosomes are "spot welds," and gap junctions form channels linking the cytoplasm of adjacent cells.

Q: *Which intercellular junction is the most likely to allow substances to move from one cell to another?*

Answer can be found in Appendix G on page 938.

TABLE 5.1 | Types of Intercellular Junctions

Type	Characteristics	Example
Tight junctions	Close space between cells by fusing cell membranes	Cells that line the small intestine
Desmosomes	Bind cells by forming "spot welds" between cell membranes	Cells of the outer skin layer
Gap junctions	Form tubular channels between cells that allow exchange of substances	Muscle cells of the heart and digestive tract

TABLE 5.2 | Tissues

Type	Function	Location	Distinguishing Characteristics
Epithelial	Protection, secretion, absorption, excretion	Cover body surface, cover and line internal organs, compose glands	Lack blood vessels, cells readily divide, cells are tightly packed
Connective	Bind, support, protect, fill spaces, store fat, produce blood cells	Widely distributed throughout the body	Mostly have good blood supply, cells are farther apart than epithelial cells, with extracellular matrix in between
Muscle	Movement	Attached to bones, in the walls of hollow internal organs, heart	Able to contract in response to specific stimuli
Nervous	Conduct impulses for coordination, regulation, integration, and sensory reception	Brain, spinal cord, nerves	Cells communicate with each other and other body parts

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. 5.2).

Substances pass rather easily through simple squamous epithelium. This tissue is common at sites of diffusion and filtration. 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 vessels, and is part of the membranes that line body cavities and cover the viscera. 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. 5.3).

Simple cuboidal epithelium lines the follicles of the thyroid gland, covers the ovaries, and lines the kidney tubules and ducts of certain glands, where the free surface faces the hollow channel or **lumen.** In the kidneys, it functions in tubular secretion and tubular reabsorption; in glands, it secretes glandular products.

Simple Columnar Epithelium

Simple columnar epithelium is composed of a single layer of cells that are longer than they are wide and whose nuclei are usually at about the same level, near the basement membrane (fig. 5.4). The cells of this tissue can be ciliated or nonciliated. *Cilia,* 7 to 10 μm in length, extend from the free surfaces of the cells, and they move constantly. In the female, cilia aid in moving the egg cell through the uterine tube to the uterus.

Nonciliated simple columnar epithelium lines the uterus and portions of the digestive tract, including the stomach and 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. Those cells specialized for absorption typically have many tiny, cylindrical processes, called *microvilli,* extending from their free surfaces. They are 0.5 to 1.0 μm long. Microvilli increase the surface area of the cell membrane where it is exposed to substances being absorbed (fig. 5.5).

Specialized flask-shaped glandular cells are scattered among the cells of simple columnar epithelium. These cells, called *goblet cells,* secrete a protective fluid called *mucus* onto the free surface of the tissue (see fig. 5.4).

Pseudostratified Columnar Epithelium

The cells of **pseudostratified** (soo″do-strat′ĭ-fīd) **columnar epithelium** appear stratified or layered, but they are not. A layered effect occurs because the nuclei are at two or more levels in the row of aligned cells. However, the cells, which vary in shape, all reach the basement membrane, even though some of them may not contact the free surface.

Pseudostratified columnar epithelial cells commonly have cilia, which extend from the free surfaces. Goblet cells scattered throughout this tissue secrete mucus, which the cilia sweep away (fig. 5.6).

Pseudostratified columnar epithelium lines the passages of the respiratory system. Here, the mucous-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.

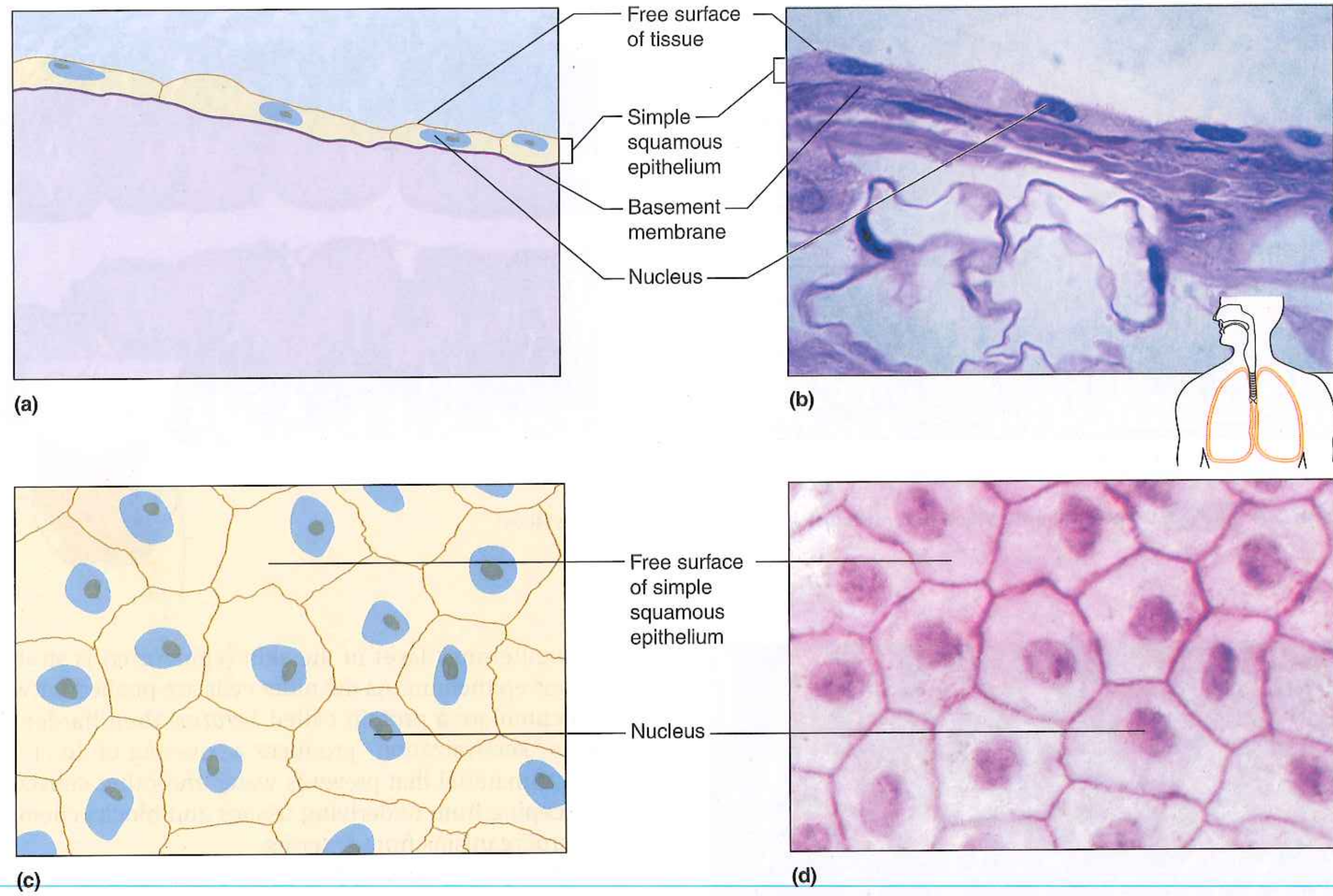


FIGURE 5.2 AP|R Simple squamous epithelium consists of a single layer of tightly packed, flattened cells. (*a*) and (*b*) side view (320×). (*c*) and (*d*) surface view (250x).

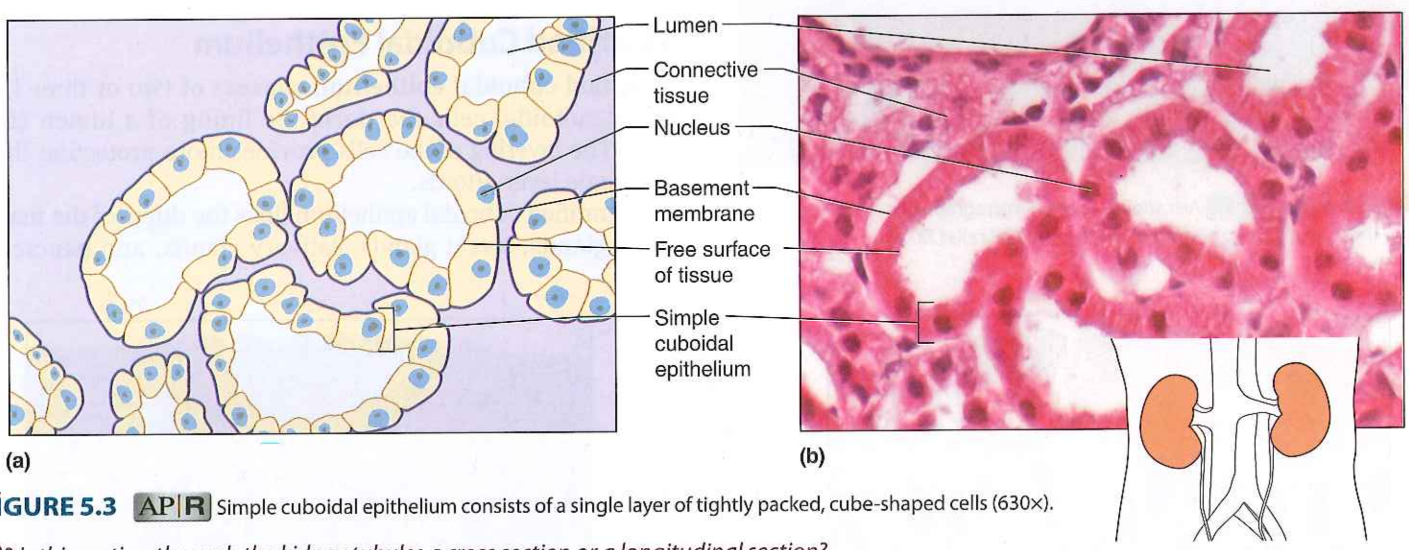


FIGURE 5.3 AP|R Simple cuboidal epithelium consists of a single layer of tightly packed, cube-shaped cells (630×).

Q: *Is this section through the kidney tubules a cross section or a longitudinal section?*

Answer can be found in Appendix G on page 938.

Stratified Squamous Epithelium

Stratified epithelium is named for the shape of the cells forming the outermost layers. **Stratified squamous epithelium** consists of many layers of cells, making this tissue relatively thick. Cells nearest the free surface are flattened the most, whereas those in the deeper layers, where cell division occurs, are cuboidal or columnar. As the newer cells grow, older ones are pushed farther and farther outward, where they flatten (fig. 5.7).

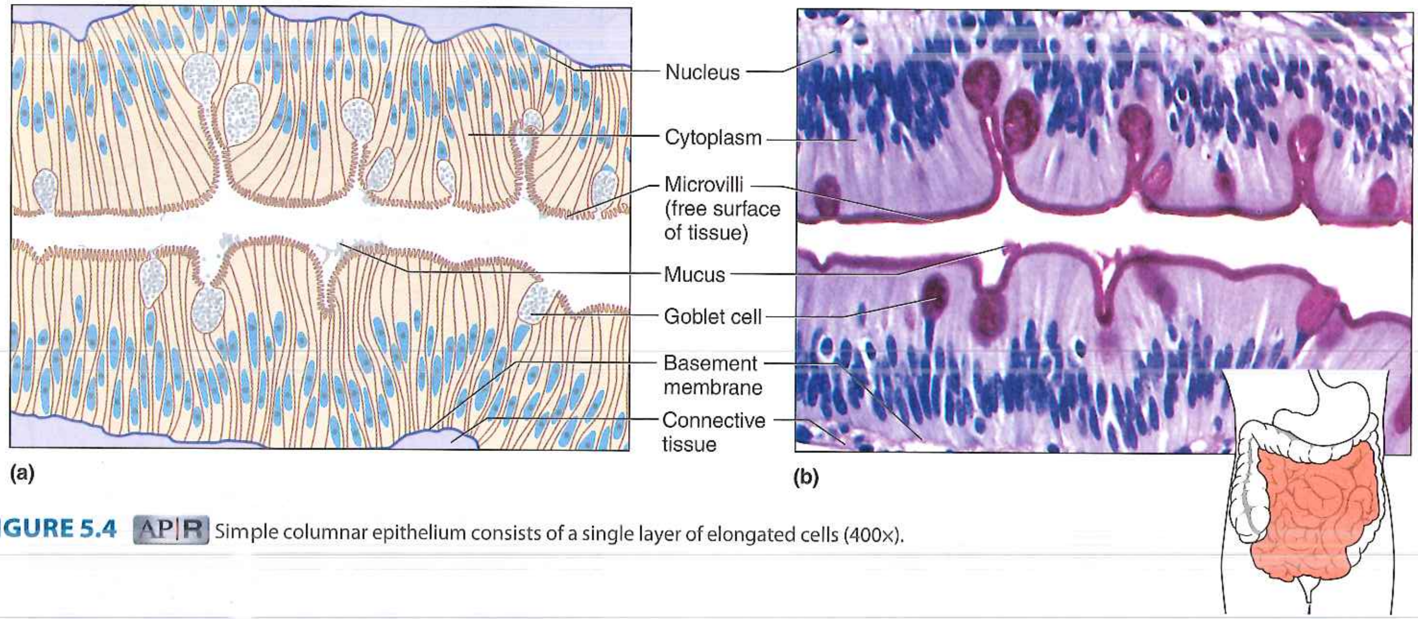


FIGURE 5.4 AP|R Simple columnar epithelium consists of a single layer of elongated cells (400×).

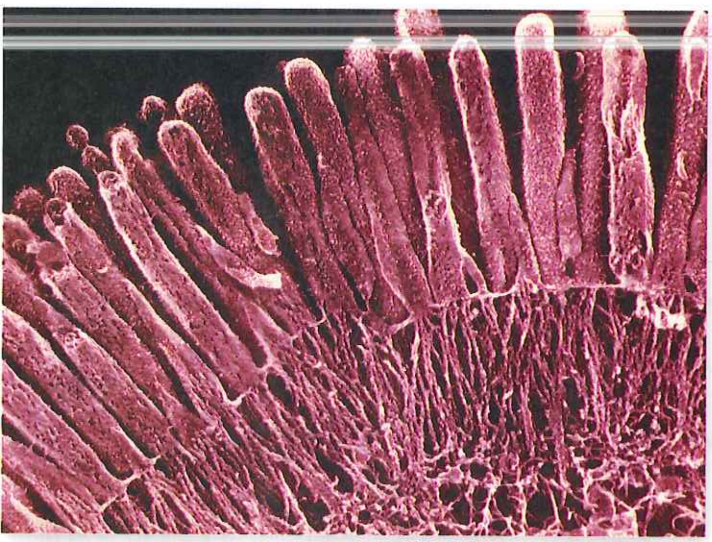


FIGURE 5.5 AP|R A scanning electron micrograph of microvilli, which fringe the free surfaces of some columnar epithelial cells (33,000×).

The outermost layer of the skin (epidermis) is stratified squamous epithelium. As the older cells are pushed outward, they accumulate a protein called *keratin*, then harden and die. This "keratinization" produces a covering of dry, tough, protective material that prevents water and other substances from escaping from underlying tissues and blocks chemicals and microorganisms from entering.

Stratified squamous epithelium also lines the oral cavity, esophagus, 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 (fig. 5.8). The layering of the cells provides more protection than the single layer affords.

Stratified cuboidal epithelium lines the ducts of the mammary glands, sweat glands, salivary glands, and pancreas.

