Histology

4

Clinical Case Study

As a medical student, you are rotating with a gastroenterologist who is performing an upper endoscopy on a patient with long-standing gastroesophageal reflux (heartburn). During the procedure, the doctor quizzes you on what type of cells line the esophagus. What is your answer? He takes a biopsy of the lower esophagus just above the stomach. Later, the specimen is fixed, and you examine it under the microscope. You see a single layer of nonciliated, tall, column-shaped cells. What type of tissue are you examining?

FIGURE: Knowing the structure and function of body tissues elucidates how they may adapt to provide protection to body organs.

DEFINITION AND CLASSIFICATION OF TISSUES

Histology is the specialty of anatomy that involves study of the microscopic structure of tissues. Tissues are assigned to four basic categories on the basis of their cellular composition and histological appearance.

Objective 1 Define *tissue* and discuss the importance of histology.

Objective 2 Describe the functional relationship between cells and tissues.

Objective 3 List the four principal tissue types and briefly describe the functions of each type.

Although cells are the structural and functional units of the body, the cells of a complex multicellular organism are so specialized that they do not function independently. *Tissues* are aggregations of similar cells and cell products that perform specific functions. The various types of tissues are established during early embryonic development. As the embryo grows, organs form from specific arrangements of tissues. Many adult organs, including the heart, brain and muscles, contain the original cells and tissues that were formed prenatally, although some functional changes occur in the tissues as they are acted upon by hormones or as their effectiveness diminishes with age.

The study of tissues is referred to as **histology.** It provides a foundation for understanding the microscopic structure and functions of the organs discussed in the chapters that follow. Many diseases profoundly alter the tissues within an affected organ; therefore, by knowing the normal tissue structure, a physician can recognize the abnormal. In medical schools a course in histology is usually followed by a course in *pathology,* the study of abnormal tissues in diseased organs.

Although histologists employ many different techniques for preparing, staining, and sectioning tissues, only two basic kinds of microscopes are used to view the prepared tissues. The *light microscope* is used to observe overall tissue structure (fig. 4.1), and the *electron microscope* to observe the fine details of tissue and cellular structure. Most of the histological photomicrographs in this text are at the light microscopic level. However, where fine structural detail is needed to understand a particular function, electron micrographs are used.

Many tissue cells are surrounded and bound together by a nonliving intercellular **matrix** (*ma′triks*) that the cells secrete. Matrix varies in composition from one tissue to another and may take the form of a liquid, semisolid, or solid. Blood, for example, has a liquid matrix, permitting this tissue to flow through vessels. By contrast, bone cells are separated by a solid matrix, permitting this tissue to support the body.

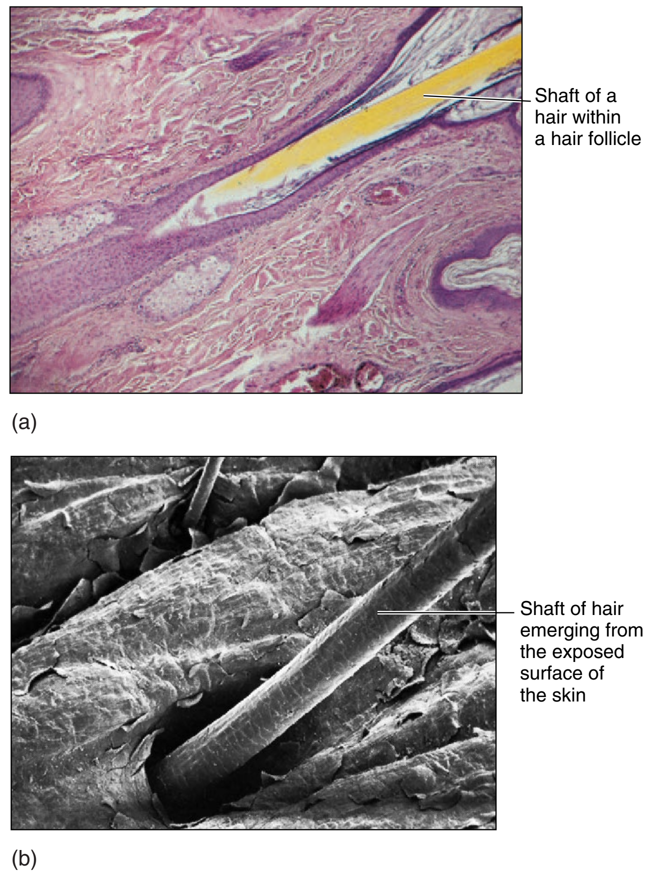

FIGURE 4.1 The appearance of skin (*a*) magnified 25 times, as seen through a compound light microscope, and (*b*) magnified 280 times, as seen through a scanning electron microscope (SEM).

The tissues of the body are assigned to four principal types on the basis of structure and function: (1) *epithelial (ep″ĭ-the′le-al) tissue* covers body surfaces, lines body cavities and ducts, and forms glands; (2) *connective tissue* binds, supports, and protects body parts; (3) *muscle tissue* contracts to produce movement; and (4) *nervous tissue* initiates and transmits nerve impulses from one body part to another.

Knowledge Check

1. Define *tissue* and explain why histology is important to the study of anatomy, physiology, and medicine.
2. Cells are the functional units of the body. Explain how the matrix permits specific kinds of cells to be even more effective and functional as tissues.
3. What are the four principal kinds of body tissues? What are the basic functions of each type?

histology: Gk. *histos,* web (tissue); *logos,* study
pathology: Gk. *pathos,* suffering, disease; *logos,* study
matrix: L. *matris,* mother

Developmental Exposition

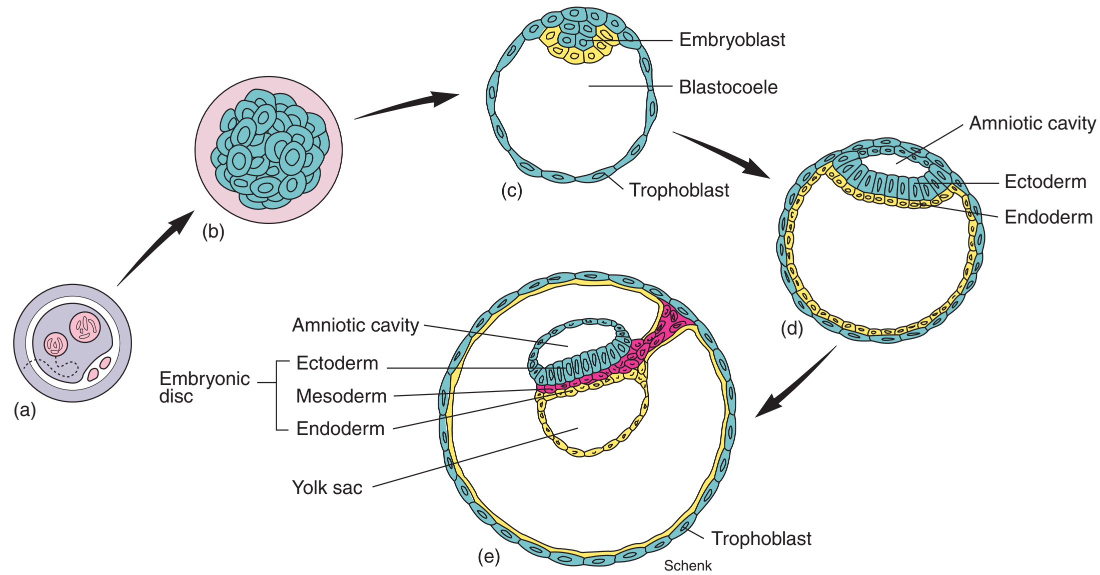

EXHIBIT 1 The early stages of embryonic development. (*a*) Fertilization and the formation of the zygote, (*b*) the morula at about the third day, (*c*) the early blastocyst at the time of implantation between the fifth and seventh day, (*d*) a blastocyst at 2 weeks, and (*e*) a blastocyst at 3 weeks showing the three primary germ layers that constitute the embryonic disc.

The Tissues

EXPLANATION

Human prenatal development is initiated by the fertilization of an ovulated ovum (egg) from a female by a sperm cell from a male. The chromosomes within the nucleus of a **zygote** (*zī′gōt*) (fertilized egg) contain all the genetic information necessary for the differentiation and development of all body structures.

zygote: Gk. *zygotos*, yolked

Within 30 hours after fertilization, the zygote undergoes a mitotic division as it moves through the uterine tube toward the uterus (see chapter 22). After several more cellular divisions, the embryonic mass consists of 16 or more cells and is called a **morula** (*mor′yoo-lă*), as shown in exhibit I. Three or 4 days after conception, the morula enters the uterine cavity where it remains unattached for about 3 days. During this time, the center of the morula fills with fluid absorbed from the uterine cavity. As the fluid-filled space develops inside the morula, two distinct groups of cells form. The single layer of cells forming the outer

morula: Gk. *morus*, mulberry

(continued)

EPITHELIAL TISSUE

There are two major categories of epithelia: membranous and glandular. Membranous epithelia are located throughout the body and form such structures as the outer layer of the skin; the inner lining of body cavities, tubes, and ducts; and the covering of visceral organs. Glandular epithelia are specialized tissues that form the secretory portion of glands.

Objective 4 Compare and contrast the various types of membranous epithelia.

Objective 5 Discuss the functions of the membranous epithelia in different locations in the body.

Objective 6 Define *gland* and compare and contrast the various types of glands in the body.

epithelium: Gk. *epi*, upon; *thelium*, to cover

Characteristics of Membranous Epithelia

Membranous epithelia always have one free surface exposed to a body cavity, a lumen (hollow portion of a body tube), or to the skin surface. Some membranous epithelia are derived from ectoderm, such as the outer layer of the skin; some from mesoderm,

(continued)

TABLE 4A Derivatives of the Germ Layers

Ectoderm	Mesoderm	Endoderm
Epidermis of skin and epidermal derivatives: hair, nails, glands of the skin; linings of oral, nasal, anal, and vaginal cavities	Muscle: smooth, cardiac, skeletal	Epithelium of pharynx, auditory canal, tonsils, thyroid, parathyroid, thymus, larynx, trachea, lungs, GI tract, urinary bladder and urethra, and vagina
Nervous tissue; sense organs	Connective tissue: embryonic, mesenchyme, connective tissue proper, cartilage, bone, blood	Liver and pancreas
Lens of eye; enamel of teeth	Dermis of skin; dentin of teeth	
Pituitary gland	Epithelium (endothelium) of blood vessels, lymphatic vessels, body cavities, joint cavities	
Adrenal medulla	Internal reproductive organs	
	Kidneys and ureters	
	Adrenal cortex	

wall is known as the **trophoblast,** and the inner aggregation of cells is known as the **embryoblast.** With further development, the trophoblast differentiates into a structure that will later form part of the placenta; the embryoblast will eventually become the embryo. With the establishment of these two groups of cells, the morula becomes known as a **blastocyst** (*blas′tŏ-sist*). Implantation of the blastocyst in the uterine wall begins between the fifth and seventh day (see chapter 22).

As the blastocyst completes implantation during the second week of development, the embryoblast undergoes marked differentiation. A slitlike space called the **amniotic** (*am′ne-ot-ic*) **cavity** forms within the embryoblast, adjacent to the trophoblast. The embryoblast now consists of two layers: an upper **ectoderm,** which is closer to the amniotic cavity, and a lower **endoderm,** which borders the **blastocoel** (blastocyst cavity). A short time later, a third layer called the **mesoderm** forms between the endoderm and ectoderm. These three layers constitute the **primary germ layers.**

The primary germ layers are of great significance because all the cells and tissues of the body are derived from them (see fig. 22.9). Ectodermal cells form the nervous system; the outer layer of skin (epidermis), including hair, nails, and skin glands; and portions of the sensory organs. Mesodermal cells form the skeleton, muscles, blood, reproductive organs, dermis of the skin, and connective tissue. Endodermal cells produce the lining of the GI tract, the digestive organs, the respiratory tract and lungs, and the urinary bladder and urethra. The derivatives of the primary germ layers are summarized in table 4A.

trophoblast: Gk. *trophe,* nourishment; *blastos,* germ
embryoblast: Gk. *embryon,* to be full, swell; *blastos,* germ
ectoderm: Gk. *ecto,* outside; *derm,* skin

endoderm: Gk. *endo,* within; *derm,* skin
mesoderm: Gk. *meso,* middle; *derm,* skin

such as the inside lining of blood vessels; and others from endoderm, such as the inside lining of the digestive tract (gastrointestinal, or GI, tract).

Membranous epithelia may be one or several cell layers thick. The upper surface may be exposed to gases, as in the case of epithelium in the integumentary and respiratory systems; to liquids, as in the circulatory and urinary systems; or to semisolids, as in the GI tract. The deep surface of most membranous epithelia is bound to underlying supportive tissue by a **basement membrane,** that consists of glycoprotein from the epithelial cells and a meshwork of collagenous and reticular fibers from the underlying connective tissue. With few exceptions, membranous epithelia are avascular (without blood vessels) and must be nourished by diffusion from underlying connective tissues. Cells that make up membranous epithelia are tightly packed together, with little intercellular matrix between them.

Some of the functions of membranous epithelia are quite specific, but certain generalities can be made. Epithelia that cover or line surfaces provide protection from pathogens, physical injury, toxins, and desiccation. Epithelia lining the GI tract function in absorption. The epithelium of the kidneys provides filtration, whereas that within the pulmonary alveoli (air sacs) of the lungs allows for diffusion. Highly specialized *neuroepithelium* in the taste buds and in the nasal region has a chemoreceptor function.

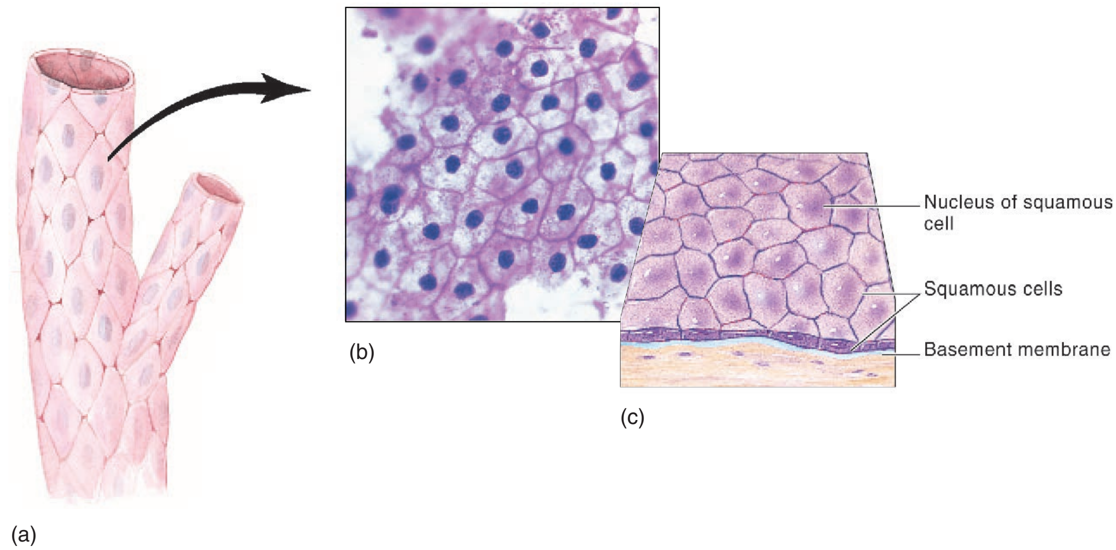

FIGURE 4.2 (*a*) Simple squamous epithelium lines the lumina of vessels, where it permits diffusion. (*b*) A photomicrograph of this tissue and (*c*) a labeled diagram. Simple squamous epithelia that line the lumina of vessels are referred to as endothelia, and that which cover visceral organs are referred to as mesothelia.

Many membranous epithelia are exposed to friction or harmful substances from the outside environment. For this reason, epithelial tissues have remarkable regenerative abilities. The mitotic replacement of the outer layer of skin and the lining of the GI tract, for example, is a continuous process.

