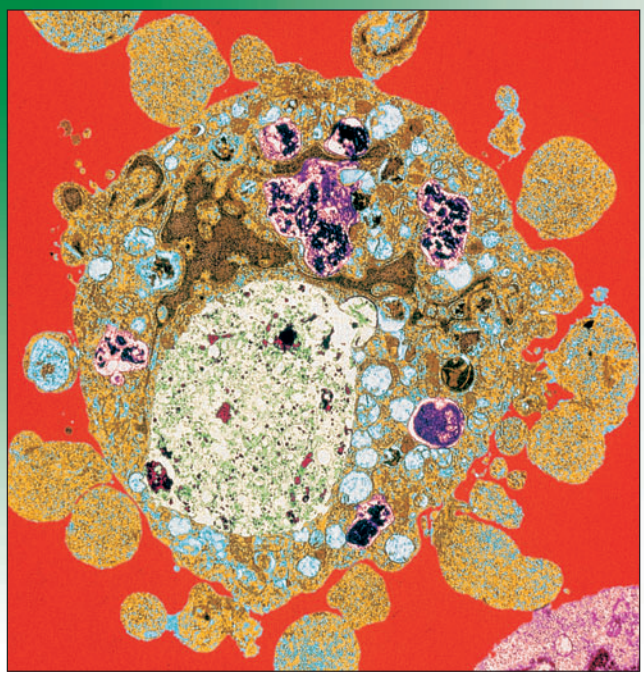
CHAPTER

5



A cell undergoing apoptosis (programmed cell death) (TEM)

Histology

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Brushing Up

To understand this chapter, it is important that you understand or brush up on the following concepts:
- Body cavities and membranes (p. 36)
- Glycoproteins and proteoglycans (p. 75)
- Terminology of cell shapes (p. 94)
- Secretory vesicles and exocytosis (p. 114)

With its 50 trillion cells and thousands of organs, the human body may seem to be a structure of forbidding complexity. Fortunately for our health, longevity, and self-understanding, the biologists of past generations were not discouraged by this complexity, but discovered patterns that made it more understandable. One of these patterns is the fact that these trillions of cells belong to only 200 different types or so, and these cells are organized into tissues that fall into just four broad categories—*epithelial, connective, nervous,* and *muscular tissue*.

An organ is a structure with discrete boundaries that is composed of two or more of these tissue types (usually all four). Organs derive their function not from their cells alone but from how the cells are organized into tissues. Cells are specialized for certain tasks—muscle contraction, defense, enzyme secretion, and so forth. No one cell type has the mechanisms to carry out all of the body's vital functions. Cells work together at certain tasks and form tissues that carry out a particular function, such as nerve signaling or nutrient digestion.

The study of tissues and how they are arranged into organs is called **histology,**[1] or **microscopic anatomy.** That is the subject of this chapter. Here we study the four tissue classes; the variations within each class; how to recognize tissue types microscopically and relate their microscopic anatomy to their function; how tissues are arranged to form an organ; and how tissues change over the life of the individual as they grow, shrink, or change from one tissue type to another. Histology bridges the gap between the *cytology* of the preceding chapters and the *organ system* approach of the chapters that follow.

The Study of Tissues

Objectives

When you have completed this section, you should be able to

- name the four primary classes into which all adult tissues are classified.
- name the three embryonic germ layers and some adult tissues derived from each; and
- visualize the three-dimensional shape of a structure from a two-dimensional tissue section.

The Primary Tissue Classes

A **tissue** is a group of similar cells and cell products that arise from the same region of the embryo and work together to perform a specific structural or physiological role in an organ. The four *primary tissues* are epithelial, connective, nervous, and muscular tissue (table 5.1). These tissues differ from each other in the types and functions of their cells, the characteristics of the **matrix (extracellular material)** that surrounds the cells, and the relative amount of space occupied by cells versus matrix. In muscle and epithelium, the cells are so close together that the matrix is scarcely visible, while in connective tissues, the matrix usually occupies much more space than the cells do.

The matrix is composed of fibrous proteins and, usually, a clear gel variously known as **ground substance, tissue fluid, extracellular fluid (ECF), interstitial**[2] **fluid,** or **tissue gel.** In cartilage and bone, it can be rubbery or stony in consistency. The ground substance contains water, gases, minerals, nutrients, wastes, and other chemicals. In summary, a tissue is composed of cells and matrix, and the matrix is composed of fibers and ground substance.

Embryonic Tissues

Human development begins with a single cell, the fertilized egg, which soon divides to produce scores of identical, smaller cells. The first tissues appear when these cells start to organize themselves into layers—first two, and soon three strata called the **primary germ layers,** which give rise to all of the body's mature tissues. The three layers are called *ectoderm, mesoderm,* and *endoderm*. The **ectoderm**[3] is an outer layer that gives rise to the epidermis and nervous system. The inner layer, the **endoderm,**[4] gives rise to the mucous membranes of the digestive and respiratory tracts and to the digestive glands, among other things. Between these two is the **mesoderm,**[5] a layer of more loosely organized cells. Mesoderm eventually turns to a gelatinous tissue called **mesenchyme,** composed of fine, wispy collagen (protein) fibers and branching cells called *fibroblasts* embedded in a gelatinous ground substance. Mesenchyme closely resembles the connective tissue layer in figure 5.11*a*. It gives rise to muscle, bone, and blood, among other tissues. Most organs are composed of tissues derived from two or more primary germ layers. The rest of this chapter concerns the "mature" tissues that exist from infancy through adulthood.

Interpreting Tissue Sections

Histologists use a variety of techniques for preserving, sectioning (slicing), and staining tissues to show their structural details as clearly as possible. Tissue specimens are preserved in a **fixative**—a chemical such as formalin that prevents decay. After fixation, most tissues are cut into very thin slices called **histological sections.** These sections are typically only one or two cells thick, to allow the light of a microscope to pass through and to reduce the confusion of the image that would result from many layers of overlapping cells. They are mounted on slides and arti-

[1] *histo* = tissue + *logy* = study of

[2] *inter* = between + *stit* = to stand

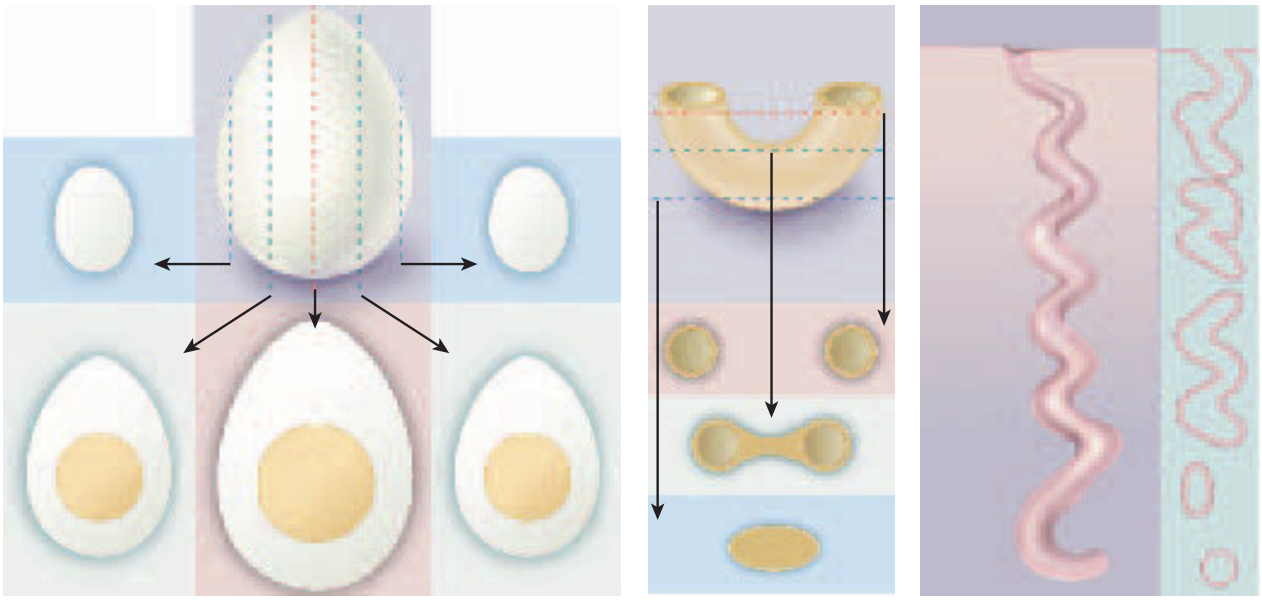
[3] *ecto* = outer + *derm* = skin

[4] *endo* = inner

[5] *meso* = middle

Table 5.1 The Four Primary Tissue Classes

Type	Definition	Representative Locations
Epithelial	Tissue composed of layers of closely spaced cells that cover organ surfaces, form glands, and serve for protection, secretion, and absorption	Epidermis Inner lining of digestive tract Liver and other glands
Connective	Tissue with more matrix than cell volume, often specialized to support, bind together, and protect organs	Tendons and ligaments Cartilage and bone Blood
Nervous	Tissue containing excitable cells specialized for rapid transmission of coded information to other cells	Brain Spinal cord Nerves
Muscular	Tissue composed of elongated, excitable cells specialized for contraction	Skeletal muscles Heart (cardiac muscle) Walls of viscera (smooth muscle)



(a) (b) (c)

Figure 5.1 Three-Dimensional Interpretation of Two-Dimensional Images. (*a*) A boiled egg. Note that grazing sections (*far left* and *right*) would miss the yolk, just as a tissue section may miss a nucleus or other structure. (*b*) Elbow macaroni, which resembles many curved ducts and tubules. A section far from the bend would give the impression of two separate tubules; a section near the bend would show two interconnected lumina (cavities); and a section still farther down could miss the lumen completely. (*c*) A coiled gland in three dimensions and as it would look in a vertical tissue section.

ficially colored with histological **stains** to bring out detail. If they were not stained, most tissues would appear very pale gray. With stains that bind to different components of a tissue, however, you may see pink cytoplasm, violet nuclei, and blue, green, or golden brown protein fibers, depending on the stain used.

Sectioning a tissue reduces a three-dimensional structure to a two-dimensional slice. You must keep this in mind and try to translate the microscopic image into a mental image of the whole structure. Like the boiled egg and elbow macaroni in figure 5.1, an object may look quite different when it is cut at various levels, or *planes of section*. A coiled tube, such as a gland of the uterus (fig. 5.1*c*), is often broken up into multiple portions since it meanders in and out of the plane of section. An experienced viewer, however, would recognize that the separated pieces are parts of a single tube winding its way to the organ surface. Note that a grazing slice through a boiled

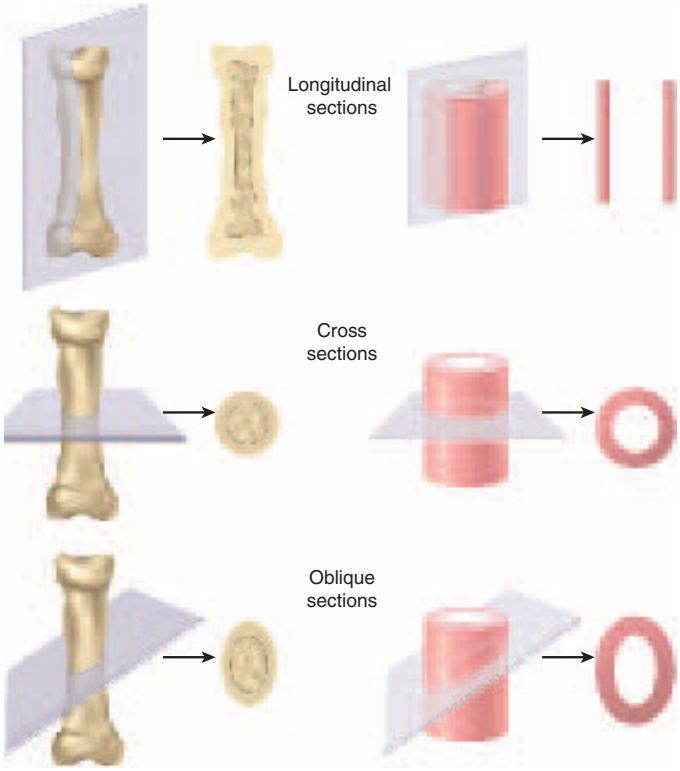


Figure 5.2 Longitudinal, Cross, and Oblique Sections. Note the effect of the plane of section on the two-dimensional appearance of elongated structures such as bones and blood vessels.
Would you classify the egg sections in the previous figure as longitudinal, cross, or oblique sections? How would the egg look if sectioned in the other two planes?

egg might miss the yolk, just as a tissue section might miss the nucleus of a cell or an egg in the ovary, even though these structures were present.

