Classification of Epithelial Tissue

Types of covering and lining epithelial tissue are classified according to two characteristics: the arrangement of cells into layers and the shapes of the cells (Figure 4.5).

1. ***Arrangement of cells in layers*** (Figure 4.5). The cells are arranged in one or more layers depending on function:
   a. *Simple epithelium* is a single layer of cells that functions in diffusion, osmosis, filtration, secretion, or absorption. **Secretion** is the production and release of substances such as mucus, sweat, or enzymes. **Absorption** is the intake of fluids or other substances such as digested food from the intestinal tract.
   b. *Pseudostratified epithelium* (*pseudo-* = false) appears to have multiple layers of cells because the cell nuclei lie at different levels and not all cells reach the apical surface; it is actually a simple epithelium because all its cells rest on the basement membrane. Cells that do extend to the apical surface may contain cilia; others (goblet cells) secrete mucus.
   c. *Stratified epithelium* (*stratum* = layer) consists of two or more layers of cells that protect underlying tissues in locations where there is considerable wear and tear.
2. ***Cell shapes*** (Figure 4.5). Epithelial cells vary in shape depending on their function:
   a. *Squamous* cells (SKWĀ-mus = flat) are thin, which allows for the rapid passage of substances through them.
   b. *Cuboidal* cells are as tall as they are wide and are shaped like cubes or hexagons. They may have microvilli at their apical surface and function in either secretion or absorption.
   c. *Columnar* cells are much taller than they are wide, lik umns, and protect underlying tissues. Their apical su may have cilia or microvilli, and they often are speci: for secretion and absorption.
   d. *Transitional* cells change shape, from squamous to c dal and back, as organs such as the urinary bladder s (distend) to a larger size and then collapse to a smalle

When we combine the two characteristics (arrangeme layers and cell shapes), we come up with the following ty epithelial tissues:

I. Simple epithelium
   A. Simple squamous epithelium
   B. Simple cuboidal epithelium
   C. Simple columnar epithelium (nonciliated and ciliate
   D. Pseudostratified columnar epithelium (nonciliated ciliated)

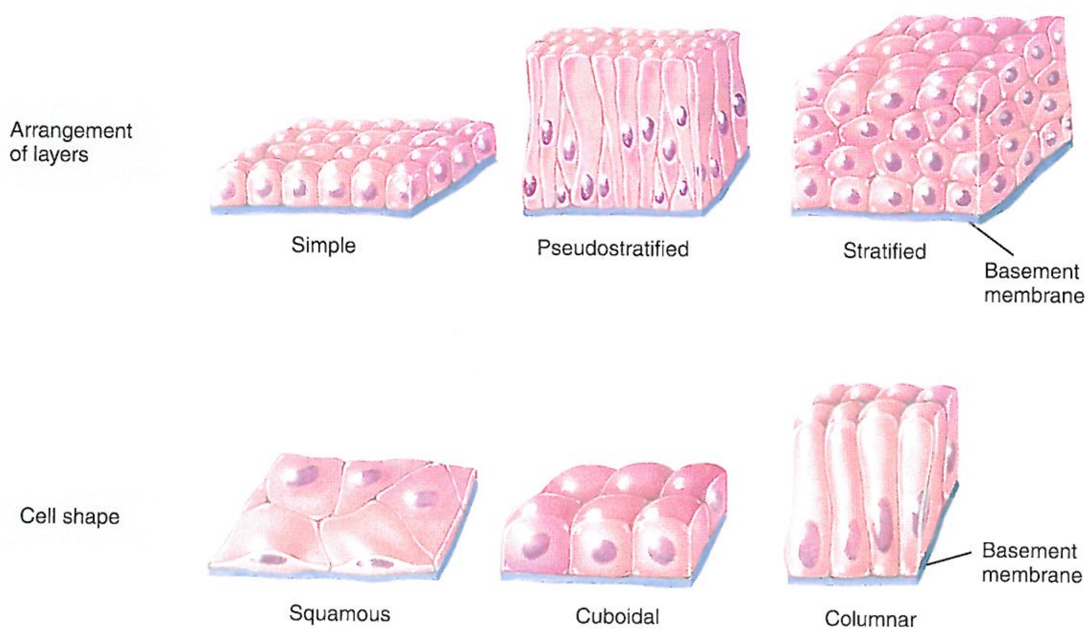
II. Stratified epithelium
   A. Stratified squamous epithelium (keratinized, when su cells are dead and become hardened, and nonkeratin when surface cells remain alive)*
   B. Stratified cuboidal epithelium*
   C. Stratified columnar epithelium*
   D. Transitional epithelium

We will now examine the important features of covering lining epithelium.

*This classification is based on the shape of the cells in the apical laye

Figure 4.5 **Cell shapes and arrangement of layers for covering and lining epithelium.**

Cell shapes and arrangement of layers are the bases for classifying covering and lining epithelium.



Which cell shape is best adapted for the rapid movement of substances from one cell to another?

Covering and Lining Epithelium

As noted earlier, covering and lining epithelium forms the outer covering of the skin and some internal organs. It also forms the inner lining of blood vessels, ducts, and body cavities, and the interior of the respiratory, digestive, urinary, and reproductive systems. Table 4.1 describes covering and lining epithelium in more detail. The discussion of each type consists of a photomicrograph, a corresponding diagram, and an inset that identifies a major location of the tissue in the body. Descriptions, locations, and functions of the tissues accompany each illustration.

TABLE 4.1

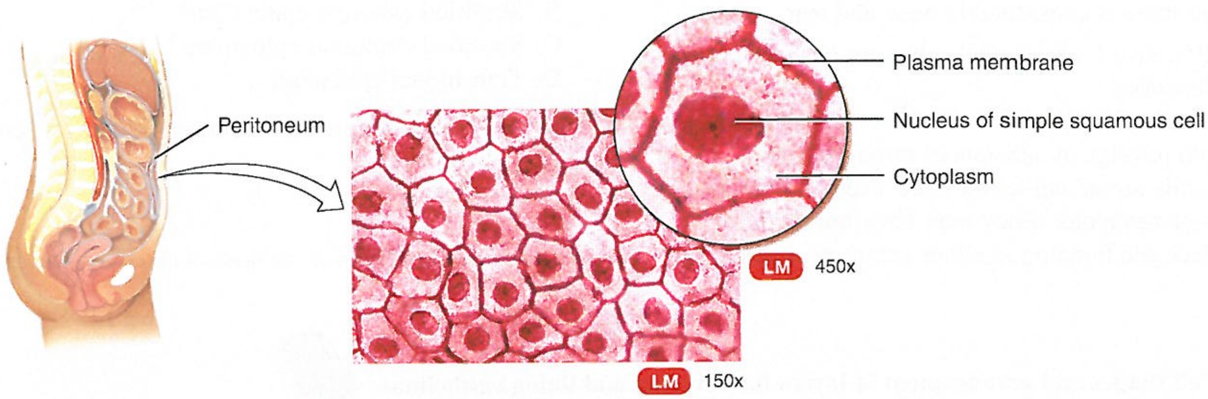
Epithelial Tissue: Covering and Lining Epithelium

A. SIMPLE SQUAMOUS EPITHELIUM

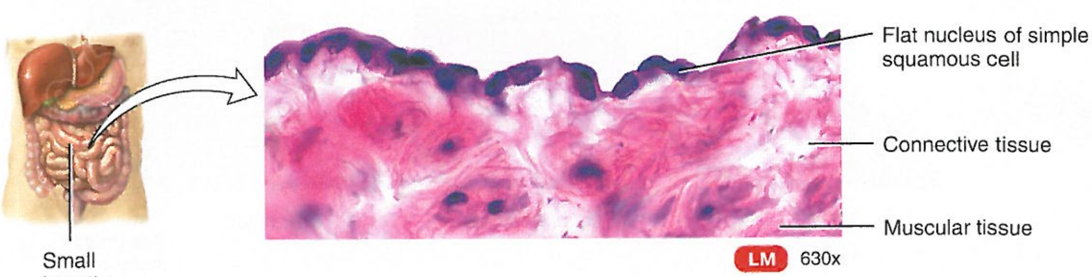
Description **Simple squamous epithelium** is a single layer of flat cells that resembles a tiled floor when viewed from apical surface; centrally located nucleus that is flattened and oval or spherical in shape.

Location Most commonly (1) lines the cardiovascular and lymphatic system (heart, blood vessels, lymphatic vessel linings), where it is known as **endothelium** (en′-dō-THĒ-lē-um; *endo-* = within; *-thelium* = covering), and (2) forms the epithelial layer of serous membranes (peritoneum, pleura, pericardium), where it is called **mesothelium** (mez′-ō-THĒ-lē-um; *meso-* = middle). Also found in air sacs of lungs, glomerular (Bowman's) capsule of kidneys, inner surface of tympanic membrane (eardrum).

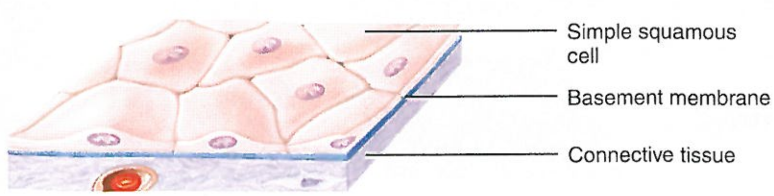
Function Present at sites of filtration (such as blood filtration in kidneys) or diffusion (such as diffusion of oxygen into blood vessels of lungs) and at site of secretion in serous membranes. Not found in body areas subject to mechanical stress (wear and tear).



Surface view of simple squamous epithelium of mesothelial lining of peritoneum



Sectional view of simple squamous epithelium (mesothelium) of peritoneum of small intestine



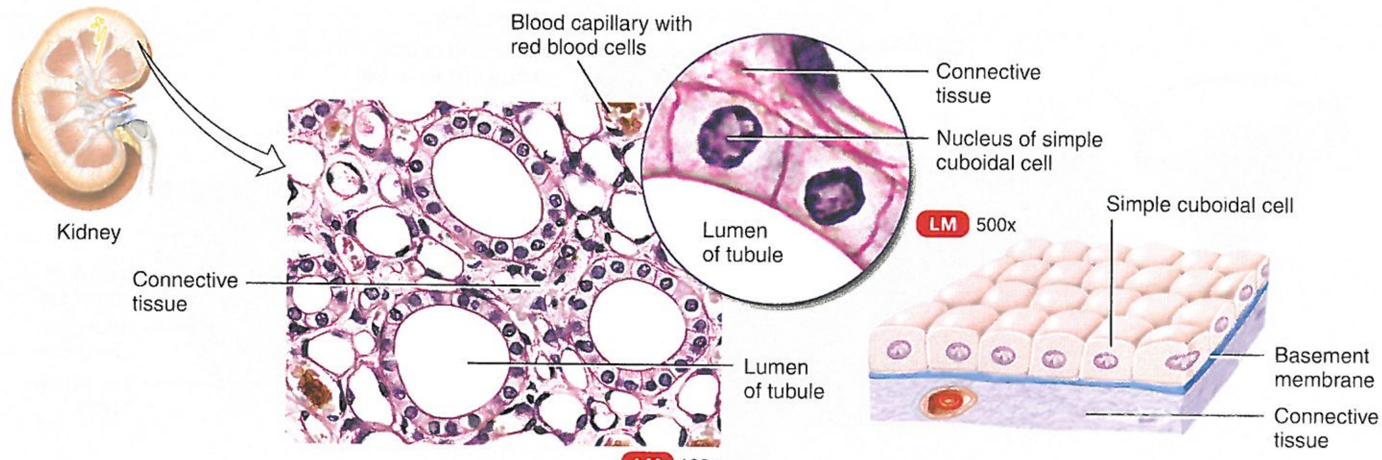
Simple squamous epithelium

B. SIMPLE CUBOIDAL EPITHELIUM

Description **Simple cuboidal epithelium** is a single layer of cube-shaped cells; round, centrally located nucleus. Cuboidal cell shape is obvious when tis is sectioned and viewed from the side. (Note: Strictly cuboidal cells could not form small tubes; these cuboidal cells are more pie-shaped bu nearly as high as they are wide at the base.)

Location Covers surface of ovary; lines anterior surface of capsule of lens of the eye; forms pigmented epithelium at posterior surface of retina of the eye; lines kidney tubules and smaller ducts of many glands; makes up secreting portion of some glands such as thyroid gland and ducts of sc glands such as pancreas.

Function Secretion and absorption.