Membranous epithelia are histologically classified by the number of layers of cells and the shape of the cells along the exposed surface. Epithelial tissues that are composed of a single layer of cells are called *simple;* those that are layered are said to be *stratified. Squamous* cells are flattened; *cuboidal* cells are cube-shaped; and *columnar* cells are taller than they are wide.

Simple Epithelia

Simple epithelial tissue is a single cell layer thick and is located where diffusion, absorption, filtration, and secretion are principal functions. The cells of simple epithelial tissue range from thin, flattened cells to tall, columnar cells. Some of these cells have cilia that create currents for the movement of materials across cell surfaces. Others have microvilli that increase the surface area for absorption.

Simple Squamous Epithelium

Simple squamous (*skwa′mus*) epithelium is composed of flattened, irregularly shaped cells that are tightly bound together in a mosaiclike pattern (fig. 4.2). Each cell contains an oval or spherical central nucleus. This epithelium is adapted for diffusion and filtration. It occurs in the pulmonary alveoli within the lungs (where gaseous exchange occurs), in portions of the kidney (where blood is filtered), on the inside walls of blood vessels, in the lining of body cavities, and in the covering of the viscera. The simple squamous epithelium lining the inner walls of blood and lymphatic vessels is termed **endothelium** (*en″do-the′le-um*) (fig. 4.2*b*). That which covers visceral organs and lines body cavities is called **mesothelium** (*mes″ŏ-the′le-um*).

Simple Cuboidal Epithelium

Simple cuboidal epithelium is composed of a single layer of tightly fitted cube-shaped cells (fig. 4.3). This type of epithelium is found lining small ducts and tubules that have excretory, secretory, or absorptive functions. It occurs on the surface of the ovaries, forms a portion of the tubules within the kidney, and lines the ducts of the salivary glands and pancreas.

Simple Columnar Epithelium

Simple columnar epithelium is composed of tall, columnar cells (fig. 4.4). The height of the cells varies, depending on the site and function of the tissue. Each cell contains a single nucleus which is usually located near the basement membrane.

squamous: L. *squamosus,* scaly

endothelium: Gk. *endon,* within; *thelium,* to cover

mesothelium: Gk. *meso,* middle; *thelium,* to cover

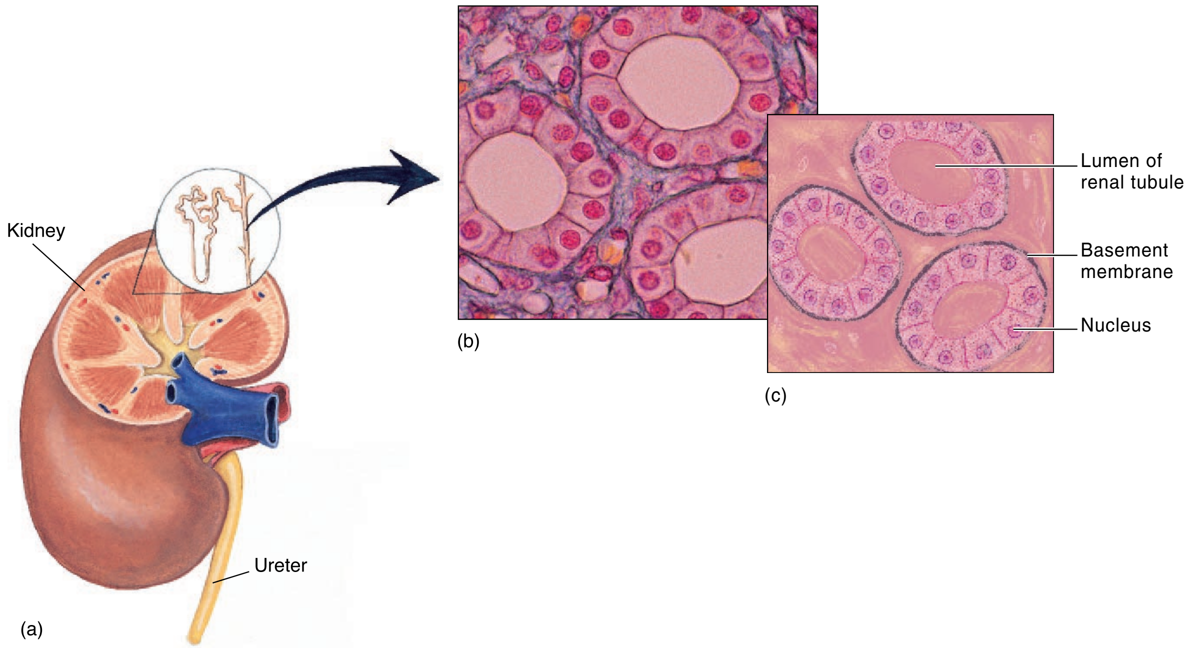

FIGURE 4.3 (*a*) Simple cuboidal epithelium lines the lumina of ducts; for example, in the kidneys, where it permits movement of fluids and ions. (*b*) A photomicrograph of this tissue and (*c*) a labeled diagram.

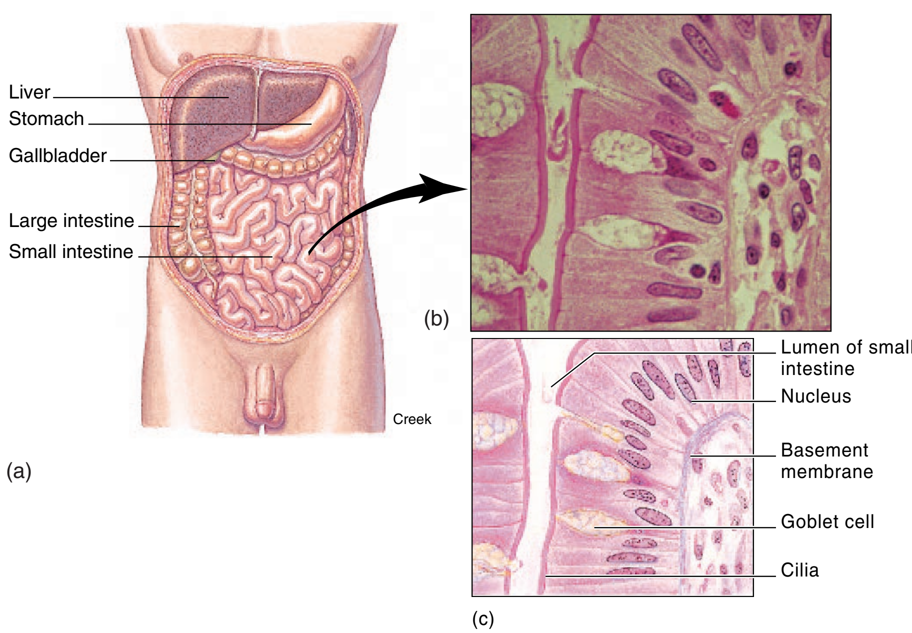

FIGURE 4.4 (*a*) Simple columnar epithelium lines the lumen of the digestive tract, where it permits secretion and absorption. (*b*) A photomicrograph of this tissue and (*c*) a labeled diagram.

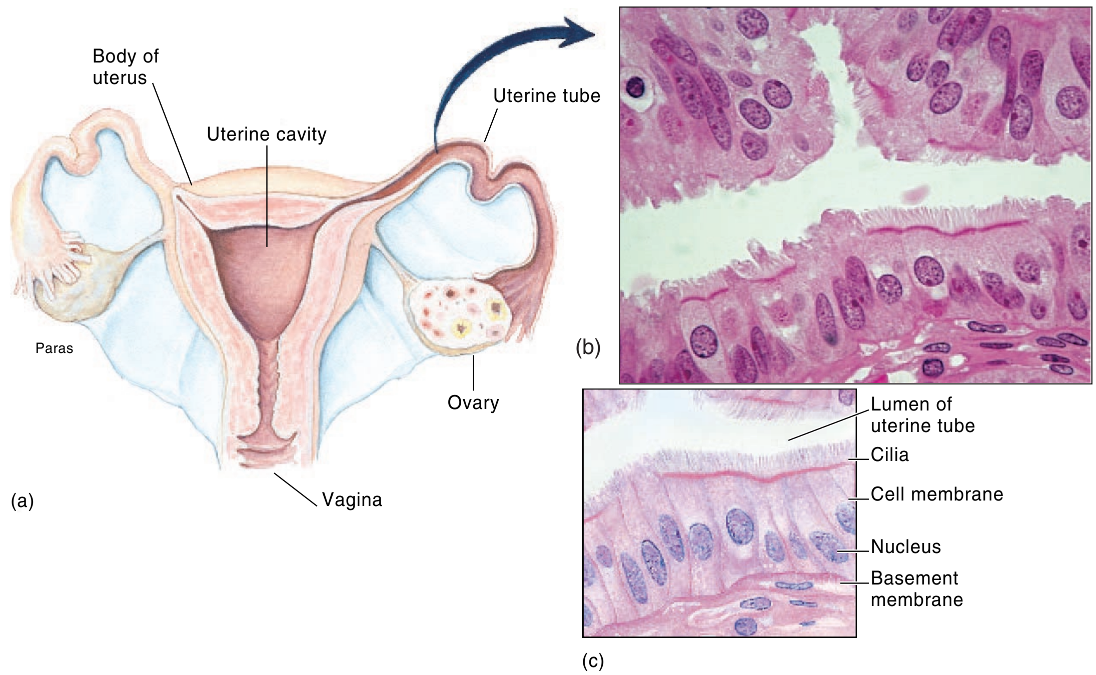

FIGURE 4.5 (*a*) Simple ciliated columnar epithelium lines the lumen of the uterine tube, where currents generated by the cilia propel the ovum (egg cell) toward the uterus. (*b*) a photomicrograph of this tissue and (*c*) a labeled diagram.

Specialized unicellular glands called **goblet cells** are scattered through this tissue at most locations. Goblet cells secrete a lubricative and protective mucus along the free surfaces of the cells. Simple columnar epithelium is found lining the inside walls of the stomach and intestine. In the digestive system, it forms a highly absorptive surface and also secretes certain digestive chemicals. Within the stomach, simple columnar epithelium has a tremendous mitotic rate. It replaces itself every 2 to 3 days.

Simple Ciliated Columnar Epithelium

Simple ciliated columnar epithelium is characterized by the presence of cilia along its free surface (fig. 4.5). By contrast, the simple columnar type is unciliated. Cilia produce wavelike movements that transport materials through tubes or passageways. This type of epithelium occurs in the female uterine tubes to move the ovum (egg cell) toward the uterus.

Not only do the cilia function to propel the ovum, but recent evidence indicates that sperm introduced into the female vagina during sexual intercourse may be moved along the return currents, or eddies, generated by ciliary movement. This greatly enhances the likelihood of fertilization.

Pseudostratified Ciliated Columnar Epithelium

As the name implies, this type of epithelium has a layered appearance (*strata* = layers). Actually, it is not multilayered (*pseudo* = false), because each cell is in contact with the basement membrane. Not all cells are exposed to the surface, however (fig. 4.6). The tissue appears to be stratified because the nuclei of the cells are located at different levels. Numerous goblet cells and a ciliated exposed surface are characteristic of this epithelium. It is found lining the inside walls of the trachea and the bronchial tubes; hence, it is frequently called *respiratory epithelium*. Its function is to remove foreign dust and bacteria entrapped in mucus from the lower respiratory system.

Coughing and sneezing, or simply "clearing the throat," are protective reflex mechanisms for clearing the respiratory passages of obstruction or of inhaled particles that have been trapped in the mucus along the ciliated lining. The material that is coughed up consists of the mucus-entrapped particles.

Stratified Epithelia

Stratified epithelia have two or more layers of cells. In contrast to the single-layered simple epithelia, they are poorly suited for absorption and secretion. Stratified epithelia have a primarily protective function that is enhanced by rapid cell divisions. They are classified according to the shape of the surface layer of cells, because the layer in contact with the basement membrane is always cuboidal or columnar in shape.

Stratified Squamous Epithelium

Stratified squamous epithelium is composed of a variable number of cell layers that are flattest at the surface (fig. 4.7). Mitosis occurs only at the deepest layers (see table 5.2). The mitotic rate

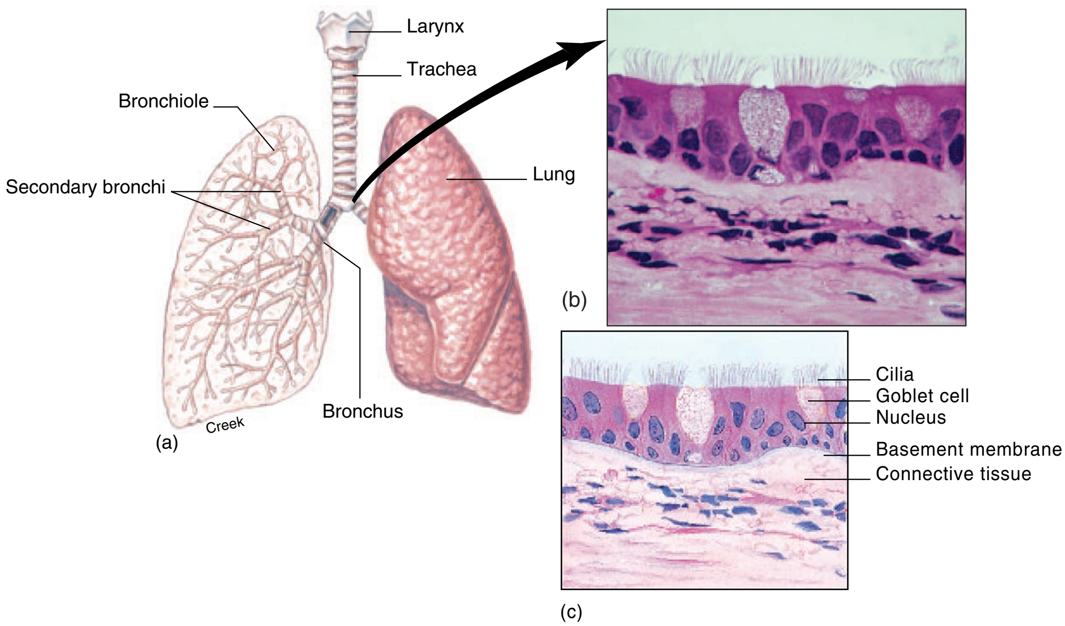

FIGURE 4.6 (*a*) Pseudostratified ciliated columnar epithelium lines the lumen of the respiratory tract, where it traps foreign material and moves it away from the pulmonary alveoli of the lungs. (*b*) a photomicrograph of this tissue and (*c*) a labeled diagram.