Many anatomical structures are significantly longer in one direction than another—the humerus and esophagus, for example. A tissue cut in the long direction is called a **longitudinal section (l.s.),** and one cut perpendicular to this is a **cross section** (**c.s.** or **x.s.**), or **transverse section (t.s.).** A section cut at an angle between a longitudinal and cross section is an **oblique section.** Figure 5.2 shows how certain organs look when sectioned on each of these planes.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

1. Classify each of the following into one of the four primary tissue classes: the skin surface, fat, the spinal cord, most heart tissue, bones, tendons, blood, and the inner lining of the stomach.
2. What are tissues composed of in addition to cells?
3. What embryonic germ layer gives rise to nervous tissue? To the liver? To muscle?
4. What is the term for a thin, stained slice of tissue mounted on a microscope slide?

Epithelial Tissue

Objectives

When you have completed this section, you should be able to

- describe the properties that distinguish epithelium from other tissue classes;
- list and classify eight types of epithelium, distinguish them from each other, and state where each type can be found in the body;
- explain how the structural differences between epithelia relate to their functional differences; and
- visually recognize each epithelial type from specimens or photographs.

Epithelial[6] **tissue** consists of a flat sheet of closely adhering cells, one or more cells thick, with the upper surface usually exposed to the environment or to an internal space in the body. Epithelium covers the body surface, lines body cavities, forms the external and internal linings of many organs, and constitutes most gland tissue. The extracellular material is so thin it is not visible with the light microscope, and epithelia allow no room for blood vessels. They do, however, almost always lie on a layer of loose connective tissue and depend on its blood vessels for nourishment and waste removal.

Between an epithelium and the underlying connective tissue is a layer called the **basement membrane,** usually too thin to be visible with the light microscope. It contains collagen, adhesive glycoproteins called *laminin* and *fibronectin,* and a large protein-carbohydrate complex called *heparan sulfate.* It gradually blends with collagenous and reticular fibers on the connective tissue side. The basement membrane serves to anchor an epithelium to the connective tissue below it. The surface of an epithelial cell that faces the basement membrane is its *basal surface,* and the one that faces away from the basement membrane is the *apical surface.*

Epithelia are classified into two broad categories—*simple* and *stratified*—with four types in each category. In a simple epithelium, every cell touches the basement membrane, whereas in a stratified epithelium, some cells rest on top of other cells and do not contact the basement membrane (fig. 5.3).

[6] *epi* = upon + *theli* = nipple, female

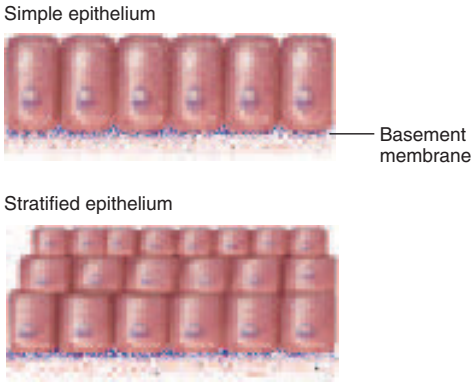


Figure 5.3 **Comparison of Simple and Stratified Epithelia.**

Simple Epithelia

Generally, a **simple epithelium** has only one layer of cells, although this is a somewhat debatable point in the *pseudostratified* type. Three types of simple epithelia are named for the shapes of their cells: **simple squamous**[7] (thin scaly cells), **simple cuboidal** (square or round cells), and **simple columnar** (tall narrow cells). In the fourth type, **pseudostratified columnar,** not all cells reach the free surface; the shorter cells are covered over by the taller ones. This epithelium looks stratified in most tissue sections, but careful examination, especially with the electron microscope, shows that every cell reaches the basement membrane. Simple columnar and pseudostratified columnar epithelia often produce protective mucous coatings over the mucous membranes. The mucus is secreted by wineglass-shaped **goblet cells.**

Table 5.2 illustrates and summarizes the structural and functional differences among these four types.

Stratified Epithelia

Stratified epithelia range from 2 to 20 or more layers of cells, with some cells resting directly on others and only the deepest layer resting on the basement membrane. Three of the stratified epithelia are named for the shapes of their surface cells: **stratified squamous, stratified cuboidal,** and **stratified columnar epithelia.** The deeper cells, however, may be of a different shape than the surface cells. The fourth type, **transitional epithelium,** was named when it was thought to represent a transitional stage between stratified squamous and stratified columnar epithelium. This is now known to be untrue, but the name has persisted.

Stratified columnar epithelium is rare—seen only in places where two other epithelial types meet, as in limited regions of the pharynx, larynx, anal canal, and male urethra. We will not consider this type any further. The other three types are illustrated and summarized in table 5.3.

The most widespread epithelium in the body is stratified squamous epithelium, which deserves further discussion. Its deepest layer of cells are cuboidal to columnar and undergo continual mitosis. Their daughter cells push toward the surface and become flatter (more *squamous,* or scalelike) as they migrate farther upward, until they finally die and flake off. Their separation from the surface is called **exfoliation,** or **desquamation** (fig. 5.12); the study of exfoliated cells is called *exfoliate cytology.* You can easily study exfoliated cells by scraping your gums with a toothpick, smearing this material on a slide, and staining it. A similar procedure is used in the *Pap smear*, an examination of exfoliated cells from the cervix for signs of uterine cancer (see chapter 28, fig. 28.5, for normal and cancerous Pap smears).

Stratified squamous epithelia are of two kinds—keratinized and nonkeratinized. A **keratinized** epithelium, found on the skin surface (epidermis), is covered with a layer of compact, dead squamous cells. These cells are packed with the durable protein keratin and coated with water repellent. The skin surface is therefore relatively dry, it retards water loss from the body, and it resists penetration by disease organisms. (Keratin is also the protein of which animal horns are made, hence its name.[8]) The tongue, oral mucosa, esophagus, vagina, and a few other internal membranes are covered with the **nonkeratinized** type, which lacks the surface layer of dead cells. This type provides a surface that is, again, abrasion-resistant, but also moist and slippery. These characteristics are well suited to resist stress produced by the chewing and swallowing of food and by sexual intercourse and childbirth.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

5. Distinguish between simple and stratified epithelia, and explain why pseudostratified columnar epithelium belongs in the former category.
6. Explain how to distinguish a stratified squamous epithelium from a transitional epithelium.
7. What function do keratinized and nonkeratinized stratified squamous epithelia have in common? What is the structural difference between these two? How is this structural difference related to a functional difference between them?
8. How do the epithelia of the esophagus and stomach differ? How does this relate to their respective functions?

[7] *squam* = scale

[8] *kerat* = horn

Table 5.2 Simple Epithelia

Simple Squamous Epithelium

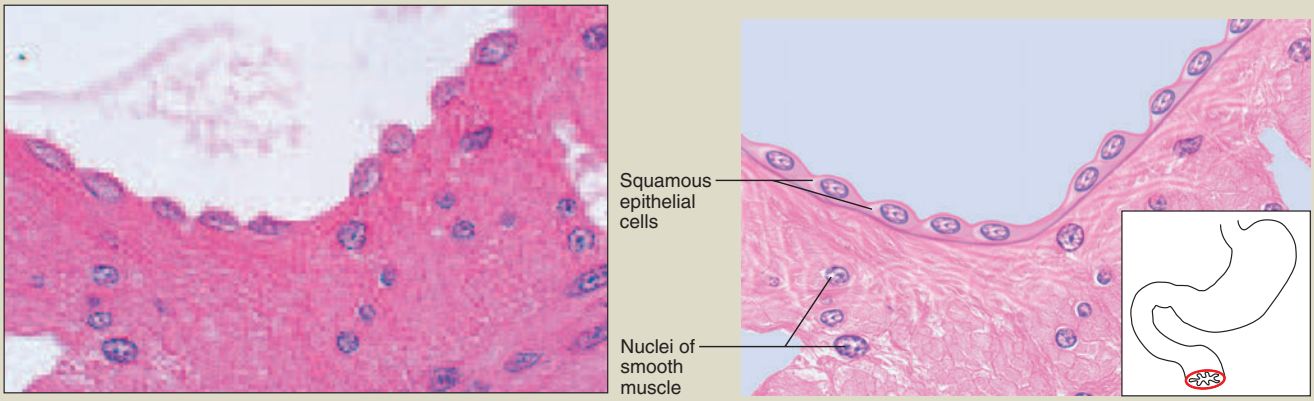


Figure 5.4 External Surface (Serosa) of the Small Intestine.

Microscopic appearance: Single layer of thin cells, shaped like fried eggs with bulge where nucleus is located; nucleus flattened in the plane of the cell, like an egg yolk; cytoplasm may be so thin it is hard to see in tissue sections; in surface view, cells have angular contours and nuclei appear round

Representative locations: Air sacs (alveoli) of lungs; glomerular capsules of kidneys; some kidney tubules; inner lining (endothelium) of heart and blood vessels; serous membranes of stomach, intestines, and some other viscera; surface mesothelium of pleurae, pericardium, peritoneum, and mesenteries

Functions: Allows rapid diffusion or transport of substances through membrane; secretes lubricating serous fluid

Simple Cuboidal Epithelium

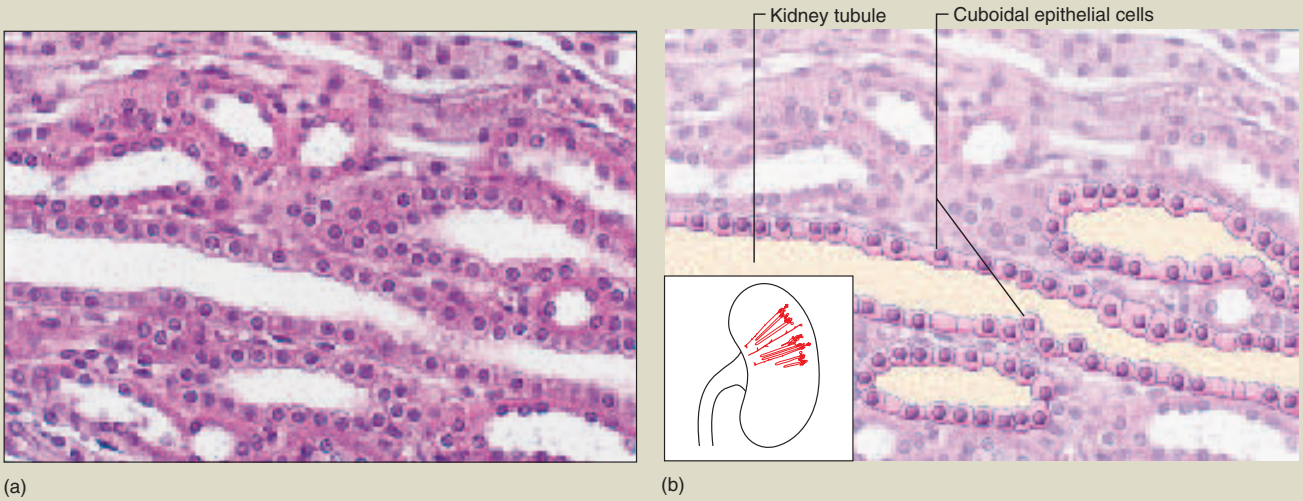


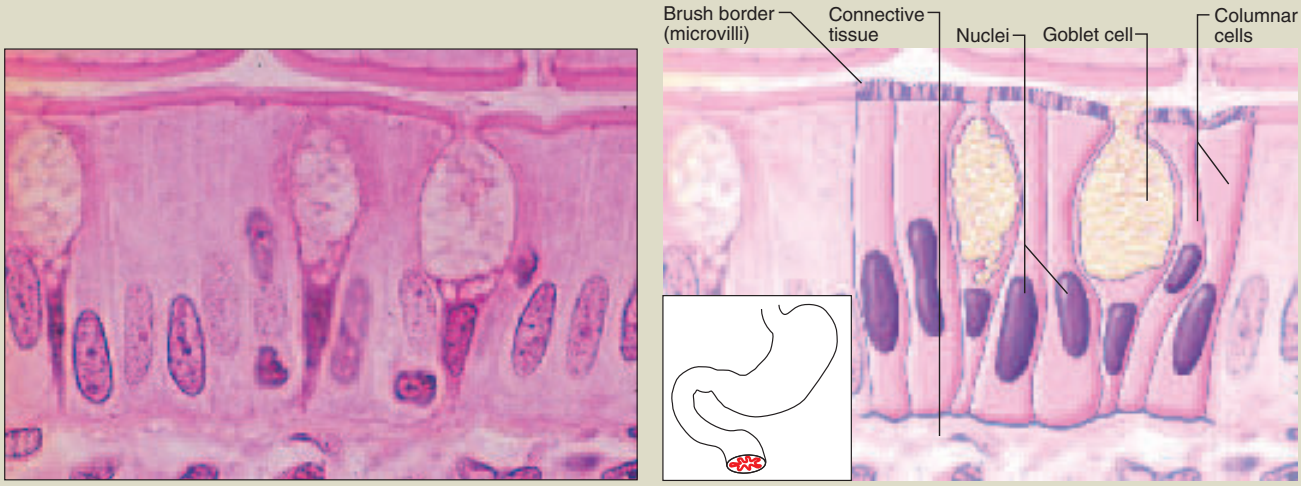
Figure 5.5 Kidney Tubules.