Sectional view of simple cuboidal epithelium of urinary tubules

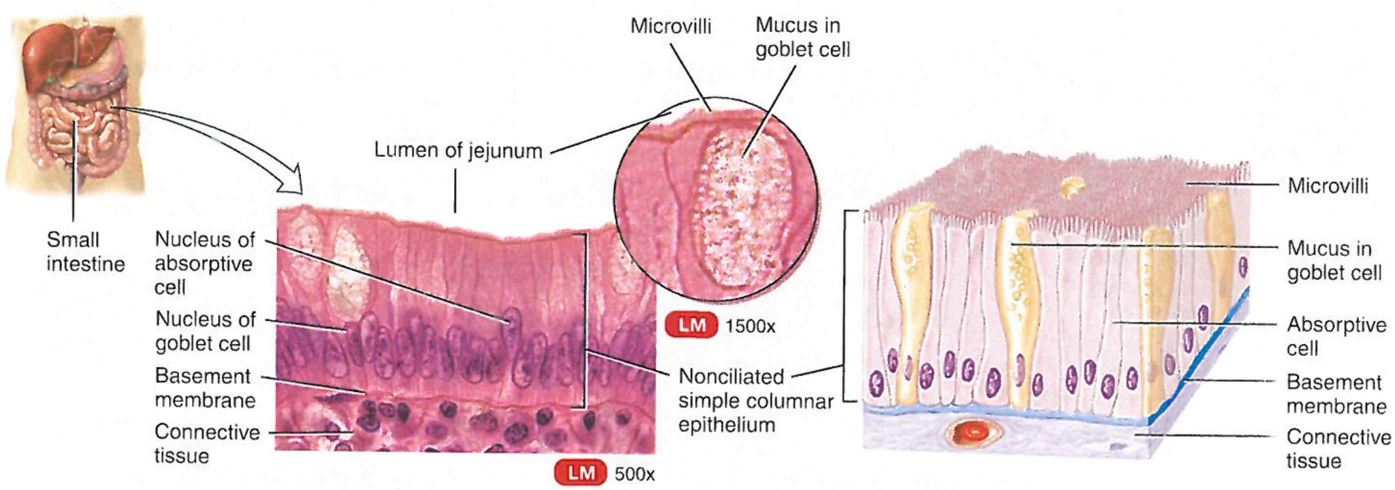
Simple cuboidal epithelium

C. NONCILIATED SIMPLE COLUMNAR EPITHELIUM

Description **Nonciliated simple columnar epithelium** is a single layer of nonciliated columnlike cells with oval nuclei near base of cells; contains (1) columnar epithelial cells with microvilli at apical surface and (2) goblet cells. **Microvilli**, fingerlike cytoplasmic projections, increase surface area of plasma membrane (see Figure 3.1), thus increasing cell's rate of absorption. **Goblet cells** are modified columnar epithelial cells that secrete mucus, a slightly sticky fluid, at their apical surfaces. Before release, mucus accumulates in upper portion of cell, causing it to bu and making the whole cell resemble a goblet or wine glass.

Location Lines gastrointestinal tract (from stomach to anus), ducts of many glands, and gallbladder.

Function Secretion and absorption; larger columnar cells contain more organelles and thus are capable of higher level of secretion and absorption than are cuboidal cells. Secreted mucus lubricates linings of digestive, respiratory, and reproductive tracts, and most of urinary tract; helps prevent destruction of stomach lining by acidic gastric juice secreted by stomach.



Sectional view of nonciliated simple columnar epithelium of lining of jejunum of small intestine

Nonciliated simple columnar epithelium

TABLE 4.1 CONTINUED

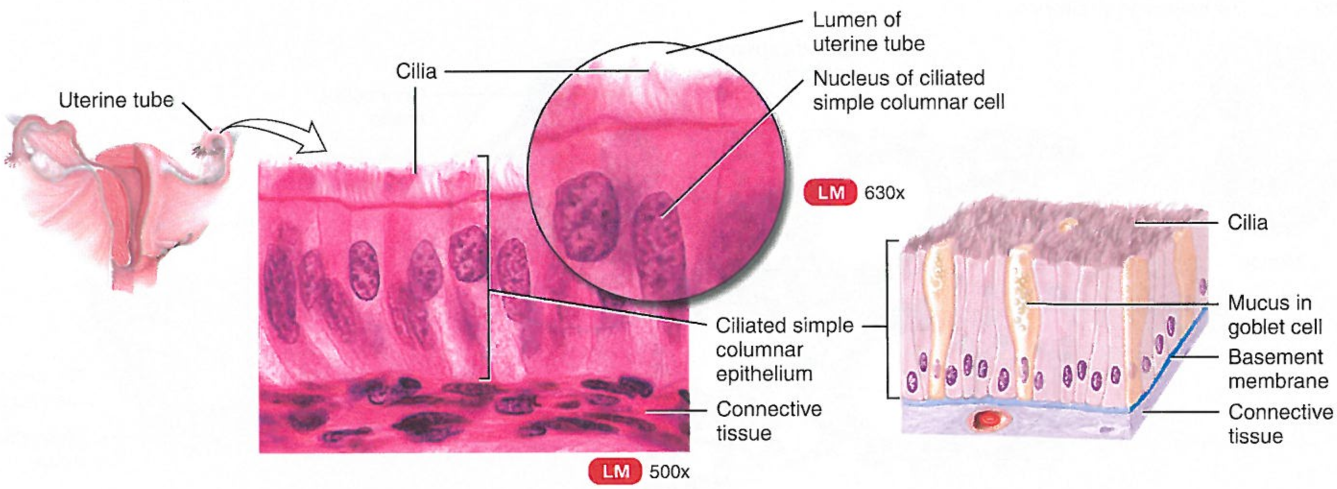
Epithelial Tissue: Covering and Lining Epithelium

D. CILIATED SIMPLE COLUMNAR EPITHELIUM

Description **Ciliated simple columnar epithelium** is a single layer of ciliated columnlike cells with oval nuclei near base of cells. Goblet cells are usually interspersed.

Location Lines some bronchioles (small tubes) of respiratory tract, uterine (fallopian) tubes, uterus, some paranasal sinuses, central canal of spinal cord, and ventricles of brain.

Function Cilia beat in unison, moving mucus and foreign particles toward throat, where they can be coughed up and swallowed or spit out. Coughing and sneezing speed up movement of cilia and mucus. Cilia also help move oocytes expelled from ovaries through uterine (fallopian) tubes into uterus.



Sectional view of ciliated simple columnar epithelium of uterine tube

Ciliated simple columnar epithelium

E. PSEUDOSTRATIFIED COLUMNAR EPITHELIUM

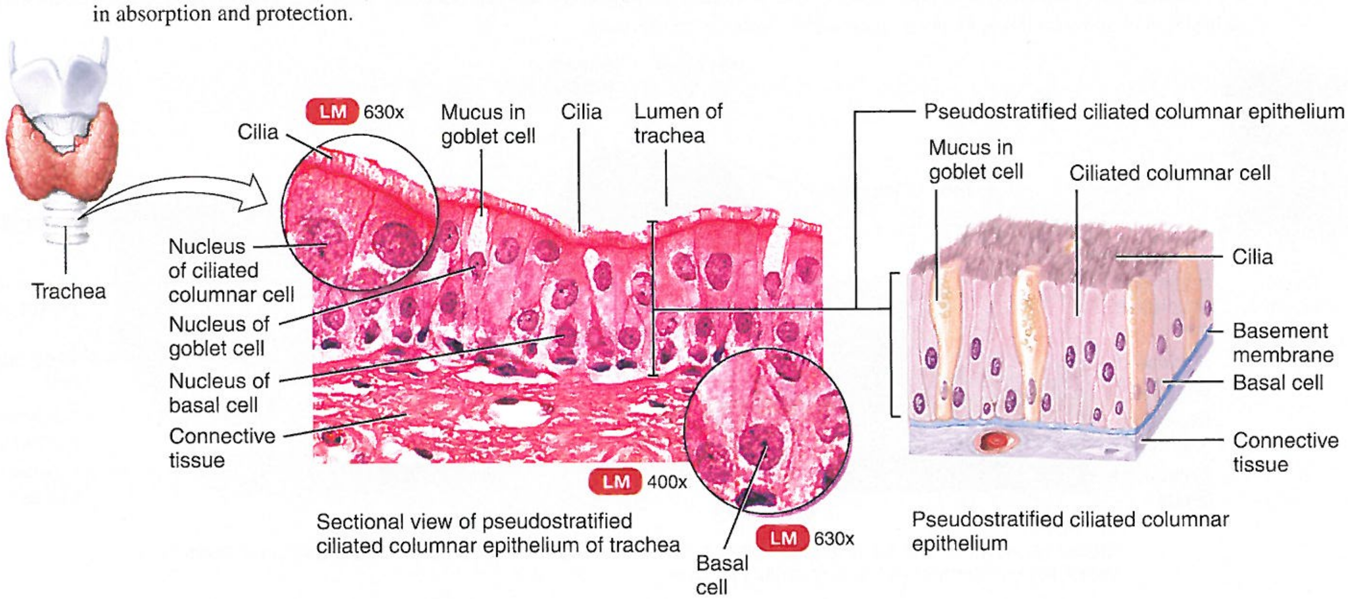
Description **Pseudostratified columnar epithelium** appears to have several layers because cell nuclei are at various levels. All cells are attached to basement membrane in a single layer, but some cells do not extend to apical surface. When viewed from side, these features give false impression of a multilayered tissue (thus the name pseudostratified; *pseudo* = false).

Pseudostratified ciliated columnar epithelium contains cells that extend to surface and secrete mucus (goblet cells) or bear cilia.

Pseudostratified nonciliated columnar epithelium contains cells without cilia and lacks goblet cells.

Location Ciliated variety lines airways of most of upper respiratory tract; nonciliated variety lines larger ducts of many glands, epididymis, and part of male urethra.

Function Ciliated variety secretes mucus that traps foreign particles, and cilia sweep away mucus for elimination from body; noncilated variety functions in absorption and protection.



Sectional view of pseudostratified ciliated columnar epithelium of trachea

Pseudostratified ciliated columnar epithelium

F. STRATIFIED SQUAMOUS EPITHELIUM

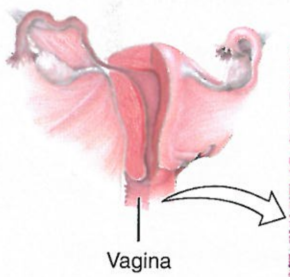
Description **Stratified squamous epithelium** has two or more layers of cells; cells in apical layer and several layers deep to it are squamous; cells in de layers vary from cuboidal to columnar. As basal cells divide, daughter cells arising from cell divisions push upward toward apical layer. As t move toward surface and away from blood supply in underlying connective tissue, they become dehydrated and less metabolically active. T proteins predominate as cytoplasm is reduced, and cells become tough, hard structures that eventually die. At apical layer, after dead cells lo cell junctions they are sloughed off, but they are replaced continuously as new cells emerge from basal cells.

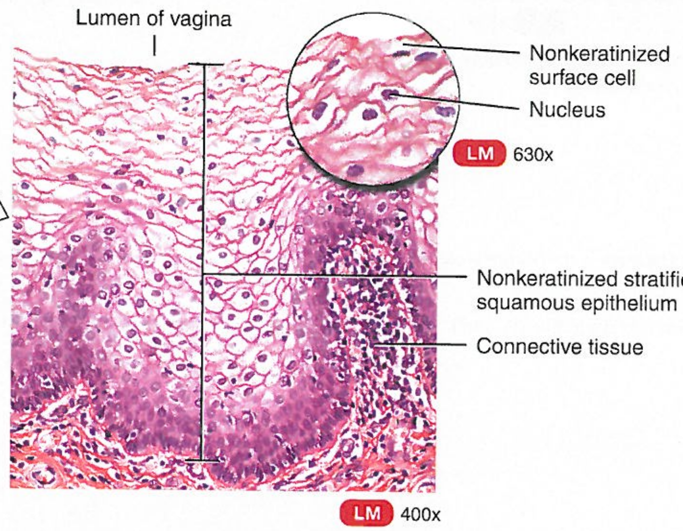
Keratinized stratified squamous epithelium develops tough layer of keratin in apical layer of cells and several layers deep to it (see Figure 5. (**Keratin** is a tough, fibrous intracellular protein that helps protect skin and underlying tissues from heat, microbes, and chemicals.) Relative amount of keratin increases in cells as they move away from nutritive blood supply and organelles die.

Nonkeratinized stratified squamous epithelium does not contain large amounts of keratin in apical layer and several layers deep and is const moistened by mucus from salivary and mucous glands; organelles are not replaced.

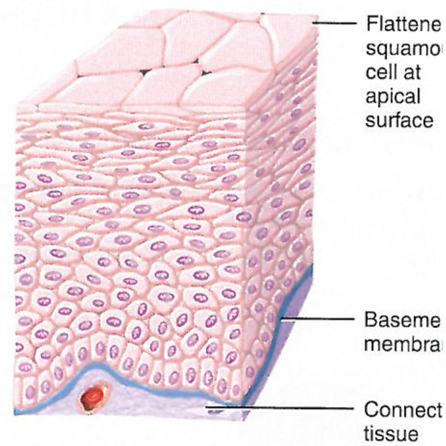
Location Keratinized variety forms superficial layer of skin; nonkeratinized variety lines wet surfaces (lining of mouth, esophagus, part of epiglottis, p of pharynx, and vagina) and covers tongue.

Function Protection against abrasion, water loss, ultraviolet radiation, and foreign invasion. Both types form first line of defense against microbes.