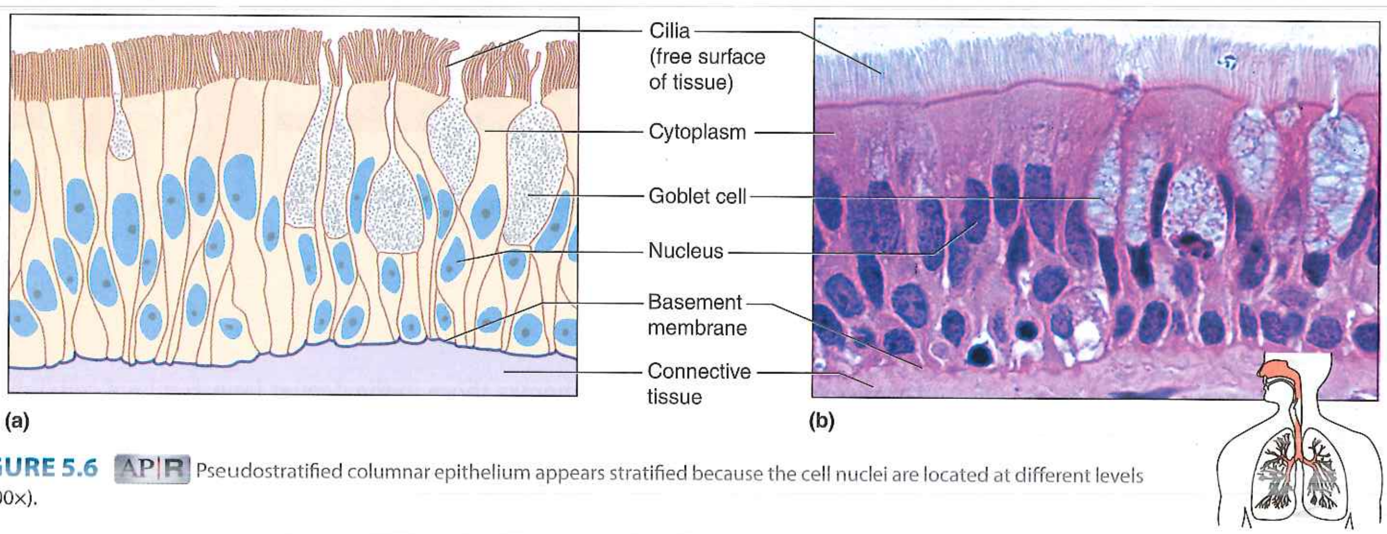


FIGURE 5.6 AP|R Pseudostratified columnar epithelium appears stratified because the cell nuclei are located at different levels (1,000×).

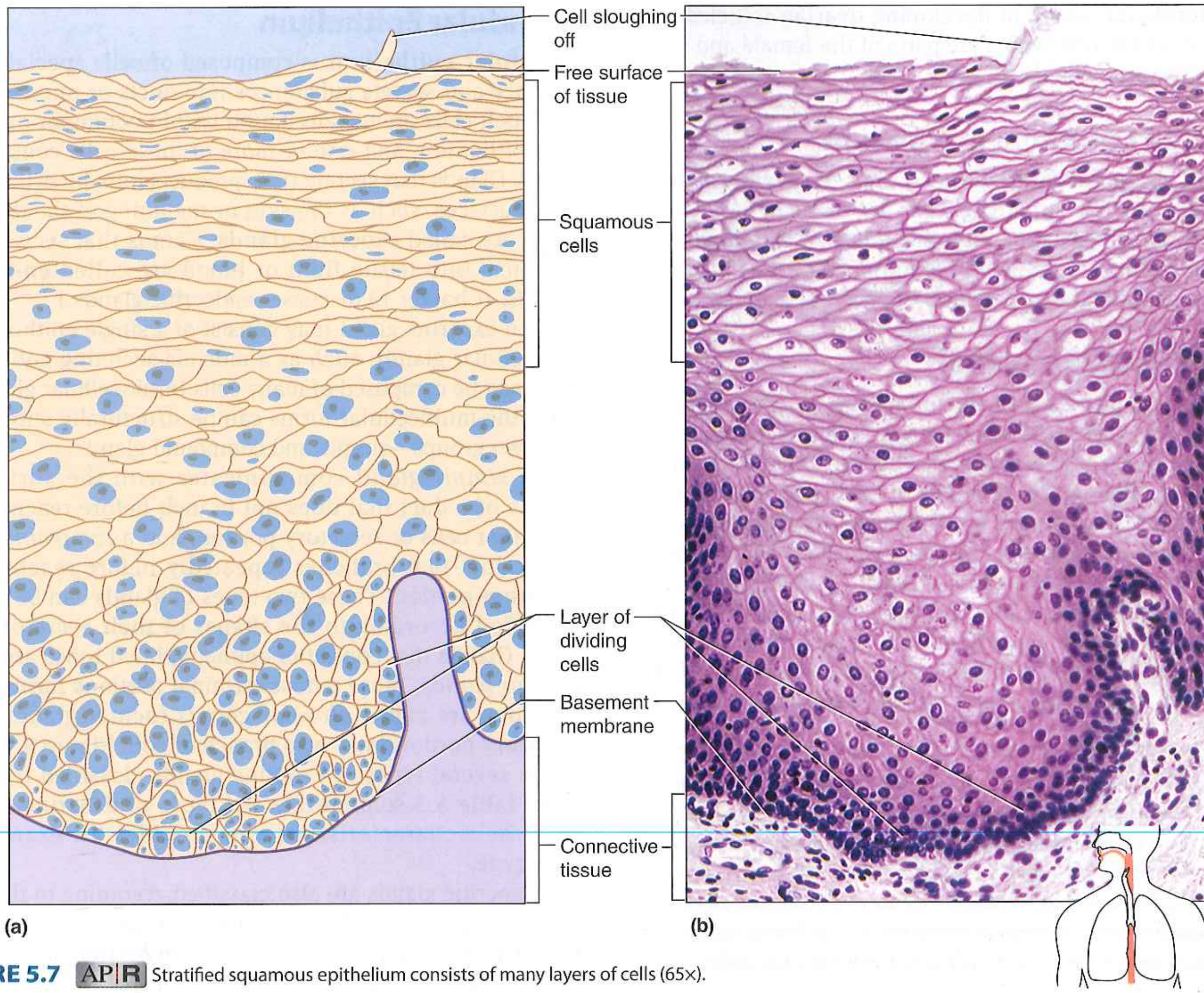


FIGURE 5.7 APIR Stratified squamous epithelium consists of many layers of cells (65×).

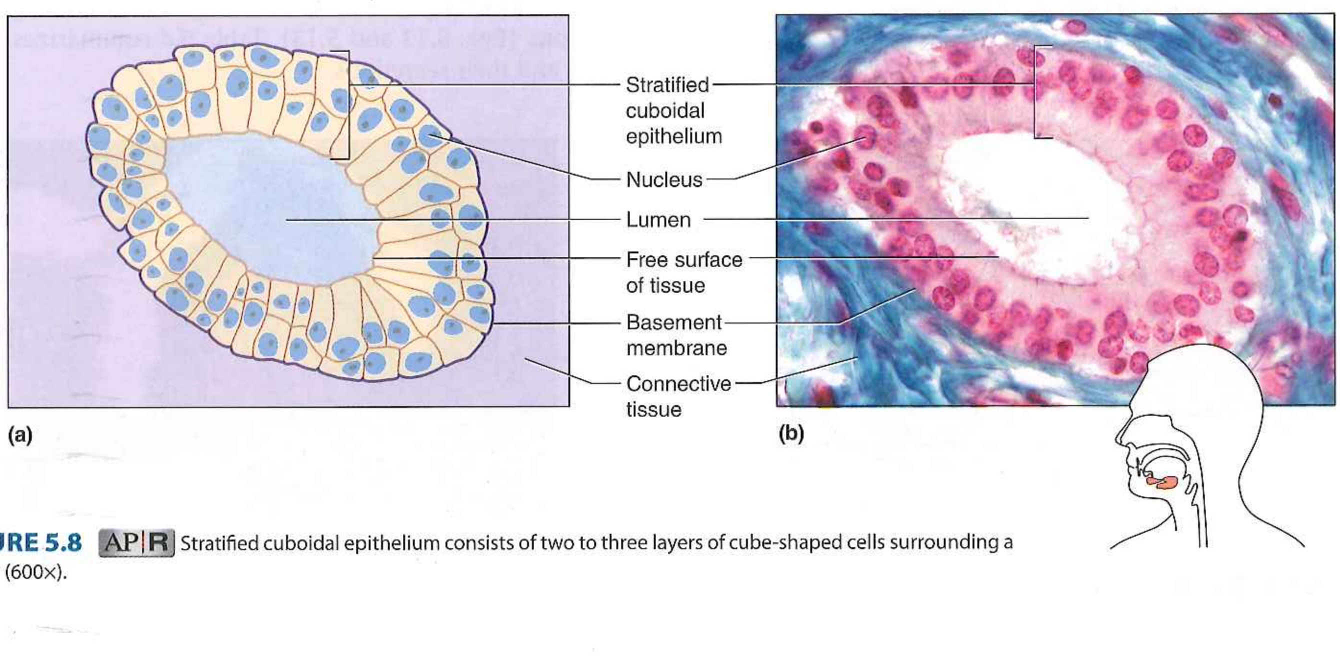


FIGURE 5.8 APIR Stratified cuboidal epithelium consists of two to three layers of cube-shaped cells surrounding a lumen (600×).

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. 5.9). The superficial cells are elongated, whereas the basal layers consist of cube-shaped cells. Although rare, stratified columnar epithelium is found in part of the male urethra and lining the larger ducts of exocrine glands.

Transitional Epithelium

Transitional epithelium (uroepithelium) is specialized to change in response to increased tension. It forms the inner lining of the urinary bladder and lines the ureters and the superior urethra. When the wall of one of these organs contracts, the tissue consists of several layers of cuboidal cells. When the organ is distended, however, the tissue stretches, and the physical relationships among the cells change. While distended, the tissue appears to contain only a few layers of cells (fig. 5.10). 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 human cancers are *carcinomas,* 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 intestines in the digestive tract. This observation suggests that the more common cancer-causing agents may not deeply penetrate tissues. Carcinomas may also arise internally, such as in a duct in a breast or in the prostate gland.

PRACTICE

6 Describe the structure of each type of epithelium.

7 Describe the special functions of each type of epithelium.

Glandular Epithelium

Glandular epithelium is composed of cells specialized to produce and secrete substances into ducts or into body fluids. Such cells are usually found within columnar or cuboidal epithelium, and one or more of these cells constitute a *gland.* Glands that secrete their products into ducts that open onto surfaces, such as the skin or the lining of the digestive tract, are called **exocrine glands.** Glands that secrete their products into tissue fluid or blood are called **endocrine glands.** (Chapter 13 discusses endocrine glands.)

An exocrine gland may consist of a single epithelial cell (unicellular gland), such as a mucous-secreting goblet cell, or it may be composed of many cells (multicellular gland). In turn, the multicellular forms can be structurally subdivided into two groups—simple and compound glands.

A *simple gland* communicates with the surface by means of a duct that does not branch before reaching the glandular cells or secretory portion, and a *compound gland* has a duct that branches repeatedly before reaching the secretory portion. These two types of glands can be further classified according to the shapes of their secretory portions. Glands that consist of epithelial-lined tubes are called *tubular glands;* those whose terminal portions form saclike dilations are called *alveolar glands* (acinar glands). The secretory portions may also branch or coil. Figure 5.11 illustrates several types of exocrine glands classified by structure. Table 5.3 summarizes the types of exocrine glands, lists their characteristics, and provides an example of each type.

Exocrine glands are also classified according to the ways these glands secrete their products. Glands that release fluid products 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.** Glands that release entire cells are called **holocrine** (ho'lo-krin) **glands.** After release, the cells containing accumulated secretory products disintegrate, liberating their secretions (figs. 5.12 and 5.13). Table 5.4 summarizes these glands and their secretions.

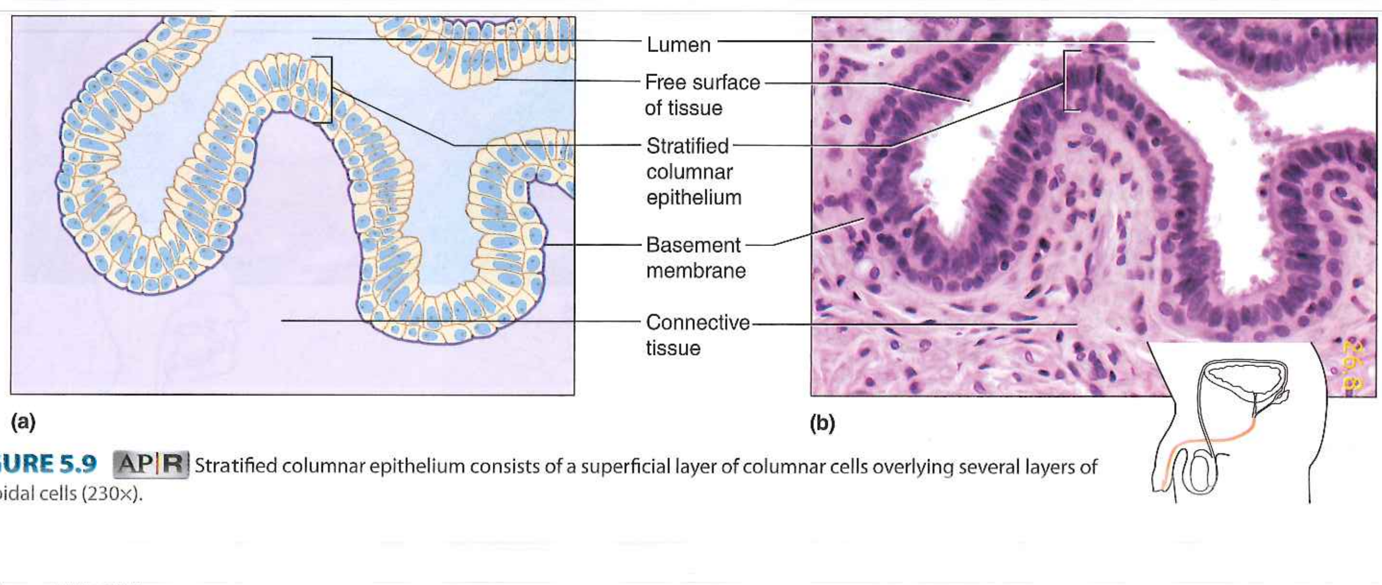


FIGURE 5.9 AP|R Stratified columnar epithelium consists of a superficial layer of columnar cells overlying several layers of cuboidal cells (230x).

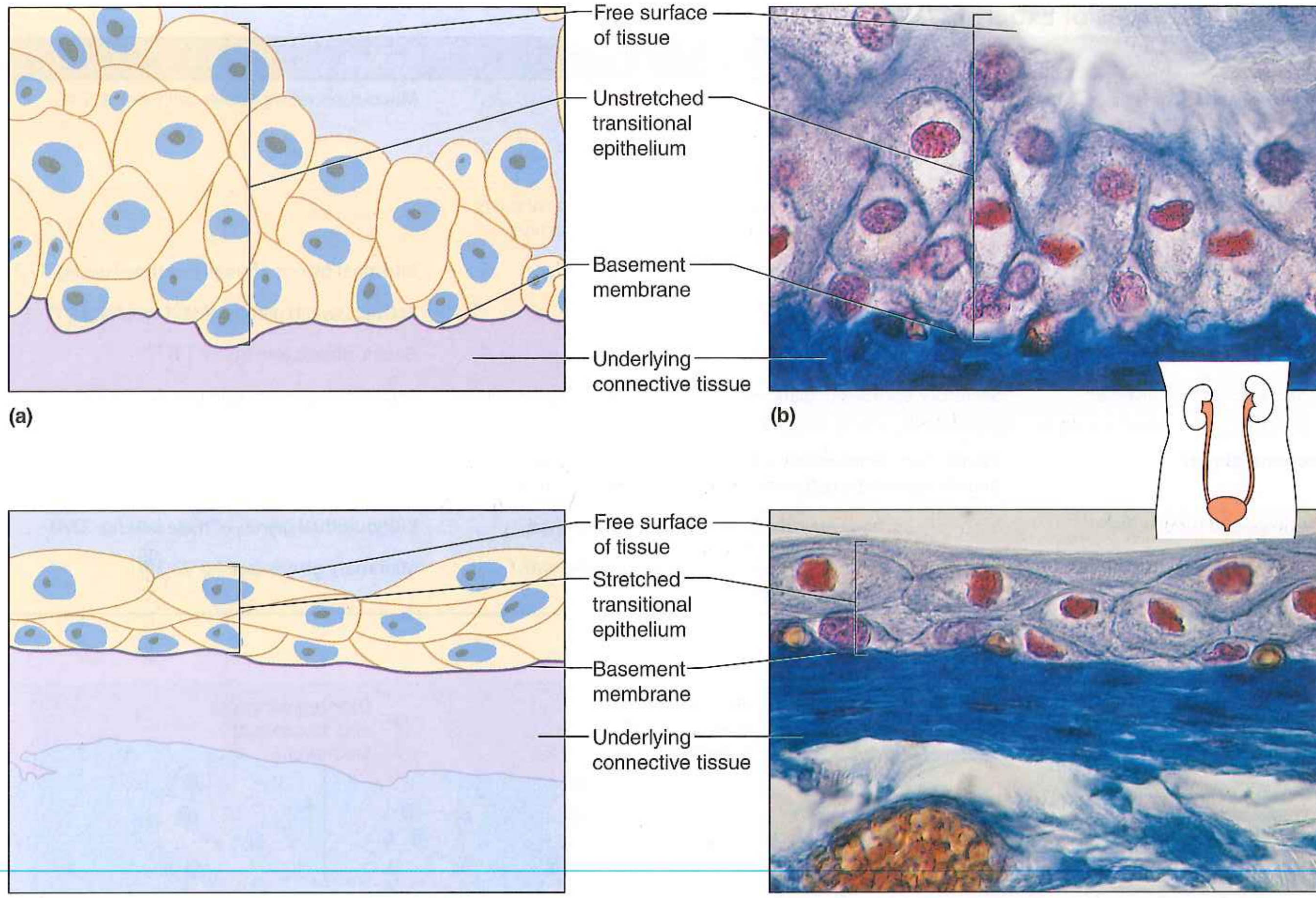


FIGURE 5.10 AP|R Transitional epithelium. (*a* and *b*) When the organ wall contracts, transitional epithelium is unstretched and consists of many layers (675×). (*c* and *d*) When the organ is distended, the tissue stretches and appears thinner (675×).