Microscopic appearance: Single layer of square or round cells; in glands, cells often pyramidal and arranged like segments of an orange around a central space; spherical, centrally placed nuclei; often with a brush border of microvilli in some kidney tubules; ciliated in bronchioles of lung

Representative locations: Liver, thyroid, mammary, salivary, and other glands; most kidney tubules; bronchioles

Functions: Absorption and secretion; production of protective mucous coat; movement of respiratory mucus

Simple Columnar Epithelium



(a) (b)

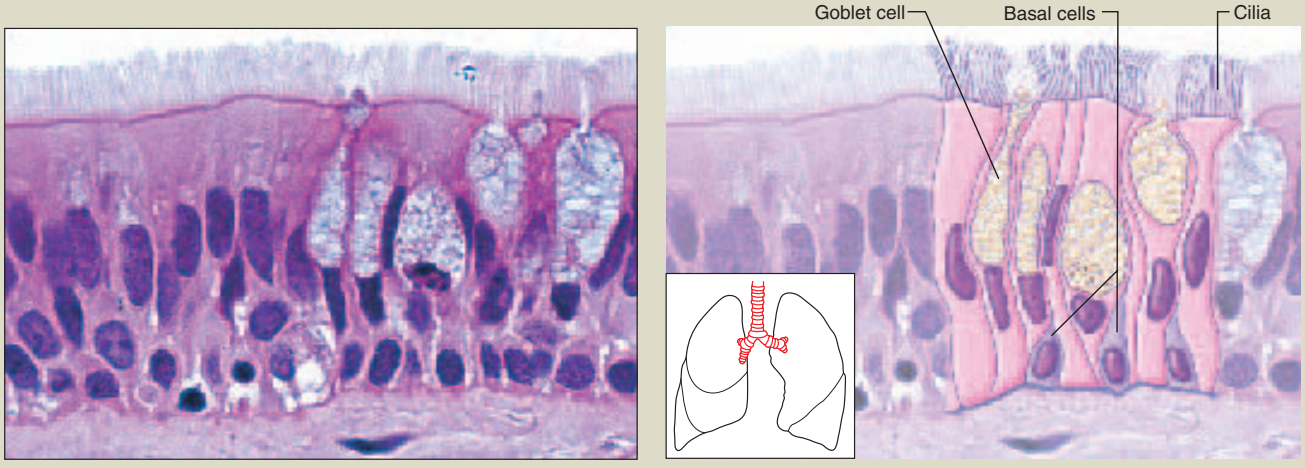
Figure 5.6 Internal Surface (Mucosa) of the Small Intestine.

Microscopic appearance: Single layer of tall, narrow cells; oval or sausage-shaped nuclei, vertically oriented, usually in basal half of cell; apical portion of cell often shows secretory vesicles visible with TEM; often shows a brush border of microvilli; ciliated in some organs; may possess goblet cells

Representative locations: Inner lining of stomach, intestines, gallbladder, uterus, and uterine tubes; some kidney tubules

Functions: Absorption and secretion; movement of egg and embryo in uterine tube; secretion of mucus

Pseudostratified Columnar Epithelium



(a) (b)

Figure 5.7 Mucosa of the Trachea.

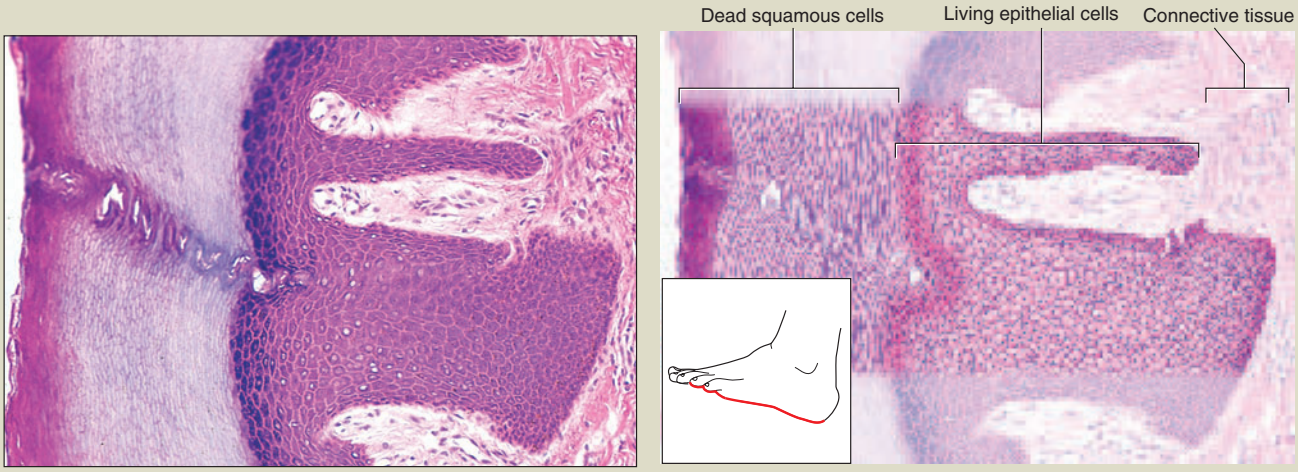
Microscopic appearance: Looks multilayered; some cells do not reach free surface but all cells reach basement membrane; nuclei at several levels in deeper half of epithelium; often with goblet cells; often ciliated

Representative locations: Respiratory tract from nasal cavity to bronchi; portions of male reproductive tract

Functions: Secretes and propels mucus

Table 5.3 Stratified Epithelia

Stratified Squamous Epithelium—Keratinized



(a) (b)

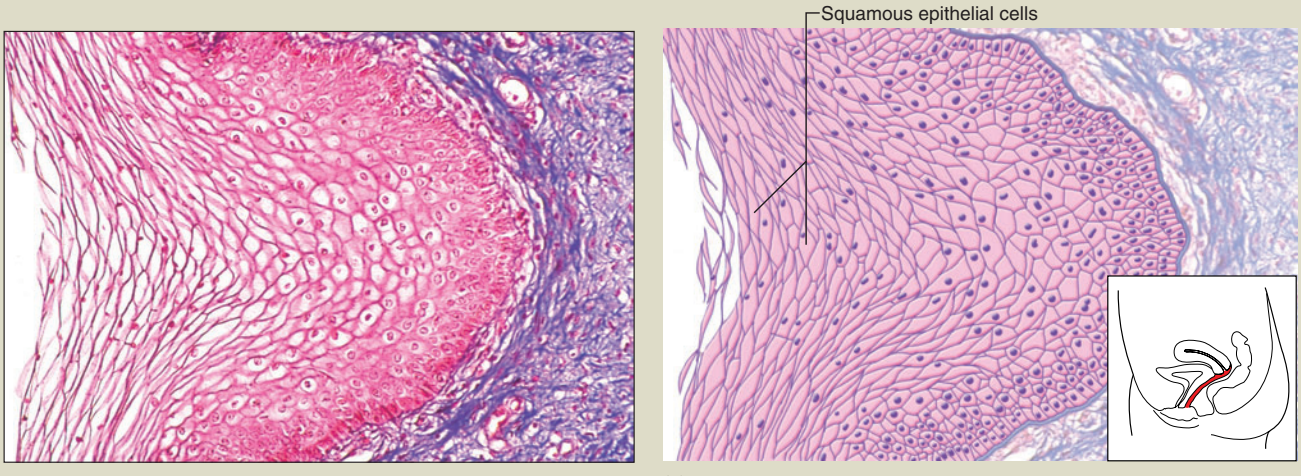
Figure 5.8 Skin from the Sole of the Foot.

Microscopic appearance: Multiple cell layers with cells becoming increasingly flat and scaly toward surface; surface covered with a layer of compact dead cells without nuclei; basal cells may be cuboidal to columnar

Representative locations: Epidermis; palms and soles are especially heavily keratinized

Functions: Resists abrasion; retards water loss through skin; resists penetration by pathogenic organisms

Stratified Squamous Epithelium—Nonkeratinized



(a) (b)

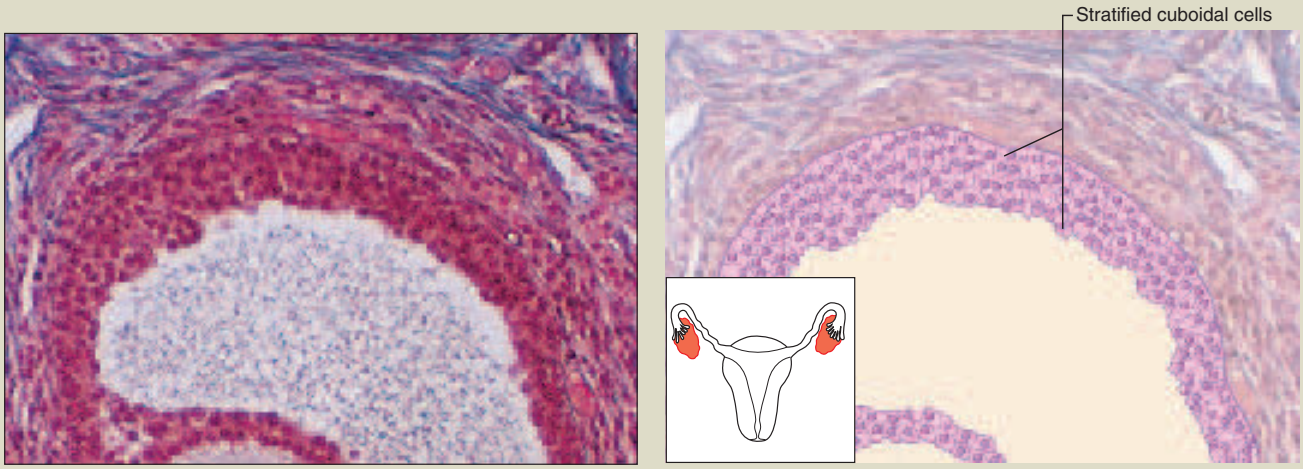
Figure 5.9 Mucosa of the Vagina.

Microscopic appearance: Same as keratinized epithelium but without the surface layer of dead cells

Representative locations: Tongue, oral mucosa, esophagus, anal canal, vagina

Functions: Resists abrasion and penetration by pathogenic organisms

Stratified Cuboidal Epithelium



(a) (b)

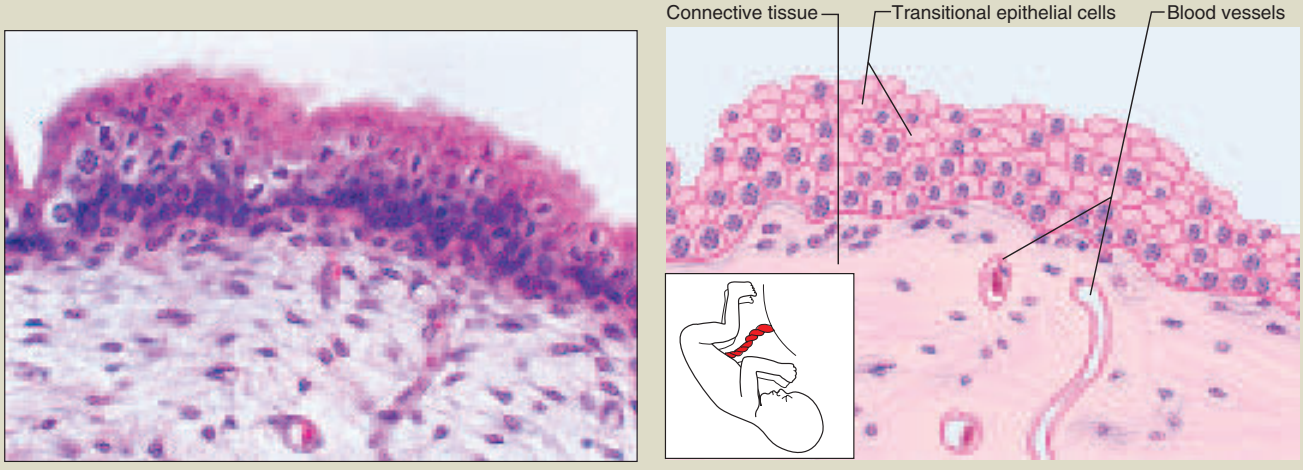
Figure 5.10 Wall of a Follicle in the Ovary.