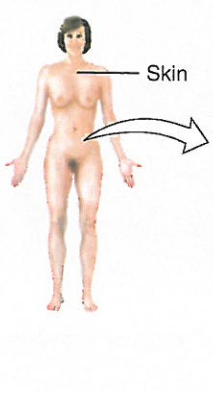


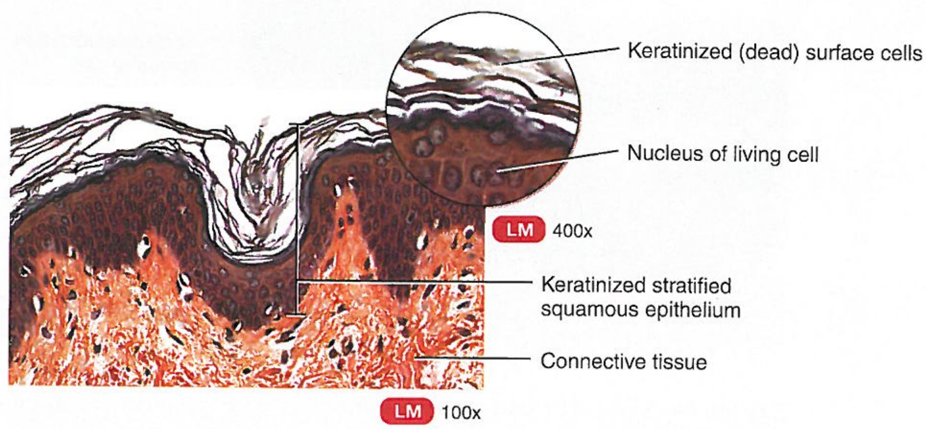


Sectional view of nonkeratinized stratified squamous epithelium of lining of vagina



Nonkeratinized stratified squamous epithelium





Sectional view of keratinized stratified squamous epithelium of epidermis

TABLE 4.1 CONTINUED

Epithelial Tissue: Covering and Lining Epithelium

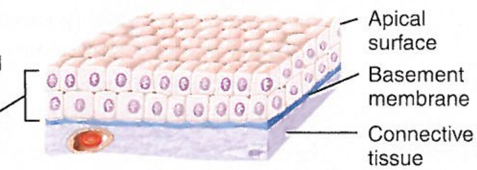
G. STRATIFIED CUBOIDAL EPITHELIUM

Description **Stratified cuboidal epithelium** has two or more layers of cells; cells in apical layer are cube-shaped; fairly rare type.

Location Ducts of adult sweat glands and esophageal glands, part of male urethra.

Function Protection; limited secretion and absorption.

Sectional view of stratified cuboidal epithelium of the duct of an esophageal gland



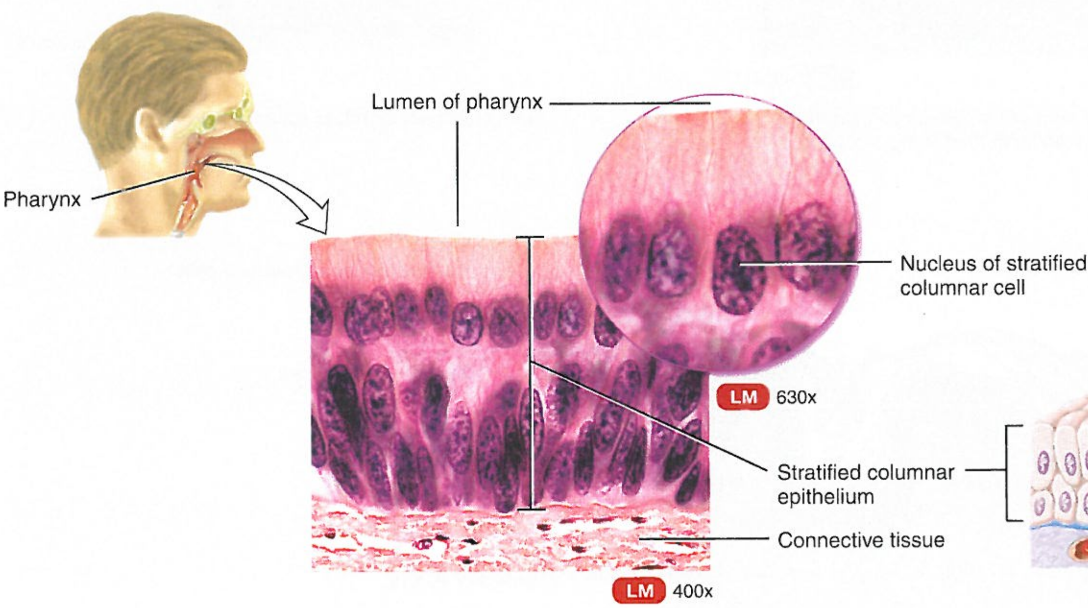
Stratified cuboidal epithelium

H. STRATIFIED COLUMNAR EPITHELIUM

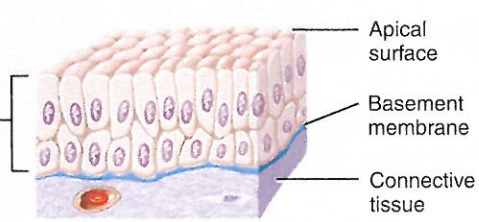
Description Basal layers in **stratified columnar epithelium** usually consist of shortened, irregularly shaped cells; only apical layer has columnar cells; uncommon.

Location Lines part of urethra; large excretory ducts of some glands, such as esophageal glands; small areas in anal mucous membrane; part of conjunctiva of eye.

Function Protection and secretion.



Sectional view of stratified columnar epithelium of lining of pharynx



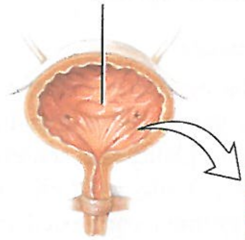
Stratified columnar epithelium

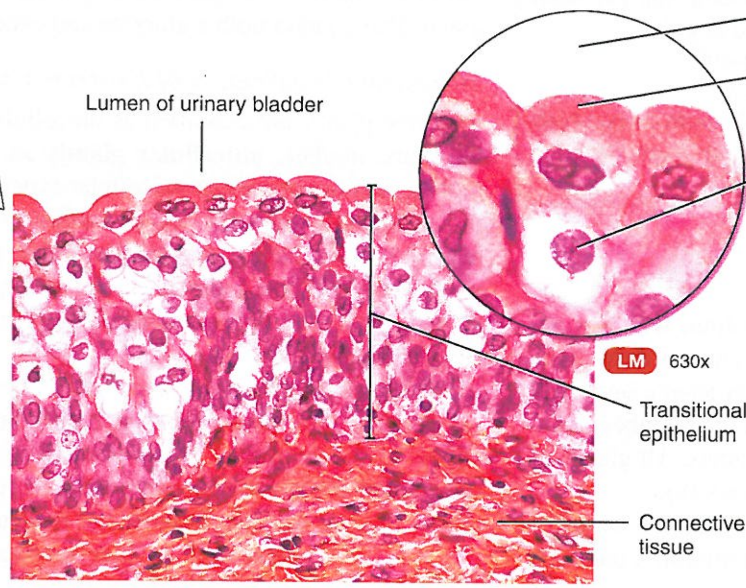
I. TRANSITIONAL EPITHELIUM

Description **Transitional epithelium** has a variable appearance (transitional). In relaxed or unstretched state, looks like stratified cuboidal epithelium, except apical layer cells tend to be large and rounded. As tissue is stretched, cells become flatter, giving the appearance of stratified squamo epithelium. Multiple layers and elasticity make it ideal for lining hollow structures (urinary bladder) subject to expansion from within.

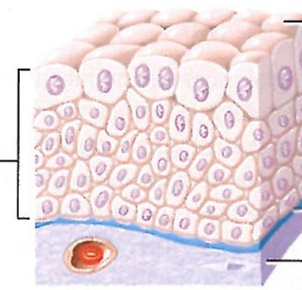
Location Lines urinary bladder and portions of ureters and urethra.

Function Allows urinary organs to stretch and maintain protective lining while holding variable amounts of fluid without rupturing.

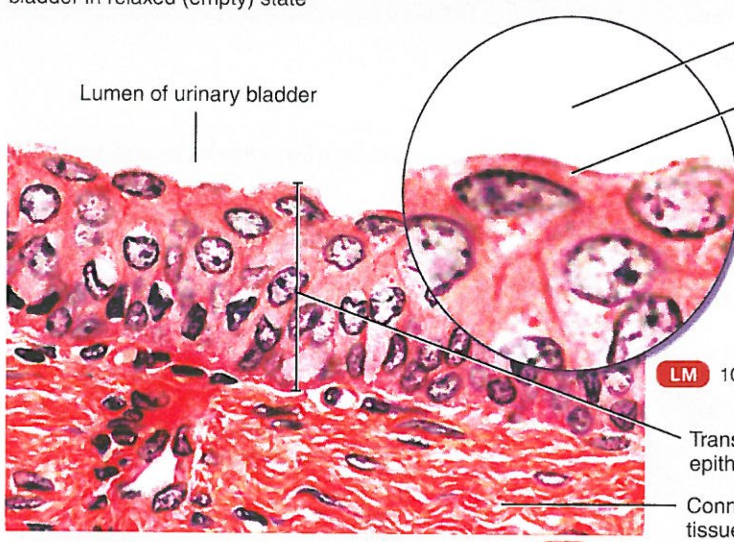




Sectional view of transitional epithelium of urinary bladder in relaxed (empty) state



Relaxed transitional epithelium



Sectional view of transitional epithelium of urinary bladder in filled state

CLINICAL CONNECTION | *Papanicolaou Test*

A **Papanicolaou test** (pa-pa-NI-kō-lō), also called a *Pap test* or *Pap smear*, involves collection and microscopic examination of epithelial cells that have been scraped off the apical layer of a tissue. A very common type of Pap test involves examining the cells from the nonkeratinized stratified squamous epithelium of the vagina and cervix (inferior portion) of the uterus. This type of Pap test is performed mainly to detect early changes in the cells of the female reproductive system that may indicate a precancerous condition or cancer. In performing a Pap smear, the cells are scraped from the tissue and then smeared on a microscope slide. The slides are then sent to a laboratory for analysis. It is recommended that Pap tests should be performed every three years beginning at age 21. It is further recommended that females aged 30 to 65 should have Pap testing and HPV (human pappilomavirus) testting (cotesting) every five years or a Pap test alone every three years. Females with certain high risk factors may need more frequent screening or even continue screening beyond age 65. •

Glandular Epithelium

The function of glandular epithelium is secretion, which is accomplished by glandular cells that often lie in clusters deep to the covering and lining epithelium. A **gland** may consist of a single cell or a group of cells that secrete substances into ducts (tubes), onto a surface, or into the blood in the absence of ducts. All glands of the body are classified as either endocrine or exocrine.

The secretions of **endocrine glands** (EN-dō-krin; *endo-* = inside; *-crine* = secretion; Table 4.2), called hormones, enter the interstitial fluid and then diffuse directly into the bloodstream without flowing through a duct. Endocrine glands will be described in detail in Chapter 18. Endocrine secretions have far-reaching effects because they are distributed throughout the body by the bloodstream.

Exocrine glands (EK-sō-krin; *exo-* = outside; Table 4.2) secrete their products into ducts that empty onto the surface of a covering and lining epithelium such as the skin surface or the lumen of a hollow organ. The secretions of exocrine glands have limited effects and some of them would be harmful if they entered the bloodstream. As you will learn later in the text, some glands of the body, such as the pancreas, ovaries, and testes, are mixed glands that contain both endocrine and exocrine tissue.

Structural Classification of Exocrine Glands

Exocrine glands are classified as unicellular or multicellular. As the name implies, **unicellular glands** are single-celled glands. Goblet cells are important unicellular exocrine glands that secrete mucus directly onto the apical surface of a lining epithelium. Most exocrine glands are **multicellular glands,** composed of many cells that form a distinctive microscopic structure or macroscopic organ. Examples include sudoriferous (sweat), sebaceous (oil), and salivary glands.

Multicellular glands are categorized according to two criteria: (1) whether their ducts are branched or unbranched and (2) the shape of the secretory portions of the gland (Figure 4.6). If the duct of the gland does not branch, it is a **simple gland** (Figure 4.6a–e). If the duct branches, it is a **compound gland** (Figure 4.6f–h). Glands with tubular secretory parts are **tubular**

TABLE 4.2

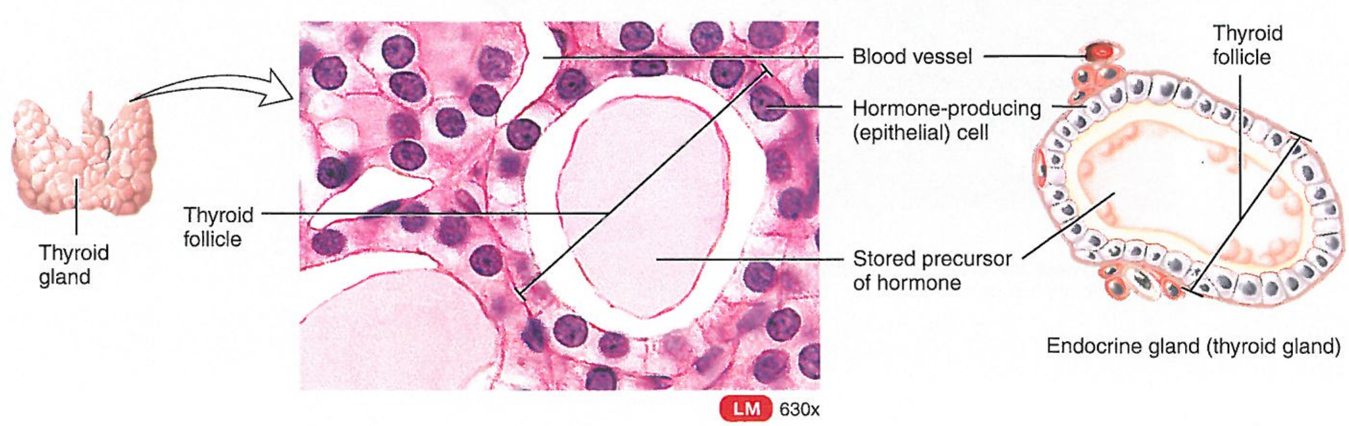
Epithelial Tissue: Glandular Epithelium

A. ENDOCRINE GLANDS

Description Secretions (*hormones*) enter interstitial fluid and diffuse directly into bloodstream without flowing through a duct. Endocrine glands will be described in detail in Chapter 18.

Location Examples include pituitary gland at base of brain, pineal gland in brain, thyroid and parathyroid glands near larynx (voice box), adrenal glands superior to kidneys, pancreas near stomach, ovaries in pelvic cavity, testes in scrotum, thymus in thoracic cavity.