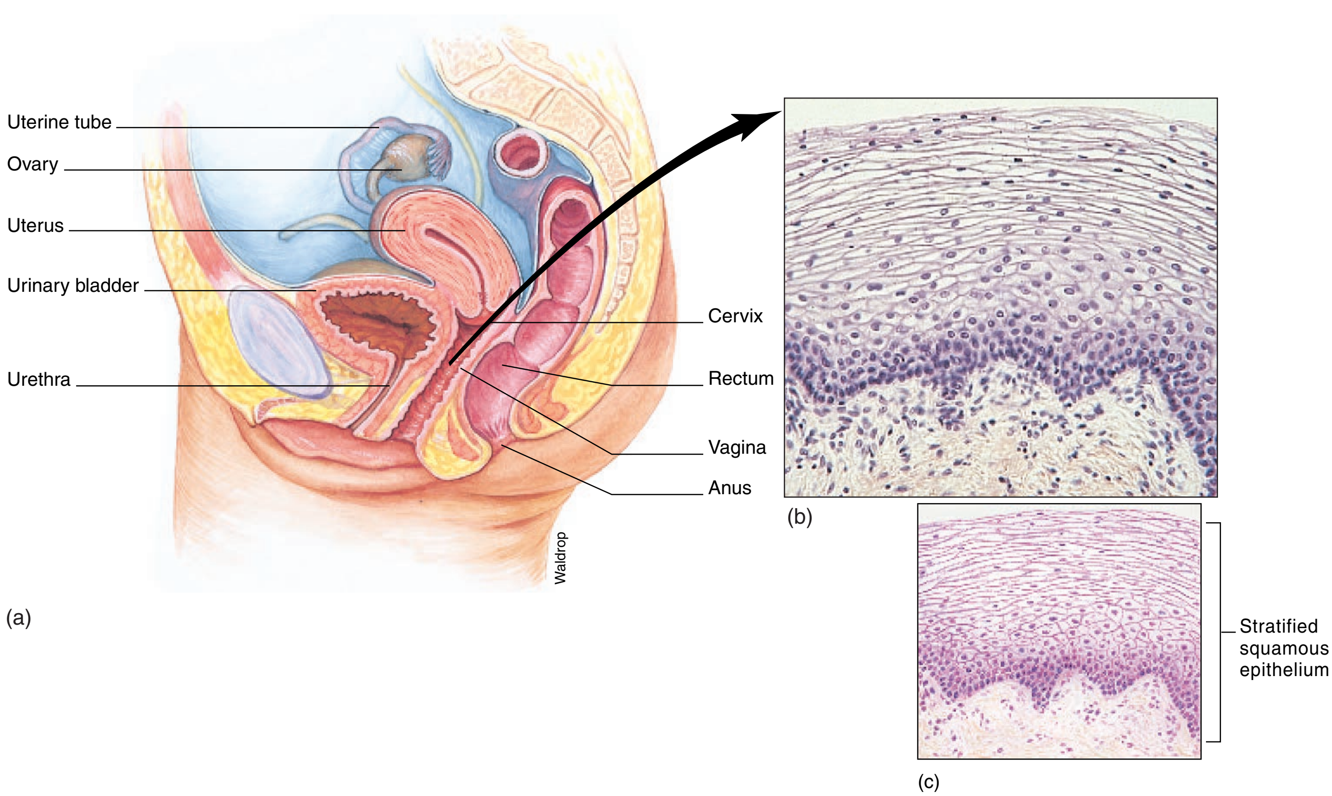

FIGURE 4.7 Stratified squamous epithelium forms the outer layer of skin and the lining of body openings. In the moistened areas, such as in the vagina (*a*), it is nonkeratinized, whereas in the epidermis of the skin it is keratinized. (*b*) a photomicrograph of this tissue and (*c*) a labeled diagram.

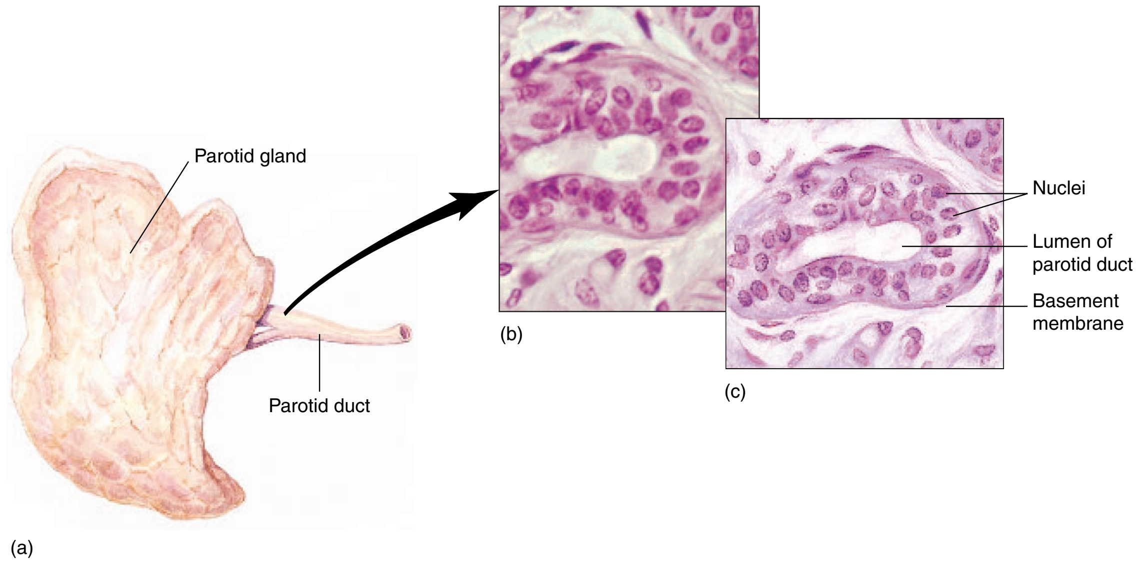

FIGURE 4.8 (*a*) Stratified cuboidal epithelium lines the lumina of large ducts like the parotid duct, which drains saliva from the parotid gland. (*b*) a photomicrograph of this tissue and (*c*) a labeled diagram.

approximates the rate at which cells are sloughed off at the surface. As the newly produced cells grow in size, they are pushed toward the surface, where they replace the cells that are sloughed off. Movement of the epithelial cells away from the supportive basement membrane is accompanied by the production of *keratin (ker′ă-tin)* (described below), progressive dehydration, and flattening.

There are two types of stratified squamous epithelial tissues: *keratinized* and *nonkeratinized*.

1. **Keratinized stratified squamous epithelium** contains *keratin*, a protein that strengthens the tissue. Keratin makes the epidermis (outer layer) of the skin somewhat waterproof and protects it from bacterial invasion. The outer layers of the skin are dead, but glandular secretions keep them soft (see chapter 5).
2. **Nonkeratinized stratified squamous epithelium** lines the oral cavity and pharynx, nasal cavity, vagina, and anal canal. This type of epithelium, called *mucosa (myoo-ko′să)*, is well adapted to withstand moderate abrasion but not fluid loss. The cells on the exposed surface are alive and are always moistened.

Stratified squamous epithelium is the first line of defense against the entry of living organisms into the body. Stratification, rapid mitotic activity, and keratinization within the epidermis of the skin are important protective features. An acidic pH along the surfaces of this tissue also helps to prevent disease. The pH of the skin is between 4.0 and 6.8. The pH in the oral cavity ranges from 5.8 to 7.1, which tends to retard the growth of microorganisms. The pH of the anal region is about 6, and the pH along the vaginal lining is 4 or lower.

keratin: Gk. *keras*, horn

Stratified Cuboidal Epithelium

Stratified cuboidal epithelium usually consists of only two or three layers of cuboidal cells (fig. 4.8). This type of epithelium is confined to the linings of the large ducts of sweat glands, salivary glands, and the pancreas, where its stratification probably provides a more robust lining than would simple epithelium.

Transitional Epithelium

Transitional epithelium is similar to nonkeratinized stratified squamous epithelium except that the surface cells of the former are large and round rather than flat, and some may have two nuclei (fig. 4.9). Transitional epithelium is found only in the urinary system, particularly lining the cavity of the urinary bladder and lining the lumina of the ureters. This tissue is specialized to permit distension (stretching) of the urinary bladder as it fills with urine. The inner, exposed cells actually transform from being rounded when the urinary bladder is empty to being somewhat flattened as it distends with urine.

A summary of membranous epithelial tissue is presented in table 4.1.

Body Membranes

Body membranes are composed of thin layers of epithelial tissue and, in certain locations, epithelial tissue coupled with supporting connective tissue. Body membranes cover, separate, and support visceral organs and line body cavities. The two basic types of body membranes, **mucous membranes** and **serous membranes,** are described in detail in chapter 2 under the heading "Body Cavities and Membranes" (see p. 41).

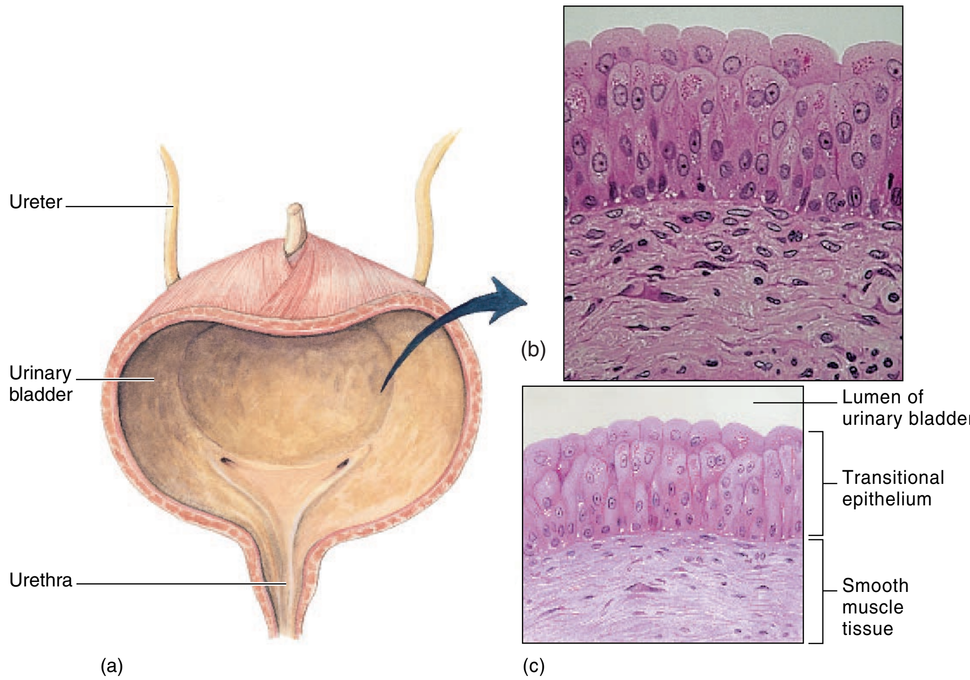

FIGURE 4.9 (*a*) Transitional epithelium lines the lumina of the ureters, part of the urethra and the cavity of the urinary bladder, where it permits distention. (*b*) a photomicrograph of this tissue and (*c*) a labeled diagram.

TABLE 4.1 Summary of Membranous Epithelial Tissue

Type	Structure and Function	Location
Simple Epithelia	Single layer of cells; function varies with type	Covering visceral organs; linings of body cavities, tubes, and ducts
Simple squamous epithelium	Single layer of flattened, tightly bound cells; diffusion and filtration	Capillary walls; pulmonary alveoli of lungs; covering visceral organs; linings of body cavities
Simple cuboidal epithelium	Single layer of cube-shaped cells; excretion, secretion, or absorption	Surface of ovaries; linings of renal tubules, salivary ducts, and pancreatic ducts
Simple columnar epithelium	Single layer of nonciliated, tall, column-shaped cells; protection, secretion, and absorption	Lining of most of GI tract
Simple ciliated columnar epithelium	Single layer of ciliated, column-shaped cells; transportive role through ciliary motion	Lining of uterine tubes
Pseudostratified ciliated columnar epithelium	Single layer of ciliated, irregularly shaped cells; many goblet cells; protection, secretion, ciliary movement	Lining of respiratory passageways
Stratified Epithelia	Two or more layers of cells; function varies with type	Epidermal layer of skin; linings of body openings, ducts, and urinary bladder
Stratified squamous epithelium (keratinized)	Numerous layers containing keratin, with outer layers flattened and dead; protection	Epidermis of skin
Stratified squamous epithelium (nonkeratinized)	Numerous layers lacking keratin, with outer layers moistened and alive; protection and pliability	Linings of oral and nasal cavities, vagina, and anal canal
Stratified cuboidal epithelium	Usually two layers of cube-shaped cells; strengthening of luminal walls	Large ducts of sweat glands, salivary glands, and pancreas
Transitional epithelium	Numerous layers of rounded, nonkeratinized cells; distension	Walls of ureters, part of urethra, and urinary bladder

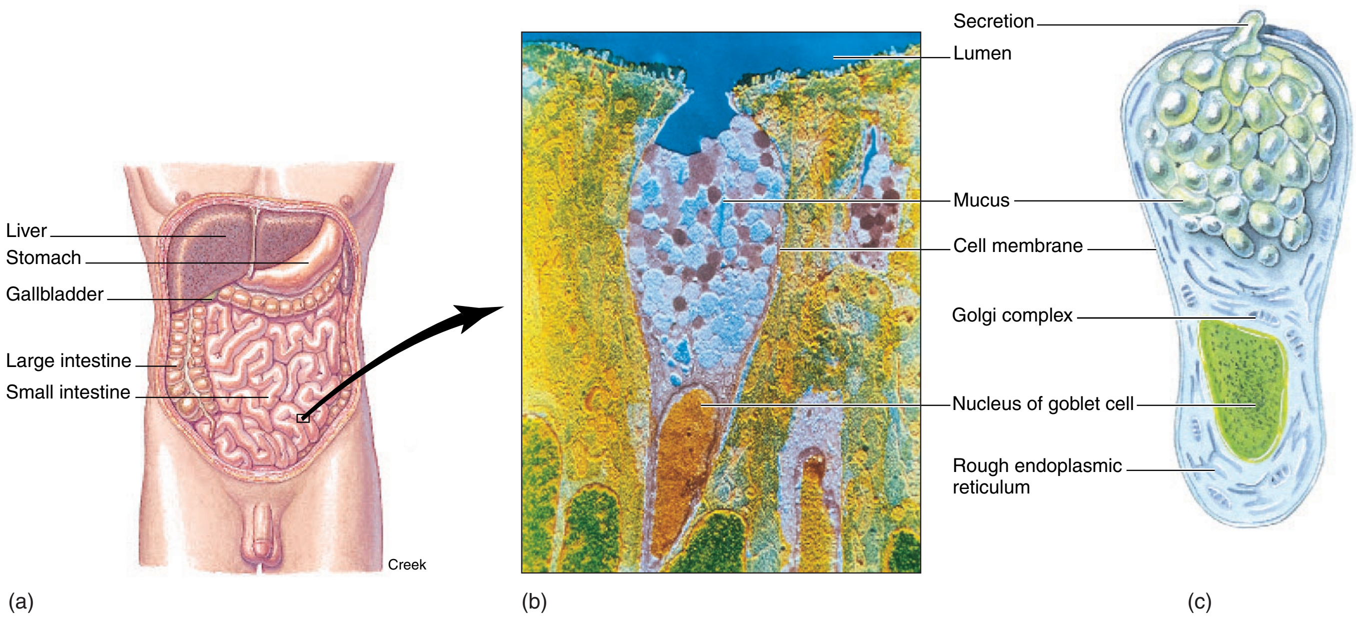

FIGURE 4.10 A goblet cell is a unicellular gland that secretes mucus, which lubricates and protects surface linings. (*a*) Goblet cells are abundant in the columnar epithelium lining the lumen of the small intestine. (*b*) A photomicrograph of a goblet cell and (*c*) a labeled diagram.

Glandular Epithelia

As tissues develop in the embryo, tiny invaginations (infoldings) or evaginations (outfoldings) of membranous epithelia give rise to specialized secretory structures called **exocrine** (*ek'sŏ-krin*) **glands.** These glands remain connected to the epithelium by ducts, and their secretions pass through the ducts onto body surfaces or into body cavities. Exocrine glands should not be confused with endocrine glands, which are ductless, and which secrete their products (hormones) into the blood or surrounding extracellular fluid. Exocrine glands within the skin include oil (sebaceous) glands, sweat glands, and mammary glands. Exocrine glands within the digestive system include the salivary and pancreatic glands.

Exocrine glands are classified according to their structure and how they discharge their products. Classified according to structure, there are two types of exocrine glands, *unicellular* and *multicellular glands*.

1. **Unicellular glands** are single-celled glands, such as *goblet cells* (fig. 4.10). They are modified columnar cells that occur within most epithelial tissues. Goblet cells are found in the epithelial linings of the respiratory and digestive systems. The mucus secretion of these cells lubricates and protects the surface linings.
2. **Multicellular glands,** as their name implies, are composed of both secretory cells and cells that form the walls of the ducts. Multicellular glands are classified as *simple* or *compound glands*. The ducts of the simple glands do not branch, whereas those of the compound type do (fig. 4.11). Multicellular glands are also classified according to the shape of their secretory portion. They are identified as *tubular glands* if the secretory portion resembles a tube and as acinar glands if the secretory portion resembles a flask. Multicellular glands with a secretory portion that resembles both a tube and a flask are termed *tubuloacinar glands*.