Microscopic appearance: Two or more layers of cells; surface cells square or round

Representative locations: Sweat gland ducts; egg-producing vesicles (follicles) of ovaries; sperm-producing ducts (seminiferous tubules) of testis

Functions: Contributes to sweat secretion; secretes ovarian hormones; produces sperm

Transitional Epithelium



(a) (b)

Figure 5.11 Allantoic Duct of Umbilical Cord.

Microscopic appearance: Somewhat resembles stratified squamous epithelium, but surface cells are rounded, not flattened, and often bulge above surface; typically five or six cells thick when relaxed and two or three cells thick when stretched; cells may be flatter and thinner when epithelium is stretched (as in a distended bladder); some cells have two nuclei

Representative locations: Urinary tract—part of kidney, ureter, bladder, part of urethra; allantoic duct in umbilical cord

Functions: Stretches to allow filling of urinary tract

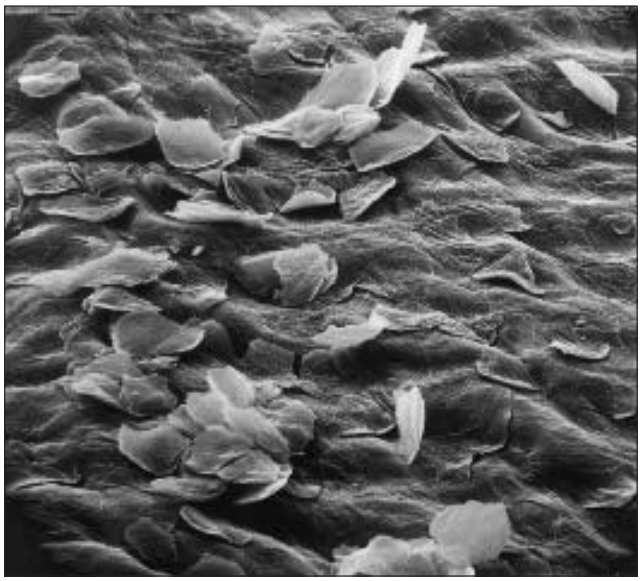


Figure 5.12 Exfoliation of Squamous Cells from the Mucosal Surface of the Vagina. From R. G. Kessel and R. H. Kardon, *Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy* (W. H. Freeman, 1979). Aside from the gums and vagina, name another epithelium in the body that would look like this to the scanning electron microscope.

Connective Tissue

Objectives

When you have completed this section, you should be able to

- describe the properties that most connective tissues have in common;
- discuss the types of cells found in connective tissue;
- explain what the matrix of a connective tissue is and describe its components;
- name 10 types of connective tissue, describe their cellular components and matrix, and explain what distinguishes them from each other; and
- visually recognize each connective tissue type from specimens or photographs.

Overview

Connective tissue typically consists mostly of fibers and ground substance, with widely separated cells. It is the most abundant, widely distributed, and histologically variable of the primary tissues. As the name implies, it often serves to connect organs to each other—for example, the way a tendon connects muscle to bone—or serves in other ways to support, bind, and protect organs. This category includes fibrous tissue, fat, cartilage, bone, and blood.

The functions of connective tissue include the following:

- **Binding of organs.** Tendons bind muscle to bone, ligaments bind one bone to another, fat holds the kidneys and eyes in place, and fibrous tissue binds the skin to underlying muscle.
- **Support.** Bones support the body, and cartilage supports the ears, nose, trachea, and bronchi.
- **Physical protection.** The cranium, ribs, and sternum protect delicate organs such as the brain, lungs, and heart; fatty cushions around the kidneys and eyes protect these organs.
- **Immune protection.** Connective tissue cells attack foreign invaders, and connective tissue fiber forms a "battlefield" under the skin and mucous membranes where immune cells can be quickly mobilized against disease agents.
- **Movement.** Bones provide the lever system for body movement, cartilages are involved in movement of the vocal cords, and cartilages on bone surfaces ease joint movements.
- **Storage.** Fat is the body's major energy reserve; bone is a reservoir of calcium and phosphorus that can be drawn upon when needed.
- **Heat production.** Brown fat generates heat in infants and children.
- **Transport.** Blood transports gases, nutrients, wastes, hormones, and blood cells.

The mesenchyme described earlier in this chapter is a form of embryonic connective tissue. The connective tissues present after birth fall into three broad categories: *fibrous connective tissues, supportive connective tissues* (cartilage and bone), and *fluid connective tissue* (blood).

Fibrous Connective Tissue

Fibrous connective tissues are the most diverse type of connective tissue. They are also called *fibroconnective tissue* or *connective tissue proper.* Nearly all connective tissues contain fibers, but the tissues considered here are classified together because the fibers are so conspicuous. Fibers are, of course, just one component of the tissue, which also includes cells and ground substance. Before examining specific types of fibroconnective tissue, let's examine these components.

Components of Fibrous Connective Tissue

Cells The cells of fibrous connective tissue include the following types:

- **Fibroblasts.**[9] These are large, flat cells that often appear tapered at the ends and show slender, wispy branches. They produce the fibers and ground substance that form the matrix of the tissue. Fibroblasts that have finished this task and become inactive are called *fibrocytes* by some histologists.
- **Macrophages.**[10] These are large phagocytic cells that wander through the connective tissues, where they engulf and destroy bacteria, other foreign particles, and dead or dying cells of our own body, and activate the immune system when they sense foreign matter called *antigens.* They arise from certain white blood cells called *monocytes* or from the same stem cells that produce monocytes.
- **Leukocytes,**[11] or **white blood cells (WBCs).** WBCs travel briefly in the bloodstream, then crawl out through the capillary walls and spend most of their time in the connective tissues. Most of them are *neutrophils,* which wander about in search of bacteria. Our mucous membranes often exhibit dense patches of tiny WBCs called *lymphocytes,* which react against bacteria, toxins, and other foreign agents.
- **Plasma cells.** Certain lymphocytes turn into plasma cells when they detect foreign agents. The plasma cells then synthesize disease-fighting proteins called *antibodies.* Plasma cells are rarely seen except in the walls of the intestines and in inflamed tissue.
- **Mast cells.** These cells, found especially alongside blood vessels, secrete a chemical called *heparin* that inhibits blood clotting, and one called *histamine* that increases blood flow by dilating blood vessels.
- **Adipocytes** (AD-ih-po-sites), or **fat cells.** These are large rounded cells filled mainly with a droplet of triglyceride, which forces the nucleus and cytoplasm to occupy only a thin layer just beneath the plasma membrane. They appear in small clusters in some fibrous connective tissues. When they dominate an area, the tissue is called *adipose tissue.*

Fibers Three types of protein fibers are found in fibrous connective tissues:

- **Collagenous** (col-LADJ-eh-nus) **fibers.** These fibers, made of collagen, are tough and flexible and resist stretching. Collagen is about 25% of the body's protein, the most abundant type. It is the base of such animal products as gelatin, leather, and glue.[12] In fresh tissue, collagenous fibers have a glistening white appearance, as seen in tendons and some cuts of meat (fig. 5.13); thus, they are often called *white fibers.* In tissue sections, collagen forms coarse, wavy bundles, often dyed pink, blue, or green by the most common histological stains. Tendons, ligaments, and the deep layer of the skin (the dermis) are made mainly of collagen. Less visibly, collagen pervades the matrix of cartilage and bone.

[9] *fibro* = fiber + *blast* = producing
[10] *macro* = big + *phage* = eater
[11] *leuko* = white + *cyte* = cell
[12] *colla* = glue + *gen* = producing

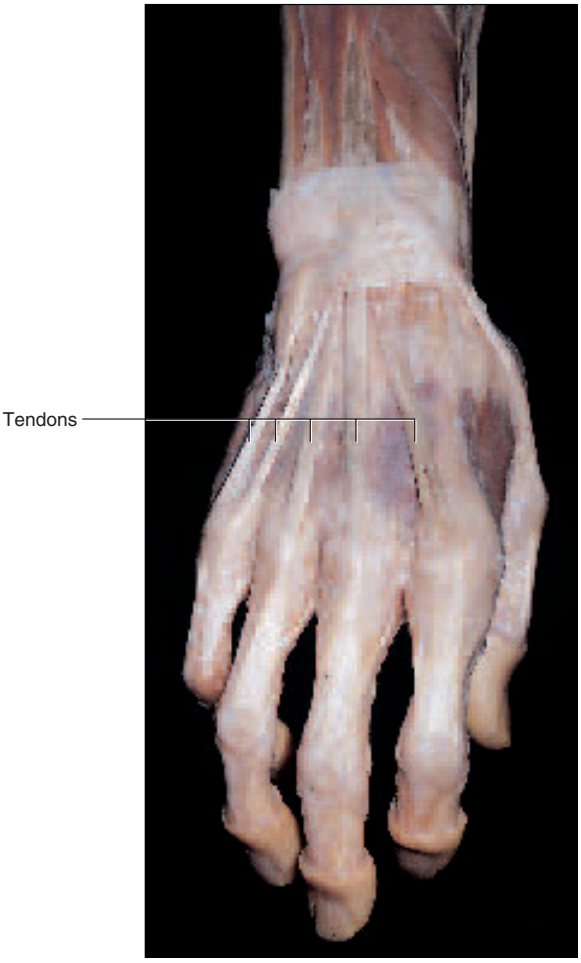


Figure 5.13 Tendons of the Hand. The white glistening appearance results from the collagen of which tendons are composed. The bracelet-like band across the wrist is also composed of collagen.

- **Reticular**[13] **fibers.** These are thin collagen fibers coated with glycoprotein. They form a spongelike framework for such organs as the spleen and lymph nodes.
- **Elastic fibers.** These are thinner than collagenous fibers, and they branch and rejoin each other along their course. They are made of a protein called **elastin,** whose coiled structure allows it to stretch and recoil like a rubber band. Elastic fibers account for the ability of the skin, lungs, and arteries to spring back after they are stretched. (Elasticity is not the ability to stretch, but the tendency to recoil when tension is released.) Fresh elastic fibers are yellowish and therefore often called *yellow fibers.*

Ground Substance Amid the cells and fibers in some tissue sections, there appears to be a lot of empty space. In life, this space is occupied by the featureless **ground substance.** Ground substance usually has a gelatinous to rubbery consistency resulting from three classes of large molecules: glycosaminoglycans, proteoglycans, and adhesive glycoproteins. It absorbs compressive forces and, like the styrofoam packing in a shipping carton, protects the more delicate cells from mechanical injury.

A **glycosaminoglycan (GAG)** (gly-COSE-ah-MEE-no-GLY-can) is a long polysaccharide composed of unusual disaccharides called *amino sugars* and *uronic acid.* GAGs are negatively charged and thus tend to attract sodium and potassium ions, which in turn causes the GAGs to absorb and hold water. Thus, GAGs play an important role in regulating the water and electrolyte balance of tissues. The most abundant GAG is **chondroitin** (con-DRO-ih-tin) **sulfate.** It is abundant in blood vessels and bones and is responsible for the relative stiffness of cartilage. Some other GAGs that you will read of elsewhere in this book are *heparin* (an anticoagulant) and *hyaluronic* (HY-uh-loo-RON-ic) *acid.* The latter is a gigantic molecule up to 20 μm long, as large as most cells. It is a viscous, slippery substance that forms a very effective lubricant in the joints and constitutes much of the jellylike *vitreous humor* of the eyeball.

A **proteoglycan** is another gigantic molecule. It is shaped somewhat like a test tube brush (fig. 5.14), with the central core composed of protein and the bristlelike outgrowths composed of GAGs. The entire proteoglycan may be attached to hyaluronic acid, thus forming an enormous molecular complex. Proteoglycans form thick colloids similar to those of gravy, pudding, gelatin, and glue. This gel slows the spread of pathogenic organisms through the tissues. Some proteoglycans are embedded in the plasma membranes of cells, attached to the cytoskeleton on the inside and to other extracellular molecules on the outside. Thus, they create a strong structural bond between cells and extracellular macromolecules and help to hold tissues together.

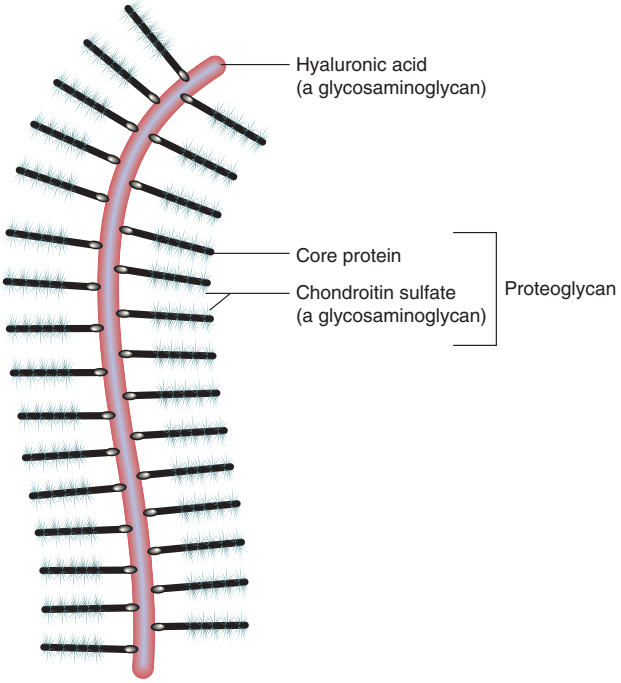


Figure 5.14 Proteoglycan Molecules Linked to a Hyaluronic Acid Core. The resulting hydrophilic complex is larger than many cells.