Function Hormones regulate many metabolic and physiological activities to maintain homeostasis.



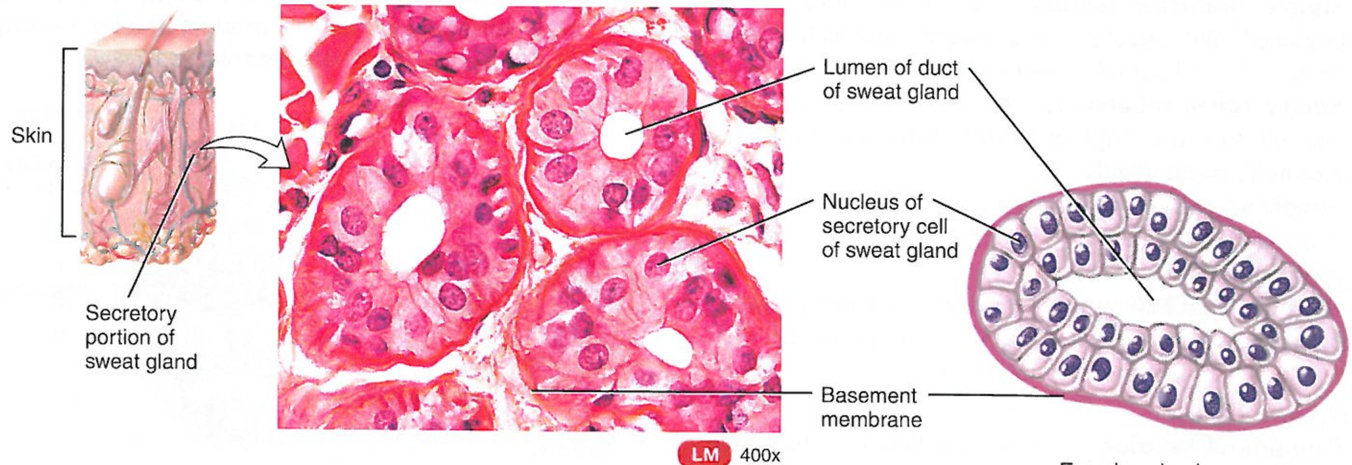
Sectional view of endocrine gland (thyroid gland)

B. EXOCRINE GLANDS

Description Secretory products released into ducts that empty onto surface of a covering and lining epithelium, such as skin surface or lumen of holl organ.

Location Sweat, oil, and earwax glands of skin; digestive glands such as salivary glands (secrete into mouth cavity) and pancreas (secretes into small intestine).

Function Produce substances such as sweat to help lower body temperature, oil, earwax, saliva, or digestive enzymes.

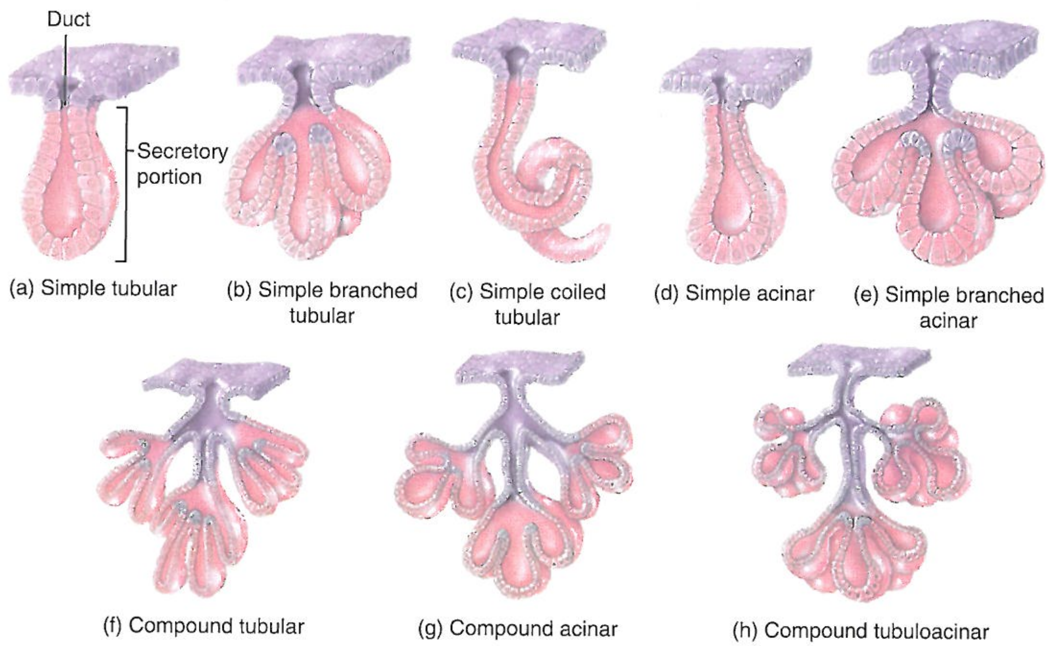


Sectional view of the secretory portion of an exocrine gland (eccrine sweat gland)

Exocrine gland (eccrine sweat gland)

Figure 4.6 Multicellular exocrine glands. Pink represents the secretory portion; lavender represents the duct.

Structural classification of multicellular exocrine glands is based on the branching pattern of the duct and the shape of th secreting portion.



How do simple multicellular exocrine glands differ from compound ones?

glands; those with rounded secretory portions are **acinar glands** (AS-i-nar; *acin-* = berry), also called *alveolar glands*. **Tubuloacinar glands** have both tubular and more rounded secretory parts.

Combinations of these features are the criteria for the following structural classification scheme for multicellular exocrine glands:

I. Simple glands
- A. **Simple tubular.** Tubular secretory part is straight and attaches to a single unbranched duct (Figure 4.6a). Example: glands in the large intestine.
- B. **Simple branched tubular.** Tubular secretory part is branched and attaches to a single unbranched duct (Figure 4.6b). Example: gastric glands.
- C. **Simple coiled tubular.** Tubular secretory part is coiled and attaches to a single unbranched duct (Figure 4.6c). Example: sweat glands.
- D. **Simple acinar.** Secretory portion is rounded, attaches to single unbranched duct (Figure 4.6d). Example: glands of penile urethra.
- E. **Simple branched acinar.** Rounded secretory part is branched and attaches to a single unbranched duct (Figure 4.6e). Example: sebaceous glands.

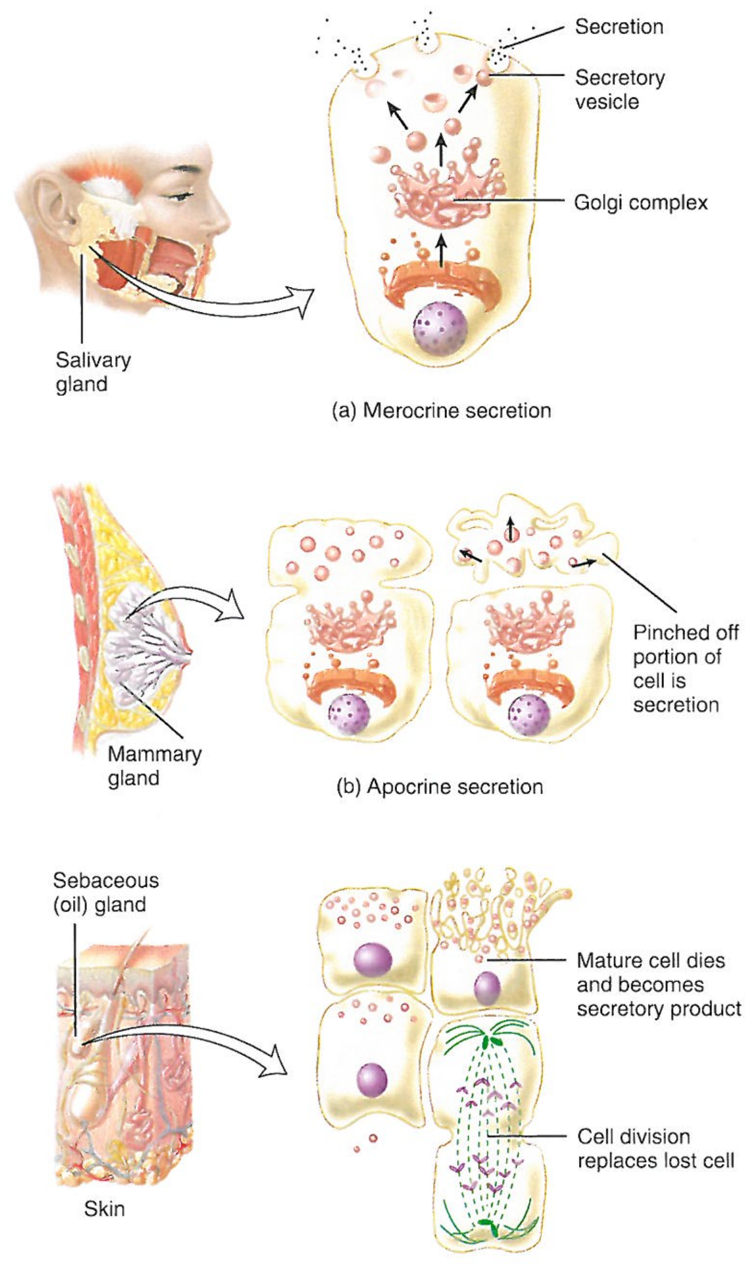
II. Compound glands
- A. **Compound tubular.** Secretory portion is tubular and attaches to a branched duct (Figure 4.6f). Example: bulbourethral (Cowper's) glands.
- B. **Compound acinar.** Secretory portion is rounded and attaches to a branched duct (Figure 4.6g). Example: mammary glands.
- C. **Compound tubuloacinar.** Secretory portion is both tubular and rounded and attaches to a branched duct (Figure 4.6h). Example: acinar glands of the pancreas.

Functional Classification of Exocrine Glands

The functional classification of exocrine glands is based on how their secretions are released. Each of these secretory processes begins with the endoplasmic reticulum and Golgi complex working together to form intracellular secretory vesicles that contain the secretory product. Secretions of **merocrine glands** (MER-ō-krin; *mero-* = a part) are synthesized on ribosomes attached to rough ER; processed, sorted, and packaged by the Golgi complex; and released from the cell in secretory vesicles via exocytosis (Figure 4.7a). Most exocrine glands of the body are merocrine glands. Examples include the salivary glands and pancreas. **Apocrine glands** (AP-ō-krin; *apo-* = from) accumulate their secretory product at the apical surface of the secreting cell. Then, that portion of the cell pinches off by exocytosis from the rest of the cell to release the secretion (Figure 4.7b). The cell repairs itself and repeats the process. Electron microscopy has confirmed that this is the mechanism of secretion of milk fats in the mammary glands. Recent evidence reveals that the sweat glands of the skin, named apocrine sweat glands after this mode of secretion, actually undergo merocrine secretion. The cells of **holocrine glands** (HŌ-lō-krin; *holo-* = entire) accumulate a secretory product in their cytosol. As the secretory cell matures, it ruptures and becomes the secretory product (Figure 4.7c). Because the cell ruptures in this mode of secretion, the secretion contains large amounts of lipids from the plasma membrane and intracellular membranes. The sloughed off cell is replaced by a new cell. One example of a holocrine gland is a sebaceous gland of the skin.

Figure 4.7 Functional classification of multicellular exocrine glands.

The functional classification of exocrine glands is based on whether a secretion is a product of a cell or consists of an entire or a partial glandular cell.



(a) Merocrine secretion

(b) Apocrine secretion

(c) Holocrine secretion

To what class of glands do sebaceous (oil) glands belong? Salivary glands?

contain **keratan sulfate**. Also present in the ground substance are **adhesion proteins**, which are responsible for linking components of the ground substance to one another and to the surfaces of cells. The main adhesion protein of connective tissues is **fibronectin**, which binds to both collagen fibers (discussed shortly) and ground substance, linking them together. Fibronectin also attaches cells to the ground substance.

CLINICAL CONNECTION | Chondroitin Sulfate, Glucosamine, and Joint Disease

Chondroitin sulfate and **glucosamine** (a proteoglycan) have been used as nutritional supplements either alone or in combination to promote and maintain the structure and function of joint cartilage, to provide pain relief from osteoarthritis, and to reduce joint inflammation. Although these supplements have benefited some individuals with moderate to severe osteoarthritis, the benefit is minimal in lesser cases. More research is needed to determine how they act and why they help some people and not others. •

Fibers

Three types of **fibers** are embedded in the extracellular matrix between the cells: collagen fibers, elastic fibers, and reticular fibers (Figure 4.8). They function to strengthen and support connective tissues.

Collagen fibers (KOL-a-jen; *colla* = glue) are very strong and resist pulling forces (tension), but they are not stiff, which allows tissue flexibility. The properties of different types of collagen fibers vary from tissue to tissue. For example, the collagen fibers found in cartilage and bone form different associations with surrounding molecules. As a result of these associations, the collagen fibers in cartilage are surrounded by more water molecules than those in bone, which gives cartilage a more cushioning effect. Collagen fibers often occur in parallel bundles (see Table 4.5A, dense regular connective tissue). The bundle arrangement adds great tensile strength to the tissue. Chemically, collagen fibers consist of the protein *collagen,* which is the most abundant protein in your body, representing about 25% of the total. Collagen fibers are found in most types of connective tissues, especially bone, cartilage, tendons (which attach muscle to bone), and ligaments (which attach bone to bone).