Multicellular glands are also classified according to the means by which they release their product (fig. 4.12).

1. **Merocrine** (*mer'ŏ-krin*) **glands** are those that secrete a watery substance through the cell membrane of the secretory cells. Salivary glands, pancreatic glands, and certain sweat glands are of this type.
2. **Apocrine** (*ap'ŏ-krin*) **glands** are those in which the secretion accumulates on the surface of the secretory cell; then, a portion of the cell, along with the secretion, is pinched off to be discharged. Mammary glands are of this type.

exocrine: Gk. *exo*, outside; *krinein*, to separate

merocrine: Gk. *meros*, part; *krinein*, to separate

apocrine: Gk. *apo*, off; *krinein*, to separate

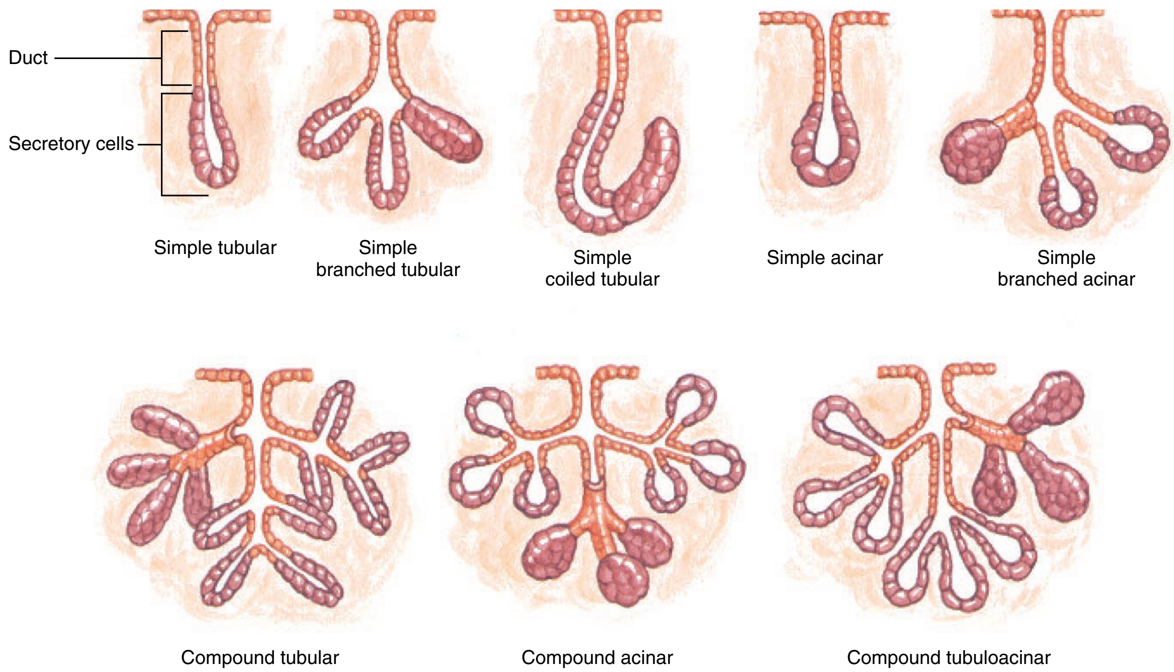

FIGURE 4.11 Structural classification of multicellular exocrine glands. The ducts of the simple glands either do not branch or have few branches, whereas those of the compound glands have multiple branches.

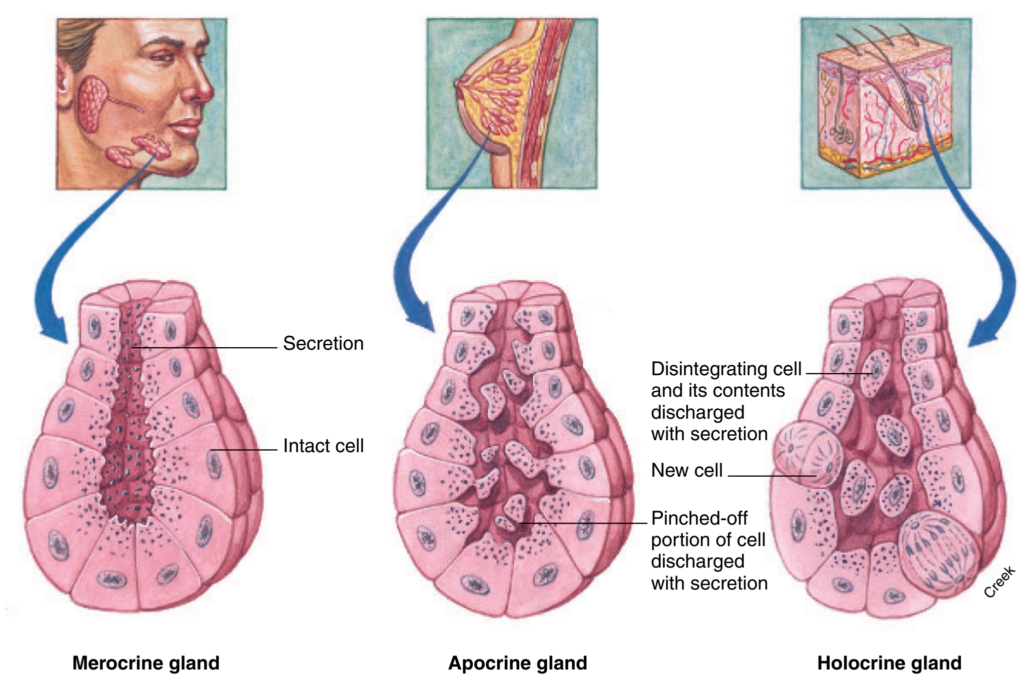

FIGURE 4.12 Examples of multicellular exocrine glands.

TABLE 4.2 Summary of Glandular Epithelial Tissue

Classification of Exocrine Glands by Structure

Type	Function	Example
I. Unicellular	Lubricate and protect	Goblet cells of digestive, respiratory, urinary, and reproductive systems
II. Multicellular	Protect, cool body, lubricate, aid in digestion, maintain body homeostasis	Sweat glands, digestive glands, liver, mammary glands, sebaceous glands
A. Simple		
1. Tubular	Aid in digestion	Intestinal glands
2. Branched tubular	Protect, aid in digestion	Uterine glands, gastric glands
3. Coiled tubular	Regulate temperature	Certain sweat glands
4. Acinar	Provide additive for spermatozoa	Seminal vesicles of male reproductive system
5. Branched acinar	Condition skin	Sebaceous glands of the skin
B. Compound		
1. Tubular	Lubricate urethra of male, assist body digestion	Bulbourethral glands of male reproductive system, liver
2. Acinar	Provide nourishment for infant, aid in digestion	Mammary glands, salivary glands (sublingual and submandibular)
3. Tubuloacinar	Aid in digestion	Salivary gland (parotid), pancreas

Classification of Exocrine Glands by Mode of Secretion

Type	Description of Secretion	Example
Merocrine glands	Watery secretion for regulating temperature or enzymes that promote digestion	Salivary and pancreatic glands, certain sweat glands
Apocrine glands	Portion of secretory cell and secretion are discharged; provides nourishment for infant, assists in regulating temperature	Mammary glands, certain sweat glands
Holocrine glands	Entire secretory cell with enclosed secretion is discharged; conditions skin	Sebaceous glands of the skin

3. **Holocrine** (*hol'ŏ-krin*) **glands** are those in which the entire secretory cell is discharged, along with the secretory product. An example of a holocrine gland is an oil-secreting (sebaceous) gland of the skin (see chapter 5).

A summary of glandular epithelial tissue is presented in table 4.2.

Knowledge Check

4. List the functions of simple squamous epithelia.
5. What are the three types of columnar epithelia? What do they have in common? How are they different?
6. What are the two types of stratified squamous epithelia and how do they differ?
7. Distinguish between unicellular and multicellular glands. Explain how multicellular glands are classified according to their mechanism of secretion.
8. In what ways are mammary glands and certain sweat glands similar?

holocrine: Gk. *holos*, whole; *krinein*, to separate

CONNECTIVE TISSUE

Connective tissue is divided into subtypes according to the matrix that binds the cells. Connective tissue provides structural and metabolic support for other tissues and organs of the body.

Objective 7 Describe the general characteristics, locations, and functions of connective tissue.

Objective 8 Explain the functional relationship between embryonic and adult connective tissue.

Objective 9 List the various ground substances, fiber types, and cells that constitute connective tissue and explain their functions.

Characteristics and Classification of Connective Tissue

Connective tissue is the most abundant tissue in the body. It supports other tissues or binds them together and provides for the metabolic needs of all body organs. Certain types of connective tissue store nutritional substances; other types manufacture protective and regulatory materials.

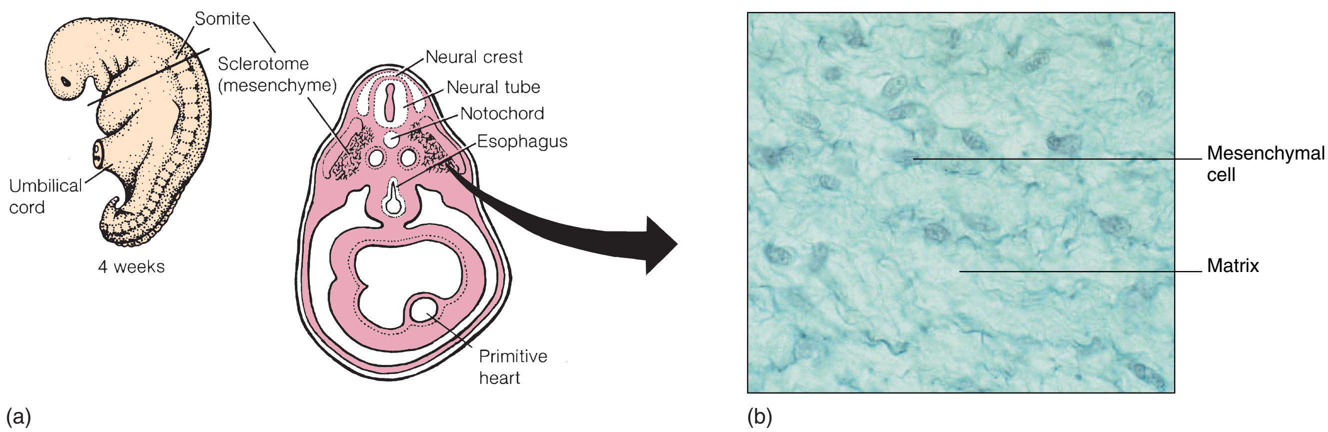

FIGURE 4.13 Mesenchyme is a type of embryonic connective tissue that can migrate and give rise to all other kinds of connective tissue. (*a*) It is found within an early developing embryo and (*b*) consists of irregularly shaped cells lying in a jellylike homogeneous matrix.

Although connective tissue varies widely in structure and function, all types of connective tissue have similarities. With the exception of mature cartilage, connective tissue is highly vascular and well nourished. It is able to replicate and, by so doing, is responsible for the repair of body organs. Unlike epithelial tissue, which is composed of tightly fitted cells, connective tissue contains considerably more matrix (intercellular material) than cells. Connective tissue does not occur on free surfaces of body cavities or on the surface of the body, as does epithelial tissue. Furthermore, connective tissue is embryonically derived from mesoderm, whereas epithelial tissue derives from ectoderm, mesoderm, and endoderm.

The classification of connective tissue is not exact, and several schemes have been devised. In general, however, the various types are named according to the kind and arrangement of the matrix. The following are the basic kinds of connective tissues:

A. Embryonic connective tissue
B. Connective tissue proper
   1. Loose (areolar) connective tissue
   2. Dense regular connective tissue
   3. Dense irregular connective tissue
   4. Elastic connective tissue
   5. Reticular connective tissue
   6. Adipose tissue
C. Cartilage
   1. Hyaline cartilage
   2. Fibrocartilage
   3. Elastic cartilage
D. Bone tissue
E. Blood (vascular tissue)

Embryonic Connective Tissue

The embryonic period of development, which lasts 6 weeks (from the start of the third to the end of the eighth week), is characterized by extensive tissue differentiation and organ formation. At the beginning of the embryonic period, all connective tissue looks alike and is referred to as **mesenchyme** (*mez′en-kīm*). Mesenchyme is undifferentiated embryonic connective tissue that is derived from mesoderm. It consists of irregularly shaped cells surrounded by large amounts of a homogeneous, jellylike matrix (fig. 4.13). In certain periods of development, mesenchyme migrates to predisposed sites where it interacts with other tissues to form organs. Once mesenchyme has completed its embryonic migration to a predetermined destination, it differentiates into all other kinds of connective tissue.

Some mesenchymal-like tissue persists past the embryonic period in certain sites within the body. Good examples are the undifferentiated cells that surround blood vessels and form fibroblasts if the vessels are traumatized. Fibroblasts assist in healing wounds (see chapter 5).

Another kind of prenatal connective tissue exists only in the fetus (the fetal period is from 9 weeks to birth) and is called *mucous connective tissue* or *Wharton's jelly*. It gives a turgid consistency to the umbilical cord.

Connective Tissue Proper

Connective tissue proper has a loose, flexible matrix, frequently called *ground substance*. The most common cell within connec-

Wharton's jelly: from Thomas Wharton, English anatomist, 1614–73

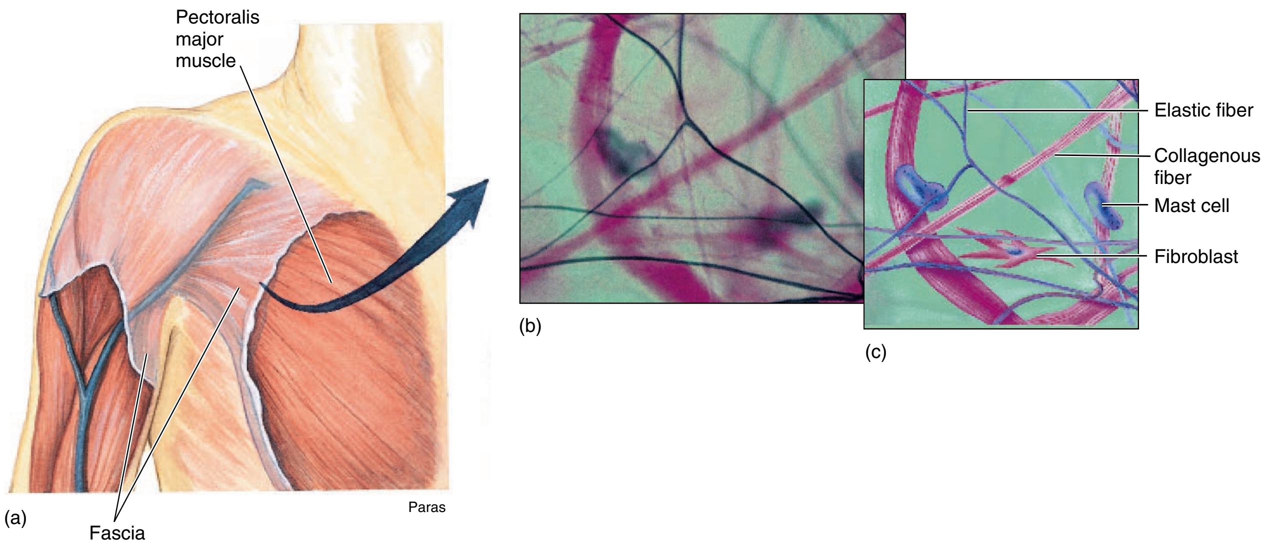

FIGURE 4.14 Loose connective tissue is packing and binding tissue that surrounds muscles (*a*), nerves, and vessels and binds the skin to the underlying muscles. (*b*) A photomicrograph of the tissue and (*c*) a labeled diagram.

tive tissue proper is called a **fibroblast** (*fi′bro-blast*). Fibroblasts are large, star-shaped cells that produce **collagenous** (*kŏ-laj′ĕ-nus*), **elastic,** and **reticular** (*rĕ-tik′yoo-lar*) **fibers. Collagenous fibers** are composed of a protein called *collagen (kol′ă-jen);* they are flexible, yet they have tremendous strength. **Elastic fibers** are composed of a protein called *elastin,* which provides certain tissues with elasticity. Collagenous and elastic fibers may be either sparse and irregularly arranged, as in loose connective tissue, or tightly packed, as in dense connective tissue. Tissues with loosely arranged fibers generally form packing material that cushions and protects various organs, whereas those that are tightly arranged form the binding and supportive connective tissues of the body.