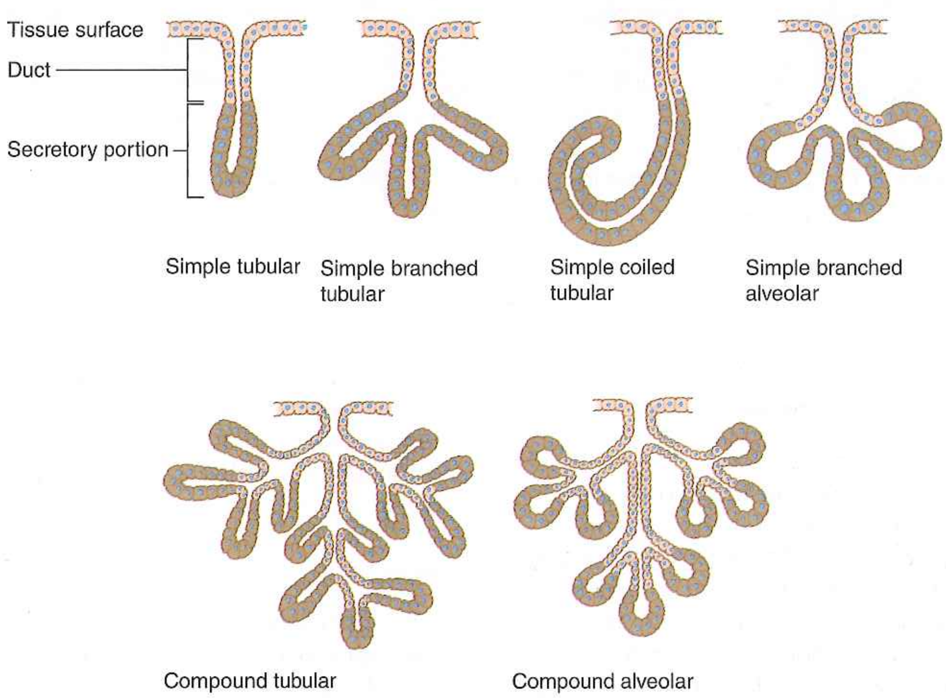


FIGURE 5.11 Structural types of exocrine glands.

TABLE 5.3 | Types of Exocrine Glands

Type	Characteristics	Example
Unicellular glands	A single secretory cell	Mucous-secreting goblet cell (see fig. 5.4)
Multicellular glands	Glands that consist of many cells	
Simple glands	Glands that communicate with the surface by means of ducts that do not branch before reaching the secretory portion	
1. Simple tubular gland	Straight tubelike gland that opens directly onto surface	Intestinal glands of small intestine (see fig. 17.3)
2. Simple coiled tubular gland	Long, coiled, tubelike gland; long duct	Eccrine (sweat) glands of skin (see fig. 6.11)
3. Simple branched tubular gland	Branched, tubelike gland; duct short or absent	Gastric glands (see fig. 17.19)
4. Simple branched alveolar gland	Secretory portions of gland expand into saclike compartments along duct	Sebaceous gland of skin (see fig. 5.13)
Compound glands	Glands that communicate with surface by means of ducts that branch repeatedly before reaching the secretory portion	
1. Compound tubular gland	Secretory portions are coiled tubules, usually branched	Bulbourethral glands of male (see fig. 22.4)
2. Compound alveolar gland	Secretory portions are irregularly branched tubules with numerous saclike outgrowths	Mammary glands (see fig. 23.29)

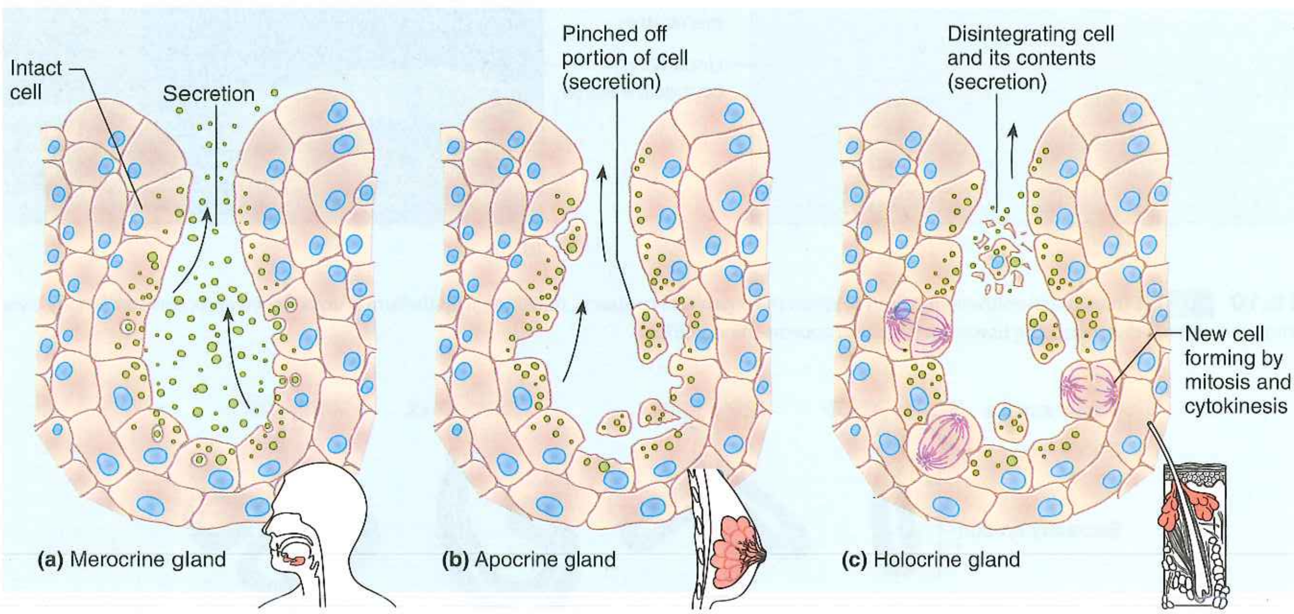


FIGURE 5.12 APIR Glandular secretions. *(a)* Merocrine glands release secretions without losing cytoplasm. *(b)* Apocrine glands lose small portions of their cell bodies during secretion. *(c)* Holocrine glands release entire cells filled with secretory products.

RECONNECT

To Chapter 3, Movements into and out of the Cell, page 106.

Most exocrine secretory cells are merocrine, and they can be further subclassified based on their secretion of serous fluid or mucus. **Serous fluid** is typically watery and has a high concentration of enzymes. Serous cells secreting this fluid, which lubricates, are commonly associated with the visceral and parietal membranes of the thoracic and abdominopelvic cavities. The thicker fluid, **mucus,** is rich in the glycoprotein *mucin*. Cells in the inner linings of the digestive, respiratory, and reproductive systems secrete abundant mucus, which is protective. Mucous cells and goblet cells secrete mucus, but in different parts of the body. Table 5.5 summarizes the characteristics of the different types of epithelial tissues.

PRACTICE

8 Distinguish between exocrine and endocrine glands.
9 Explain how exocrine glands are classified.
10 Distinguish between serous fluid and mucus.

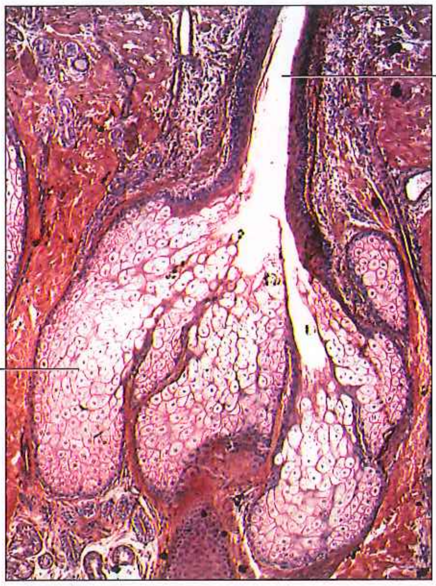


FIGURE 5.13 The sebaceous gland associated with a hair follicle is a simple-branched alveolar gland that secretes entire cells (40×).

TABLE 5.4 | Exocrine Glandular Secretions

Type	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 pinch off during secretion	Mammary glands, ceruminous glands lining the external acoustic meatus
Holocrine glands	Disintegrated entire cells filled with secretory products	Sebaceous glands of the skin

5.3 CONNECTIVE TISSUES AP|R

General Characteristics

Connective (kŏ-nek′tiv) **tissues** comprise much of the body and are the most abundant type of tissue by weight. They 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 abundant **extracellular matrix** (eks″trah-sel′u-lar ma′triks) between them. This extracellular matrix is composed of *protein fibers* and a *ground substance* consisting of nonfibrous protein and other molecules, and fluid. The consistency of the extracellular matrix varies from fluid to semisolid to solid. The ground substance binds, supports, and provides a medium through which substances may be transferred between the blood and cells of the tissue. Clinical Application 5.1 discusses the extracellular matrix and its relationship to disease.

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 rigid. Loose connective tissue and dense connective tissue are more flexible.

Major Cell Types

Connective tissues include a variety of cell types. Some of them are called *fixed cells* because they reside in the specific connective tissue type for an extended period. These include fibroblasts and mast cells. Other cells, such as macrophages,

TABLE 5.5 | Epithelial Tissues

Type	Description	Function	Location
Simple squamous epithelium	Single layer, flattened cells	Filtration, diffusion, osmosis, covers surface	Air sacs of lungs, walls of capillaries, linings of blood and lymph vessels
Simple cuboidal epithelium	Single layer, cube-shaped cells	Secretion, absorption	Surface of ovaries, linings of kidney tubules, and linings of ducts of certain glands
Simple columnar epithelium	Single layer, elongated cells	Protection, secretion, absorption	Linings of uterus, stomach, and intestines
Pseudostratified columnar epithelium	Single layer, elongated cells	Protection, secretion, movement of mucus and substances	Linings of respiratory passages
Stratified squamous epithelium	Many layers, top cells flattened	Protection	Outer layer of skin, linings of oral cavity, vagina, and anal canal
Stratified cuboidal epithelium	2 to 3 layers, cube-shaped cells	Protection	Linings of ducts of mammary glands, sweat glands, salivary glands, and pancreas
Stratified columnar epithelium	Top layer of elongated cells, lower layers of cube-shaped cells	Protection, secretion	Part of the male urethra and lining of larger ducts of excretory glands
Transitional epithelium	Many layers of cube-shaped and elongated cells	Distensibility, protection	Inner lining of urinary bladder and linings of ureters and part of urethra
Glandular epithelium	Unicellular or multicellular	Secretion	Salivary glands, sweat glands, endocrine glands

5.1 CLINICAL APPLICATION

The Body's Glue: The Extracellular Matrix

The extracellular matrix (ECM) is more than a "filler" between cells. It is a complex and changing mix of molecules that modifies the tissue to suit different organs and conditions. The ECM serves as a scaffolding to organize cells into tissues, and also relays the biochemical signals that control cell division, differentiation, tissue repair, and cell migration.

The ECM has two basic components: the basement membrane that covers epithelial cell surfaces, and the rest of the material between cells, called the interstitial matrix. The basement membrane is mostly composed of tightly packed collagenous fibers from which large, cross-shaped glycoproteins called laminins extend. The laminins (and other glycoproteins such as fibronectin, the proteoglycans, and tenascin) traverse the interstitial matrix and contact receptors, called integrins, on other cells (fig. 5A). In this way, the ECM connects cells into tissues. At least twenty types of collagen and precursors of hormones, enzymes, growth factors, and immune system biochemicals (cytokines) comprise the various versions of the ECM. The precursor molecules are activated under certain conditions.

The components of the ECM are always changing, as its cells synthesize proteins while enzymes called proteases break down specific proteins. The balance of components is important to maintaining and repairing organ structure. Disrupt the balance, and disease can result. Here are three common examples:

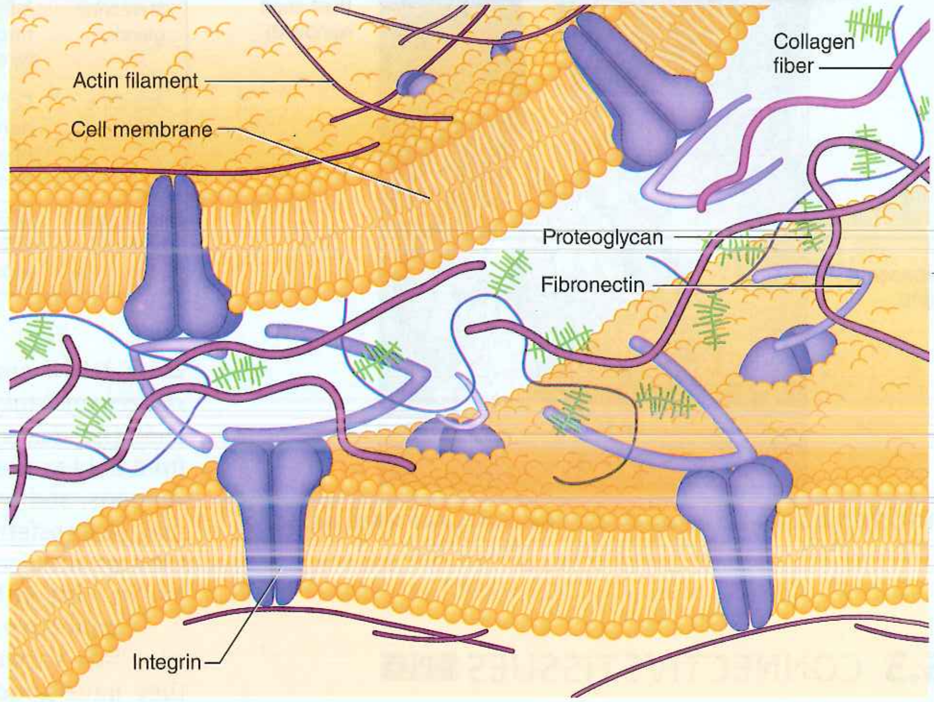


FIGURE 5A The extracellular matrix (ECM) is a complex and dynamic meshwork of various proteins and glycoproteins. Collagen is abundant. Other common components include integrins that anchor the ECM to cells, proteoglycans, and fibronectin. The ECM may also include precursors of growth factors, hormones, enzymes, and cytokines. It is vital to maintaining the specialized characteristics of tissues and organs.

Cancer

The spread of a cancerous growth takes advantage of the normal ability of fibroblasts to contract as they close a wound, where they are replaced with normal epithelium. Chemical signals from cancer cells make fibroblasts more contractile (myofibroblasts), and they take on the characteristics of cancer cells. At the same time, alterations in laminins loosen the connections of the fibroblasts to surrounding cells. This abnormal flexibility enables the changed fibroblasts to migrate, helping the cancer spread.