Adhesive glycoproteins are protein-carbohydrate complexes that bind plasma membrane proteins to collagen and proteoglycans outside the cell. They bind all the components of a tissue together and mark pathways that guide migrating embryonic cells to their destinations in a tissue.

Types of Fibrous Connective Tissue

Fibrous connective tissue is divided into two broad categories according to the relative abundance of fiber: *loose* and *dense connective tissue.* In **loose connective tissue,** much of the space is occupied by ground substance, which is dissolved out of the tissue during histological fixation and leaves empty space in prepared tissue sections. The loose connective tissues we will discuss are *areolar, reticular,* and *adipose tissue.* In **dense connective tissue,** fiber occupies more space than the cells and ground substance, and appears closely packed in tissue sections. The two dense connective tissues we will discuss are *dense regular* and *dense irregular connective tissue.*

Areolar[14] (AIR-ee-OH-lur) **tissue** exhibits loosely organized fibers, abundant blood vessels, and a lot of seemingly empty space. It possesses all six of the aforementioned cell types. Its fibers run in random directions and are mostly

[13] *ret* = network + *icul* = little

[14] *areola* = little space

collagenous, but elastic and reticular fibers are also present. Areolar tissue is highly variable in appearance. In many serous membranes, it looks like figure 5.15, but in the skin and mucous membranes, it is more compact (see fig. 5.8) and sometimes difficult to distinguish from dense irregular connective tissue. Some advice on how to tell them apart is given after the discussion of dense irregular connective tissue.

Areolar tissue is found in tissue sections from almost every part of the body. It surrounds blood vessels and nerves and penetrates with them even into the small spaces of muscles, tendons, and other tissues. Nearly every epithelium rests on a layer of areolar tissue, whose blood vessels provide the epithelium with nutrition, waste removal, and a ready supply of infection-fighting WBCs in times of need. Because of the abundance of open, fluid-filled space, WBCs can move about freely in areolar tissue and can easily find and destroy pathogens.

Reticular tissue is a mesh of reticular fibers and fibroblasts. It forms the structural framework (stroma) of such organs and tissues as the lymph nodes, spleen, thymus, and bone marrow. The space amid the fibers is filled with blood cells. If you imagine a kitchen sponge soaked with blood, the sponge fibers would be analogous to the reticular tissue stroma.

Adipose tissue, or **fat,** is tissue in which adipocytes are the dominant cell type. Adipocytes may also occur singly or in small clusters in areolar tissue. Adipocytes usually range from 70 to 120 μm in diameter, but they may be five times as large in obese people. The space between adipocytes is occupied by areolar tissue, reticular tissue, and blood capillaries.

Fat is the body's primary energy reservoir. The quantity of stored triglyceride and the number of adipocytes are quite stable in a person, but this doesn't mean stored fat is stagnant. New triglycerides are constantly synthesized and stored as others are hydrolyzed and released into circulation. Thus, there is a constant turnover of stored triglyceride, with an equilibrium between synthesis and hydrolysis, energy storage and energy use. Adipose tissue also provides thermal insulation, and it contributes to body contours such as the female breasts and hips. Most adipose tissue is a type called *white fat,* but fetuses, infants, and children also have a heat-generating tissue called *brown fat,* which accounts for up to 6% of an infant's weight. Brown fat gets its color from an unusual abundance of blood vessels and certain enzymes in its mitochondria. It stores lipid in the form of multiple droplets rather than one large one. Brown fat has numerous mitochondria, but their oxidation pathway is not linked to ATP synthesis. Therefore, when these cells oxidize fats, they release all of the energy as heat. Hibernating animals accumulate brown fat in preparation for winter.

Table 5.4 summarizes the three types of loose fibrous connective tissues.

Think About It

Why would infants and children have more need for brown fat than adults do? (Hint: Smaller bodies have a higher ratio of surface area to volume than larger bodies do.)

Dense regular connective tissue is named for two properties: (1) the collagen fibers are closely packed and leave relatively little open space, and (2) the fibers are parallel to each other. It is found especially in tendons and ligaments. The parallel arrangement of fibers is an adaptation to the fact that tendons and ligaments are pulled in predictable directions. With some minor exceptions such as blood vessels and sensory nerve fibers, the only cells in this tissue are fibroblasts, visible by their slender, violet-staining nuclei squeezed between bundles of collagen. This type of tissue has few blood vessels, so injured tendons and ligaments are slow to heal.

The vocal cords, suspensory ligament of the penis, and some ligaments of the vertebral column are made of a type of dense regular connective tissue called **yellow elastic tissue.** In addition to the densely packed collagen fibers, it exhibits branching elastic fibers and more fibroblasts. The fibroblasts have larger, more conspicuous nuclei than seen in most dense regular connective tissue.

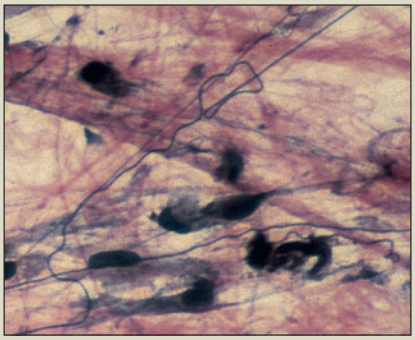
Elastic tissue also takes the form of wavy sheets in the walls of the large and medium arteries. When the heart pumps blood into the arteries, these sheets enable them to expand and relieve some of the pressure on smaller vessels downstream. When the heart relaxes, the arterial wall springs back and keeps the blood pressure from dropping too low between heartbeats. The importance of this elastic tissue becomes especially clear when there is not enough of it—for example, in Marfan syndrome (see insight 5.1, p. 172)—or when it is stiffened by arteriosclerosis (see chapter 19).

Dense irregular connective tissue also has thick bundles of collagen and relatively little room for cells and ground substance, but the collagen bundles run in random directions. This arrangement enables the tissue to resist unpredictable stresses. This tissue constitutes most of the dermis, where it binds the skin to the underlying muscle and connective tissue. It forms a protective capsule around organs such as the kidneys, testes, and spleen and a tough fibrous sheath around the bones, nerves, and most cartilages.

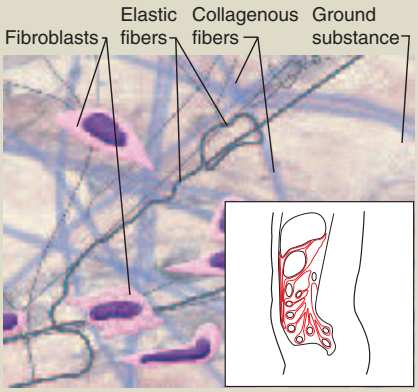
It is sometimes difficult to judge whether a tissue is areolar or dense irregular. In the dermis, for example, these tissues occur side by side, and the transition from one to the other is not at all obvious. A relatively large amount of clear space suggests areolar tissue, and thicker bundles of collagen with relatively little clear space suggests dense irregular tissue. The dense connective tissues are summarized in table 5.5.

Table 5.4 Loose Connective Tissues

Areolar Tissue



(a)



(b)

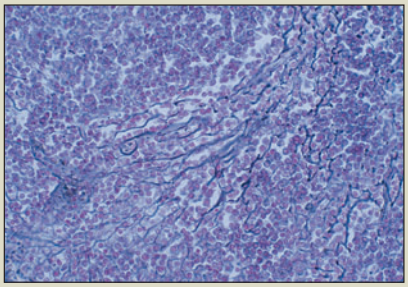
Figure 5.15 Spread of the Mesentery.

Microscopic appearance: Loose arrangement of collagenous and elastic fibers; scattered cells of various types; abundant ground substance; numerous blood vessels

Representative locations: Underlying nearly all epithelia; surrounding blood vessels, nerves, esophagus, and trachea; fascia between muscles; mesenteries; visceral layers of pericardium and pleura

Functions: Loosely binds epithelia to deeper tissues; allows passage of nerves and blood vessels through other tissues; provides an arena for immune defense; blood vessels provide nutrients and waste removal for overlying epithelia

Reticular Tissue



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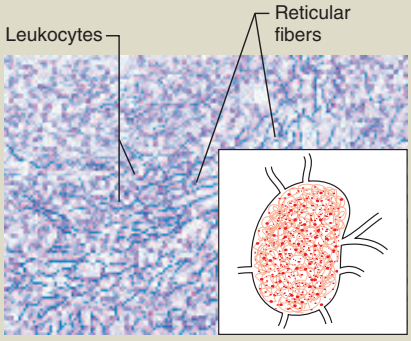


(b)

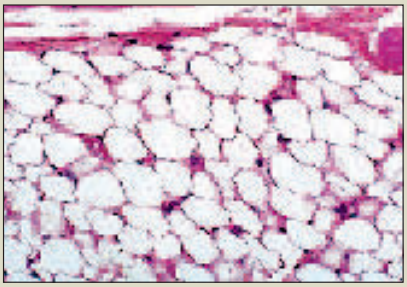
Figure 5.16 Lymph Node.

Microscopic appearance: Loose network of reticular fibers and cells, infiltrated with numerous lymphocytes and other blood cells

Representative locations: Lymph nodes, spleen, thymus, bone marrow

Functions: Supportive stroma (framework) for lymphatic organs

Adipose Tissue



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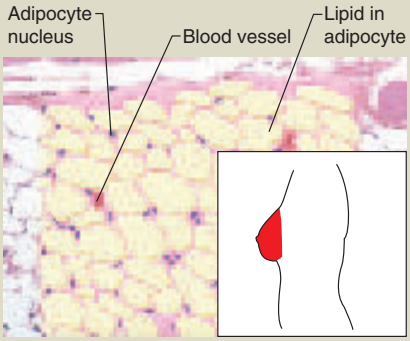


(b)

Figure 5.17 Adipose Tissue.

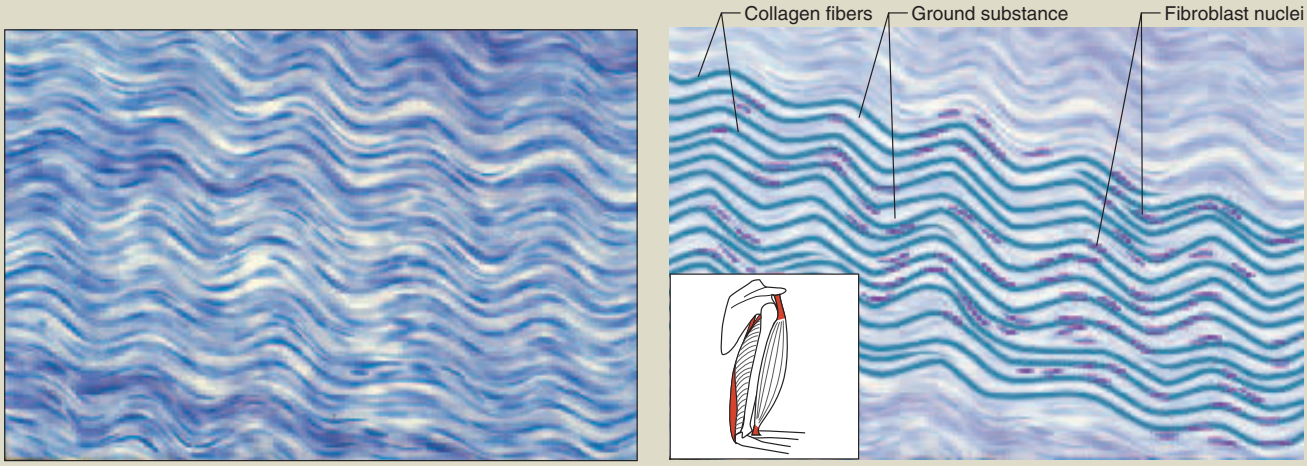
Microscopic appearance: Dominated by adipocytes—large, empty-looking cells with thin margins; tissue sections often very pale because of scarcity of stained cytoplasm; adipocytes shrunken; nucleus pressed against plasma membrane; blood vessels often present

Representative locations: Subcutaneous fat beneath skin; breast; heart surface; surrounding organs such as kidneys and eyes

Functions: Energy storage; thermal insulation; heat production by brown fat; protective cushion for some organs; filling space, shaping body

Table 5.5 Dense Connective Tissues

Dense Regular Connective Tissue



(a) (b)

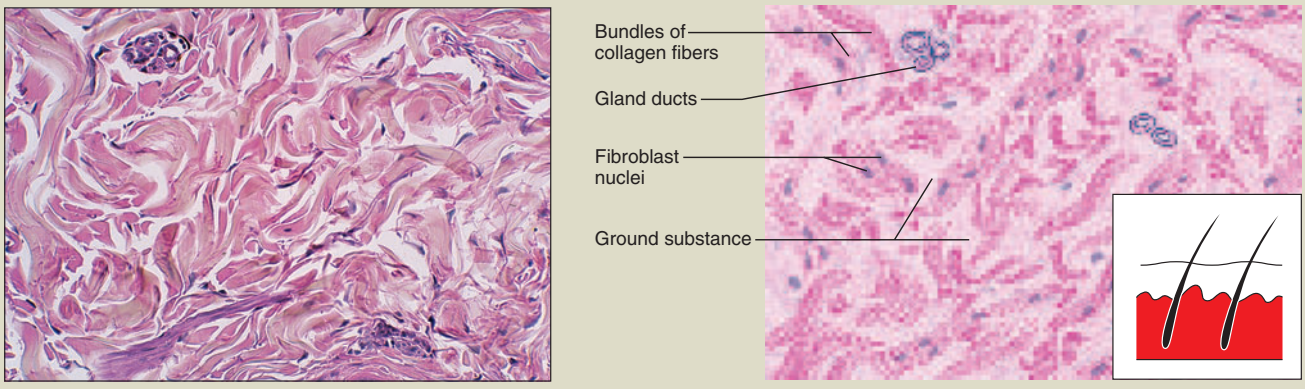
Figure 5.18 Tendon.