Resilience in tissues that contain elastic fibers is extremely important for several physical functions of the body. Consider, for example, that elastic fibers are found in the walls of large arteries and in the walls of the lower respiratory passageways. As these walls are expanded by blood moving through vessels or by inspired air, the elastic fibers must first stretch and then recoil. This maintains the pressures of the fluid or air moving through the lumina, thus ensuring adequate flow rates and rates of diffusion through capillary and lung surfaces.

Reticular fibers reinforce by branching and joining to form a delicate lattice or reticulum. Reticular fibers are common in lymphatic glands, where they form a meshlike center called the *stroma*.

collagen: Gk, *kolla,* glue
elastin: Gk. *elasticus,* to drive
reticular: L. *rete,* net or netlike
stroma: Gk. *stroma,* a couch or bed

Six basic types of connective tissue proper are generally recognized. These tissues are distinguished by the consistency of the ground substance and the type and arrangement of the reinforcement fibers.

Loose Connective (Areolar) Tissue

Loose connective tissue is distributed throughout the body as a binding and packing material. It binds the skin to the underlying muscles and is highly vascular, providing nutrients to the skin. Loose connective tissue that binds skin to underlying muscles is known as **fascia** (*fash′e-ă*). It also surrounds blood vessels and nerves, where it provides both protection and nourishment. Specialized cells called **mast cells** are dispersed throughout the loose connective tissue surrounding blood vessels. Mast cells produce *heparin* (*hep′ă-rin*), an anticoagulant that prevents blood from clotting within the vessels. They also produce *histamine,* which is released during inflammation. Histamine acts as a powerful vasodilator.

The cells of loose connective tissue are predominantly fibroblasts, with collagenous and elastic fibers dispersed throughout the ground substance (fig. 4.14). The irregular arrangement of this tissue provides flexibility, yet strength, in any direction. It is this tissue layer, for example, that permits the skin to move when a part of the body is rubbed.

fascia: L. *fascia,* a band or girdle
heparin: Gk. *hepatos,* the liver

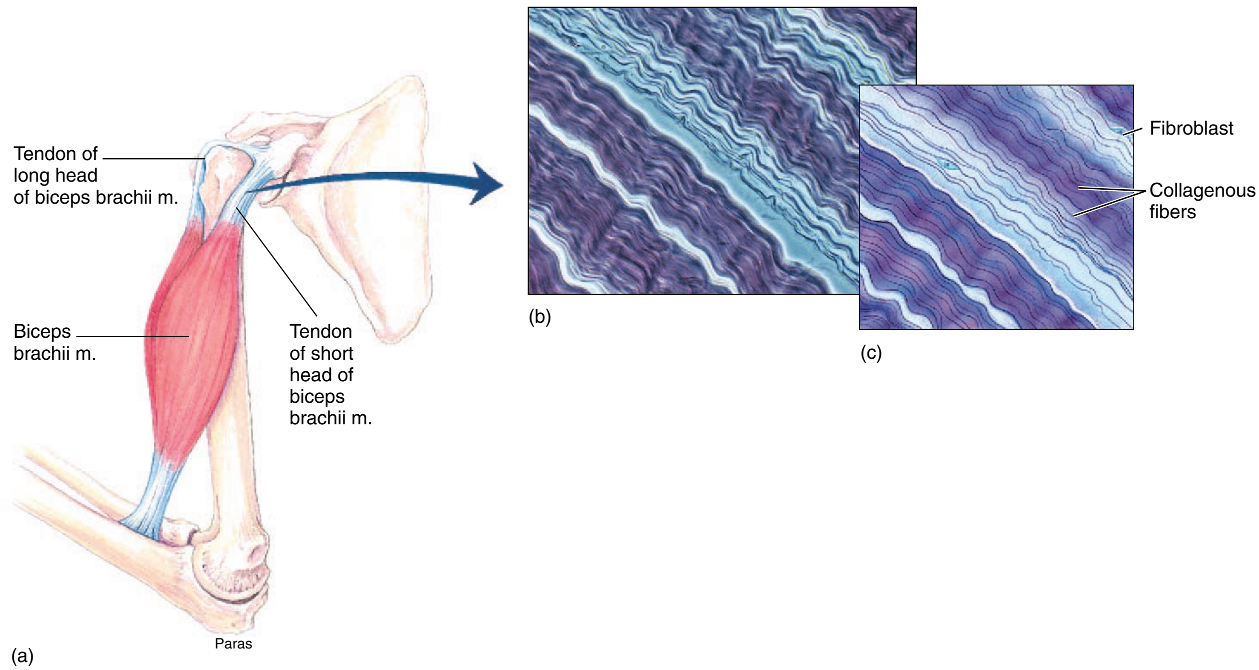

FIGURE 4.15 Dense regular connective tissue forms the strong and highly flexible tendons (*a*) and ligaments. (*b*) A photomicrograph of the tissue and (*c*) a labeled diagram.

Much of the fluid of the body is found within loose connective tissue and is called *interstitial fluid* (tissue fluid). Sometimes excessive tissue fluid accumulates, causing a swollen condition called *edema (ĕ-de′mă).* Edema is a symptom of numerous dysfunctions or disease processes.

Dense Regular Connective Tissue

Dense regular connective tissue is characterized by large amounts of densely packed collagenous fibers that run parallel to the direction of force placed on the tissue during body movement. Because this tissue is silvery white in appearance, it is sometimes called white fibrous connective tissue.

Dense regular connective tissue occurs where strong, flexible support is needed (fig. 4.15). **Tendons,** which attach muscles to bones and transfer the forces of muscle contractions, and **ligaments,** which connect bone to bone across articulations, are composed of this type of tissue.

Trauma to ligaments, tendons, and muscles are common sports-related injuries. A *strain* is an excessive stretch of the tissue composing the tendon or muscle, with no serious damage. A *sprain* is a tearing of the tissue of a ligament and may be slight, moderate, or complete. A complete tear of a major ligament is especially painful and disabling. Ligamentous tissue does not heal well because it has a poor blood supply. Surgical reconstruction is generally needed for the treatment of a severed ligament.

tendon: L. *tendere*, to stretch
ligament: L. *ligare*, bind

Dense Irregular Connective Tissue

Dense irregular connective tissue is characterized by large amounts of densely packed collagenous fibers that are interwoven to provide tensile strength in any direction. This tissue is found in the dermis of the skin and the submucosa of the GI tract. It also forms the fibrous capsules of organs and joints (fig. 4.16).

Elastic Connective Tissue

Elastic connective tissue is composed primarily of elastic fibers that are irregularly arranged and yellowish in color (fig. 4.17). They can be stretched to one and a half times their original lengths and will snap back to their former size. Elastic connective tissue is found in the walls of large arteries, in portions of the larynx, and in the trachea and bronchial tubes of the lungs. It is also present between the arches of the vertebrae that make up the vertebral column.

Reticular Connective Tissue

Reticular connective tissue is characterized by a network of reticular fibers woven through a jellylike matrix (fig. 4.18). Certain specialized cells within reticular tissue are *phagocytic* (*fag″ŏ-sit′ik*) (macrophages) and therefore can ingest foreign materials. The liver, spleen, lymph nodes, and bone marrow contain reticular connective tissue.

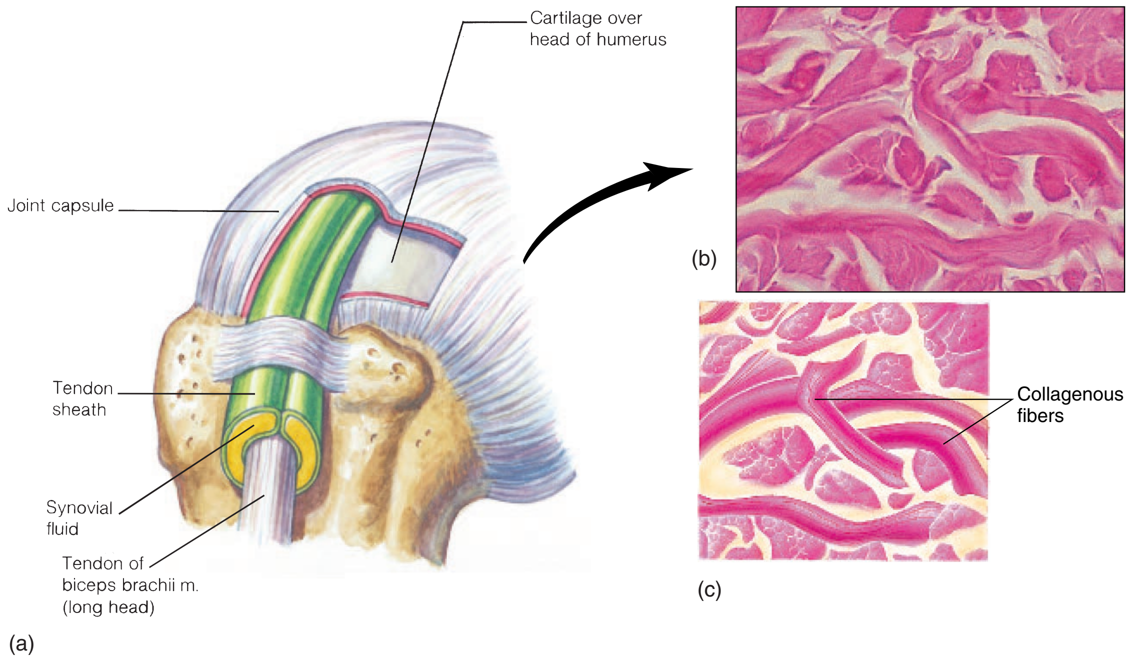

FIGURE 4.16 Dense irregular connective tissue forms joint capsules (*a*) that contain synovial fluid for lubricating movable joints. (*b*) A photomicrograph of the tissue and (*c*) a labeled diagram.

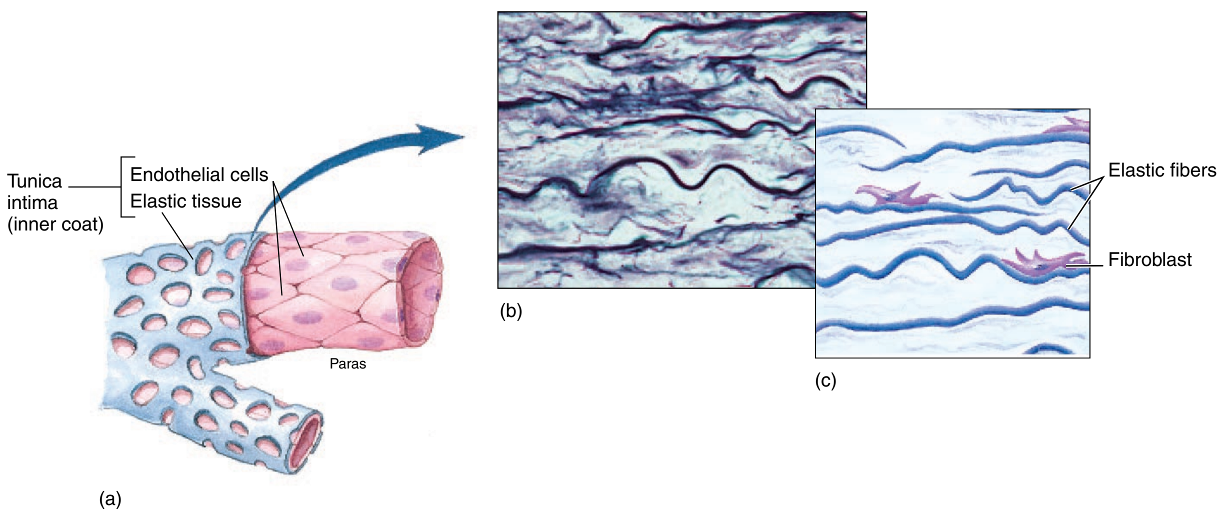

FIGURE 4.17 Elastic connective tissue permits stretching of a large artery (*a*) as blood flows through. (*b*) A photomicrograph of the tissue and (*c*) a labeled diagram.

Adipose Tissue

Adipose tissue is a specialized type of loose fibrous connective tissue that contains large quantities of **adipose cells,** or **adipocytes** (*ad′ĭ-po-sīts*). Adipose cells form from mesenchyme and, for the most part, are formed prenatally and during the first year of life. Adipose cells store droplets of fat within their cytoplasm, causing them to swell and forcing their nuclei to one side (fig. 4.19).

Adipose tissue is found throughout the body but is concentrated around the kidneys, in the hypodermis of the skin, on the surface of the heart, surrounding joints, and in the

adipose: L. *adiposus*, fat

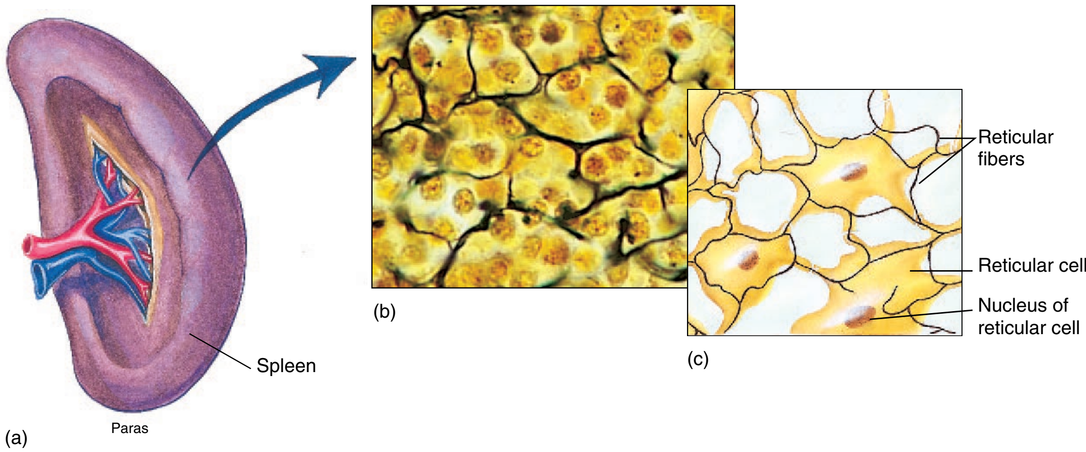

FIGURE 4.18 Reticular connective tissue forms the stroma, or framework, of such organs as the spleen (*a*), liver, thymus, and lymph nodes. (*b*) A photomicrograph of this tissue and (*c*) a labeled diagram.