Elastic fibers, which are smaller in diameter than collagen fibers, branch and join together to form a fibrous network within a connective tissue. An elastic fiber consists of molecules of the protein *elastin* surrounded by a glycoprotein named *fibrillin,* which adds strength and stability. Because of their unique molecular structure, elastic fibers are strong but can be stretched up to 150% of their relaxed length without breaking. Equally important, elastic fibers have the ability to return to their original shape after being stretched, a property called *elasticity.* Elastic fibers are plentiful in skin, blood vessel walls, and lung tissue.

Reticular fibers (*reticul-* = net), consisting of *collagen* arranged in fine bundles with a coating of glycoprotein, provide support in the walls of blood vessels and form a network around the c
some tissues, such as areolar connective tissue (a-RĒ-ō-lar; *ar*
small space), adipose tissue, nerve fibers, and smooth m
tissue. Produced by fibroblasts, reticular fibers are much th
than collagen fibers and form branching networks. Like col
fibers, reticular fibers provide support and strength. Reti
fibers are plentiful in reticular connective tissue, which forn
stroma (supporting framework) of many soft organs, such
spleen and lymph nodes. These fibers also help form the
ment membrane.

Classification of Connective Tissue

Because of the diversity of cells and extracellular matrix an
differences in their relative proportions, the classificati
connective tissue is not always clear-cut and several class
tions exist. We offer the following classification scheme:

I. Embryonic connective tissue
- A. Mesenchyme
- B. Mucous connective tissue

II. Mature connective tissue
- A. Loose connective tissue
  1. Areolar connective tissue
  2. Adipose tissue
  3. Reticular connective tissue
- B. Dense connective tissue
  1. Dense regular connective tissue
  2. Dense irregular connective tissue
  3. Elastic connective tissue
- C. Cartilage
  1. Hyaline cartilage
  2. Fibrocartilage
  3. Elastic cartilage
- D. Bone tissue
- E. Liquid connective tissue
  1. Blood tissue
  2. Lymph

Embryonic Connective Tissue

Note that our classification scheme has two major subclass
connective tissue: embryonic and mature. **Embryonic conne
tissue** is of two types: **mesenchyme** and **mucous conne
tissue**. Mesenchyme is present primarily in the *embryo,* the
veloping human from fertilization through the first two mont
pregnancy, and in the *fetus,* the developing human from the
month of pregnancy to birth (Table 4.3).

Mature Connective Tissue

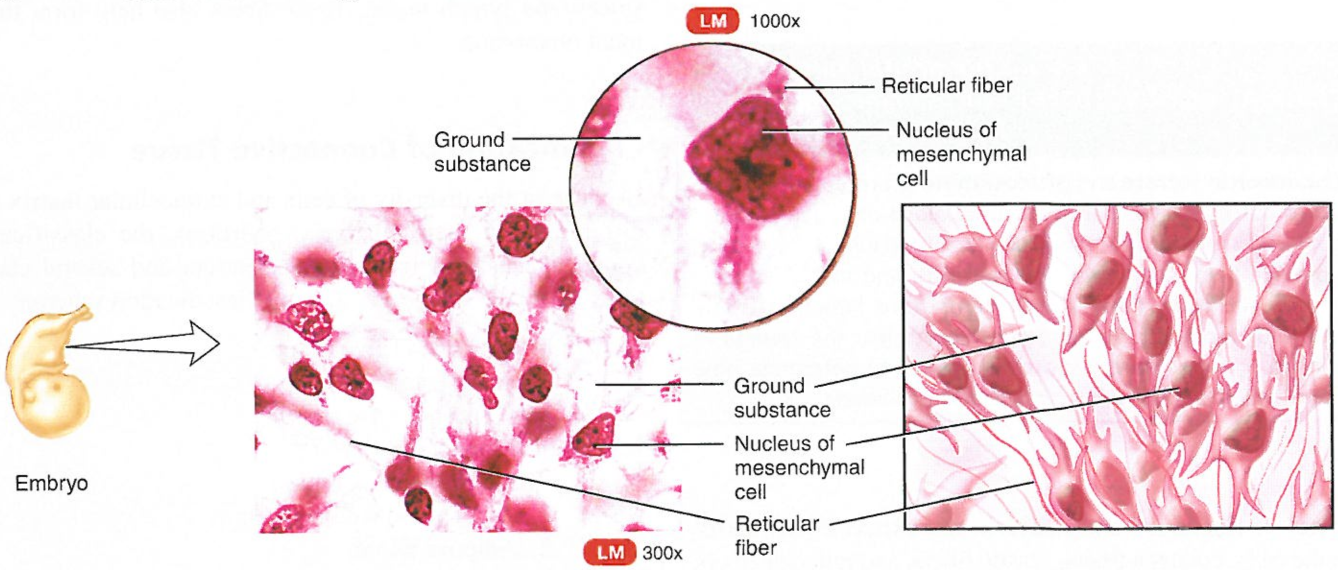
The second major subclass of connective tissue, **ma
connective tissue,** is present in the newborn. Its cells arise
marily from mesenchyme. In the next section we explore

TABLE 4.3

Embryonic Connective Tissues

A. MESENCHYME

Description	**Mesenchyme** has irregularly shaped mesenchymal cells embedded in semifluid ground substance that contains delicate reticular fibers.
Location	Almost exclusively under skin and along developing bones of embryo; some in adult connective tissue, especially along blood vessels.
Function	Forms almost all other types of connective tissue.

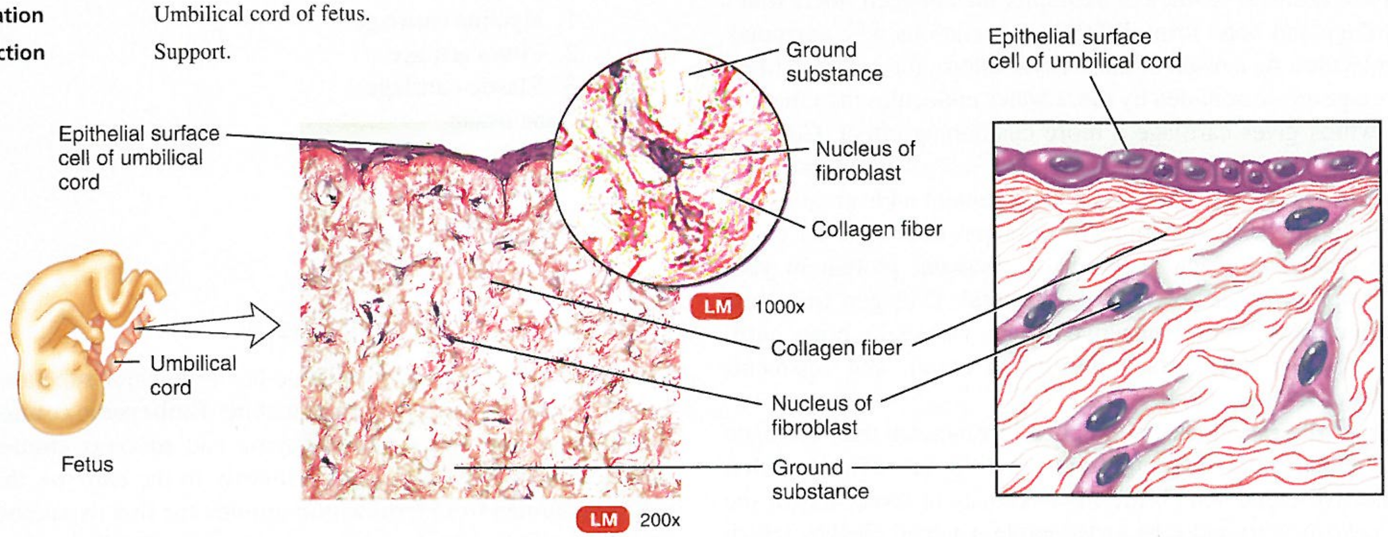


Sectional view of mesenchyme of a developing embryo

Mesenchyme

B. MUCOUS CONNECTIVE TISSUE

Description	**Mucous connective tissue** has widely scattered fibroblasts embedded in viscous, jellylike ground substance that contains fine collagen fibers.
Location	Umbilical cord of fetus.
Function	Support.



Sectional view of mucous connective tissue of the umbilical cord

Mucous connective tissue

numerous types of mature connective tissue. The five types of mature connective tissue are (1) *loose connective tissue*, (2) *dense connective tissue*, (3) *cartilage*, (4) *bone tissue*, and (5) *liquid connective tissue* (blood and lymph). We now examine each in detail.

Loose Connective Tissue

The fibers of **loose connective tissue** are *loosely* arranged between cells. The types of loose connective tissue are areolar connective tissue, adipose tissue, and reticular connective tissue (Table 4.4).

TABLE 4.4

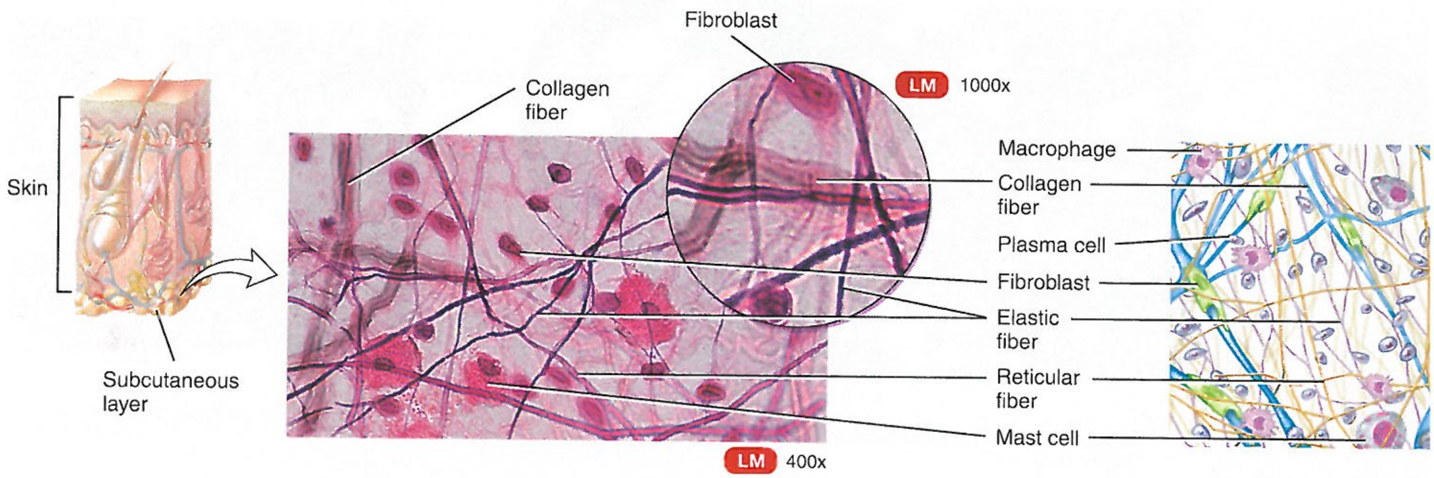
Mature Connective Tissue: Loose Connective Tissue

A. AREOLAR CONNECTIVE TISSUE

Description **Areolar connective tissue** is one of the most widely distributed connective tissues; consists of fibers (collagen, elastic, reticular) arran randomly and several kinds of cells (fibroblasts, macrophages, plasma cells, adipocytes, mast cells, and a few white blood cells) embe in semifluid ground substance (hyaluronic acid, chondroitin sulfate, dermatan sulfate, and keratan sulfate).

Location In and around nearly every body structure (thus, called "packing material" of the body): in subcutaneous layer deep to skin; papillary (superficial) region of dermis of skin; lamina propria of mucous membranes; around blood vessels, nerves, and body organs.

Function Strength, elasticity, support.



Sectional view of subcutaneous areolar connective tissue

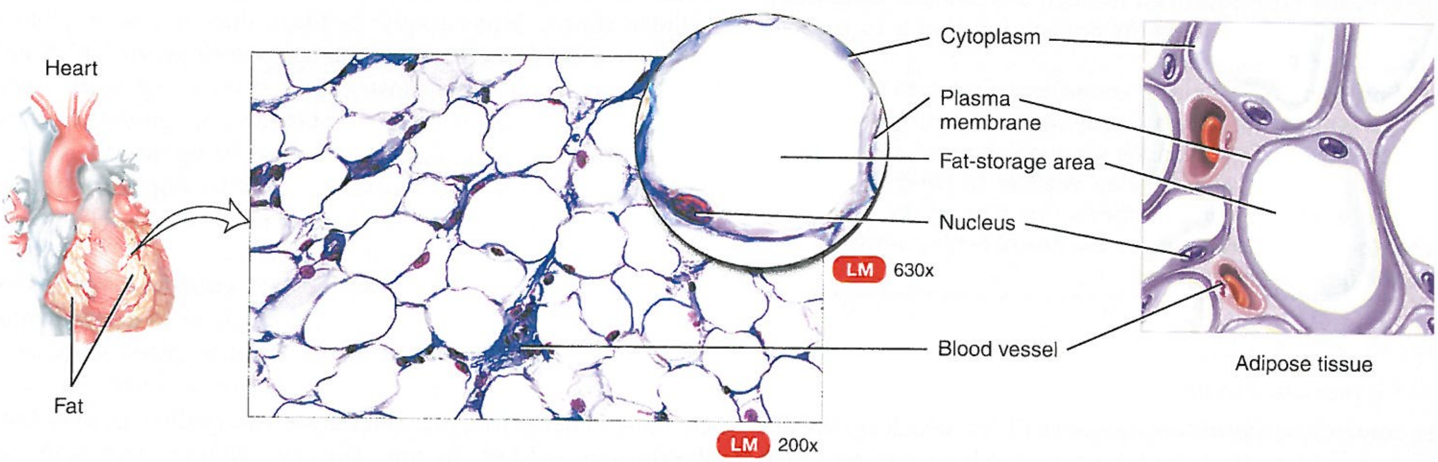
Areolar connective tiss

B. ADIPOSE TISSUE

Description **Adipose tissue** has cells derived from fibroblasts (called *adipocytes*) that are specialized for storage of triglycerides (fats) as a large, centrally located droplet. Cell fills up with a single, large triglyceride droplet, and cytoplasm and nucleus are pushed to periphery of ce With weight gain, amount of adipose tissue increases and new blood vessels form. Thus, an obese person has many more blood vessels than does a lean person, a situation that can cause high blood pressure, since the heart has to work harder. Most adipose tissue in adults is *white adipose tissue* (just described). *Brown adipose tissue* (BAT) is darker due to very rich blood supply and numerous pigmented mitochondria that participate in aerobic cellular respiration. BAT is widespread in the fetus and infant; adults have only small amounts.