Liver Fibrosis

In fibrosis, a part of all chronic liver diseases, collagen deposition increases so that the ECM exceeds its normal 3% of the organ. Healthy liver ECM sculpts a framework that supports the epithelial and vascular tissues of the organ. In liver fibrosis, hepatic stellate cells secrete collagenous fibers in the areas where the epithelium and blood vessels meet, in response to a damaging agent such as a virus, alcohol, or a toxic drug. Such limited fibrosis seals off the affected area, preventing its spread. But if the process continues—if an infection is not treated or the noxious stimulus not removed—the ECM grows and eventually blocks the interaction between liver cells and the bloodstream. The liver tissue hardens and loses normal function, which is a dangerous condition called *cirrhosis.*

Heart Failure and Atherosclerosis

The heart's ECM organizes cells into a three-dimensional network that coordinates their contractions into the rhythmic heartbeat necessary to pump blood. This ECM consists of collagen, fibronectin, laminin, and elastin surrounding cardiac muscle cells and myofibroblasts and is also in the walls of arteries. Heart failure and atherosclerosis (buildup of fatty material on artery wall interiors) reflect imbalances of collagen production and degradation. As in the liver, the natural response of ECM buildup is to wall off an area where circulation is blocked, but if it continues, the extra scaffolding stiffens the heart, which can lead to heart failure. In atherosclerosis, excess ECM accumulates on the interior linings of arteries, blocking blood flow. During a myocardial infarction (heart attack), collagen synthesis and deposition increase in affected and nonaffected heart parts, which is why damage can continue even after pain stops. ■

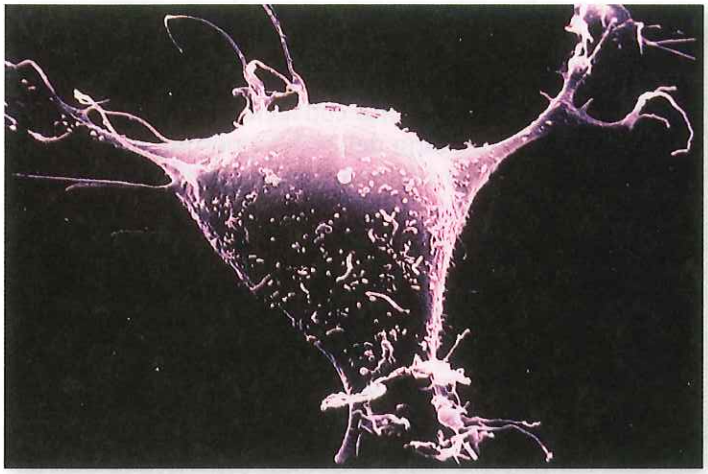


FIGURE 5.14 A scanning electron micrograph of a fibroblast, the most abundant cell type of connective tissue (4,000×).

are *wandering cells.* They move through and 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 tissues. These large, star-shaped cells produce fibers by secreting proteins into the extracellular matrix of connective tissues (fig. 5.14).

Macrophages (mak′ro-fājez), or histiocytes, originate as white blood cells (see chapter 14, p. 535) and are almost as numerous as fibroblasts in some connective tissues. They are usually attached to fibers but can detach and actively move about. Macrophages are specialized to carry on phagocytosis. As scavenger cells, they can clear foreign particles from tissues, providing an important defense against infection (fig. 5.15). Macrophages play additional roles in immunity (see chapter 16, p. 630).

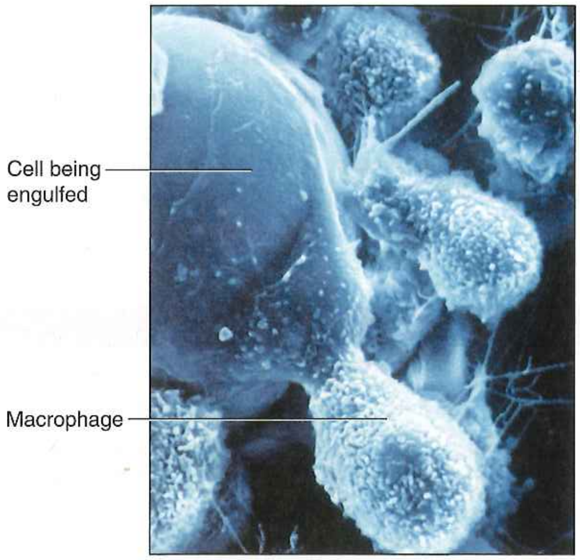


FIGURE 5.15 Macrophages are scavenger cells common in connective tissues. This scanning electron micrograph shows a number of macrophages engulfing parts of a larger cell (3,330×).

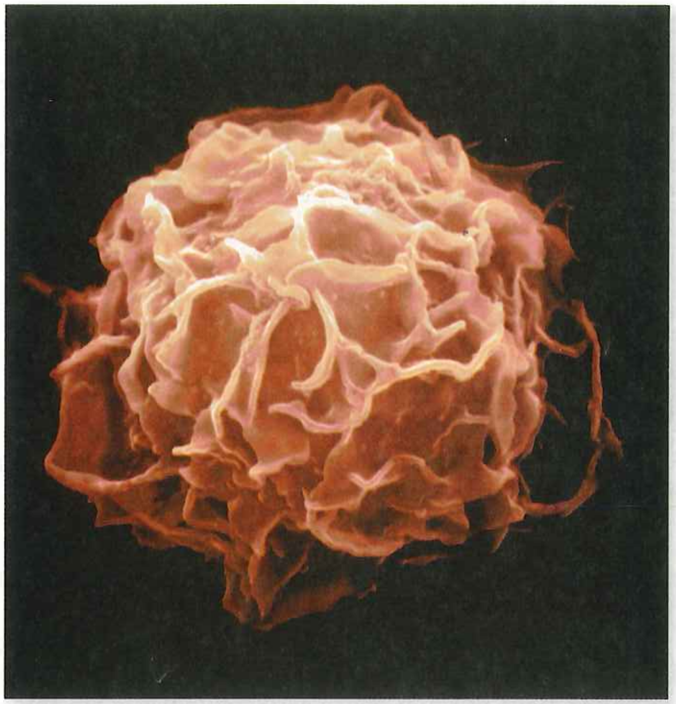


FIGURE 5.16 Scanning electron micrograph of a mast cell which releases heparin and histamine (6,600×).

Mast cells are large and widely distributed in connective tissues, where they are usually near blood vessels (fig. 5.16). They release *heparin,* a compound that prevents blood clotting. Mast cells also release *histamine,* which is a substance that promotes some of the reactions associated with inflammation and allergies, such as asthma and hay fever (see chapter 16, p. 637).

> Release of histamine stimulates inflammation by dilating the small arterioles that feed capillaries, the tiniest blood vessels. The increased blood flow, with the resulting swelling and redness, is inhospitable to infectious bacteria and viruses and also dilutes toxins. Inappropriate histamine release as part of an allergic response can be most uncomfortable. Allergy medications called antihistamines counter this misplaced inflammation.

Connective Tissue Fibers

Fibroblasts produce three types of connective tissue fibers: collagenous fibers, elastic fibers, and reticular fibers. Collagenous and elastic fibers are the most abundant.

Collagenous (kol-laj′ĕ-nus) **fibers** are thick threads of the protein **collagen** (kol′ah-jen), the major structural protein of the body. Collagenous fibers are grouped in long, parallel bundles, and they are flexible but only slightly elastic (fig. 5.17). More importantly, they have great tensile strength—that is, they can resist considerable pulling force. Thus, collagenous fibers are important components of body parts that hold structures together, such as **ligaments** (which

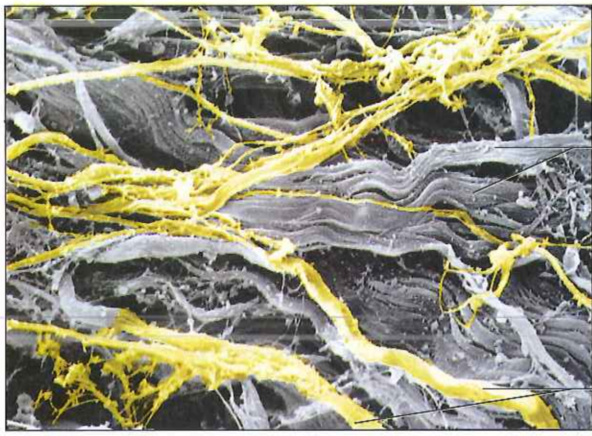


FIGURE 5.17 Scanning electron micrograph of collagenous fibers (shades of white to gray) and elastic fibers (yellow) (4,100×).

connect bones to bones) and **tendons** (which connect muscles to bones).

Tissue containing abundant collagenous fibers is called *dense connective tissue.* It appears white, and for this reason collagenous fibers of dense connective tissue are sometimes called white fibers. *Loose connective tissue,* on the other hand, has sparse collagenous fibers. Clinical Application 5.2 describes disorders that result from abnormal collagen.

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 penetrate the skin.

Elastic fibers are composed of a springlike protein called **elastin.** These fibers branch, forming complex networks in various tissues. Elastic fibers are weaker than collagenous fibers, but they are easily stretched or deformed and will resume their original lengths and shapes when the force acting upon them is removed. Elastic fibers are common in body parts normally subjected to stretching, such as the vocal cords and air passages of the respiratory system. They are sometimes called yellow fibers, because tissues amply supplied with them appear yellowish (fig. 5.17).

Reticular fibers are thin collagenous fibers. They are highly branched and form delicate supporting networks in a variety of tissues, including those of the spleen. Table 5.6 summarizes the components of connective tissue.

PRACTICE

11 What are the general characteristics of connective tissue?
12 What are the major types of cells in connective tissue?
13 What is the primary function of fibroblasts?
14 What are the characteristics of collagen and elastin?

Categories of Connective Tissues

Connective tissue is divided into two major categories. *Connective tissue proper* includes loose connective tissue (areolar, adipose, reticular) and dense connective tissue (dense regular, dense irregular, elastic). The *specialized connective tissues* include cartilage, bone, and blood. The following sections describe each type of connective tissue.

Areolar Connective Tissue

Areolar (ah-re′o-lar) **connective 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 ground substance that contains many collagenous and elastic fibers that fibroblasts secrete (fig. 5.18).

Areolar connective tissue is found in the subcutaneous layer beneath the skin and surrounding organs. It underlies most layers of epithelium, where its many blood vessels nourish nearby epithelial cells.

Adipose Connective Tissue

Adipose (ad′ĭ-pōs) **connective tissue,** or fat, develops when certain cells (adipocytes) store fat in droplets in their cytoplasm. At first, these cells resemble fibroblasts, but as they accumulate fat, they enlarge, and their nuclei are pushed to

TABLE 5.6 | Components of Connective Tissue

Component	Characteristic	Function
Fibroblasts	Widely distributed, large, star-shaped cells	Secrete proteins that become fibers
Macrophages	Motile cells sometimes attached to fibers	Clear foreign particles from tissues by phagocytosis
Mast cells	Large cells, usually located near blood vessels	Release substances that may help prevent blood clotting (heparin) and promote inflammation (histamine)
Collagenous fibers (white fibers)	Thick, threadlike fibers of collagen with great tensile strength	Hold structures together
Elastic fibers (yellow fibers)	Bundles of microfibrils embedded in elastin	Provide elastic quality to parts that stretch
Reticular fibers	Thin fibers of collagen	Form delicate supportive networks within tissues

5.2 CLINICAL APPLICATION

Abnormalities of Collagen

Much of the human body consists of the protein collagen. It accounts for more than 60% of the protein in bone and cartilage and provides 50% to 90% of the dry weight of skin, ligaments, tendons, and the dentin of teeth. Collagen is in the eyes, blood vessel linings, basement membranes, and connective tissue. It is not surprising that defects in collagen cause a variety of medical problems.

Collagen abnormalities are devastating because this protein has an extremely precise structure that is easily disrupted, even by slight alterations that might exert little noticeable effect in other proteins. Collagen is sculpted from a precursor molecule called procollagen. Three procollagen chains coil and entwine to form a regular triple helix.

Triple helices form as the procollagen is synthesized, but once secreted from the cell, the helices are trimmed. The collagen fibrils continue to associate outside the cell, building the networks that hold the body together. Collagen is rapidly synthesized and assembled into its rigid architecture. Many types of mutations can disrupt the protein's structure, including missing procollagen chains, kinks in the triple helix, failure to cut mature collagen, and defects in aggregation outside the cell.

Table 5A details some collagen disorders. Knowing which specific mutations cause disorders offers a way to identify the condition before symptoms arise. This can be helpful if early treatment can follow. A woman who has a high risk of developing hereditary osteoporosis, for example, might take calcium supplements before symptoms appear. Aortic aneurysm is a more serious connective tissue disorder that can be presymptomatically detected if an underlying mutation is discovered. In aortic aneurysm, a weakened aorta (the largest blood vessel in the body, which emerges from the heart) bursts. Knowing that the mutant gene has not been inherited can ease worries. Knowing that it has been inherited can warn affected individuals to have frequent ultrasound exams to detect aortic weakening early enough for corrective surgery. ■

TABLE 5A | Collagen Disorders

Disorder	Molecular Defect	Signs and Symptoms
Chondrodysplasia	Collagen chains are too wide and asymmetric	Stunted growth; deformed joints
Dystrophic epidermolysis bullosa	Breakdown of collagen fibrils that attach skin layers to each other	Stretchy, easily scarred skin; lax joints
Hereditary osteoarthritis	Substituted amino acid in collagen chain alters shape	Painful joints
Marfan syndrome	Too little fibrillin, an elastic connective tissue protein	Long limbs, sunken chest, lens dislocation, spindly fingers, weakened aorta
Osteogenesis imperfecta type I	Too few collagen triple helices	Easily broken bones; deafness; blue sclera (whites of the eyes)
Stickler syndrome	Short collagen chains	Joint pain; degeneration of retina and fluid around it

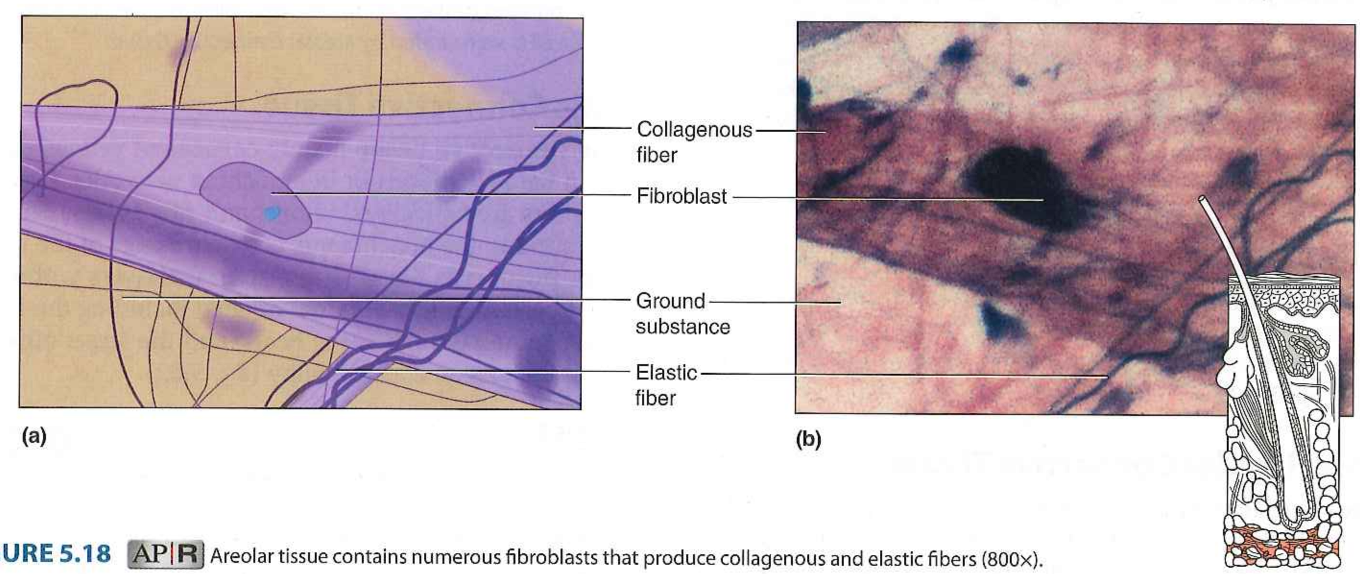


FIGURE 5.18 AP|R Areolar tissue contains numerous fibroblasts that produce collagenous and elastic fibers (800×).