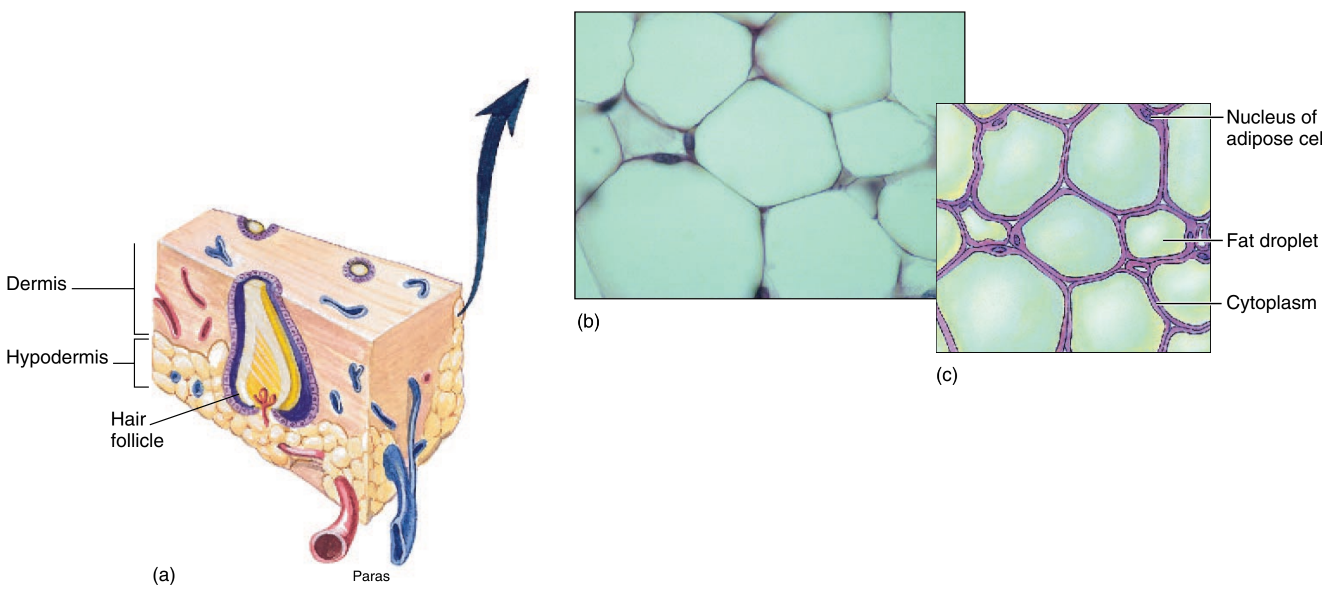

FIGURE 4.19 Adipose tissue is abundant in the hypodermis of the skin (*a*) and around various internal organs. (*b*) A photomicrograph of the tissue and (*c*) a labeled diagram.

breasts of sexually mature females. Fat functions not only as a food reserve, but also supports and protects various organs. It is a good insulator against cold because it is a poor conductor of heat.

Excessive fat can be unhealthy by placing a strain on the heart and perhaps causing early death. For these reasons, good exercise programs and sensible diets are extremely important. Adipose tissue can also retain lipid-soluble, environmental pollutants that are ingested or absorbed through the skin. Dieting eliminates the fat stored within adipose tissue but not the tissue itself.

The surgical procedure of *suction lipectomy* may be used to remove small amounts of adipose tissue from localized body areas such as the breasts, abdomen, buttocks, and thighs. Suction lipectomy is used for cosmetic purposes rather than as a treatment for obesity, and the risks for potentially detrimental side effects need to be seriously considered. Potential candidates should be between 30 and 40 years old and only about 15 to 20 pounds overweight. They should also have good skin elasticity.

The characteristics, functions, and locations of connective tissue proper are summarized in table 4.3.

TABLE 4.3 Summary of Connective Tissue Proper

Type	Structure and Function	Location
Loose connective (areolar) tissue	Predominantly fibroblast cells with lesser amounts of collagen and elastin proteins; binds organs, holds tissue fluids	Surrounding nerves and vessels, between muscles, beneath the skin
Dense regular connective tissue	Densely packed collagenous fibers that run parallel to the direction of force; provides strong, flexible support	Tendons, ligaments
Dense irregular connective tissue	Densely packed collagenous fibers arranged in a tight interwoven pattern; provides tensile strength in any direction	Dermis of skin, fibrous capsules of organs and joints, periosteum of bone
Elastic connective tissue	Predominantly irregularly arranged elastic fibers; supports, provides framework	Large arteries, lower respiratory tract, between the arches of vertebrae
Reticular connective tissue	Reticular fibers that form a supportive network; stores, performs phagocytic function	Lymph nodes, liver, spleen, thymus, bone marrow
Adipose tissue	Adipose cells; protects, stores fat, insulates	Hypodermis of skin, surface of heart, omentum, around kidneys, back of eyeball, surrounding joints

Cartilage

Cartilage (*kar′tĭ-lij*) consists of cartilage cells, or **chondrocytes** (*kon′dro-sīts*), and a semisolid matrix that imparts marked elastic properties to the tissue. It is a supportive and protective connective tissue that is frequently associated with bone. Cartilage forms a precursor to one type of bone and persists at the articular surfaces on the bones of all movable joints.

The chondrocytes within cartilage may occur singly but are frequently clustered. Chondrocytes occupy cavities, called **lacunae** (*lă-kyoo′ne*—singular *lacuna*), within the matrix. Most cartilage is surrounded by a dense irregular connective tissue called **perichondrium** (*per″ĭ-kon′dre-um*). Cartilage at the articular surfaces of bones (articular cartilage) lacks a perichondrium. Because mature cartilage is avascular, it must receive nutrients through diffusion from the perichondrium and the surrounding tissue. For this reason, cartilaginous tissue has a slow rate of mitotic activity; if damaged, it heals with difficulty.

There are three kinds of cartilage: *hyaline (hi′ă-līn) cartilage*, *fibrocartilage*, and *elastic cartilage*. They are distinguished by the type and amount of fibers embedded within the matrix.

Hyaline Cartilage

Hyaline cartilage, commonly called "gristle," has a homogeneous, bluish-staining matrix in which the collagenous fibers are so fine that they can be observed only with an electron microscope. When viewed through a light microscope, hyaline cartilage has a clear, glassy appearance (fig. 4.20).

Hyaline cartilage is the most abundant cartilage within the body. It covers the articular surfaces of bones, supports the tubular trachea and bronchi of the respiratory system, reinforces the nose, and forms the flexible bridge, called **costal cartilage,** between the anterior portion of each of the first 10 ribs and the sternum. Most of the bones of the body form first as hyaline cartilage and later become bone in a process called *endochondral ossification*.

lacuna: L. *lacuna*, hole or pit
hyaline: Gk. *hyalos*, glass

Fibrocartilage

Fibrocartilage has a matrix that is reinforced with numerous collagenous fibers (fig. 4.21). It is a durable tissue adapted to withstand tension and compression. It is found at the symphysis pubis, where the two pelvic bones articulate, and between the vertebrae as intervertebral discs. It also forms the cartilaginous wedges within the knee joint, called *menisci* (see chapter 8).

By the end of the day, the intervertebral discs of the vertebral column are somewhat compacted. So a person is actually slightly shorter in the evening than in the morning, following a recuperative rest. Aging, however, brings with it a gradual compression of the intervertebral discs that is irreversible.

Elastic Cartilage

Elastic cartilage is similar to hyaline cartilage except for the presence of abundant elastic fibers that make elastic cartilage very flexible without compromising its strength (fig. 4.22). The numerous elastic fibers also give it a yellowish appearance. This tissue is found in the outer ear, portions of the larynx, and in the auditory canal.

The three types of cartilage are summarized in table 4.4.

Bone Tissue

Bone tissue is the most rigid of all the connective tissues. Unlike cartilage, bone tissue has a rich vascular supply and is the site of considerable metabolic activity. The hardness of bone is largely due to the calcium phosphate (calcium hydroxyapatite) deposited within the intercellular matrix. Numerous collagenous fibers, also embedded within the matrix, give bone some flexibility.

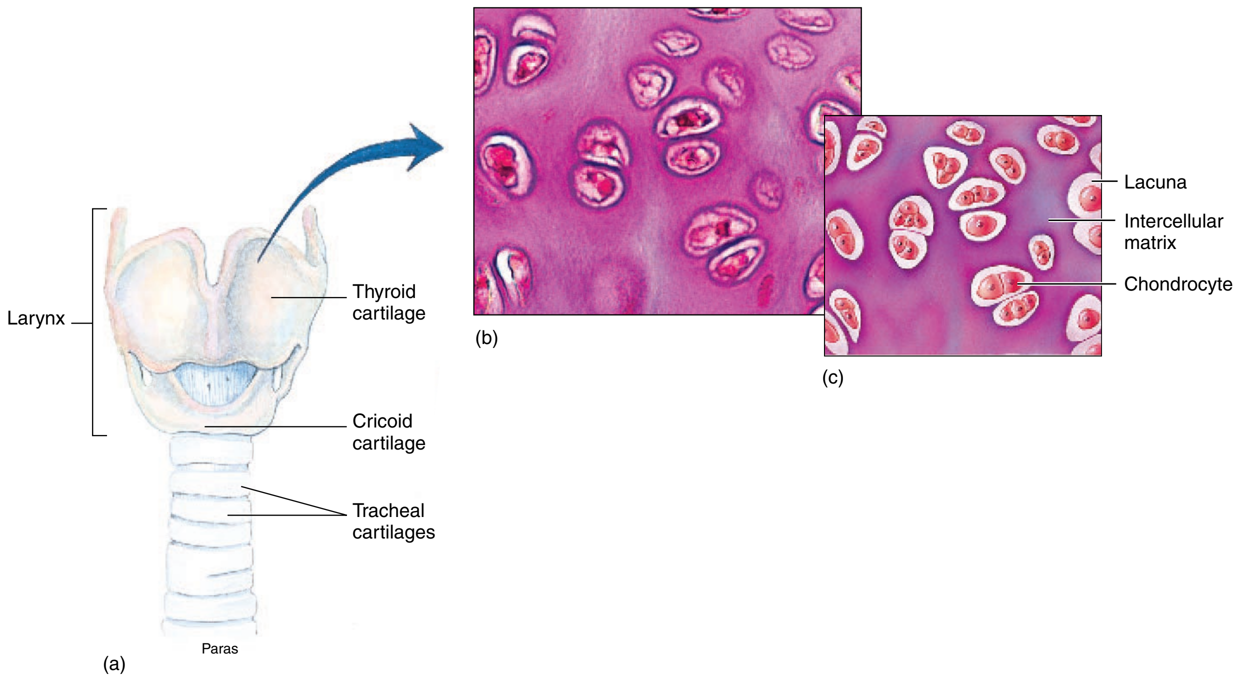

FIGURE 4.20 Hyaline cartilage is the most abundant cartilage in the body. It occurs in places such as the larynx (*a*), trachea, portions of the rib cage, and embryonic skeleton. (*b*) A photomicrograph of the tissue and (*c*) a labeled diagram.

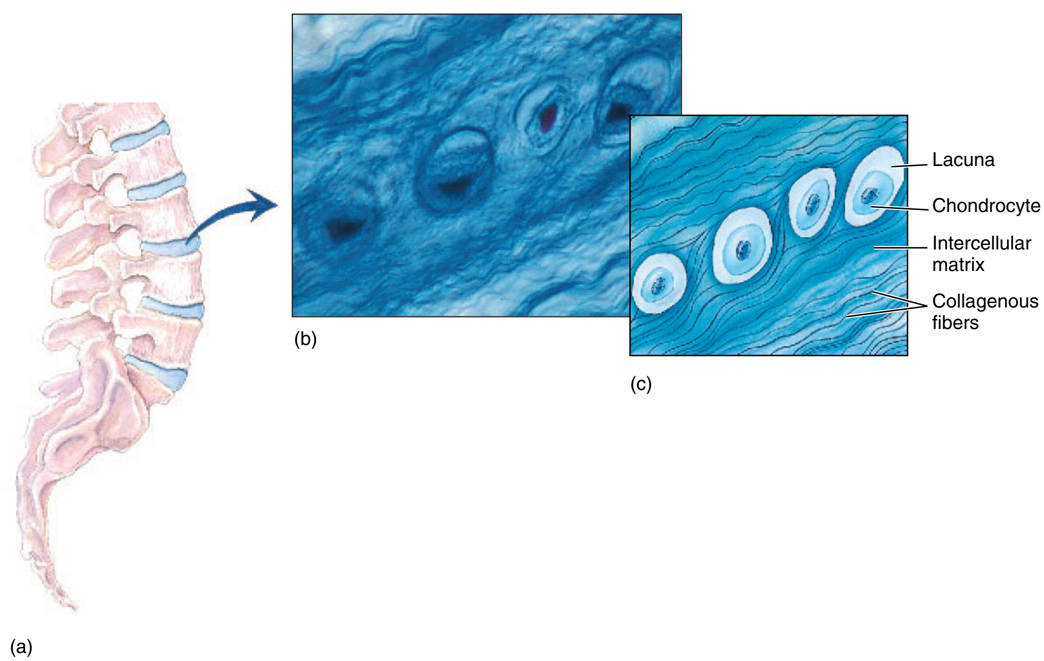

FIGURE 4.21 Fibrocartilage is located at the symphysis pubis, within the knee joints, and between the vertebrae as the intervertebral discs (*a*). A photomicrograph of the tissue is shown in (*b*) and a labeled diagram in (*c*).

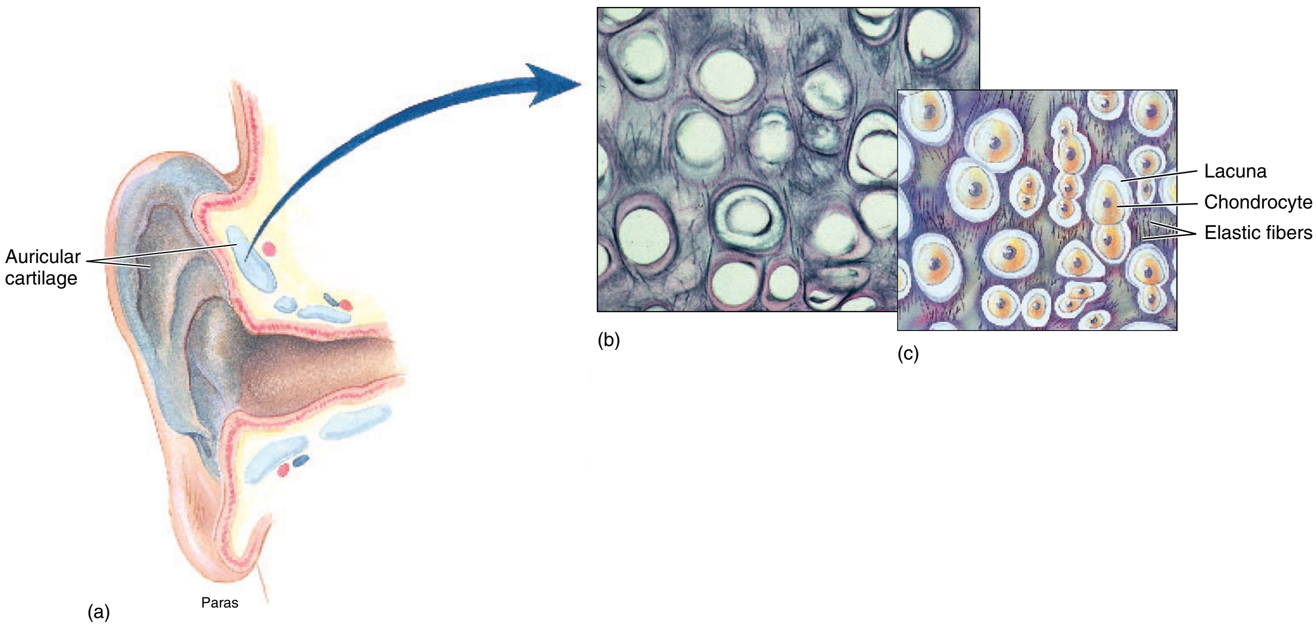

FIGURE 4.22 Elastic cartilage gives support to the outer ear (*a*), auditory canal, and parts of the larynx. A photomicrograph of the tissue is shown in (*b*) and a labeled diagram in (*c*).

TABLE 4.4 Summary of Cartilage

Type	Structure and Function	Location
Hyaline cartilage	Homogeneous matrix with extremely fine collagenous fibers; provides flexible support, protects, is precursor to bone	Articular surfaces of bones, nose, walls of respiratory passages, fetal skeleton
Fibrocartilage	Abundant collagenous fibers within matrix; supports, withstands compression	Symphysis pubis, intervertebral discs, knee joint
Elastic cartilage	Abundant elastic fibers within matrix; supports, provides flexibility	Framework of outer ear, auditory canal, portions of larynx

When bone is placed in a weak acid, the calcium salts dissolve away and the bone becomes pliable. It retains its basic shape but can be easily bent and twisted (fig. 4.23). In calcium deficiency diseases, such as *rickets,* the bone tissue becomes pliable and bends under the weight of the body (see fig. 5.11).