Location Wherever areolar connective tissue is located: subcutaneous layer deep to skin, around heart and kidneys, yellow bone marrow, paddin around joints and behind eyeball in eye socket.

Function Reduces heat loss through skin; serves as an energy reserve; supports and protects organs. In newborns, BAT generates heat to maintain proper body temperature.



Sectional view of adipose tissue showing adipocytes of white fat and details of an adipocyte

Adipose tissue

TABLE 4.4 CONTINUED

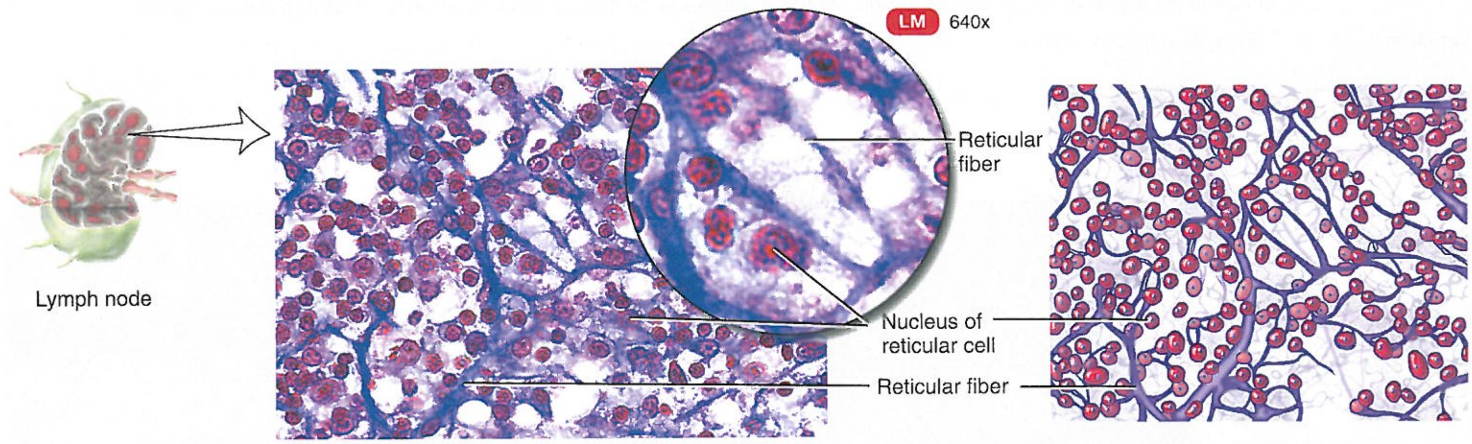
Mature Connective Tissue: Loose Connective Tissue

C. RETICULAR CONNECTIVE TISSUE

Description **Reticular connective tissue** is a fine interlacing network of reticular fibers (thin form of collagen fiber) and reticular cells.

Location Stroma (supporting framework) of liver, spleen, lymph nodes; red bone marrow; reticular lamina of basement membrane; around blood vessels and muscles.

Function Forms stroma of organs; binds smooth muscle tissue cells; filters and removes worn-out blood cells in spleen and microbes in lymph nodes.



Lymph node

Sectional view of reticular connective tissue of a lymph node

Reticular connective tissue

CLINICAL CONNECTION | *Liposuction and Cryolipolysis*

Liposuction (LIP-ō-suk′-shun; *lip-* = fat) is a procedure in which small amounts of adipose tissue are suctioned out of different areas of the body, such as the abdomen, thighs, buttocks, arms, and breasts, for body sculpting. Liposuction can also be used to transfer fat from one part of the body to another. In one type of liposuction, the removal of fat involves making an incision in the skin into the area where fat is to be removed and inserting a *cannula* (stainless steel tube). With the assistance of a powerful vacuum device, the fat is suctioned through the cannula. Liposuction is not a treatment for obesity. Its primary function is to improve body contour and proportions.

Cryolipolysis (*cryo-* = cold) or *coolsculpting* refers to the destruction of fat cells by the external application of controlled cooling. Since fat crystallizes faster than the surrounding tissue, the cold temperature kills fat cells while sparing damage to nerve cells, blood vessels, and other structures. Within a few days of the procedure, *apoptosis* (genetically programmed cell death) begins; within several months the fat cells are removed. •

Dense Connective Tissue

Dense connective tissue contains more fibers, which are thicker and more *densely* packed, but have considerably fewer cells than loose connective tissue. There are three types: dense regular connective tissue, dense irregular connective tissue, and elastic connective tissue (Table 4.5).

Cartilage

Cartilage (KAR-ti-lij) consists of a dense network of collagen fibers and elastic fibers firmly embedded in chondroitin sulfate, a gel-like component of the ground substance. Cartilage can endure considerably more stress than loose and dense connective tissues. The strength of cartilage is due to its collagen fibers, and its *resilience* (ability to assume its original shape after deformation) is due to chondroitin sulfate.

Like other connective tissue, cartilage has few cells and large quantities of extracellular matrix. It differs from other connective tissue, however, in not having nerves or blood vessels in its extracellular matrix. Interestingly, cartilage does not have a blood supply because it secretes an *antiangiogenesis factor* (an′-tī-an′-jē-ō-JEN-e-sis; *anti-* = against; *angio-* = vessel; *-genesis* = production), a substance that prevents blood vessel growth. Because of this property, antiangiogenesis factor is being studied as a possible cancer treatment. If cancer cells can be stopped from promoting new blood vessel growth, their rapid rate of cell division and expansion can be slowed or even halted.

The cells of mature cartilage, called **chondrocytes** (KON-drō-sīts; *chondro-* = cartilage), occur singly or in groups within spaces called **lacunae** (la-KOO-nē = little lakes; singular is *lacuna,* pronounced la-KOO-na) in the extracellular matrix. A covering of dense irregular connective tissue called the **perichondrium** (per′-i-KON-drē-um; *peri-* = around) surrounds the surface of most cartilage and contains blood vessels and nerves and is the source of new cartilage cells. Since cartilage has no blood supply, it heals poorly following an injury.

TABLE 4.5

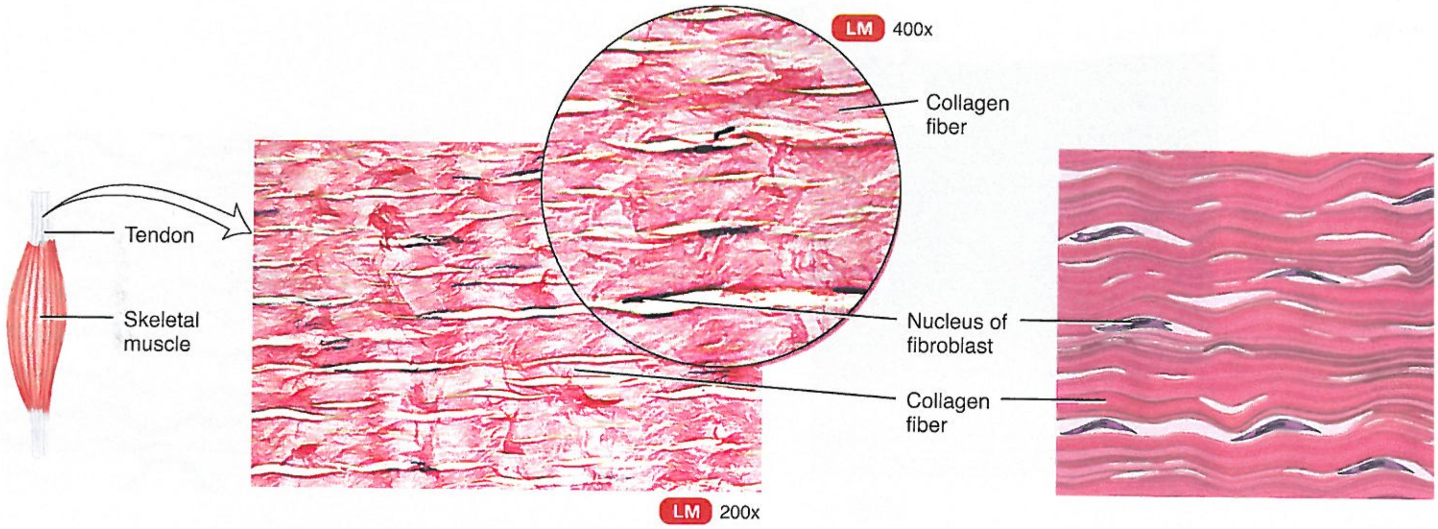
Mature Connective Tissue: Dense Connective Tissue

A. DENSE REGULAR CONNECTIVE TISSUE

Description — **Dense regular connective tissue** forms shiny white extracellular matrix; mainly collagen fibers *regularly* arranged in bundles with fibroblasts in rows between them. Collagen fibers (protein structures secreted by fibroblasts) are not living, so damaged tendons and ligaments heal slowly.

Location — Forms tendons (attach muscle to bone), most ligaments (attach bone to bone), and aponeuroses (sheetlike tendons that attach muscle to muscle or muscle to bone).

Function — Provides strong attachment between various structures. Tissue structure withstands pulling (tension) along long axis of fibers.



Sectional view of dense regular connective tissue of a tendon

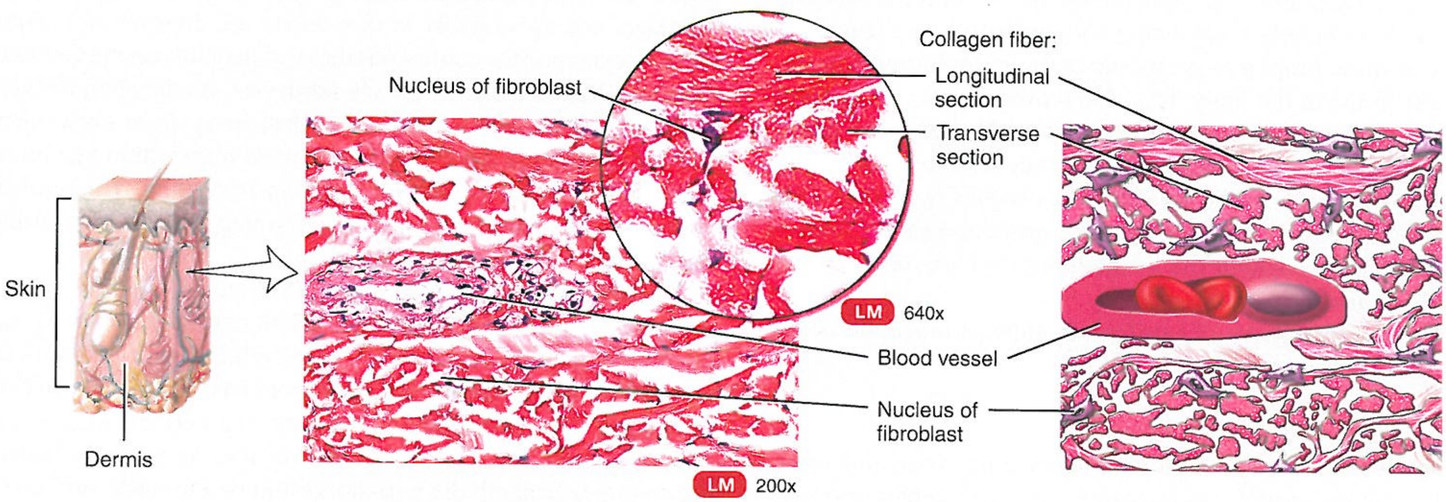
Dense regular connective tissue

B. DENSE IRREGULAR CONNECTIVE TISSUE

Description — **Dense irregular connective tissue** is made up of collagen fibers; usually *irregularly* arranged with a few fibroblasts.

Location — Often occurs in sheets, such as fasciae (tissue beneath skin and around muscles and other organs), reticular (deeper) region of dermis of skin, fibrous pericardium of heart, periosteum of bone, perichondrium of cartilage, joint capsules, membrane capsules around various organs (kidneys, liver, testes, lymph nodes); also in heart valves.

Function — Provides tensile (pulling) strength in many directions.