Microscopic appearance: Densely packed, parallel, often wavy collagen fibers; slender fibroblast nuclei compressed between collagen bundles; scanty open space (ground substance); scarcity of blood vessels

Representative locations: Tendons and ligaments

Functions: Ligaments tightly bind bones together; resist stress; tendons attach muscle to bone and transfer muscular tension to bones

Dense Irregular Connective Tissue



(a) (b)

Figure 5.19 Dermis of the Skin.

Microscopic appearance: Densely packed collagen fibers running in random directions; scanty open space (ground substance); few visible cells; scarcity of blood vessels

Representative locations: Deeper portion of dermis of skin; capsules around viscera such as liver, kidney, spleen; fibrous sheaths around cartilages and bones

Functions: Durable, hard to tear; withstands stresses applied in unpredictable directions

Insight 5.1 Clinical Application

Marfan Syndrome—A Connective Tissue Disease

Serious anatomical and functional abnormalities can result from hereditary errors in the structure of connective tissue proteins. *Marfan*[15] *syndrome,* for example, results from the mutation of a gene on chromosome 15 that codes for a glycoprotein called *fibrillin,* the structural scaffold for elastic fibers. Clinical signs of Marfan syndrome include unusually tall stature, long limbs and spidery fingers, abnormal spinal curvature, and a protruding "pigeon breast." Some other signs include hyperextensible joints, hernias of the groin, and visual problems resulting from abnormally long eyeballs and deformed lenses. More seriously, victims exhibit a weakening of the heart valves and arterial walls. The aorta, where blood pressure is the highest, is sometimes enormously dilated close to the heart, and may suddenly rupture. Marfan syndrome is present in about 1 out of 20,000 live births and kills most of its victims by their mid-30s. Some authorities think that Abraham Lincoln's tall, gangly physique and spindly fingers were signs of Marfan syndrome, which might have ended his life prematurely had he not been assassinated.

[15]Antoine Bernard-Jean Marfan (1858–1942), French physician

Chapter 5

Cartilage

Cartilage (table 5.6) is a supportive connective tissue with a flexible rubbery matrix. It gives shape to the external ear, the tip of the nose, and the larynx (voicebox)—the most easily palpated cartilages in the body. Cells called **chondroblasts**[16] (CON-dro-blasts) secrete the matrix and surround themselves with it until they become trapped in little cavities called **lacunae**[17] (la-CUE-nee). Once enclosed in lacunae, the cells are called **chondrocytes** (CON-dro-sites). Cartilage is free of blood vessels except when transforming into bone; thus nutrition and waste removal depend on solute diffusion through the stiff matrix. Because this is a slow process, chondrocytes have low rates of metabolism and cell division, and injured cartilage heals slowly. The matrix is rich in chondroitin sulfate and contains collagen fibers that range in thickness from invisibly fine to conspicuously coarse. Differences in the fibers provide a basis for classifying cartilage into three types: *hyaline cartilage, elastic cartilage,* and *fibrocartilage*.

Hyaline[18] (HY-uh-lin) **cartilage** is named for its clear, glassy microscopic appearance, which stems from the usually invisible fineness of its collagen fibers. **Elastic cartilage** is named for its conspicuous elastic fibers, and **fibrocartilage** for its coarse, readily visible bundles of collagen. Elastic cartilage and most hyaline cartilage are surrounded by a sheath of dense irregular connective tissue called the **perichondrium.**[19] A reserve population of chondroblasts between the perichondrium and cartilage contributes to cartilage growth throughout life. There is no perichondrium around fibrocartilage.

You can feel the texture of hyaline cartilage by palpating the tip of your nose, your "Adam's apple" at the front of the larynx (voicebox), and periodic rings of cartilage around the trachea (windpipe) just below the larynx. Hyaline cartilage is easily seen in many grocery items—it is the "gristle" at the ends of pork ribs, on chicken leg and breast bones, and at the joints of pigs' feet, for example. Elastic cartilage gives shape to the external ear. You can get some idea of its springy resilience by folding your ear down and releasing it.

Bone

The term *bone* refers both to organs of the body such as the femur and mandible, composed of multiple tissue types, and to the bone tissue, or **osseous tissue,** that makes up most of the mass of bones. There are two forms of osseous tissue: (1) **Spongy bone** fills the heads of the long bones. Although it is calcified and hard, its delicate slivers and plates give it a spongy appearance. (2) **Compact (dense) bone** is a more dense calcified tissue with no spaces visible to the naked eye. It forms the external surfaces of all bones, so spongy bone, when present, is always covered by compact bone.

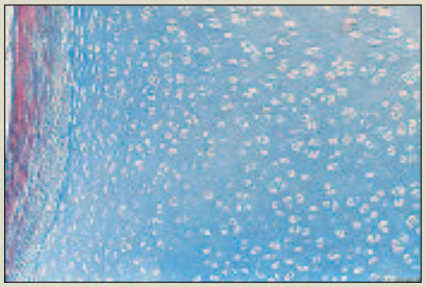
The differences between compact and spongy bone are described in chapter 7. Here, we examine only compact bone (table 5.7). Most specimens you study will probably be chips of dead, dried bone ground to microscopic thinness. In such preparations, the cells are absent but spaces reveal their former locations. Most compact bone is arranged in cylinders of tissue that surround **central (haversian**[20] or **osteonic) canals,** which run longitudinally through the shafts of long bones such as the femur. Blood vessels and nerves travel through the central canals in life. The bone matrix is deposited in **concentric lamellae,** onionlike layers around each central canal. A central canal and its surrounding lamellae are called an **osteon.** Tiny lacunae between the lamellae are occupied in life by mature bone cells, or **osteocytes.**[21] Delicate canals called **canaliculi** radiate from each lacuna to its neighbors and allow the osteocytes to keep in touch with each other. The bone as a whole is covered with a tough fibrous **periosteum** (PERR-ee-OSS-tee-um) similar to the perichondrium of cartilage.

About a third of the dry weight of bone is composed of collagen fibers and chondroitin sulfate; two-thirds consists of minerals (mainly calcium salts) deposited around the collagen fibers.

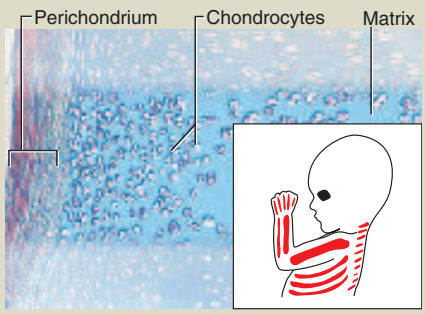
[16]*chondro* = cartilage, gristle + *blast* = forming
[17]*lacuna* = lake, cavity
[18]*hyal* = glass
[19]*peri* = around + *chondri* = cartilage
[20]Clopton Havers (1650–1702), English anatomist
[21]*osteo* = bone + *cyte* = cell

Table 5.6 Types of Cartilage

Hyaline Cartilage



(a)



(b)

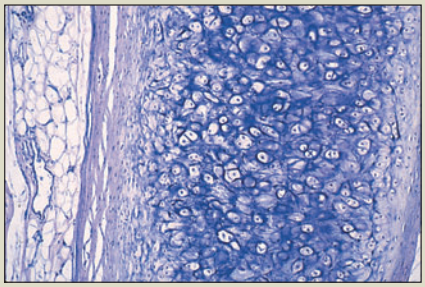
Figure 5.20 Fetal Skeleton.

Microscopic appearance: Clear, glassy matrix, often stained light blue or pink in tissue sections; fine, dispersed collagen fibers, not usually visible; chondrocytes often in small clusters of three or four cells (*cell nests*), enclosed in lacunae; usually covered by perichondrium

Representative locations: Forms a thin *articular cartilage,* lacking perichondrium, over the ends of bones at movable joints; a *costal cartilage* attaches the end of a rib to the breastbone; forms supportive rings and plates around trachea and bronchi; forms a boxlike enclosure around the larynx; forms much of the fetal skeleton

Functions: Eases joint movements; holds airway open during respiration; moves vocal cords during speech; a precursor of bone in the fetal skeleton and the growth zones of long bones of children

Elastic Cartilage



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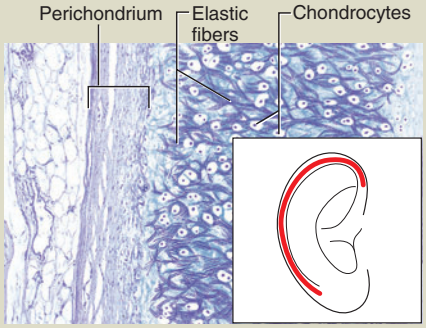


(b)

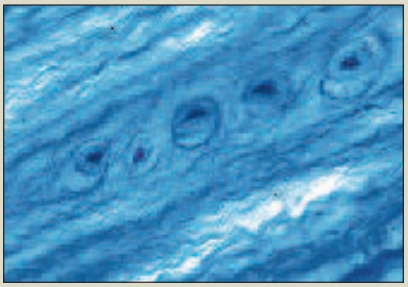
Figure 5.21 External Ear.

Microscopic appearance: Elastic fibers form weblike mesh amid lacunae; always covered by perichondrium

Representative locations: External ear; epiglottis

Functions: Provides flexible, elastic support

Fibrocartilage



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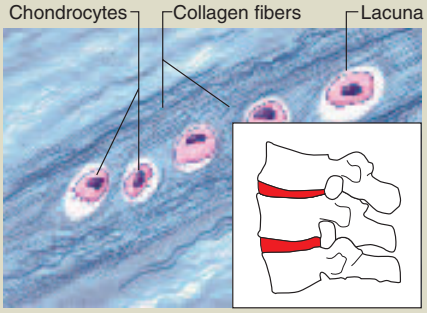


(b)

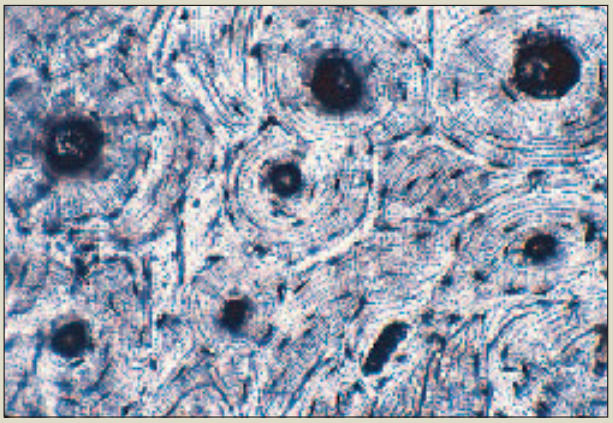
Figure 5.22 Intervertebral Disc.