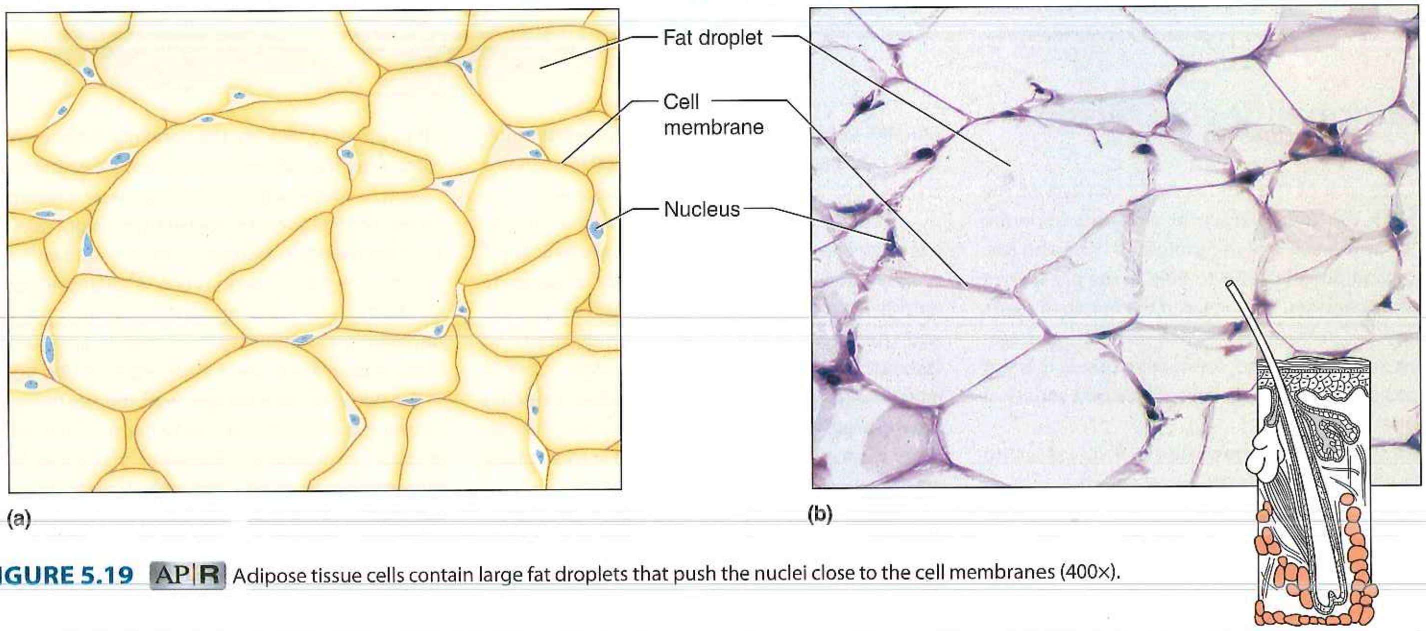


FIGURE 5.19 AP|R Adipose tissue cells contain large fat droplets that push the nuclei close to the cell membranes (400×).

one side (fig. 5.19). When adipocytes become so abundant that they crowd out other cell types, they form adipose connective tissue. This 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.

A person is born with a certain number of fat cells. Excess food calories are likely to be converted to fat and stored, so the amount of adipose tissue in the body reflects diet or an endocrine disorder. During a period of fasting, adipose cells may lose their fat droplets, shrink, and become more like fibroblasts again.

Infants and young children have a continuous layer of adipose tissue just beneath the skin, which gives their bodies a rounded appearance. In adults, this subcutaneous fat thins in some regions and remains thick in others. For example, in males, adipose tissue usually thickens in the upper back, arms, and lower back; in females, it is more likely to develop in the breasts, buttocks, and thighs.

Reticular Connective Tissue

Reticular connective tissue is composed of thin, reticular fibers in a three-dimensional network. It helps provide the framework of certain internal organs, such as the liver and spleen (fig. 5.20).

Dense Regular Connective Tissue

Dense regular connective tissue consists of many closely packed, thick, collagenous fibers; a fine network of elastic fibers; and a few cells, mostly fibroblasts. Collagenous fibers of dense regular connective tissue are very strong, enabling the tissue to withstand pulling forces (fig. 5.21). It often binds body structures as part of *tendons* and *ligaments*. The blood supply to dense regular connective tissue is poor, slowing tissue repair. This is why a sprain, which damages tissues surrounding a joint, may take considerable time to heal.

Dense Irregular Connective Tissue AP|R

Fibers of **dense irregular connective tissue** are thicker, interwoven, and more randomly organized. This allows the tissue to sustain tension exerted from many different directions. Dense irregular connective tissue is in the dermis, the inner skin layer.

A GLIMPSE AHEAD | **To Chapter 9**

Dense irregular connective tissue surrounds individual skeletal muscles *(fascia),* and separates each muscle into bundles of skeletal muscle cells called *fascicles.* Each muscle cell is surrounded by areolar connective tissue.

Elastic Connective Tissue

Elastic connective tissue mainly consists of yellow, elastic fibers in parallel strands or in branching networks. Between these fibers are collagenous fibers and fibroblasts. This tissue is found in the attachments between bones of the spinal column (ligamenta flava). It is also in the layers within the walls of certain hollow internal organs, including the larger arteries; some portions of the heart; and the larger airways, where it imparts an elastic quality (fig. 5.22).

PRACTICE

15 Differentiate between areolar connective tissue and dense connective tissue.

16 What are the functions of adipose connective tissue?

17 Distinguish between reticular and elastic connective tissues.

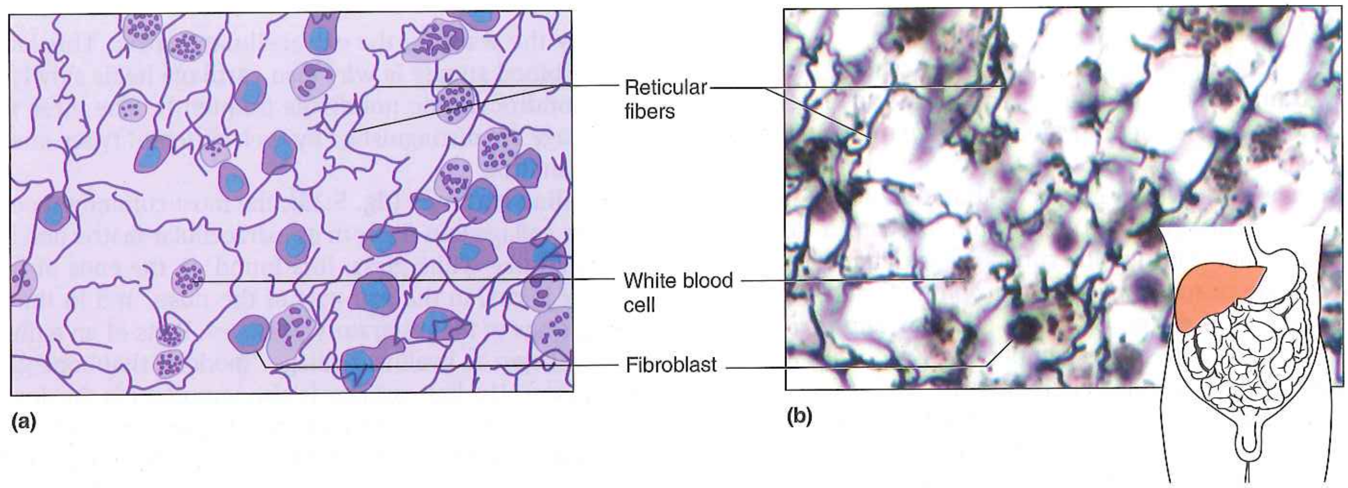


FIGURE 5.20 AP|R Reticular connective tissue is a network of thin reticular fibers, which contains numerous fibroblasts and white blood cells (1,000×).

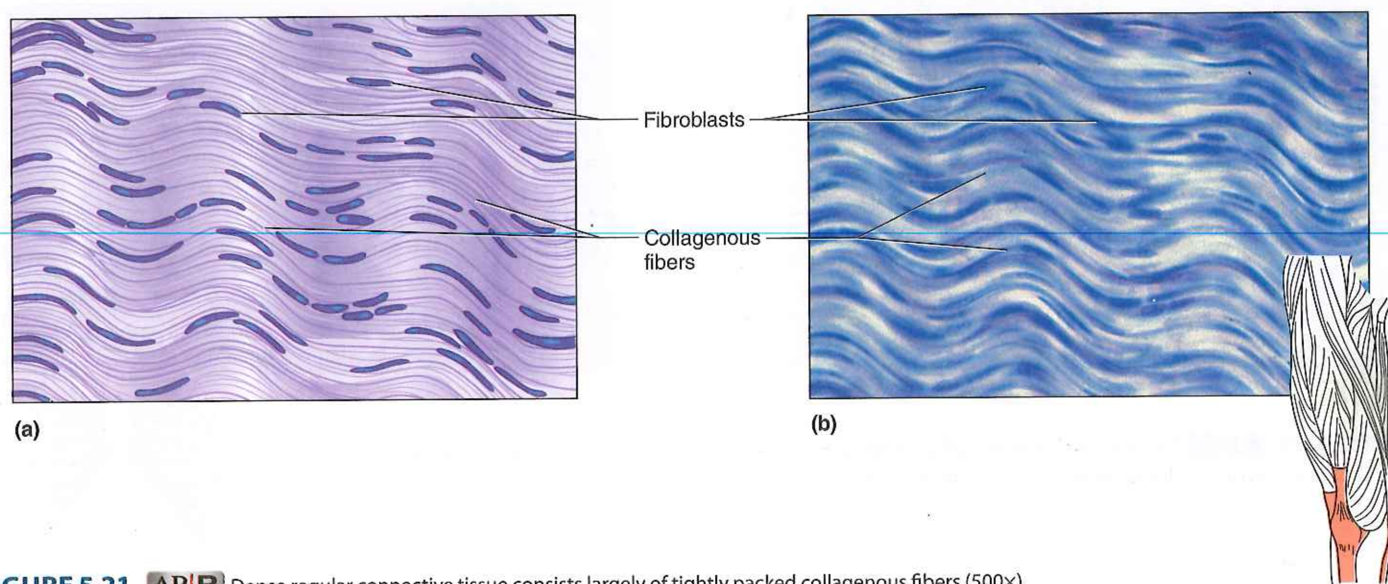


FIGURE 5.21 AP|R Dense regular connective tissue consists largely of tightly packed collagenous fibers (500×).

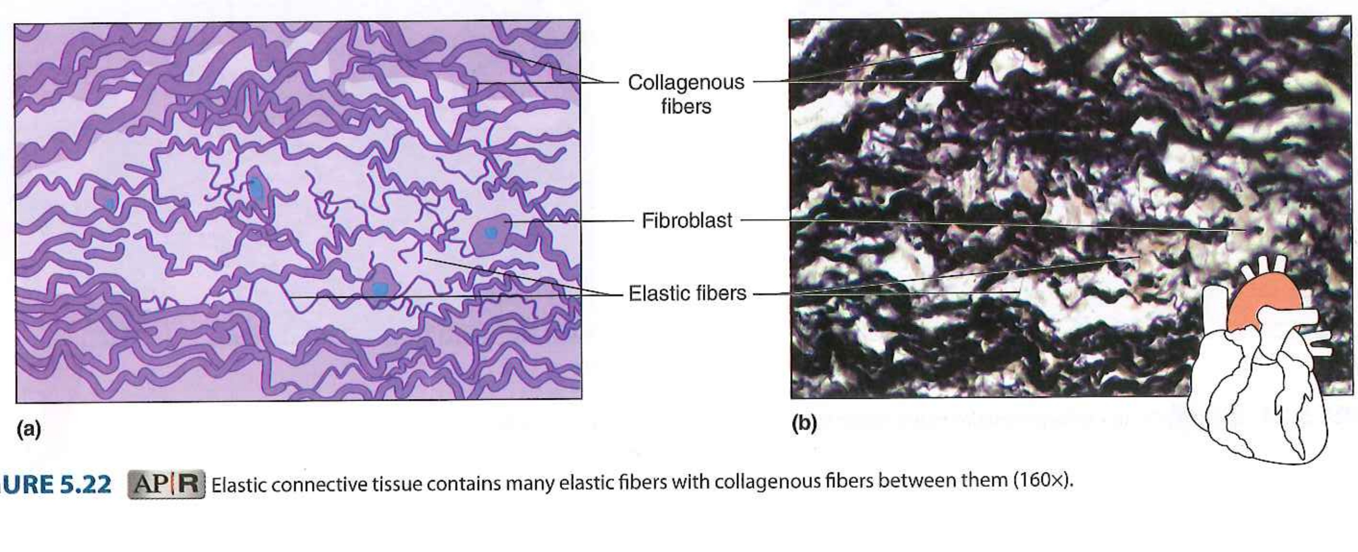


FIGURE 5.22 AP|R Elastic connective tissue contains many elastic fibers with collagenous fibers between them (160×).

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 extracellular matrix is abundant and is largely composed of collagenous fibers embedded in a gel-like ground substance. This ground substance is rich in a protein-polysaccharide complex *(chondromucoprotein)* and contains a large volume of water. Cartilage cells, or **chondrocytes** (kon′dro-sītz), occupy small chambers called *lacunae* and lie completely within the extracellular matrix.

A cartilaginous structure is enclosed in a covering of connective tissue called *perichondrium*. Although cartilage tissue lacks a direct blood supply, blood vessels are in the surrounding perichondrium. Cartilage cells near the perichondrium obtain nutrients from these vessels by diffusion, aided by the water in the extracellular matrix. This lack of a direct blood supply is why torn cartilage heals slowly and why chondrocytes do not divide frequently. The three types of cartilage are distinguished by their different types of extracellular matrix.

Hyaline cartilage (fig. 5.23), the most common type, has very fine collagenous fibers in its extracellular matrix and looks somewhat like white glass. 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. Parts of an embryo's skeleton begin as hyaline cartilage "models" that bone gradually replaces. Hyaline cartilage is also important in the development and growth of most bones (see chapter 7, p. 206).

Elastic cartilage (fig. 5.24) is more flexible than hyaline cartilage because its extracellular matrix has a dense network of elastic fibers. It provides the framework for the external ears and parts of the larynx.

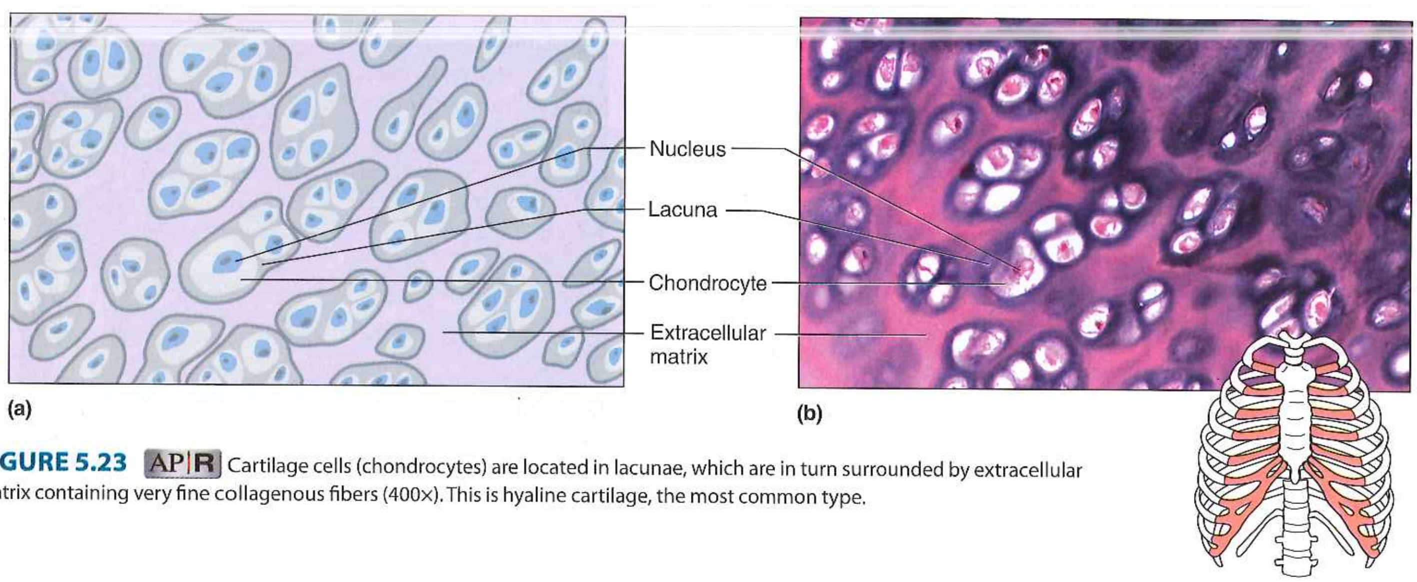


FIGURE 5.23 APIR Cartilage cells (chondrocytes) are located in lacunae, which are in turn surrounded by extracellular matrix containing very fine collagenous fibers (400×). This is hyaline cartilage, the most common type.