Sectional view of dense irregular connective tissue of reticular region of dermis

Dense irregular connective tissue

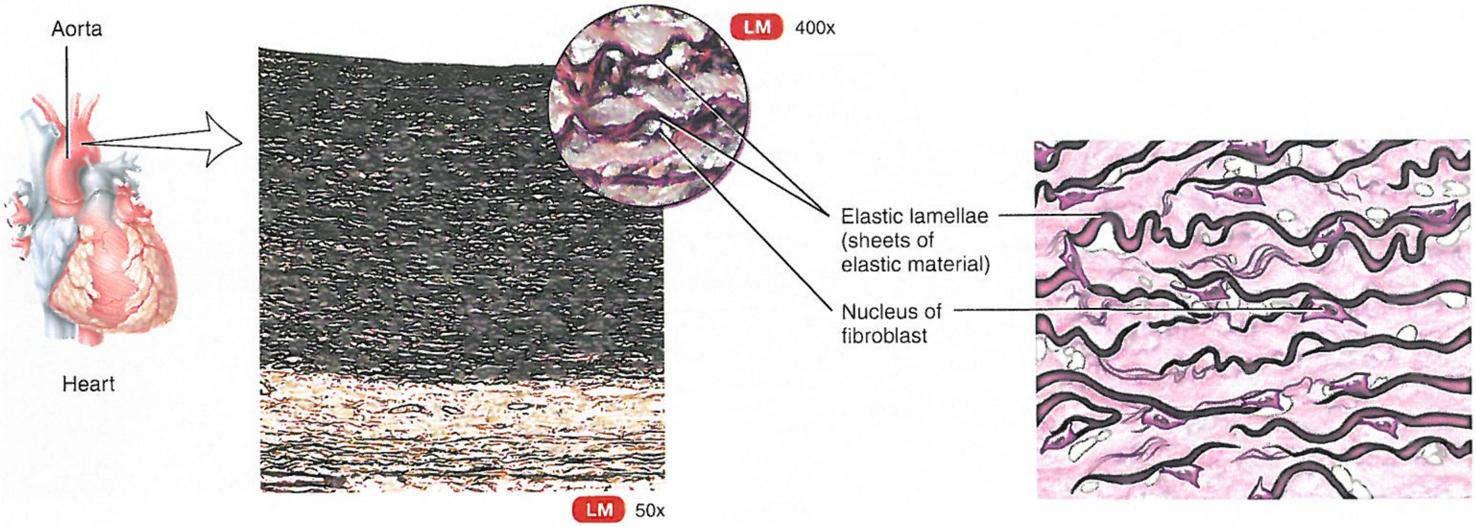
TABLE 4.5 CONTI

TABLE 4.5 CONTINUED

Mature Connective Tissue: Dense Connective Tissue

C. ELASTIC CONNECTIVE TISSUE

Description	**Elastic connective tissue** contains predominantly elastic fibers with fibroblasts between them; unstained tissue is yellowish.
Location	Lung tissue, walls of elastic arteries, trachea, bronchial tubes, true vocal cords, suspensory ligaments of penis, some ligaments between vertebrae.
Function	Allows stretching of various organs; is strong and can recoil to original shape after being stretched. Elasticity is important to normal functioning of lung tissue (recoils in exhaling) and elastic arteries (recoil between heartbeats to help maintain blood flow).



Sectional view of elastic connective tissue of aorta

Elastic connective tissue

The cells and collagen-embedded extracellular matrix of cartilage form a strong, firm material that resists tension (stretching), compression (squeezing), and shear (pushing in opposite directions). The chondroitin sulfate in the extracellular matrix is largely responsible for cartilage's resilience. Because of these properties, cartilage plays an important role as a support tissue in the body. It is also a precursor to bone, forming almost the entire embryonic skeleton. Though bone gradually replaces cartilage during further development, cartilage persists after birth as the growth plates within bone that allow bones to increase in length during the growing years. Cartilage also persists throughout life as the lubricated articular surfaces of most joints.

There are three types of cartilage: hyaline cartilage, fibrocartilage, and elastic cartilage (Table 4.6).

Repair and Growth of Cartilage

Metabolically, cartilage is a relatively inactive tissue that grows slowly. When injured or inflamed, cartilage repair proceeds slowly, in large part because cartilage is avascular. Substances needed for repair and blood cells that participate in tissue repair must diffuse or migrate into the cartilage. The growth of cartilage follows two basic patterns: interstitial growth and appositional growth.

In **interstitial growth** (in′-ter-STISH-al), there is growth from within the tissue. When cartilage grows by interstitial growth, the cartilage increases rapidly in size due to the division of existing chondrocytes and the continuous deposition of increasing amounts of extracellular matrix by the chondrocytes. As the chondrocytes synthesize new matrix, they are pushed away from each other. These events cause the cartilage to expand from within like bread rising, which is the reason for the term *inter*stitial. This growth pattern occurs while the cartilage is young and pliable, during childhood and adolescence.

In **appositional growth** (a-pō-ZISH-un-al), there is growth at the outer surface of the tissue. When cartilage grows by appositional growth, cells in the inner cellular layer of the perichondrium differentiate into chondroblasts. As differentiation continues, the chondroblasts surround themselves with extracellular matrix and become chondrocytes. As a result, matrix accumulates beneath the perichondrium on the outer surface of the cartilage, causing it to grow in width. Appositional growth starts later than interstitial growth and continues through adolescence.

TABLE 4.6

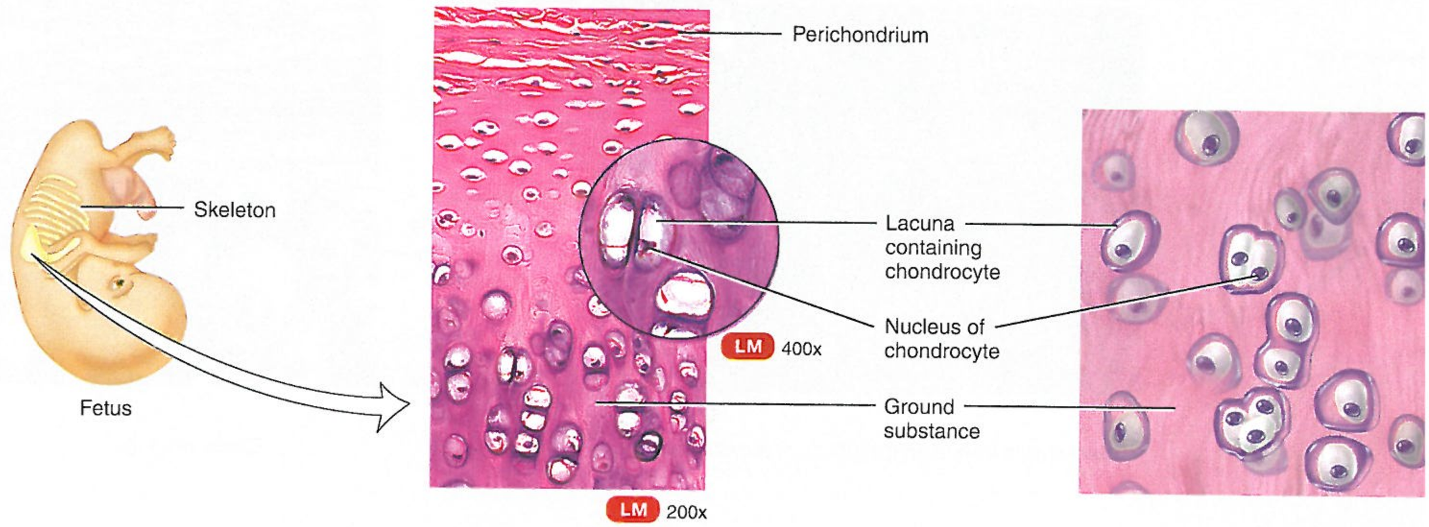
Mature Connective Tissue: Cartilage

A. HYALINE CARTILAGE

Description **Hyaline cartilage** (*hyalinos* = glassy) contains a resilient gel as ground substance and appears in the body as a bluish-white, shiny substance (can stain pink or purple when prepared for microscopic examination; fine collagen fibers are not visible with ordinary staini techniques); prominent chondrocytes are found in lacunae surrounded by perichondrium (exceptions: articular cartilage in joints and cartilage of epiphyseal plates, where bones lengthen during growth).

Location Most abundant cartilage in body; at ends of long bones, anterior ends of ribs, nose, parts of larynx, trachea, bronchi, bronchial tubes, embryonic and fetal skeleton.

Function Provides smooth surfaces for movement at joints, flexibility, and support; weakest type of cartilage and can be fractured.



Sectional view of hyaline cartilage of a developing fetal bone

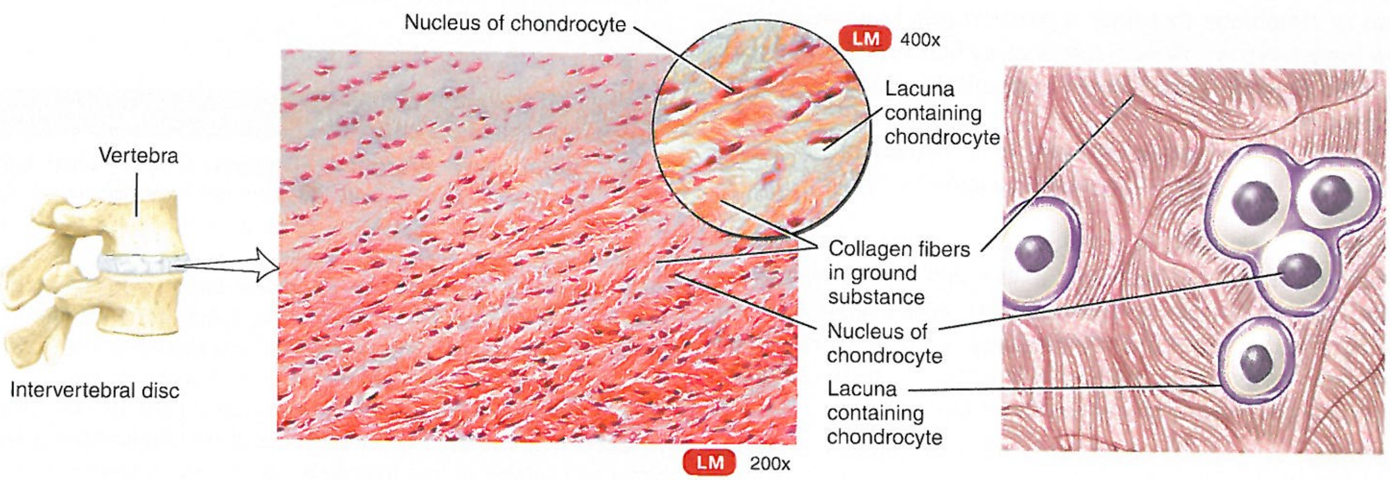
Hyaline cartilage

B. FIBROCARTILAGE

Description **Fibrocartilage** has chondrocytes among clearly visible thick bundles of collagen fibers within extracellular matrix; lacks perichondriun

Location Pubic symphysis (where hip bones join anteriorly), intervertebral discs, menisci (cartilage pads) of knee, portions of tendons that insert into cartilage.

Function Support and joining structures together. Strength and rigidity make it the strongest type of cartilage.



Sectional view of fibrocartilage of intervertebral disc

Fibrocartilage

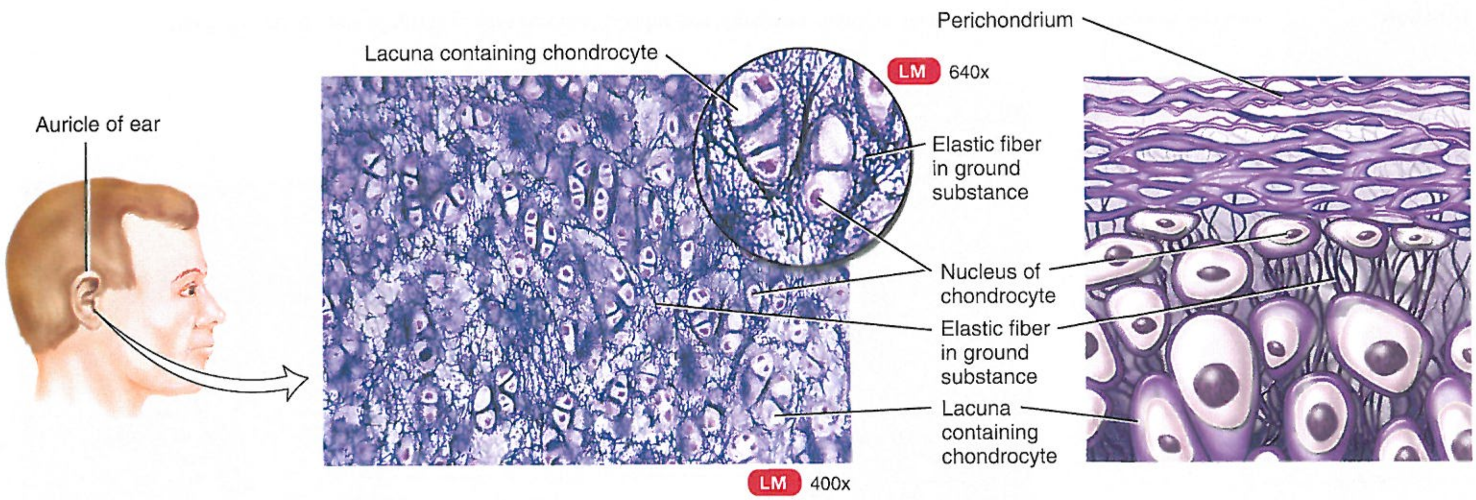
TABLE 4.6 CONTIN

TABLE 4.6 CONTINUED

Mature Connective Tissue: Cartilage

C. ELASTIC CARTILAGE

Description	**Elastic cartilage** has chondrocytes in threadlike network of elastic fibers within extracellular matrix; perichondrium present.
Location	Lid on top of larynx (epiglottis), part of external ear (auricle), auditory (eustachian) tubes.
Function	Provides strength and elasticity; maintains shape of certain structures.