Microscopic appearance: Parallel collagen fibers similar to those of tendon; rows of chondrocytes in lacunae between collagen fibers; never has a perichondrium

Representative locations: Pubic symphysis (anterior joint between two halves of pelvic girdle); intervertebral discs that separate bones of vertebral column; menisci, or pads of shock-absorbing cartilage, in knee joint; at points where tendons insert on bones near articular hyaline cartilage

Functions: Resists compression and absorbs shock in some joints; often a transitional tissue between dense connective tissue and hyaline cartilage (for example, at some tendon-bone junctions)

Table 5.7 Bone



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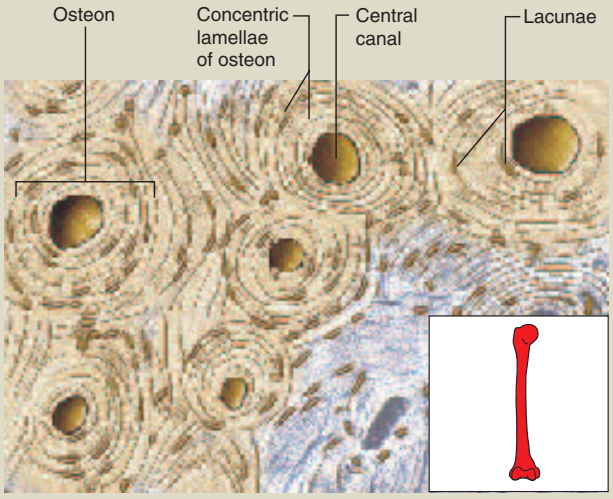


(b)

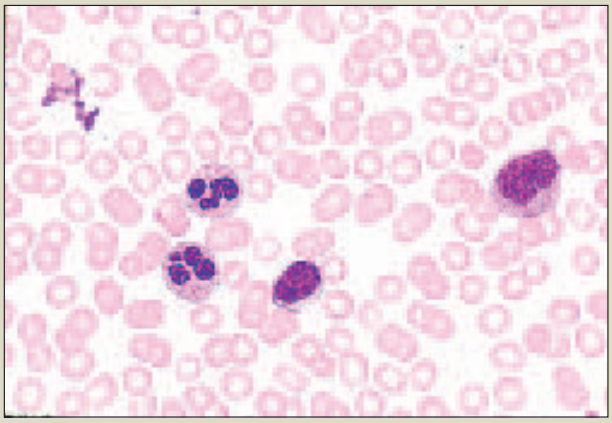
Figure 5.23 Compact Bone.

Microscopic appearance (compact bone): Calcified matrix arranged in concentric lamellae around central canals; osteocytes occupy lacunae between adjacent lamellae; lacunae interconnected by delicate canaliculi

Representative locations: Skeleton

Functions: Physical support of body; leverage for muscle action; protective enclosure of viscera; reservoir of calcium and phosphorus

Table 5.8 Blood



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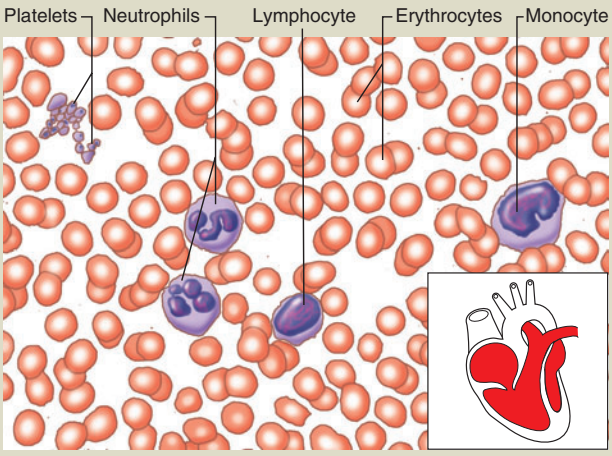


(b)

Figure 5.24 Blood Smear.

Microscopic appearance: Erythrocytes appear as pale pink discs with light centers and no nuclei; leukocytes are slightly larger, are much fewer, and have variously shaped nuclei, usually stained violet; platelets are cell fragments with no nuclei, about one-quarter the diameter of erythrocytes

Representative locations: Contained in heart and blood vessels

Functions: Transports gases, nutrients, wastes, chemical signals, and heat throughout body; provides defensive leukocytes; contains clotting agents to minimize bleeding; platelets secrete growth factors that promote tissue maintenance and repair

Blood

Blood (table 5.8) is a fluid connective tissue that travels through tubular vessels. Its primary function is to transport cells and dissolved matter from place to place. Blood consists of a ground substance called **plasma** and of cells and cell fragments collectively called **formed elements. Erythrocytes**[22] (eh-RITH-ro-sites), or red blood cells, are the most abundant formed elements. In stained blood films, they look like pink discs with a thin, pale center. They have no nuclei. Erythrocytes transport oxygen and carbon dioxide. **Leukocytes,** or white blood cells, serve various roles in defense against infection and other diseases. They travel from one organ to another in the bloodstream and lymph but spend most of their lives in the connective tissues. Leukocytes are somewhat larger than erythrocytes and have conspicuous nuclei that usually appear violet in stained preparations. There are five kinds, distinguished partly by variations in nuclear shape: *neutrophils, eosinophils, basophils, lymphocytes,* and *monocytes.* Their individual characteristics are considered in detail in chapter 18. **Platelets** are small cell fragments scattered amid the blood cells. They are involved in clotting and other mechanisms for minimizing blood loss, and in secreting growth factors that promote blood vessel growth and maintenance.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

9. What features do most or all connective tissues have in common to set this class apart from nervous, muscular, and epithelial tissue?
10. List the cell and fiber types found in fibrous connective tissues and state their functional differences.
11. What substances account for the gelatinous consistency of connective tissue ground substance?
12. What is areolar tissue? How can it be distinguished from any other kind of connective tissue?
13. Discuss the difference between dense regular and dense irregular connective tissue as an example of the relationship between form and function.
14. Describe some similarities, differences, and functional relationships between hyaline cartilage and bone.
15. What are the three basic kinds of formed elements in blood, and what are their respective functions?

Nervous and Muscular Tissue—Excitable Tissues

Objectives

When you have completed this section, you should be able to

- explain what distinguishes excitable tissues from other tissues;
- name the cell types that compose nervous tissue;
- identify the major parts of a nerve cell;
- visually recognize nervous tissue from specimens or photographs;
- name the three kinds of muscular tissue and describe the differences between them; and
- visually identify any type of muscular tissue from specimens or photographs.

Excitability is a characteristic of all living cells, but it is developed to its highest degree in nervous and muscular tissue, which are therefore described as **excitable tissues.** The basis for their excitation is an electrical charge difference (voltage) called the **membrane potential,** which occurs across the plasma membranes of all cells. Nervous and muscular tissues respond quickly to outside stimuli by means of changes in membrane potential. In nerve cells, these changes result in the rapid transmission of signals to other cells. In muscle cells, they result in contraction, or shortening of the cell.

Nervous Tissue

Nervous tissue (table 5.9) consists of **neurons** (NOOR-ons), or nerve cells, and a much greater number of **neuroglia** (noo-ROG-lee-uh), or **glial** (GLEE-ul) **cells,** which protect and assist the neurons. Neurons are specialized to detect stimuli, respond quickly, and transmit coded information rapidly to other cells. Each neuron has a prominent **soma,** or cell body, that houses the nucleus and most other organelles. This is the cell's center of genetic control and protein synthesis. Somas are usually round, ovoid, or stellate in shape. Extending from the soma, there are usually multiple short, branched processes called **dendrites**[23] that receive signals from other cells and transmit messages to the soma, and a single, much longer **axon,** or **nerve fiber,** that sends outgoing signals to other cells. Some axons are more than a meter long and extend from the brainstem to the foot. Nervous tissue is found in the brain, spinal cord, nerves, and ganglia, which are knotlike swellings in nerves. Local variations in the structure of nervous tissue are described in chapters 12 to 16.

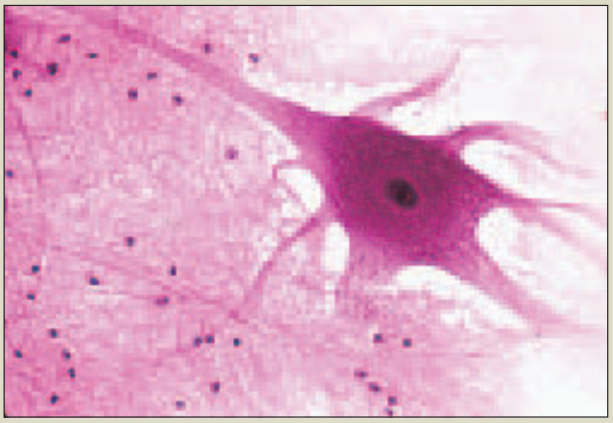
Muscular Tissue

Muscular tissue consists of elongated cells that are specialized to respond to stimulation by contracting; thus, its primary job is to exert physical force on other tissues and organs—for example, when a skeletal muscle pulls on a bone, the heart contracts and expels blood, or the bladder contracts and expels urine. Not only do movements of the body and its limbs depend on muscle, but so do such

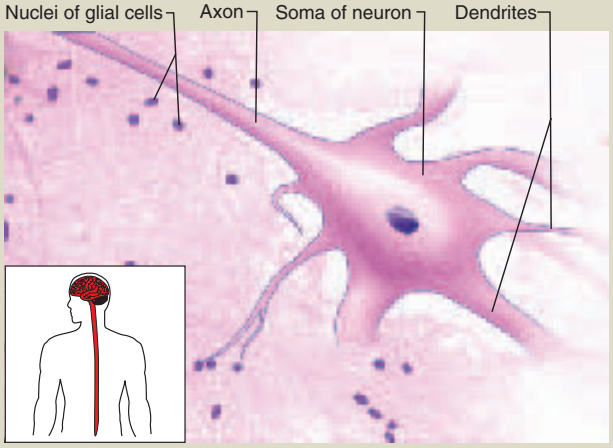
[22] *erythro* = red + *cyte* = cell

[23] *dendr* = tree + *ite* = little

Table 5.9 Nervous Tissue



(a)



(b)

Figure 5.25 **Spinal Cord Smear.**

Microscopic appearance: Most sections show a few large neurons, usually with rounded or stellate cell bodies (somas) and fibrous processes (axon and dendrites) extending from the somas; neurons are surrounded by a greater number of much smaller glial cells, which lack dendrites and axons

Representative locations: Brain, spinal cord, nerves, ganglia

Function: Internal communication

processes as digestion, waste elimination, breathing, speech, and blood circulation. The muscles are also an important source of body heat. The word *muscle* means "little mouse," apparently referring to the appearance of rippling muscles under the skin.

There are three histological types of muscle—*skeletal, cardiac,* and *smooth*—which differ in appearance, physiology, and function (table 5.10). **Skeletal muscle** consists of long, cylindrical cells called **muscle fibers.** Most of it is attached to bones, but there are exceptions in the tongue, upper esophagus, some facial muscles, and some **sphincter**[24] (SFINK-tur) muscles (ringlike or cufflike muscles that open and close body passages). Each cell contains multiple nuclei adjacent to the plasma membrane. Skeletal muscle is described as *striated* and *voluntary.* The first term refers to alternating light and dark bands, or **striations** (stry-AY-shuns), created by the overlapping pattern of cytoplasmic protein filaments that cause muscle contraction. The second term, *voluntary,* refers to the fact that we usually have conscious control over skeletal muscle.

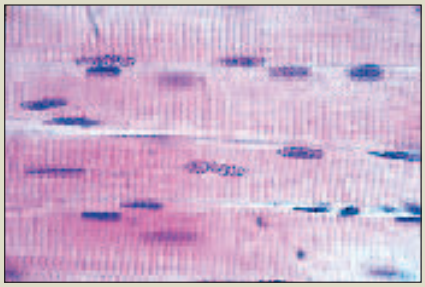
Cardiac muscle is essentially limited to the heart, though it extends slightly into the nearby blood vessels. It, too, is striated, but it differs from skeletal muscle in its other features. Its cells are much shorter, so they are commonly called **myocytes**[25] rather than fibers. The myocytes are branched and contain only one nucleus, which is located near the center. A light-staining region of glycogen often surrounds the nucleus. Cardiac myocytes are joined end to end by junctions called **intercalated**[26] (in-TUR-kuh-LAY-ted) **discs.** Electrical connections at these junctions enable a wave of excitation to travel rapidly from cell to cell, and mechanical connections keep the myocytes from pulling apart when the heart contracts. The electrical junctions allow all the myocytes of a heart chamber to be stimulated, and contract, almost simultaneously. Intercalated discs appear as dark transverse lines separating each myocyte from the next. They may be only faintly visible, however, unless the tissue has been specially stained for them. Cardiac muscle is considered *involuntary* because it is not usually under conscious control; it contracts even if all nerve connections to it are severed.