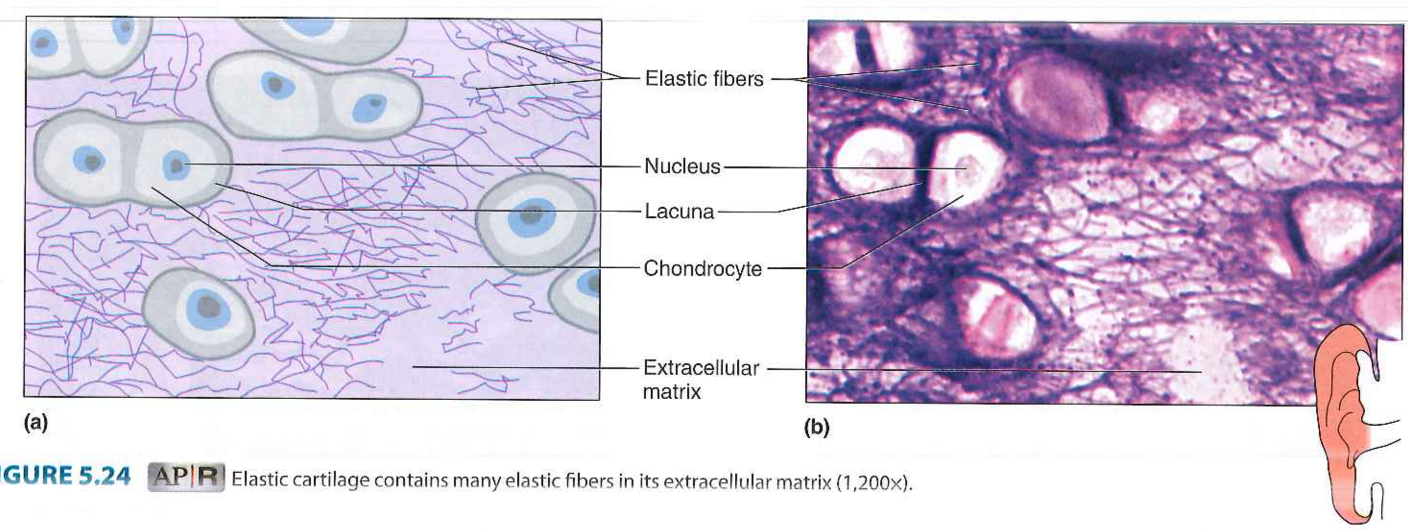


FIGURE 5.24 APIR Elastic cartilage contains many elastic fibers in its extracellular matrix (1,200×).

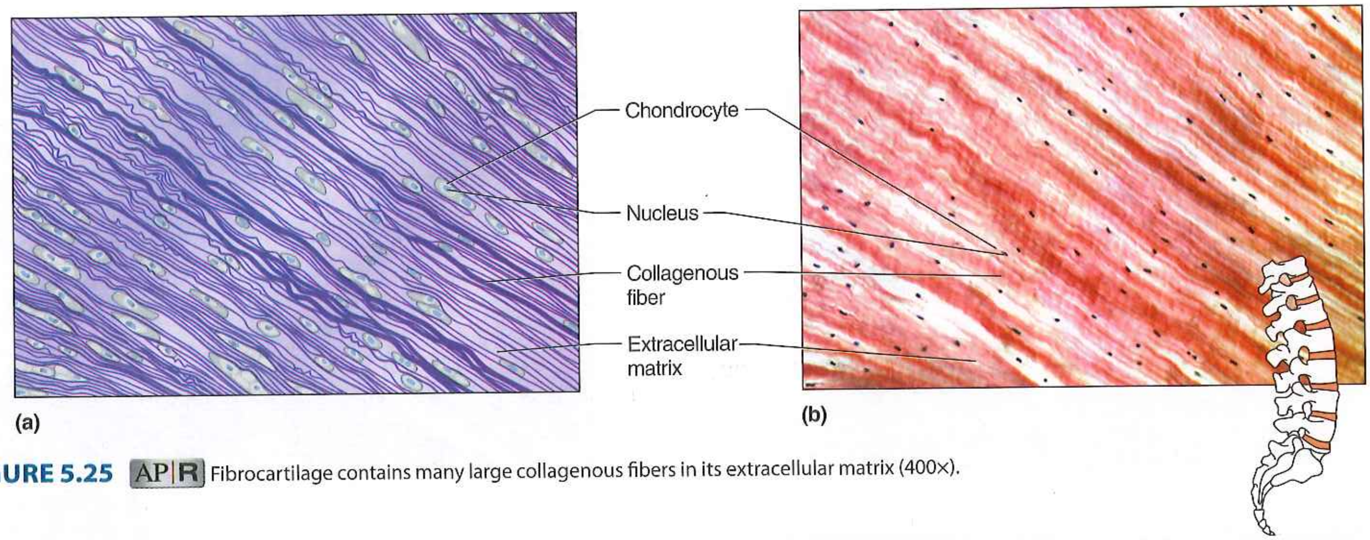


FIGURE 5.25 APIR Fibrocartilage contains many large collagenous fibers in its extracellular matrix (400×).

Fibrocartilage (fig. 5.25), a very tough tissue, has many collagenous fibers. It is a shock absorber for structures 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 (osseous tissue) is the most rigid connective tissue. Its hardness is largely due to mineral salts, such as calcium phosphate and calcium carbonate, between cells. This extracellular matrix also contains abundant collagenous fibers, which are flexible and reinforce the mineral components of bone.

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

In compact bone, bony matrix is deposited by bone cells, called *osteoblasts,* in thin layers called *lamellae,* which form concentric patterns around capillaries located within tiny longitudinal tubes called *central,* or *Haversian, canals.* Once osteoblasts are in lacunae surrounded by matrix, they are called osteocytes and are rather evenly spaced within the lamellae (fig. 5.26).

The osteocytes and layers of extracellular matrix, concentrically clustered around a central canal, form a cylinder-shaped unit called an *osteon,* or a Haversian system. Many of these units cemented together make up the more solid appearing compact bone that forms the outer portion of a bone (see chapter 7, p. 203).

Each central canal contains a blood vessel, so every bone cell is fairly close to a nutrient supply. In addition, the bone cells have many cytoplasmic processes that extend outward and pass through minute tubes in the extracellular matrix called *canaliculi.* Gap junctions attach these cellular processes to the processes of nearby cells. As a result, materials can move rapidly between blood vessels and bone cells. Thus, despite its inert appearance, bone is an active tissue. Injured bone heals much more rapidly than does injured cartilage.

The interior portion of a bone is composed of spongy bone in which bone matrix is deposited around osteocytes, forming bony plates with spaces between them. These spaces lighten the weight of the bone and provide spaces for bone marrow. (The microscopic structure of bone is described in more detail in chapter 7, pp. 203–204.)

Blood

Blood, another type of connective tissue, is composed of cells suspended in a fluid extracellular matrix called *plasma.* These cells include *red blood cells, white blood cells,* and cellular fragments called *platelets* (fig. 5.27). Red blood cells transport gases; white blood cells fight infection; and platelets are involved in blood clotting. Most blood cells form in special tissues (hematopoietic tissues) in red marrow within the hollow parts of certain bones. Chapter 14 describes blood.

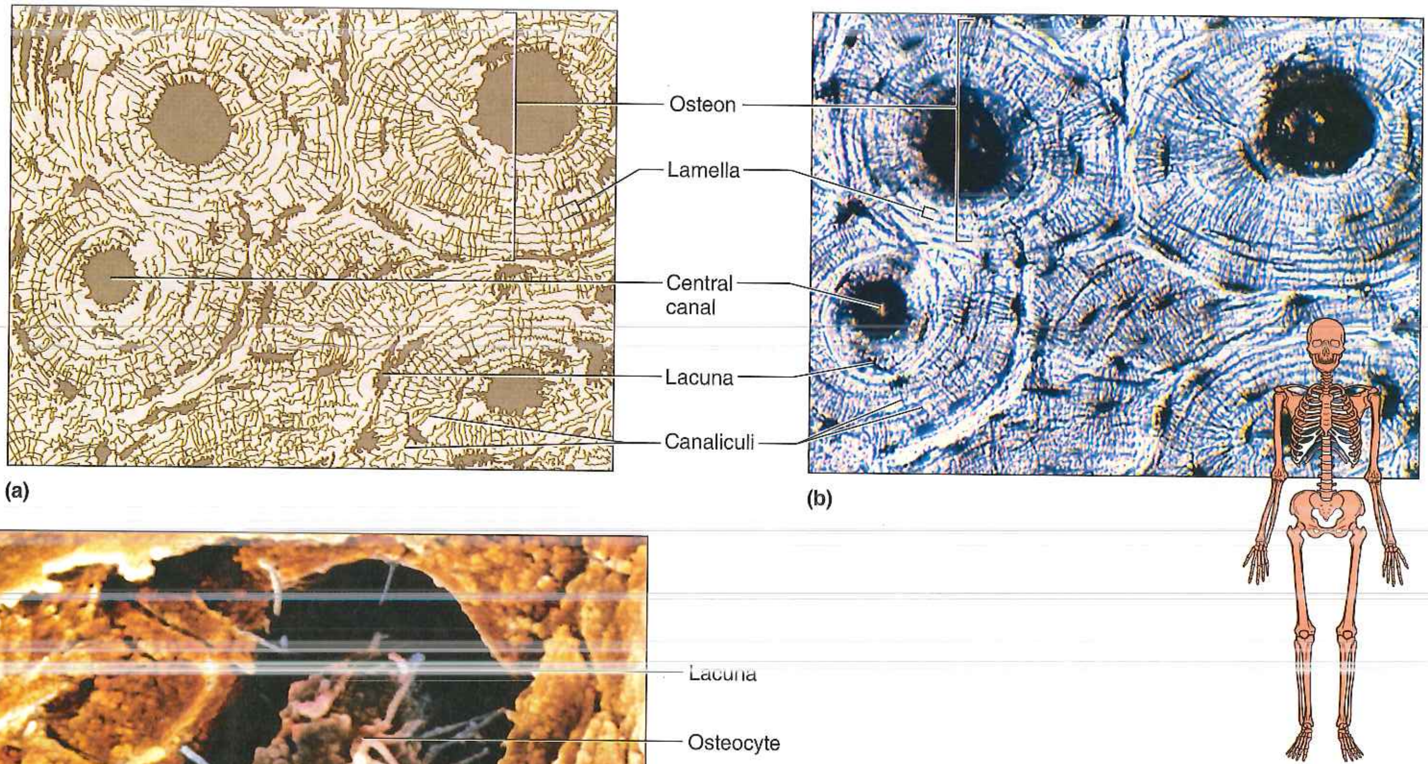
Red blood cells are the only type of blood cells that function entirely in the blood vessels. In contrast, white blood cells typically migrate from the blood through capillary walls to connective tissues, where they carry on their major activities. The white blood cells usually reside in the connective tissues until they die. Table 5.7 lists the characteristics of the connective tissues.

PRACTICE

18 Describe the general characteristics of cartilage.

19 Explain why injured bone heals more rapidly than does injured cartilage.

20 What are the major components of blood?



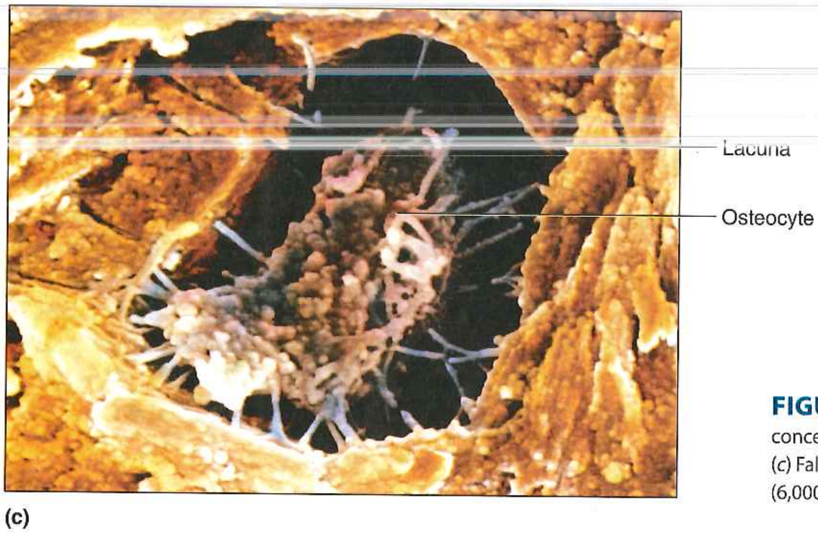


FIGURE 5.26 AP|R Bone tissue. (*a*) Bone matrix is deposited in concentric layers around central canals. (*b*) Micrograph of bone tissue (200×). (*c*) Falsely colored scanning electron micrograph of an osteocyte within a lacuna (6,000×).

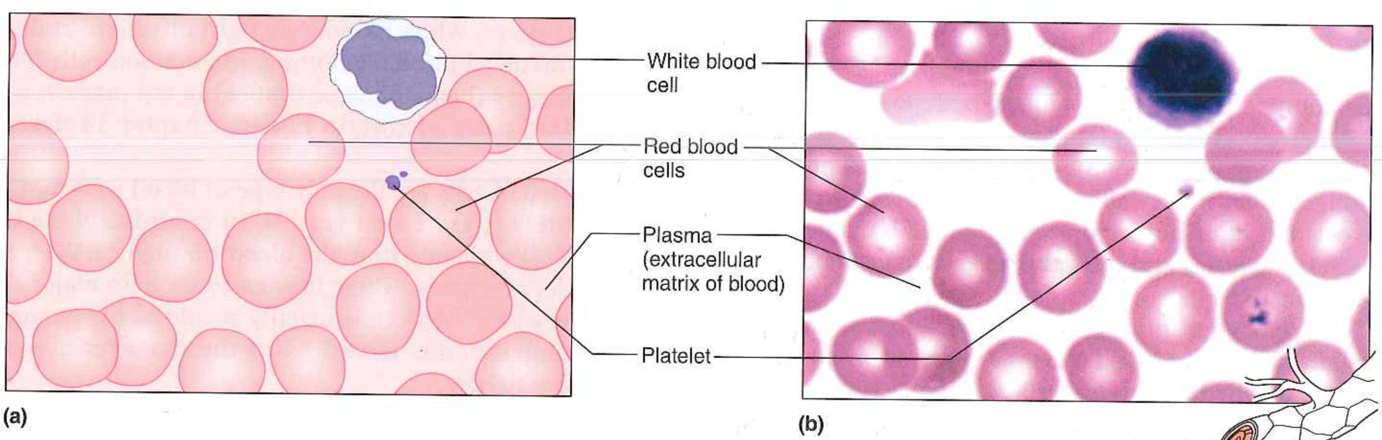


FIGURE 5.27 AP|R Blood tissue consists of red blood cells, white blood cells, and platelets suspended in plasma (1,000×).

Q: *What is the consistency of the extracellular matrix of this tissue?*

Answer can be found in Appendix G on page 938.