Sectional view of elastic cartilage of auricle of ear

Elastic cartilage

Bone Tissue

Cartilage, joints, and bones make up the skeletal system. The skeletal system supports soft tissues, protects delicate structures, and works with skeletal muscles to generate movement. Bones store calcium and phosphorus; house red bone marrow, which produces blood cells; and contain yellow bone marrow, a storage site for triglycerides. Bones are organs composed of several different connective tissues, including **bone** or *osseous tissue* (OS-ē-us), the periosteum, red and yellow bone marrow, and the endosteum (a membrane that lines a space within bone that stores yellow bone marrow). Bone tissue is classified as either compact or spongy, depending on how its extracellular matrix and cells are organized.

The basic unit of **compact bone** is an **osteon** or *haversian system* (Table 4.7). Each osteon has four parts:

1. The **lamellae** (la-MEL-lē = little plates; singular is *lamella*) are concentric rings of extracellular matrix that consist of mineral salts (mostly calcium and phosphates), which give bone its hardness and compressive strength, and collagen fibers, which give bone its tensile strength. The lamellae are responsible for the compact nature of this type of bone tissue.
2. **Lacunae**, as already mentioned, are small spaces between lamellae that contain mature bone cells called **osteocytes**.
3. Projecting from the lacunae are **canaliculi** (kan-a-LIK-ū-lī = little canals), networks of minute canals containing the processes of osteocytes. Canaliculi provide routes for nutrients to reach osteocytes and for wastes to leave them.
4. A **central canal** or *haversian canal* contains blood vessels and nerves.

Spongy bone lacks osteons. Rather, it consists of columns of bone called **trabeculae** (tra-BEK-ū-lē = little beams), which contain lamellae, osteocytes, lacunae, and canaliculi. Spaces between trabeculae are filled with red bone marrow. Chapter 6 presents bone tissue histology in more detail.

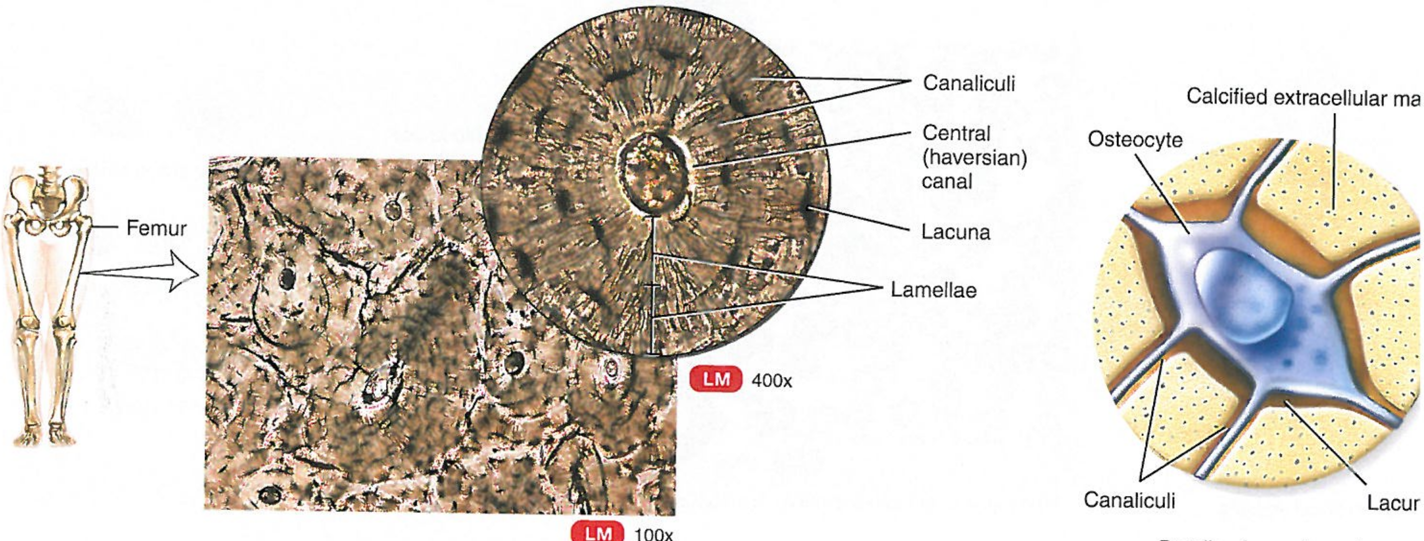
CLINICAL CONNECTION | *Tissue Engineering*

Tissue engineering is a technology that combines synthetic material with cells and has allowed scientists to grow new tissues in the laboratory to replace damaged tissues in the body. Tissue engineers have already developed laboratory-grown versions of skin and cartilage using scaffolding beds of biodegradable synthetic materials or collagen as substrates that permit body cells to be cultured. As the cells divide and assemble, the scaffolding degrades; the new, permanent tissue is then implanted in the patient. Other structures currently under development include bones, tendons, heart valves, bone marrow, and intestines. Work is also under way to develop insulin-producing cells for diabetics, dopamine-producing cells for Parkinson's disease patients, and even entire livers and kidneys. •

TABLE 4.7

Mature Connective Tissue: Bone Tissue

Description	Compact bone tissue consists of osteons (haversian systems) that contain lamellae, lacunae, osteocytes, canaliculi, and central (haversiai canals. By contrast, spongy bone tissue (see Figure 6.3) consists of thin columns called trabeculae; spaces between trabeculae are filled red bone marrow.
Location	Both compact and spongy bone tissue make up the various parts of bones of the body.
Function	Support, protection, storage; houses blood-forming tissue; serves as levers that act with muscle tissue to enable movement.



Sectional view of several osteons (haversian systems) of femur (thigh bone)

Details of an osteocyte

Liquid Connective Tissue

Blood Tissue **A liquid connective tissue** has a liquid as its extracellular matrix. **Blood**, one of the liquid connective tissues has a liquid extracellular matrix called blood plasma and formed elements. The **blood plasma** is a pale yellow fluid that consists mostly of water with a wide variety of dissolved substances—nutrients, wastes, enzymes, plasma proteins, hormones, respiratory gases, and ions. Suspended in the blood plasma are **formed elements**—red blood cells (erythrocytes), white blood cells (leukocytes), and platelets (thrombocytes) (Table 4.8). **Red blood cells** transport oxygen to body cells and remove some carbon dioxide from them. **White blood cells** are involved in phagocytosis, immunity, and allergic reactions. **Platelets** (PLĀT-lets) participate in blood clotting. The details of blood are considered in Chapter 19.

Lymph **Lymph** is the extracellular fluid that flows in lymphatic vessels. It is a liquid connective tissue that consists of several types of cells in a clear liquid extracellular matrix that is similar to blood plasma but with much less protein. The composition of lymph varies from one part of the body to another. For example, lymph leaving lymph nodes includes many lymphocytes, a type of white blood cell, in contrast to lymph from the small intestine, which has a high content of newly absorbed dietary lipids. The details of lymph are considered in Chapter 22.

CHECKPOINT

11. In what ways does connective tissue differ from epithelial tissue?
12. What are the features of the cells, ground substance and fibers that make up connective tissue?
13. How are connective tissues classified? List the variou: types.
14. Describe how the structure of the following connecti tissue is related to its function: areolar connective tiss adipose tissue, reticular connective tissue, dense regu connective tissue, dense irregular connective tissue, elastic connective tissue, hyaline cartilage, fibrocartila elastic cartilage, bone tissue, blood tissue, and lymph
15. What is the difference between interstitial and appo tional growth of cartilage?

4.6 Membranes

OBJECTIVES

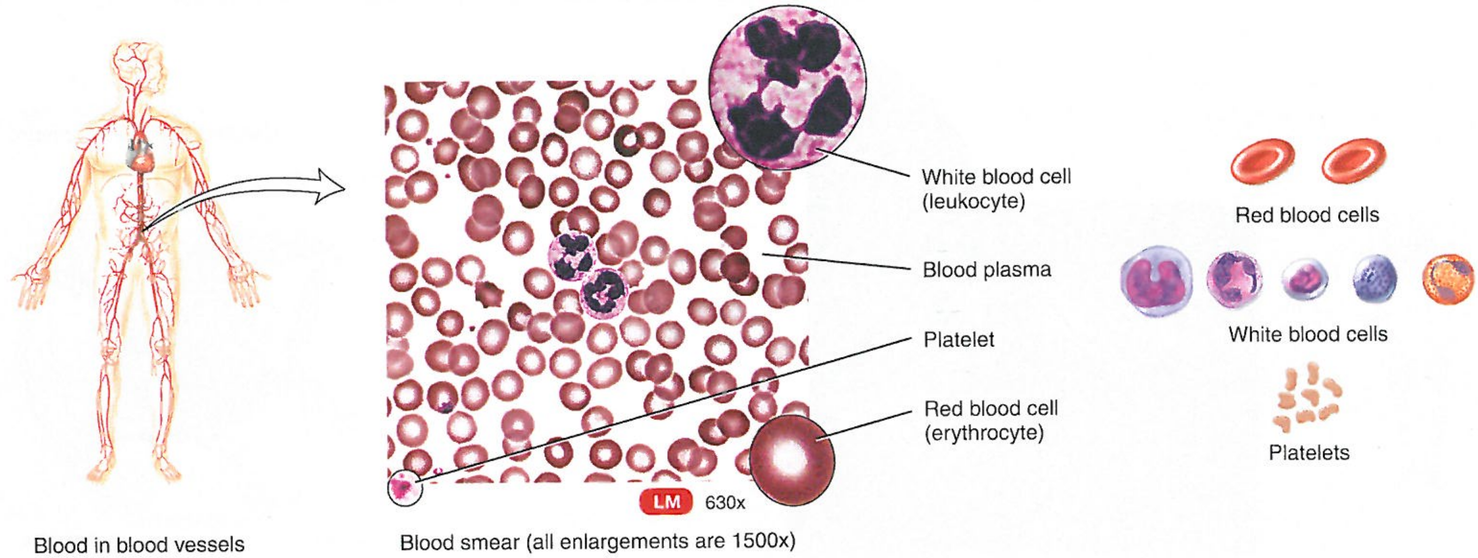
- Define a membrane.
- Describe the classification of membranes.

Membranes are flat sheets of pliable tissue that cover or line a of the body. The majority of membranes consist of an epithelial l: and an underlying connective tissue layer and are called **epithe**

TABLE 4.8

Mature Connective Tissue: Blood

Description	Blood plasma and formed elements: red blood cells (erythrocytes), white blood cells (leukocytes), platelets (thrombocytes).
Location	Within blood vessels (arteries, arterioles, capillaries, venules, veins), within chambers of heart.
Function	Red blood cells: transport oxygen and some carbon dioxide; white blood cells: carry on phagocytosis and mediate allergic reactions and immune system responses; platelets: essential for blood clotting.



membranes. The principal epithelial membranes of the body are mucous membranes, serous membranes, and the cutaneous membrane, or skin. Another type of membrane, a synovial membrane, lines joints and contains connective tissue but no epithelium.

Epithelial Membranes

Mucous Membranes

A **mucous membrane** or *mucosa* (mū-KŌ-sa) lines a body cavity that opens directly to the exterior. Mucous membranes line the entire digestive, respiratory, and reproductive tracts, and much of the urinary tract. They consist of a lining layer of epithelium and an underlying layer of connective tissue (Figure 4.9a).

The epithelial layer of a mucous membrane is an important feature of the body's defense mechanisms because it is a barrier that microbes and other pathogens have difficulty penetrating. Usually, tight junctions connect the cells, so materials cannot leak in between them. Goblet cells and other cells of the epithelial layer of a mucous membrane secrete mucus, and this slippery fluid prevents the cavities from drying out. It also traps particles in the respiratory passageways and lubricates food as it moves through the gastrointestinal tract. In addition, the epithelial layer secretes some of the enzymes needed for digestion and is the site of food and fluid absorption in the gastrointestinal tract. The epithelia of mucous membranes vary greatly in different parts of the body. For example, the mucous membrane of the small intestine is nonciliated simple columnar epithelium, and the large airways to the lungs consist of pseudostratified ciliated columnar epithelium (see Table 4.1E).

The connective tissue layer of a mucous membrane is areolar connective tissue and is called the **lamina propria** (LAM-i-na PRŌ-prē-a; *propria* = one's own), so named because it belongs to (is owned by) the mucous membrane. The lamina propria supports the epithelium, binds it to the underlying structures, allows some flexibility of the membrane, and affords some protection for underlying structures. It also holds blood vessels in place and is the vascular source for the overlying epithelium. Oxygen and nutrients diffuse from the lamina propria to the covering epithelium; carbon dioxide and wastes diffuse in the opposite direction.

Serous Membranes

A **serous membrane** (SĒR-us = watery) or *serosa* lines a body cavity that does not open directly to the exterior (thoracic or abdominal cavities), and it covers the organs that are within the cavity. Serous membranes consist of areolar connective tissue covered by mesothelium (simple squamous epithelium) (Figure 4.9b). You will recall from Chapter 1 that serous membranes have two layers: The layer attached to and lining the cavity wall is called the **parietal layer** (pa-RĪ-e-tal; *pariet-* = wall); the layer that covers and adheres to the organs within the cavity is the **visceral layer** (*viscer-* = body organ) (see Figure 1.10a). The mesothelium of a serous membrane secretes **serous fluid**, a watery lubricant that allows organs to glide easily over one another or to slide against the walls of cavities.

Recall from Chapter 1 that the serous membrane lining the thoracic cavity and covering the lungs is the **pleura**. The serous membrane lining the heart cavity and covering the heart is the **pericardium**. The serous membrane lining the abdominal cavity and covering the abdominal organs is the **peritoneum**.