Based on porosity, bone tissue is classified as either compact or spongy, and most bones have both types (fig. 4.24). **Compact** (*dense*) **bone tissue** constitutes the hard outer portion of a bone, and **spongy** (*cancellous*) **bone tissue** constitutes the porous, highly vascular inner portion. The outer surface of a bone is covered by a connective tissue layer called the *periosteum* that serves as a site of attachment for ligaments and tendons, provides protection, and gives durable strength to the bone. Spongy bone tissue makes the bone lighter and provides a space for red bone marrow, where blood cells are produced.

In compact bone tissue, mature bone cells, called **osteocytes,** are arranged in concentric layers around a **central**

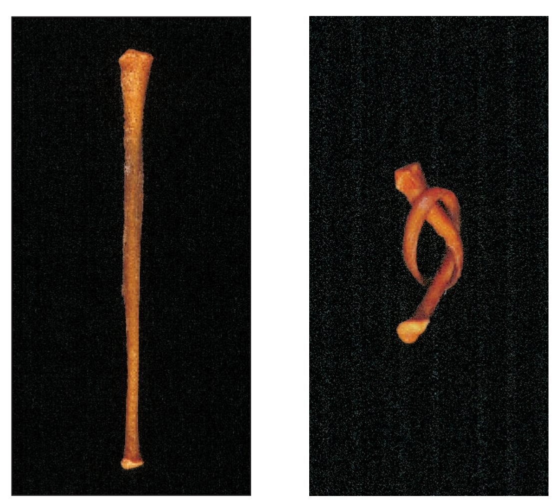

FIGURE 4.23 A bone soaked in a weak acid, such as the acidic acid in vinegar, demineralizes and becomes flexible.

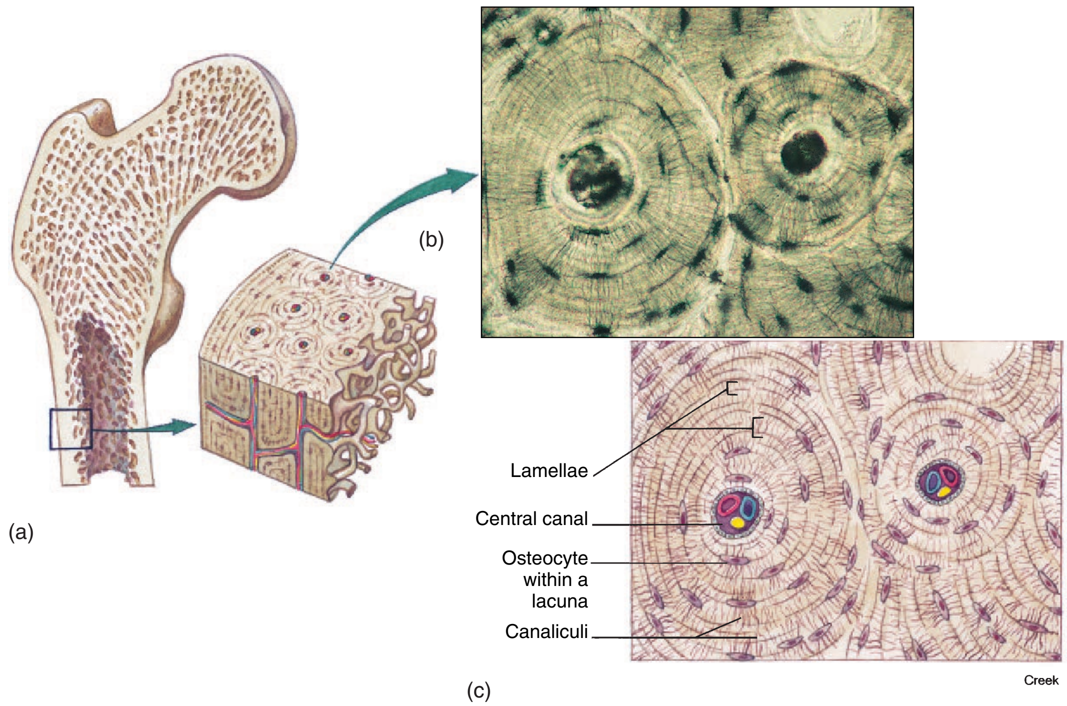

FIGURE 4.24 Bone (*a*) consists of compact and spongy tissues. (*b*) A photomicrograph of compact bone tissue and (*c*) a labeled diagram.

(haversian) **canal,** which contains a vascular and nerve supply. Each osteocyte occupies a cavity called a **lacuna.** Radiating from each lacuna are numerous minute canals, or **canaliculi,** which traverse the dense matrix of the bone tissue to adjacent lacunae. Nutrients diffuse through the canaliculi to reach each osteocyte. The matrix is deposited in concentric layers called **lamellae.** Bone tissue is described in detail in chapter 6.

Blood (Vascular Tissue)

Blood, or **vascular tissue,** is a highly specialized fluid connective tissue that plays a vital role in maintaining homeostasis. The cells, or **formed elements,** of blood are suspended in a liquid matrix called **blood plasma** (fig. 4.25). The three types of formed elements are **erythrocytes** (red blood cells), **leukocytes** (white blood cells), and **thrombocytes** (platelets). Blood is discussed fully in chapter 16.

haversian canal: from Clopton Havers, English anatomist, 1650–1702
erythrocyte: Gk. *erythros,* red; *kytos,* hollow (cell)
leukocyte: Gk. *leukos,* white; *kytos,* hollow (cell)
thrombocyte: Gk. *thrombos,* a clot; *kytos,* hollow (cell)

An injury to a portion of the body may stimulate tissue repair activity, usually involving connective tissue. A minor scrape or cut results in platelet and plasma activity of the exposed blood and the formation of a scab. The epidermis of the skin regenerates beneath the scab. A severe open wound heals through connective tissue granulation. In this process, collagenous fibers form from surrounding fibroblasts to strengthen the traumatized area. The healed area is known as a *scar.*

Knowledge Check

9. List the basic types of connective tissue and describe the structure, function, and location of each.
10. Which of the previously discussed connective tissues function to protect body organs? Which type is phagocytic? Which types bind and support various structures? Which types are associated in some way with the skin?
11. What is the developmental significance of mesenchyme and how does it differ functionally from adult connective tissue?
12. Briefly describe reticular fibers, fibroblasts, collagenous fibers, elastic fibers, and mast cells.

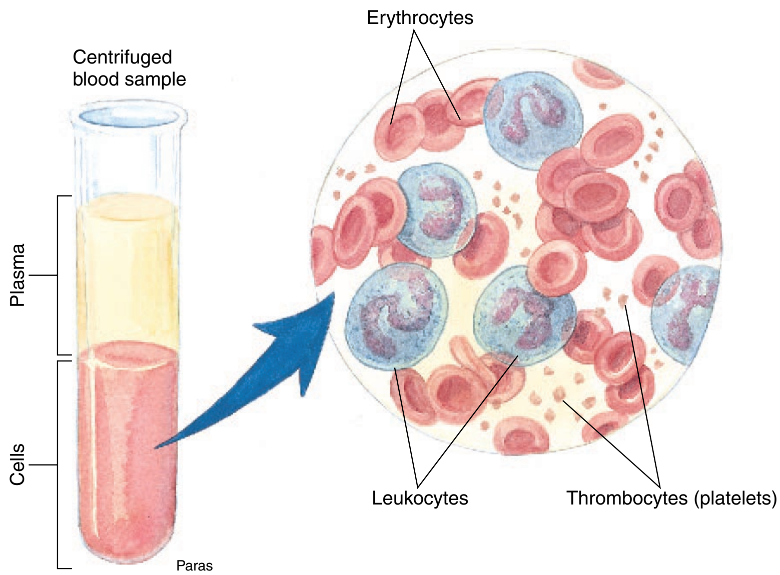

FIGURE 4.25 Blood consists of formed elements—erythrocytes (red blood cells), leukocytes (white blood cells), and thrombocytes (platelets)—suspended in a liquid plasma matrix.

MUSCLE TISSUE

Muscle tissue is responsible for the movement of materials through the body, the movement of one part of the body with respect to another, and for locomotion. Fibers in the three kinds of muscle tissue are adapted to contract in response to stimuli.

Objective 10 Describe the structure, location, and function of the three types of muscle tissue.

Muscle tissue is unique in its ability to contract, and thus make movement possible. The muscle cells, or *fibers*, are elongated in the direction of contraction, and movement is accomplished through the shortening of the fibers in response to a stimulus. Muscle tissue is derived from mesoderm. There are three types of muscle tissue in the body: *smooth*, *cardiac*, and *skeletal muscle tissue* (fig. 4.26).

Smooth Muscle

Smooth muscle tissue is common throughout the body, occurring in many of the systems. For example, in the wall of the GI tract it provides the contractile force for the peristaltic movements involved in the mechanical digestion of food. Smooth muscle is also found in the walls of arteries, the walls of respiratory passages, and in the urinary and reproductive ducts. The contraction of smooth muscle is under autonomic (involuntary) nervous control, and is discussed in more detail in chapter 13.

Smooth muscle fibers are long, spindle-shaped cells. They contain a single nucleus and lack striations. These cells are usually grouped together in flattened sheets, forming the muscular portion of a wall around a lumen.

Cardiac Muscle

Cardiac muscle tissue makes up most of the wall of the heart. This tissue is characterized by bifurcating (branching) fibers, each with a single, centrally positioned nucleus, and by transversely positioned **intercalated** (*in-ter′kă-lāt-ed*) **discs.** Intercalated discs help to hold adjacent cells together and transmit the force of contraction from cell to cell. Like skeletal muscle, cardiac muscle is striated, but unlike skeletal muscle it experiences rhythmic involuntary contractions. Cardiac muscle is further discussed in chapter 16.

Skeletal Muscle

Skeletal muscle tissue attaches to the skeleton and is responsible for voluntary body movements. Each elongated, multinucleated fiber has distinct transverse striations. Fibers of this muscle tissue are grouped into parallel fasciculi (bundles) that can be seen without a microscope in fresh muscle. Both cardiac and skeletal muscle fibers cannot replicate once tissue formation has been completed shortly after birth. Skeletal muscle tissue is further discussed in chapter 9. The three types of muscle tissue are summarized in table 4.5.

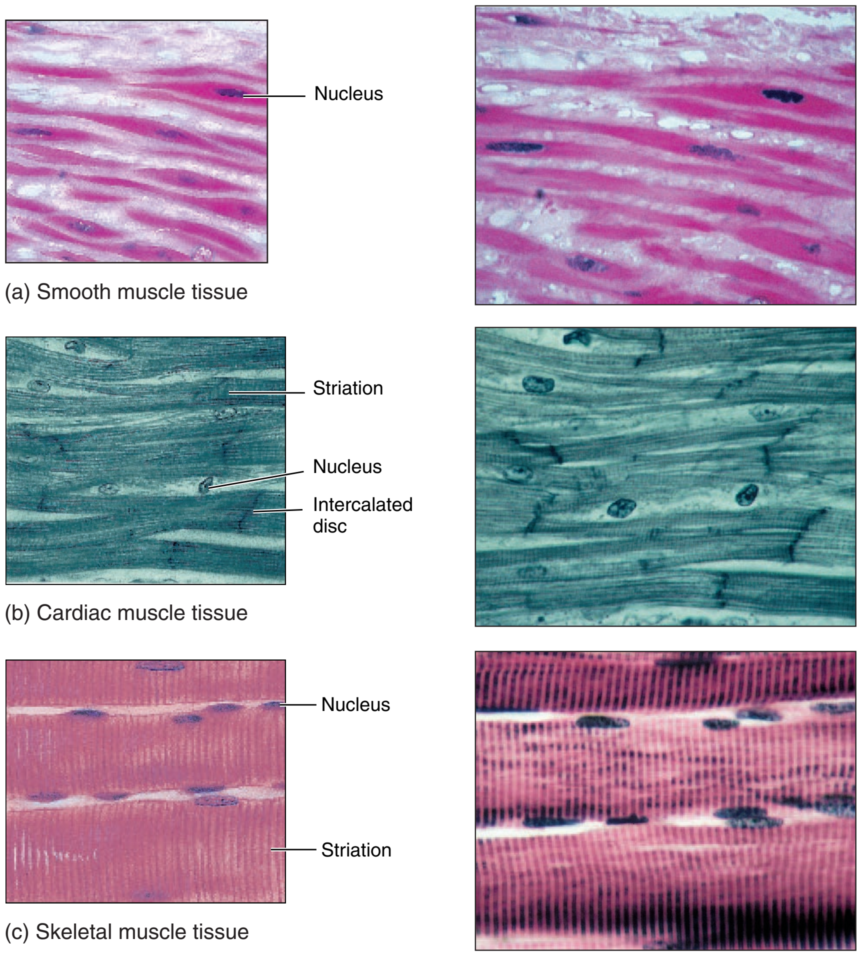

FIGURE 4.26 Muscle tissue: (*a*) smooth, (*b*) cardiac, and (*c*) skeletal.

TABLE 4.5 Summary of Muscle Tissue

Type	Structure and Function	Location
Smooth	Elongated, spindle-shaped fiber with single nucleus; involuntary movements of internal organs	Walls of hollow internal organs
Cardiac	Branched, striated fiber with single nucleus and intercalated discs; involuntary rhythmic contraction	Heart wall
Skeletal	Multinucleated, striated, cylindrical fiber that occurs in fasciculi; voluntary movement of skeletal parts	Associated with skeleton; spans joints of skeleton via tendons

Knowledge Check

13. Describe the general characteristics of muscle tissue. What is meant by *voluntary* and *involuntary* as applied to muscle tissue?
14. Distinguish between smooth, cardiac, and skeletal muscle tissue on the bases of structure, location, and function.

NERVOUS TISSUE

Nervous tissue is composed of neurons, which respond to stimuli and conduct impulses to and from all body organs, and neuroglia, which functionally support and physically bind neurons.

Objective 11 Describe the basic characteristics and functions of nervous tissue.

Objective 12 Distinguish between neurons and neuroglia.

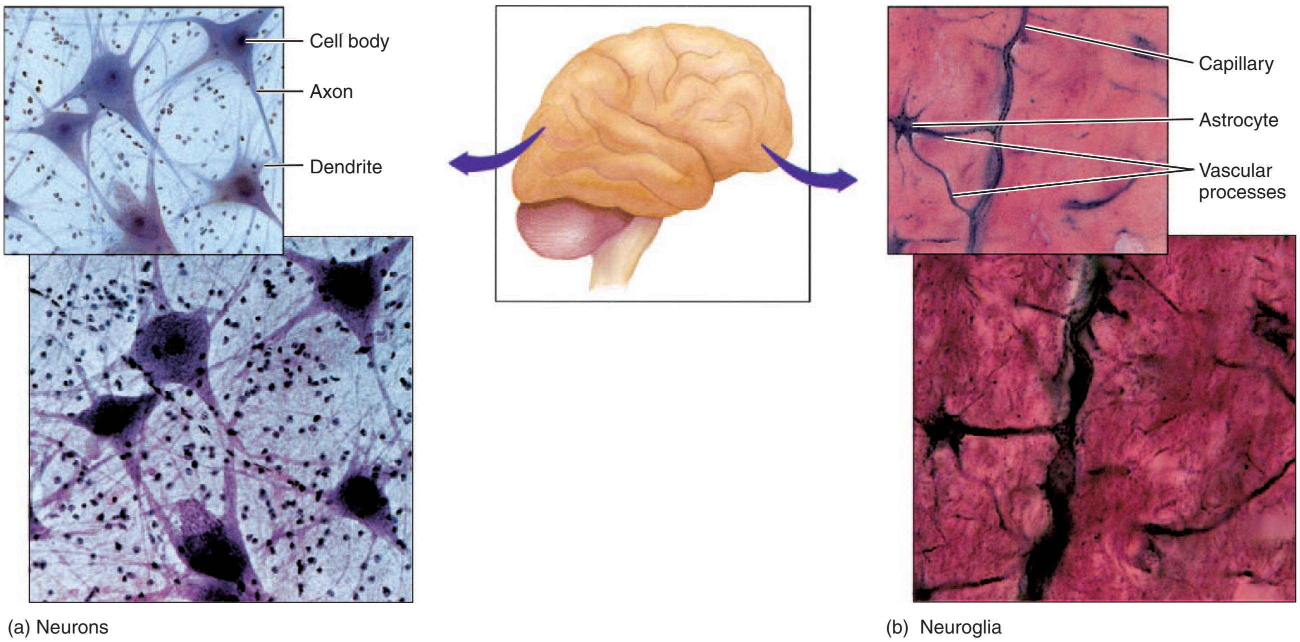

FIGURE 4.27 Nervous tissue is found within the brain, spinal cord, nerves, and ganglia. It consists of two principal kinds of cells: (*a*) neurons and (*b*) neuroglia.