TABLE 5.7 | Connective Tissues

Type	Description	Function	Location
Areolar connective tissue	Cells in fluid-gel matrix	Binds organs	Beneath the skin, surrounds organs
Adipose connective tissue	Cells in fluid-gel matrix	Protects, insulates, and stores fat	Beneath the skin, around the kidneys, behind the eyeballs, on the surface of the heart
Reticular connective tissue	Cells in fluid-gel matrix	Supports	Walls of liver and spleen
Dense regular connective tissue	Cells in fluid-gel matrix	Binds body parts	Tendons, ligaments
Dense irregular connective tissue	Cells in fluid-gel matrix	Sustains tissue tension	Dermis
Elastic connective tissue	Cells in fluid-gel matrix	Provides elastic quality	Connecting parts of the spinal column, in walls of arteries and airways
Hyaline cartilage	Cells in solid-gel matrix	Supports, protects, provides framework	Ends of bones, nose, and rings in walls of respiratory passages
Elastic cartilage	Cells in solid-gel matrix	Supports, protects, provides flexible framework	Framework of external ear and part of larynx
Fibrocartilage	Cells in solid-gel matrix	Supports, protects, absorbs shock	Between bony parts of spinal column, parts of pelvic girdle, and knee
Bone	Cells in solid matrix	Supports, protects, provides framework	Bones of skeleton, middle ear
Blood	Cells and platelets in fluid matrix	Transports gases, defends against disease, clotting	Throughout the body in a closed system of blood vessels and heart chambers

5.4 TYPES OF MEMBRANES

After discussing epithelial and connective tissues, sheets of cells called membranes are better understood. **Epithelial membranes** are thin structures that are usually composed of epithelium and underlying connective tissue. They cover body surfaces and line body cavities. The three major types of epithelial membranes are *serous, mucous,* and *cutaneous.*

Serous (se'rus) **membranes** line the body cavities that do not open to the outside and reduce friction between the organs and cavity walls. They form the inner linings of the thorax and abdomen, and they cover the organs in these cavities (see figs. 1.11 and 1.12, pp. 22–23). A serous membrane consists of a layer of simple squamous epithelium (mesothelium) and a thin layer of areolar connective tissue. Cells of a serous membrane secrete watery *serous fluid,* which helps lubricate membrane surfaces.

Mucous (mu'kus) **membranes** line the cavities and tubes that open to the outside of the body. These include the oral and nasal cavities and the tubes of the digestive, respiratory, urinary, and reproductive systems. A mucous membrane consists of epithelium overlying a layer of areolar connective tissue. However, the type of epithelium varies with the location of the membrane. For example, stratified squamous epithelium lines the oral cavity, pseudostratified columnar epithelium lines part of the nasal cavity, and simple columnar epithelium lines the small intestine. Goblet cells within a mucous membrane secrete *mucus.*

Another epithelial membrane is the **cutaneous** (ku-ta'ne-us) **membrane,** more commonly called *skin.* It is part of the integumentary system described in detail in chapter 6.

A type of membrane composed entirely of connective tissues is a **synovial** (sĭ-no've-al) **membrane.** It lines joints and is discussed further in chapter 8 (p. 273).

PRACTICE

21 Name the four types of membranes, and explain how they differ.

5.5 MUSCLE TISSUES APR

General Characteristics

Muscle tissues are contractile; they can shorten and thicken. As they contract, muscle cells pull at their attached ends, which moves body parts. The cells that comprise muscle tissues are sometimes called *muscle fibers* because they are elongated. The three types of muscle tissue, skeletal, smooth, and cardiac, are introduced here and discussed further in chapter 9.

Skeletal Muscle Tissue

Skeletal muscle tissue (fig. 5.28) forms muscles that usually attach to bones and can be controlled by conscious effort. For this reason, it is often called *voluntary* muscle tissue. Skeletal muscle cells are long—up to or more than 40 mm in length—and narrow—less than 0.1 mm in width. These threadlike cells have alternating light and dark cross-markings called *striations.* Each cell has many nuclei (multinucleate). For a muscle cell to contract, it must be stimulated by a nerve cell. Then the

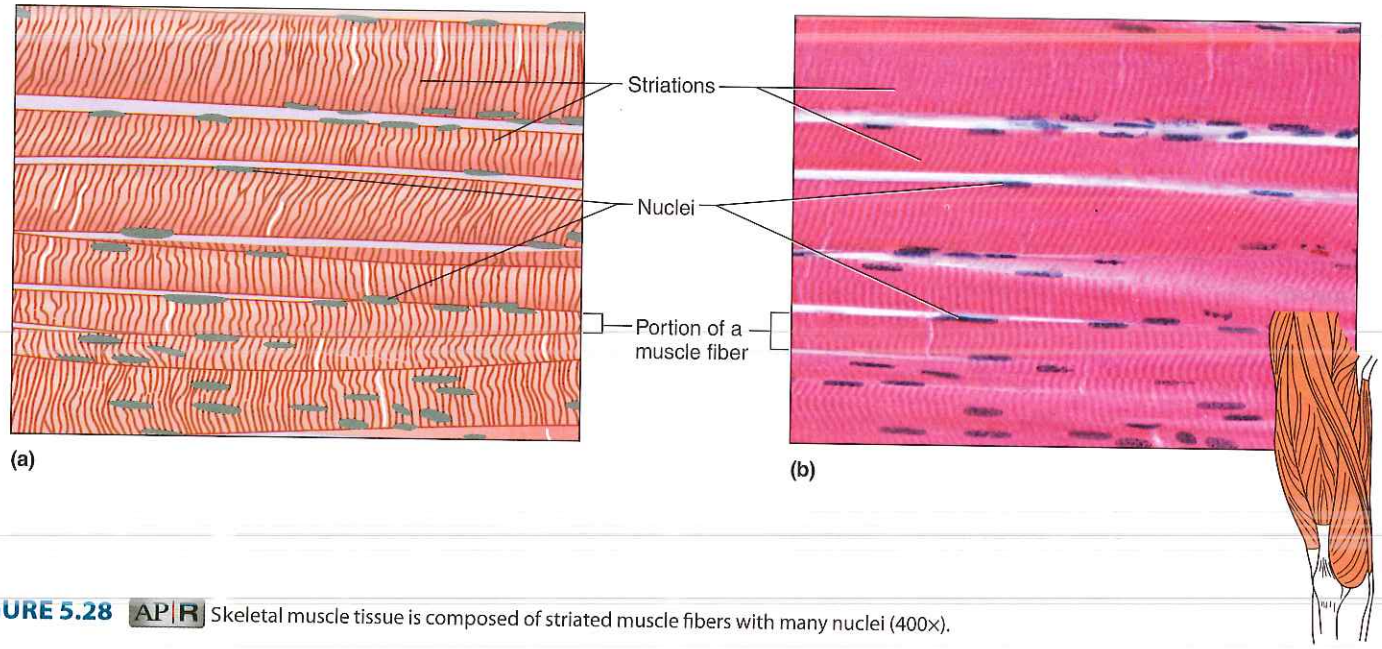


FIGURE 5.28 AP|R Skeletal muscle tissue is composed of striated muscle fibers with many nuclei (400×).

muscle cell relaxes when stimulation stops. Skeletal muscles move the head, trunk, and limbs and enable us to make facial expressions, write, talk, and sing, as well as chew, swallow, and breathe.

Smooth Muscle Tissue

Smooth muscle tissue (fig. 5.29) is called smooth because its cells lack striations. Smooth muscle cells are shorter than those of skeletal muscle and are spindle-shaped, each with a single, centrally located nucleus. This tissue comprises the walls of hollow internal organs, such as the stomach, intestines, urinary bladder, uterus, and blood vessels. Unlike skeletal muscle, smooth muscle usually cannot be stimulated to contract by conscious effort. 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

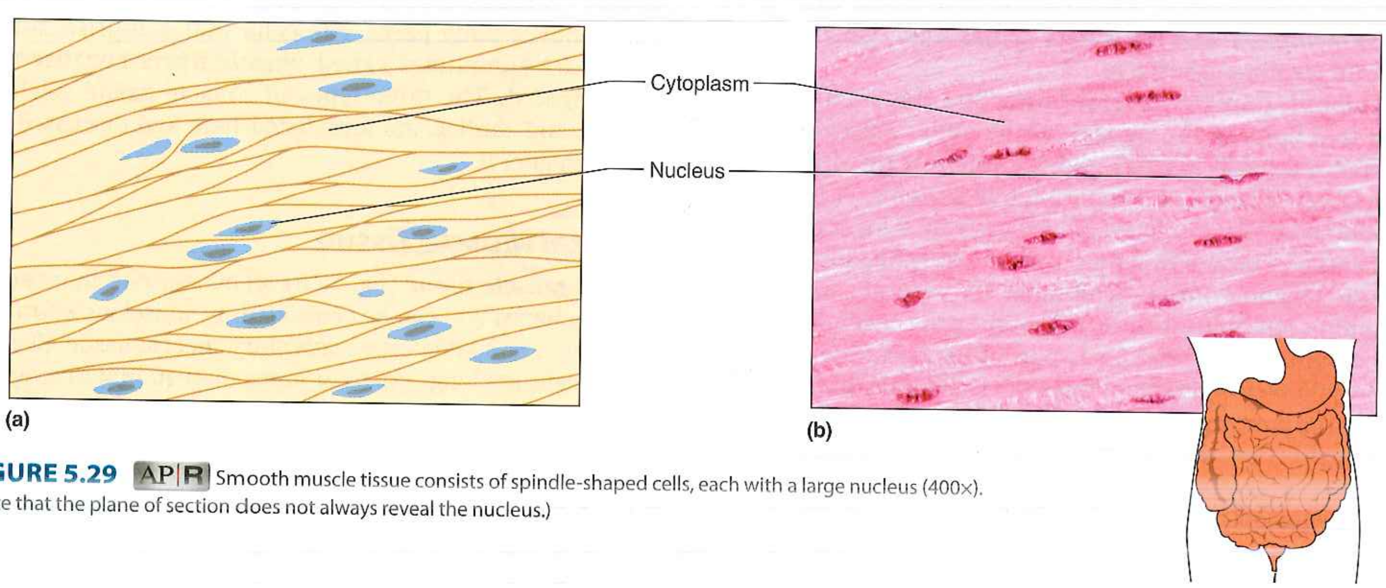
Cardiac muscle tissue is only in the heart (fig. 5.30). Its cells, striated and branched, are joined end-to-end, and interconnected in complex networks. Each cardiac muscle cell has a single nucleus. Where one cell touches another cell is a specialized intercellular junction called an *intercalated disc,* seen only in cardiac tissue.

Cardiac muscle, like smooth muscle, is controlled involuntarily. Cardiac muscle can continue to function without nervous stimulation. This tissue makes up the bulk of the heart and pumps blood through the heart chambers and into blood vessels.

PRACTICE

22 List the general characteristics of muscle tissue.

23 Distinguish among skeletal, smooth, and cardiac muscle tissues.



IGURE 5.29 AP|R Smooth muscle tissue consists of spindle-shaped cells, each with a large nucleus (400×). lote that the plane of section does not always reveal the nucleus.)

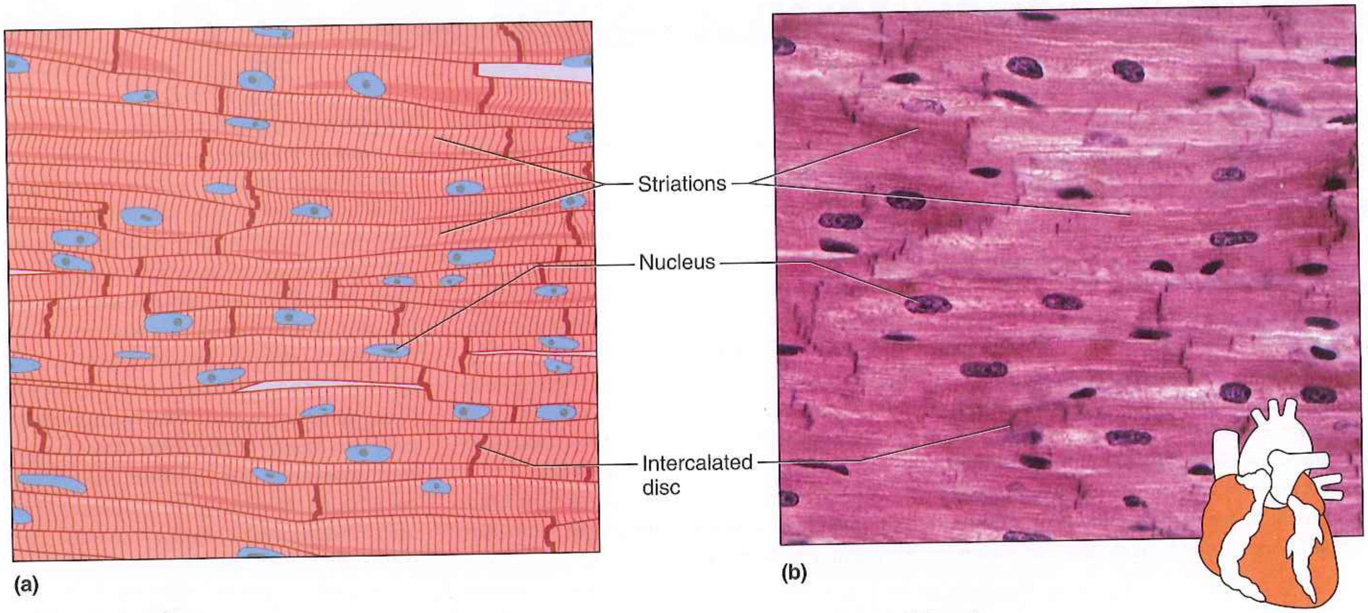


FIGURE 5.30 APR Cardiac muscle cells are branched and interconnected, with a single nucleus each (400×).

5.6 NERVOUS TISSUES APR

Nervous (ner′vus) **tissues** are found in the brain, spinal cord, and peripheral nerves. The basic cells are called *neurons,* and they are highly specialized. Neurons sense certain types of changes in their surroundings. Incoming signals stimulate cellular processes called *dendrites,* which respond by transmitting electrical impulses along cellular processes called *axons* to other neurons or to muscles or glands (fig. 5.31). As a result of the patterns by which neurons connect 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 abundant *neuroglia,* shown in figure 5.31. Neuroglia divide and are crucial to the functioning of neurons. These cells support and bind the components of nervous tissue, carry on phagocytosis, and help supply growth factors and nutrients to neurons by connecting them to blood vessels. They also play a role in cell-to-cell communications. Chapter 10 discusses nervous tissue.

Table 5.8 summarizes the general characteristics of muscle and nervous tissues. From Science to Technology 5.2 discusses tissue engineering, part of a field called regenerative medicine.

PRACTICE

24 Describe the general characteristics of nervous tissue.

25 Distinguish between neurons and neuroglia.

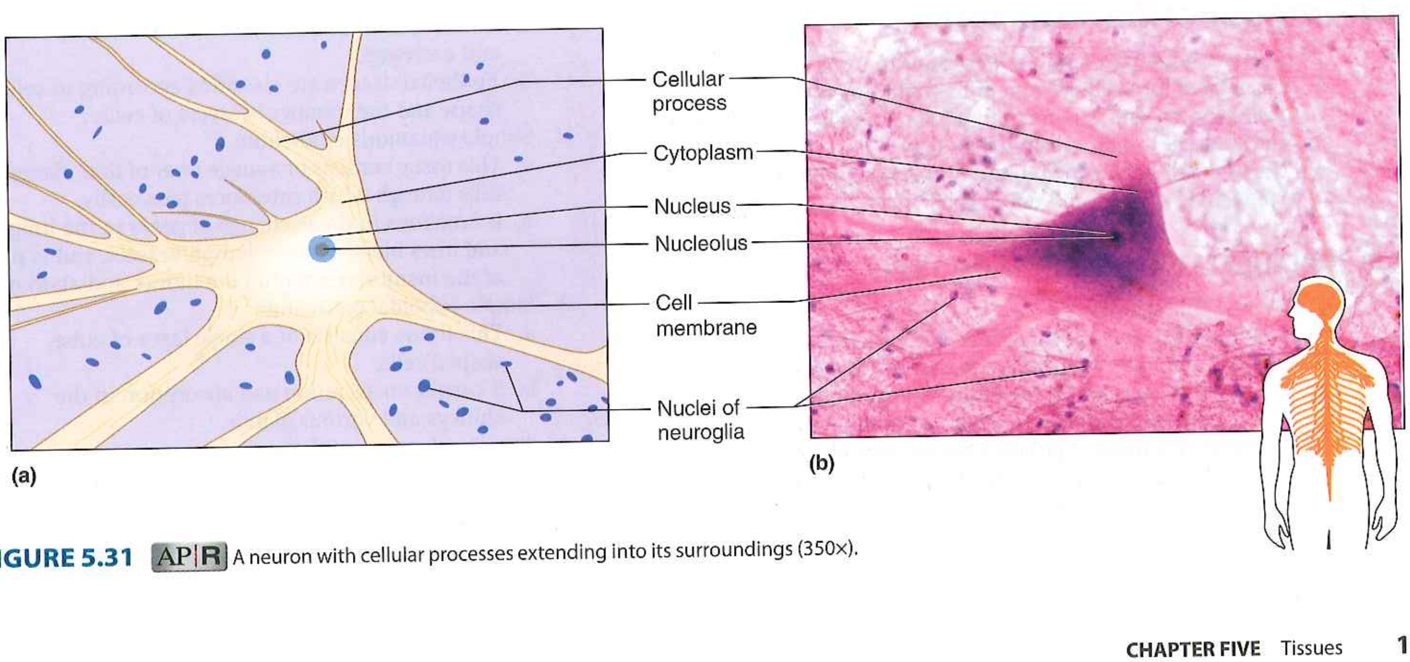


FIGURE 5.31 APR A neuron with cellular processes extending into its surroundings (350×).