Neurons

Although there are several kinds of neurons (*noor′onz*) in nervous tissue, they all have three principal components: (1) a cell body, or perikaryon; (2) dendrites; and (3) an axon (fig. 4.27). **Dendrites** are branched processes that receive stimuli and conduct nerve impulses toward the cell body. The **cell body,** or **perikaryon** (*per″ĭ-kar′e-on*), contains the nucleus and specialized organelles and microtubules. The **axon** is a cytoplasmic extension that conducts nerve impulses away from the cell body. The term **nerve fiber** refers to any process extending from the cell body of a neuron and the myelin sheath that surrounds it (see fig. 11.5).

Neurons derive from ectoderm and are the basic structural and functional units of the nervous system. They are specialized to respond to physical and chemical stimuli, convert stimuli into nerve impulses, and conduct these impulses to other neurons, muscle fibers, or glands. Of all the body's cells, neurons are probably the most specialized. As with muscle cells, the number of neurons is established prenatally (before birth); thereafter, they lack the ability to undergo mitosis, although under certain circumstances a severed portion can regenerate.

neuron: Gk. *neuron*, sinew or nerve
perikaryon: Gk. *peri*, around; *karyon*, nut or kernel

Neuroglia

In addition to neurons, nervous tissue contains neuroglia (*noo-rog′le-ă*) (fig. 4.27). Neuroglial cells, sometimes called *glial cells*, are about 5 times as abundant as neurons and have limited mitotic abilities. They do not transmit impulses but support and bind neurons together. Certain neuroglial cells are phagocytic; others assist in providing sustenance to the neurons.

Neurons and neuroglia are discussed in detail in chapter 11.

Knowledge Check

15. Compare and contrast neurons and neuroglia in terms of structure, function, and location.
16. List the structures of a neuron following the sequence of a nerve impulse passing through the cell.

CLINICAL CONSIDERATIONS

As stated at the beginning of this chapter, the study of tissues is extremely important in understanding the structure and function of organs and body systems. Histology has immense clinical

neuroglia: Gk. *neuron*, nerve; *glia*, glue

importance as well. Many diseases are diagnosed through microscopic examination of tissue sections. Even in performing an autopsy, an examination of various tissues is vital in establishing the cause of death.

Several sciences are concerned with specific aspects of tissues. *Histopathology* is the study of diseased tissues. *Histochemistry* is concerned with the physiology of tissues as they maintain homeostasis. *Histotechnology* explores the ways in which tissues can be better stained and observed. In all of these disciplines, a thorough understanding of normal, or healthy, tissues is imperative for recognizing altered, or abnormal, tissues.

Changes in Tissue Composition

Most diseases alter tissue structure *locally*, where the disease is prevalent. Some diseases, however, called *general conditions*, cause changes that are far removed from the locus of the disease. **Atrophy** (wasting of body tissue), for example, may be limited to a particular organ where the disease interferes with the metabolism of that organ, but it may also involve an entire limb if nourishment or nerve impulses are impaired. *Muscle atrophy* can be caused by a disease of the nervous system like polio, or it can be the result of a diminished blood supply to a muscle. *Senescence (sĕ-nĕ′sens) atrophy*, or simply *senescence*, is the natural aging of tissues and organs within the body. **Disuse atrophy** is a local atrophy that results from the inactivity of a tissue or organ. Muscular dystrophy causes a disuse atrophy that decreases muscle size and strength because of the loss of sarcoplasm within the muscle.

Necrosis (*nĕ-kro′sis*) is death of cells or tissues within the living body. It can be recognized by physical changes in the dead tissues. Necrosis can be caused by severe injury; physical agents (trauma, heat, radiant energy, chemical poisons); or poor nutrition of tissues. When histologically examined, the necrotic tissue usually appears opaque, with a whitish or yellowish cast. **Gangrene** is a massive necrosis of tissue accompanied by an invasion of microorganisms that live on decaying flesh.

Somatic death is the death of the body as a whole. Following somatic death, tissues undergo irreversible changes, such as **rigor mortis** (muscular rigidity), clotting of the blood, and cooling of the body. Postmortem (after death) changes occur under varying conditions at predictable rates, which is useful in estimating the approximate time of death.

Tissue Analysis

In diagnosing a disease, it is frequently important to examine tissues from a living person histologically. When this is necessary, a **biopsy** (*bi′op-se*) (removal of a section of living tissue) is performed. There are several techniques for biopsies. *Surgical removal* is usually done on large masses or tumors. *Curettage (kyoo″ rĕ-tazh′)* involves cutting and scraping tissue, as may be done in examining for uterine cancer. In a *percutaneous needle biopsy*, a biopsy needle is inserted through a small skin incision and tissue samples are withdrawn. Both normal and diseased tissues are removed for purposes of comparison.

Preparing tissues for examination is a multistep process. **Fixation** is fundamental for all histological preparation. It is the rapid killing, hardening, and preservation of tissue to maintain its existing structure. **Embedding** the tissue in a supporting medium such as paraffin wax usually follows fixation. The next step, **sectioning** the tissue into extremely thin slices, is followed by **mounting** the specimen on a slide. Some tissues are fixed by rapid freezing and then sectioned while frozen, making embedding unnecessary. Frozen sections enable the pathologist to make a quick diagnosis during a surgical operation. These are done frequently, for example, in cases of suspected breast cancer. **Staining** is the next step. Hematoxylin and eosin (H & E) stains are routinely used on all tissue specimens. They give a differential blue and red color to the basic and acidic structures within the tissue. Other dyes may be needed to stain for specific structures.

Examination is first done with the unaided eye and then with a microscope. Practically all histological conditions can be diagnosed with low magnification (40×). Higher magnification is used to clarify specific details. Further examination may be performed with an electron microscope, which reveals the intricacy of cellular structure. Histological observation provides the foundation for subsequent diagnosis, prognosis, treatment, and reevaluation.

Tissue Transplantation

In the last two decades, medical science has made tremendous advancements in tissue transplants. Tissue transplants are necessary for replacing nonfunctional, damaged, or lost body parts. The most successful transplant is one where tissue is taken from one place on a person's body and moved to another place, such as a skin graft from the thigh to replace burned tissue of the hand. Transfer of one's own tissue is termed an **autograft. Isografts** are transplants between genetically identical individuals, the only example being identical twins. These transplants also have a high success rate. **Allografts,** or **homotransplants,** are grafts between individuals of the same species but of different genotype, and **xenografts,** or **heterografts,** are grafts between individuals of different species. An example of a xenograft is the transplant of a pig valve to replace a dysfunctional or diseased human heart valve. Both allografts and xenografts present the problem of a possible *tissue-rejection reaction*. When this occurs, the recipient's immune mechanisms are triggered, and the donor's tissue is identified as foreign and is destroyed. The reaction can be minimized by "matching" recipient and donor tissue. Immunosuppressive drugs also may lessen the rejection rate. These drugs act by interfering with the recipient's immune mechanisms. Unfortunately, immunosuppressive drugs may also lower the recipient's resistance to infections. New techniques involving blood transfusions from donor to recipient before a transplant are proving successful. In any event, tissue transplants are an important aspect of medical research, and significant breakthroughs are on the horizon.

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atrophy: Gk. *a*, without; *trophe*, nourishment

necrosis: Gk. *nekros*, corpse

gangrene: Gk. *gangraina*, gnaw or eat

The use of fetal tissue transplantation to grow new tissues in adult patients has shown promise for the treatment of many clinical problems of tissues or organs. Desired cells are harvested from as many as 15 human fetuses and are then quickly implanted into the transplant recipient. The fetal cells are allowed to follow a normal course of maturation within the adult patient, with the hope that a healthy, fully functional body structure will develop. Because the typical source for fetal tissues is aborted fetuses, this procedure has become a medical ethical dilemma.

Clinical Case Study Answer

The doctor clarifies this paradox by explaining that some cells in the body undergo structural changes in response to unusual stimuli. Cigarette smoking, for example, impairs ciliary movement, inhibits function of alveolar macrophages, and leads to enlargement and proliferation of mucus-secreting glands in the airways. The net effect of this is chronic bronchitis.

Similarly, acid reflux into the esophagus can induce a transformation of stratified squamous epithelium to simple columnar epithelium. This condition is termed Barrett's esophagus and is a precursor to esophageal cancer in 5% of cases.

Chapter Summary

Definition and Classification of Tissues (p. 78)

1. Tissues are aggregations of similar cells that perform specific functions. The study of tissues is called histology.
2. Cells are surrounded and bound together by an intercellular matrix, the composition of which varies from solid to liquid.
3. The four principal types of tissues are epithelial tissue, connective tissue, muscle tissue, and nervous tissue.

Epithelial Tissue (pp. 79–89)

1. Epithelia are derived from all three germ layers and may be one or several layers thick. The lower surface of most membranous epithelia is supported by a basement membrane.
2. Simple epithelium consists of a single cell layer that varies in shape and surface characteristics. It is located where diffusion, filtration, and secretion occur.
3. Stratified epithelium consists of two or more layers of cells and is adapted for protection.
4. Transitional epithelium lines the urinary bladder, ureters, and parts of the urethra. The cells of transitional epithelium permit distension.
5. Body membranes are composed of thin layers of epithelial tissue that may be coupled with supporting connective tissue. The two basic types are mucous membranes and serous membranes.
6. Glandular epithelia are derived from developing epithelial tissue and function as secretory exocrine glands.

Connective Tissue (pp. 89–98)

1. Connective tissues are derived from mesoderm and, with the exception of cartilage, are highly vascular.
2. Connective tissue proper contains fibroblasts, collagenous fibers, and elastic fibers within a flexible ground substance.
3. Cartilage provides a flexible framework for many organs. It consists of a semisolid matrix of chondrocytes and various fibers.
4. Bone tissue consists of osteocytes, collagenous fibers, and a durable matrix of mineral salts.
5. Blood consists of formed elements (erythrocytes, leukocytes, and thrombocytes) suspended in a fluid plasma matrix.

Muscle Tissue (pp. 99–100)

1. Muscle tissues (smooth, cardiac, and skeletal) are responsible for the movement of materials through the body, the movement of one part of the body with respect to another, and for locomotion.
2. Fibers in muscle tissue are adapted to contract in response to stimuli.

Nervous Tissue (pp. 100–101)

1. Neurons are the functional units of the nervous system. They respond to stimuli and conduct nerve impulses to and from all body organs.
2. Neuroglia support and bind neurons. Some are phagocytic; others provide sustenance to neurons.

Review Activities

Objective Questions

1. Which of the following is *not* a principal type of body tissue?
   (a) nervous
   (b) integumentary
   (c) connective
   (d) muscular
   (e) epithelial
2. Which statement regarding tissues is *false?*
   (a) They are aggregations of similar kinds of cells that perform specific functions.
   (b) All of them are microscopic and are studied within the science of histology.
   (c) All of them are stationary within the body at the location of their developmental origin.
   (d) An organ is composed of two or more tissue types.
3. Connective tissue, muscle, and the dermis of the skin derive from embryonic
   (a) mesoderm.
   (b) endoderm.
   (c) ectoderm.
4. Which statement regarding epithelia is *false?*
   (a) They are derived from mesoderm, ectoderm, and endoderm.
   (b) They are strengthened by elastic and collagenous fibers.

(c) One side is exposed to a lumen, a body cavity, or to the external environment.
(d) They have very little intercellular matrix.

5. A gastric ulcer of the stomach would involve
   (a) simple cuboidal epithelium.
   (b) transitional epithelium.
   (c) simple ciliated columnar epithelium.
   (d) simple columnar epithelium.
6. Which structural and secretory designation describes mammary glands?
   (a) acinar, apocrine
   (b) tubular, holocrine
   (c) tubular, merocrine
   (d) acinar, holocrine
7. Dense regular connective tissue is found in
   (a) blood vessels. (c) tendons.
   (b) the spleen. (d) the wall of the uterus.
8. The phagocytic connective tissue found in the lymph nodes, liver, spleen, and bone marrow is
   (a) reticular. (c) mesenchyme.
   (b) loose fibrous. (d) elastic.
9. Cartilage is slow in healing following an injury because
   (a) it is located in body areas that are under constant physical strain.
   (b) it is avascular.
   (c) its chondrocytes cannot reproduce.
   (d) it has a semisolid matrix.
10. Cardiac muscle tissue has
   (a) striations.
   (b) intercalated discs.
   (c) rhythmic involuntary contractions.
   (d) all of the above.

Essay Questions

1. Define *tissue*. What are the differences between cells, tissues, glands, and organs?
2. What physiological functions are epithelial tissues adapted to perform?
3. Identify the epithelial tissue
   (a) in the pulmonary alveoli of the lungs,
   (b) lining the lumen of the GI tract,
   (c) in the outer layer of skin,
   (d) lining the cavity of the urinary bladder,
   (e) lining the uterine tube, and
   (f) lining the trachea and bronchial tubes.

   Describe the function of the tissue in each case.
4. Why are both keratinized and nonkeratinized epithelia found within the body?
5. Describe how epithelial glands are classified according to structural complexity and secretory function.
6. Identify the connective tissue
   (a) on the surface of the heart and surrounding the kidneys,
   (b) within the wall of the aorta,
   (c) forming the symphysis pubis,
   (d) supporting the outer ear,
   (e) forming the lymph nodes, and
   (f) forming the tendo calcaneus.

   Describe the function of the tissue in each case.
7. Compare and contrast the structure and location of the following: reticular fibers, collagenous fibers, elastin, fibroblasts, and mast cells.
8. What is the relationship between adipose cells and fat? Discuss the function of fat and explain the potential danger of excessive fat.
9. Discuss the mitotic abilities of each of the four principal tissue types.
10. Define the following terms: *atrophy*, *necrosis*, *gangrene*, and *somatic death*.

Critical-Thinking Questions

1. The function of a tissue is actually a function of its cells. And the function of a cell is a function of its organelles. Knowing this, what type of organelles would be particularly abundant in cardiac muscle tissue that requires a lot of energy; in reticular tissue within the liver, where cellular debris and toxins are ingested; and in dense regular connective tissue that consists of tough protein strands?
2. The aorta (a principal blood vessel) has three layers surrounding its lumen. What is the predominant tissue in each of the three layers and what is the adaptive function of each?
3. Your aunt was recently diagnosed as having brain cancer. In talking with your aunt's physician, she indicated that the cancer was actually a neuroglioma, and went on to say that cancer of neurons and muscle cells is a rare occurrence. Explain why neuroglial cells are much more susceptible to cancer than are neurons or muscle cells.
4. Compare the vascular supply of bones and ligaments and discuss how this may be relevant to the clinical course of an ankle sprain and an ankle fracture.
5. The connective tissue diseases are a group of disorders most likely caused by an abnormal immune response to a person's own connective tissue. The best known of these is rheumatoid arthritis, in which small joints of the body become inflamed and the articulating surfaces erode away. Knowing where connective tissue is found in the body, can you predict which organs might be involved in other connective tissue diseases?

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