5.2 FROM SCIENCE TO TECHNOLOGY

Tissue Engineering: Building a Replacement Bladder

If an appliance part is damaged or fails, replacing it is simple. Not so for the human body. Donor organs and tissues for transplant are in short supply, so in the future spare parts may come from tissue engineering. In this technology, a patient's cells, extracellular matrix, and other biochemicals are grown with a synthetic scaffold to form an implant. The cells come from the patient, so the immune system does not reject them. Tissue engineering has provided skin, cartilage, bone, and blood vessels. Combining engineered tissues into structures that can replace organs is where the creativity comes in. Consider the replacement bladder.

Each year in the United States, about 10,000 people need their urinary bladders repaired or replaced. Typically a urologic surgeon replaces part of the bladder with part of the large intestine. However, the function of the intestine is to absorb, and the function of the bladder is to hold waste. Tissue engineering is providing a better replacement bladder. The natural organ is balloonlike, with smooth muscle on the outside and lining tissue (urothelium) and connective tissue on the inside.

Researchers pioneered replacement bladders in children who have birth defects in which the malfunctioning bladder can harm the kidneys. Each patient donated a postage-stamp-size sample of bladder tissue that consisted of about a million cells, from which the researchers separated two types of progenitor cells—for smooth muscle and urothelium—and let them divide in culture in a specific "cocktail" of growth factors. Within seven weeks the million cells had divided to yield 1.5 billion cells, which were seeded onto domes made of a synthetic material. The confluent layers of cells that formed were attached to the lower portions of the patients' bladders, after removing the upper portions. The scaffolds degenerated over time, leaving new bladders built from the patients' own cells. Today tissue-engineered bladders are also used in adults whose bladders have been removed to treat cancer. ■

The cells of different tissues vary greatly in their abilities to divide. Cells that divide continuously include the epithelial cells of the skin and the inner lining of the digestive tract, and the connective tissue progenitor 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, fibroblasts form scar tissue after a heart attack occurs. Many organs include pockets of stem or progenitor cells that can divide and replace damaged, differentiated cells, under certain conditions.

TABLE 5.8 | Muscle and Nervous Tissues

Type	Description	Function	Location
Skeletal muscle tissue	Long, threadlike cells, striated, many nuclei	Voluntary movements of skeletal parts	Muscles usually attached to bones
Smooth muscle tissue	Shorter cells, single, central nucleus	Involuntary movements of internal organs	Walls of hollow internal organs
Cardiac muscle tissue	Branched cells, striated, single nucleus	Heart movements	Heart muscle
Nervous tissue	Cell with cytoplasmic extensions	Sensory reception and conduction of electrical impulses	Brain, spinal cord, and peripheral nerves

CHAPTER SUMMARY

5.1 INTRODUCTION (PAGE 152)

1. Cells are organized in layers or groups to form tissues.
2. Specialized intercellular junctions (tight junctions, desmosomes, and gap junctions) connect cells.
3. The study of tissues is called histology.
4. The four major types of human tissue are epithelial, connective, muscle, and nervous.

5.2 EPITHELIAL TISSUES (PAGE 152)

1. General characteristics
   a. Epithelial tissue covers all free body surfaces, forms the inner lining of body cavities, lines hollow organs, and is the major tissue of glands.
   b. A basement membrane anchors epithelium to connective tissue. Epithelial tissue lacks blood vessels, has cells that are tightly packed, and is continuously replaced.
   c. It functions in protection, secretion, absorption, and excretion.
   d. Epithelial tissues are classified according to cell shape and the number of layers of cells.
2. Simple squamous epithelium
   a. This tissue consists of a single layer of thin, flattened cells through which substances pass easily.
   b. It functions in the exchange of gases in the lungs and lines blood vessels, lymph vessels, and is part of the membranes within the thorax and abdomen.
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 near the basement membrane.
   b. It lines the uterus and digestive tract, where it functions in protection, secretion, and absorption.

c. Absorbing cells often possess microvilli.
d. This tissue has goblet cells that secrete mucus.

5. Pseudostratified columnar epithelium
   a. This tissue appears stratified because the nuclei are at two or more levels.
   b. Its cells may have cilia that move mucus over the surface of the tissue.
   c. It lines the respiratory passages.
6. Stratified squamous epithelium
   a. This tissue is composed of many layers of cells; the top layers are flattened.
   b. It protects underlying cells from harmful environmental effects.
   c. It is the outer layer of the skin and lines the oral cavity, esophagus, 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 ducts of the mammary glands, sweat glands, salivary glands, and pancreas.
   c. It functions in protection.
8. Stratified columnar epithelium
   a. The cells in the top layer of this tissue are column-shaped. Cube-shaped cells make up the bottom layers.
   b. It is in part of the male urethra and lining the larger ducts of exocrine glands.
   c. This tissue functions in protection and secretion.
9. Transitional epithelium
   a. This tissue is specialized to become distended.
   b. It lines the urinary bladder, ureters, and superior urethra.
   c. It helps prevent the contents of the urinary passageways from diffusing out.
10. Glandular epithelium
   a. Glandular epithelium is composed of cells 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 the organization of their cells.
      (1) Simple glands have ducts that do not branch before reaching the secretory portion.
      (2) Compound glands have ducts that branch repeatedly before the secretory portion.
      (3) Tubular glands consist of epithelium-lined tubes.
      (4) Alveolar glands consist of saclike dilations connected to the surface by narrowed ducts.
   d. Exocrine glands are classified according to the composition of their secretions.
      (1) Merocrine glands secrete watery fluids without loss of cytoplasm. Most secretory cells are merocrine.
         (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 secretions.

5.3 CONNECTIVE TISSUES (PAGE 161)

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 extracellular matrix between them.
   c. This extracellular matrix consists of fibers, a ground substance, and fluid.
2. Major cell types
   a. Fibroblasts produce collagenous and elastic fibers.
   b. Macrophages are phagocytes.
   c. Mast cells release heparin and histamine.
3. Connective tissue fibers
   a. Collagenous fibers are composed of collagen and have great tensile strength.
   b. Elastic fibers are composed of elastin and are stretchy.
   c. Reticular fibers are fine collagenous fibers.
4. Categories of connective tissues
   a. Connective tissue proper includes loose connective tissue (areolar, adipose, reticular) and dense connective tissue (dense regular, dense irregular, elastic).
   b. Specialized connective tissues include cartilage, bone, and blood.
5. Areolar connective tissue
   a. Areolar connective tissue forms thin membranes between organs and binds them.
   b. It is beneath the skin and surrounds organs.
6. Adipose connective tissue
   a. Adipose tissue is a specialized form of connective tissue that stores fat, cushions, and insulates.
   b. It is found beneath the skin; in certain abdominal membranes; and around the kidneys, heart, and various joints.
7. Reticular connective tissue
   a. Reticular connective tissue largely consists of thin, branched reticular fibers.
   b. It supports the walls of the liver and spleen.
8. Dense regular connective tissue
   Dense regular connective tissue is largely composed of strong, collagenous fibers that bind structures as parts of tendons and ligaments.
9. Dense irregular connective tissue
   Dense irregular connective tissue has thicker, randomly distributed collagenous fibers and is found in the dermis.
10. Elastic connective tissue
   Elastic connective tissue is mainly composed of elastic fibers and imparts an elastic quality to the walls of certain hollow internal organs such as the lungs and blood vessels.
11. Cartilage
   a. Cartilage provides a supportive framework for various structures.
   b. Its extracellular matrix is composed of fibers and a gel-like ground substance.
   c. It lacks a direct blood supply and is slow to heal.

d. Most cartilaginous structures are enclosed in a perichondrium, which contains blood vessels.
e. Major types are hyaline cartilage, elastic cartilage, and fibrocartilage.
f. Cartilage is at the ends of various bones; in the ear; in the larynx; and in the pads between the bones of the spinal column, pelvic girdle, and knees.

12. Bone
    a. The extracellular matrix of bone contains mineral salts and collagen.
    b. The cells of compact bone are arranged in a bony matrix of concentric circles around central canals, whereas the cells of spongy bone are embedded in bony plates with spaces between the plates. Canaliculi connect the cells.
    c. It is an active tissue that heals rapidly.
13. Blood
    a. Blood is composed of cells suspended in fluid.
    b. Blood cells are formed by special tissue in the hollow parts of certain bones.

5.4 TYPES OF MEMBRANES (PAGE 171)

1. Epithelial membranes
    a. Serous membranes
        (1) Serous membranes line body cavities that do not open to the outside.
        (2) They are composed of epithelium and areolar connective tissue.
        (3) Cells of serous membranes secrete watery serous fluid that lubricates membrane surfaces.
    b. Mucous membranes
        (1) Mucous membranes line cavities and tubes opening to the outside of the body.
        (2) They are composed of epithelium and areolar connective tissue.
        (3) Cells of mucous membranes secrete mucus.
    c. The cutaneous membrane is the external body covering commonly called skin.
2. Synovial membranes are composed of connective tissue only, and line joints.

5.5 MUSCLE TISSUES (PAGE 171)

1. General characteristics
    a. Muscle tissue contracts, moving structures attached to it.
    b. Three types are skeletal, smooth, and cardiac muscle tissues.
2. Skeletal muscle tissue
    a. Muscles containing this tissue usually attach to bones and can be controlled by conscious effort.
    b. Muscle cells are long and threadlike, containing several nuclei, with alternating light and dark cross-markings (striations).
    c. A muscle cell contracts when stimulated by a nerve cell, then relaxes when no longer stimulated.
3. Smooth muscle tissue
    a. This tissue of spindle-shaped cells, each with one nucleus, is in the walls of hollow internal organs.
    b. It is involuntarily controlled.
4. Cardiac muscle tissue
    a. This tissue is found only in the heart.
    b. Striated cells, each with a single nucleus, are joined by intercalated discs and form branched networks.
    c. Cardiac muscle tissue is involuntarily controlled.

5.6 NERVOUS TISSUES (PAGE 173)

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

CHAPTER ASSESSMENTS

5.1 Introduction

1 Define *tissue*. (p. 152)
2 Describe three types of intercellular junctions. (p. 152)
3 Which of the following is a major tissue type in the body? (p. 152)
a. epithelial
b. nervous
c. muscle
d. connective
e. all of the above

5.2 Epithelial Tissues

4 A general characteristic of epithelial tissues is that ______________. (p. 153)
a. numerous blood vessels are present
b. cells are spaced apart
c. cells divide rapidly
d. there is much extracellular matrix between cells
e. they contain collagenous fibers
5 Distinguish between simple epithelium and stratified epithelium. (p. 153)
6 Explain how the structure of simple squamous epithelium provides its function. (p. 154)
7 Match the epithelial tissue on the left to an organ in which the tissue is found. (pp. 154–158)

(1) simple squamous epithelium	A. lining of intestines
(2) simple cuboidal epithelium	B. lining of ducts of mammary glands
(3) simple columnar epithelium	C. lining of urinary bladder
(4) pseudostratified columnar epithelium	D. salivary glands
(5) stratified squamous epithelium	E. air sacs of lungs
(6) stratified cuboidal epithelium	F. respiratory passages
(7) stratified columnar epithelium	G. part of male urethra
(8) transitional epithelium	H. lining of kidney tubules
(9) glandular epithelium	I. outer layer of skin

8 Distinguish between an exocrine gland and an endocrine gland. (p. 158)
9 Describe how glands are classified according to the structure of their ducts and the organization of their cells. (p. 158)
10 A gland that secretes substances by exocytosis is a(n) ______________ gland. (p. 158)
a. merocrine
b. apocrine
c. holocrine
d. mammary
e. ceruminous

5.3 Connective Tissues

11 Discuss the general characteristics of connective tissue. (p. 161)
12 Define *extracellular matrix* and *ground substance*. (p. 161)
13 Describe three major types of connective tissue cells. (p. 163)
14 ______________ are thick fibers that have great tensile strength and are flexible, but only slightly elastic. (p. 163)
a. Reticular
b. Elastic
c. Collagenous
d. Mucin
e. Actin
15 Describe areolar connective tissue, and indicate where it is found in the body. (p. 164)
16 Explain how the amount of adipose tissue in the body reflects diet. (p. 166)
17 Contrast dense regular and dense irregular connective tissues. (p. 166)
18 Explain why injured dense regular connective tissue and cartilage are usually slow to heal. (p. 166)
19 Distinguish between reticular and elastic connective tissues. (p. 166)
20 Name the major types of cartilage, and describe their differences and similarities. (p. 168)
21 Describe how bone cells are organized in bone tissue. (p. 169)
22 Explain how bone cells receive nutrients. (p. 169)
23 The fluid extracellular matrix of blood is called ________. (p. 169)
a. white blood cells
b. red blood cells
c. platelets
d. plasma
e. bone marrow

5.4 Types of Membranes

24 Describe the structure of epithelial membranes in contrast to synovial membranes. (p. 171)
25 Identify locations in the body of the four types of membranes. (p. 171)

5.5 Muscle Tissues

26 Describe the general characteristics of muscle tissues. (p. 171)
27 Compare and contrast skeletal, smooth, and cardiac muscle tissues in terms of location, cell appearance, and control. (p. 171)

5.6 Nervous Tissues

28 Describe the general characteristics of nervous tissue. (p. 173)
29 Distinguish between the functions of neurons and neuroglia. (p. 173)

INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

OUTCOMES 3.2, 3.6, 5.1, 5.2, 5.3, 5.5, 5.6

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) bone, (c) muscle, and (d) blood?

OUTCOMES 3.2, 3.5, 5.2

2. In the lungs of smokers, a process called metaplasia occurs where normal lining cells of the lung are replaced by squamous metaplastic cells (many layers of squamous epithelial cells). Functionally, why is this an undesirable body reaction to tobacco smoke?

OUTCOMES 3.4, 3.5, 5.2, 5.3, 5.5, 5.6

3. Cancer-causing agents (carcinogens) usually act on dividing cells. Which of the four tissues would carcinogens most influence? Least influence?

OUTCOMES 5.2, 5.4

4. Sometimes, in response to irritants, mucous cells secrete excess mucus. What symptoms might this produce if it occurred in the (a) digestive tract or (b) respiratory passageway?

OUTCOME 5.3

5. Disorders of collagen are characterized by deterioration of connective tissues. Why would you expect such diseases to produce widely varying symptoms?

6. Collagen and elastin are added to many beauty products. What type of tissues are they normally part of?

7. Joints such as the shoulder, elbow, and knee contain considerable amounts of cartilage and dense regular connective tissue. How does this explain that joint injuries are often slow to heal?

8. Answer the following questions with respect to the presented micrograph (80×). (a) Identify the organ depicted. (b) What type of tissue is depicted (green arrow, yellow arrow)? (c) To what cell does the arrow point (red arrow, black arrow)?