Smooth muscle lacks striations and is involuntary. Smooth muscle cells are fusiform (thick in the middle and tapered at the ends) and relatively short. They have only one, centrally placed nucleus. Small amounts of smooth muscle are found in the iris of the eye and in the skin, but most of it, called **visceral muscle,** forms layers in the walls of the digestive, respiratory, and urinary tracts, blood vessels, the uterus, and other viscera. In locations such as the esophagus and small intestine, smooth muscle forms adjacent layers, with the cells of one layer encircling the organ and the cells of the other layer running longitudinally. When the circular smooth muscle contracts, it may propel contents such as food through the organ. When the longitudinal layer contracts, it makes the organ shorter and

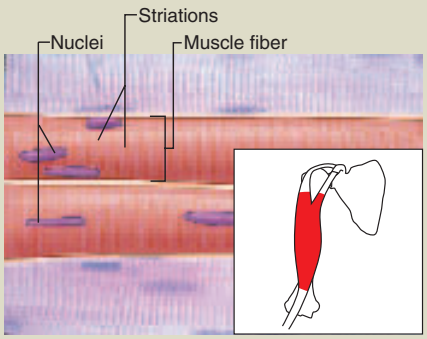
[24] *sphinc* = squeeze, bind tightly
[25] *myo* = muscle + *cyte* = cell
[26] *inter* = between + *calated* = inserted

Table 5.10 Muscular Tissue

Skeletal Muscle



(a)



(b)

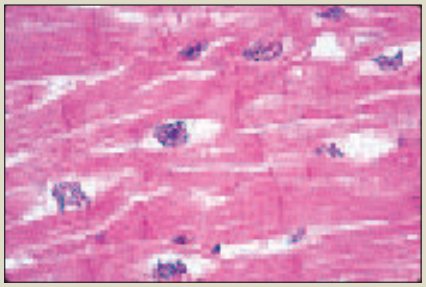
Figure 5.26 Skeletal Muscle.

Microscopic appearance: Long, cylindrical, unbranched cells (fibers), relatively parallel in longitudinal tissue sections; striations; multiple nuclei per cell, near plasma membrane

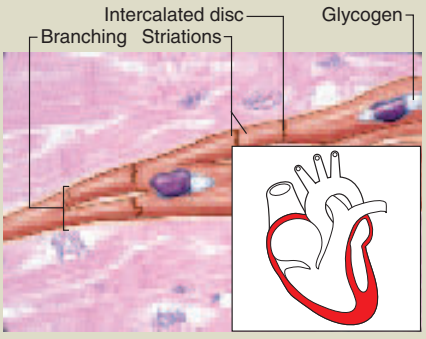
Representative locations: Skeletal muscles, mostly attached to bones but also in the tongue, esophagus, and voluntary sphincters of the lips, eyelids, urethra, and anus

Functions: Body movements, facial expression, posture, breathing, speech, swallowing, control of urination and defecation, and assistance in childbirth; under voluntary control

Cardiac Muscle



(a)



(b)

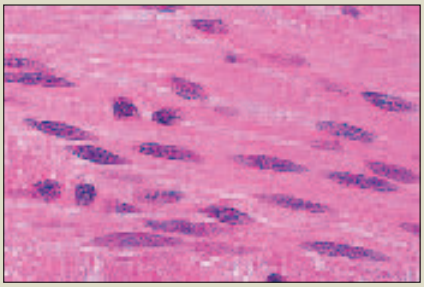
Figure 5.27 Cardiac Muscle.

Microscopic appearance: Short branched cells (myocytes); less parallel appearance in tissue sections; striations; intercalated discs; one nucleus per cell, centrally located and often surrounded by a light zone

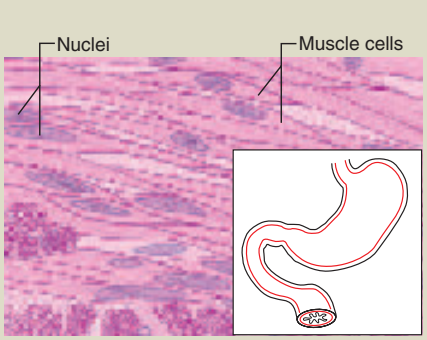
Representative locations: Heart

Functions: Pumping of blood; under involuntary control

Smooth Muscle



(a)



(b)

Figure 5.28 Smooth Muscle, Wall of Small Intestine.

Microscopic appearance: Short fusiform cells overlapping each other; nonstriated; one nucleus per cell, centrally located

Representative locations: Usually found as sheets of tissue in walls of viscera; also in iris and associated with hair follicles; involuntary sphincters of urethra and anus

Functions: Swallowing; contractions of stomach and intestines; expulsion of feces and urine; labor contractions; control of blood pressure and flow; control of respiratory airflow; control of pupillary diameter; erection of hairs; under involuntary control

thicker. By regulating the diameter of blood vessels, smooth muscle is very important in controlling blood pressure and flow. Both smooth and skeletal muscle form sphincters that control the emptying of the bladder and rectum.

Think About It

How does the meaning of the word *fiber* differ in the following uses: muscle fiber, nerve fiber, and connective tissue fiber?

Before You Go On

Answer the following questions to test your understanding of the preceding section:

16. What do nervous and muscular tissue have in common? What is the primary function of each?
17. What kinds of cells compose nervous tissue, and how can they be distinguished from each other?
18. Name the three kinds of muscular tissue, describe how to distinguish them from each other in microscopic appearance, and state a location and function for each one.

Intercellular Junctions, Glands, and Membranes

Objectives

When you have completed this section, you should be able to

- describe the junctions that hold cells and tissues together;
- describe or define different types of glands;
- describe the typical anatomy of a gland;
- name and compare different modes of glandular secretion;
- describe the way tissues are organized to form the body's membranes; and
- name and describe the major types of membranes in the body.

Intercellular Junctions

Most cells, with the exception of blood and metastatic cancer cells, must be anchored to each other and to the matrix if they are to grow and divide normally. The connections between one cell and another are called **intercellular junctions.** These attachments enable the cells to resist stress and communicate with each other. Without them, cardiac muscle cells would pull apart when they contracted, and every swallow of food would scrape away the lining of your esophagus. The principal types of intercellular junctions are shown in figure 5.29.

Tight Junctions

A **tight junction** completely encircles an epithelial cell near its apex and joins it tightly to the neighboring cells, like the plastic harness on a six-pack of soda cans. Proteins in the membranes of two adjacent cells form a zipperlike

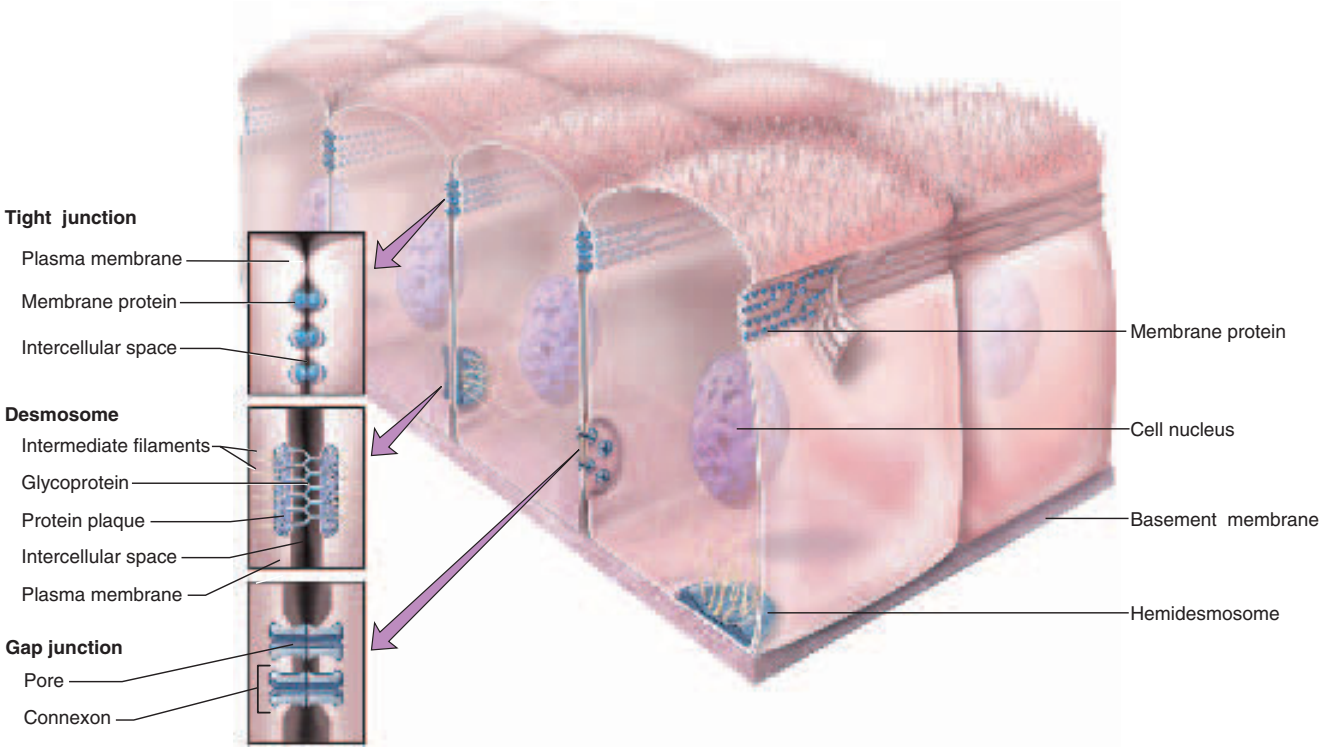


Figure 5.29 **Types of Intercellular Junctions.**
Which of these junctions allows material to pass from one cell directly into the next?

pattern of complementary grooves and ridges. This seals off the intercellular space and makes it difficult for some substances to pass between the cells. In the stomach and intestines, tight junctions prevent digestive juices from seeping between epithelial cells and digesting the underlying connective tissue. They also help to prevent intestinal bacteria from invading the tissues, and they ensure that most digested nutrients pass *through* the epithelial cells and not *between* them.

Desmosomes

If a tight junction is like a zipper, a **desmosome**[27] (DEZ-mo-some) is more like the snap on a pair of jeans, a patch that holds cells together and enables a tissue to resist mechanical stress, but does not totally encircle a cell. Desmosomes are common in the epidermis, cardiac muscle, and cervix of the uterus. The neighboring cells are separated by a small gap, which is spanned by a fine mesh of glycoprotein filaments. These filaments terminate in a thickened protein plaque at the surface of each cell. On the cytoplasmic side of each plaque, intermediate filaments from the cytoskeleton approach and penetrate the plaque, turn like a J, and return a short distance back into the cytoplasm. Each cell contributes half of the complete desmosome. The basal cells of epithelial tissue have *hemidesmosomes*—half-desmosomes that anchor them to the underlying basement membrane.

Think About It

Why would desmosomes not be suitable as the only intercellular junctions in the epithelium of the stomach?

Gap (Communicating) Junctions

A **gap junction** is formed by a ringlike *connexon,* which consists of six transmembrane proteins surrounding a water-filled channel. Ions, glucose, amino acids, and other small solutes can pass directly from the cytoplasm of one cell into the next through these channels. In the embryo, nutrients pass from cell to cell through gap junctions until the circulatory system forms and takes over the role of nutrient distribution. Gap junctions are found in the intercalated discs of cardiac muscle and between the cells of some smooth muscle. The flow of ions through these junctions allows electrical excitation to pass directly from cell to cell so that the cells contract in near-unison. Gap junctions are absent from skeletal muscle.

[27] *desmo* = band, bond, ligament + *som* = body

Insight 5.2 Clinical Application

Pemphigus Vulgaris—An Autoimmune Disease

The immune system normally produces defensive *antibodies* that selectively attack foreign substances and leave the normal tissues of our bodies alone. But in a family of disorders called *autoimmune diseases,* antibodies fail to distinguish our own cells and tissues from foreign ones. Such misguided antibodies, called *autoantibodies,* thus launch destructive attacks on our own bodies. (Autoimmune diseases are discussed in more detail in chapter 21.) One such disease is *pemphigus vulgaris*[28] (PEM-fih-gus vul-GAIR-iss), a disorder in which autoantibodies attack the proteins of the desmosomes in the skin and mucous membranes. This breaks down the attachments between epithelial cells and causes widespread blistering of the skin and oral mucosa, loss of tissue fluid, and sometimes death. The condition can be controlled with drugs that suppress the immune system, but such drugs reduce the patient's immune defenses against other diseases.

[28] *pemphigus* = blistering + *vulgaris* = common

Glands

A **gland** is a cell or organ that secretes substances for use elsewhere in the body or releases them for elimination from the body. The gland product may be something synthesized by the gland cells (such as digestive enzymes) or something removed from the tissues and modified by the gland (such as urine). Glands are composed predominantly of epithelial tissue.

Endocrine and Exocrine Glands

Glands are broadly classified as endocrine or exocrine. They originate as invaginations of a surface epithelium. In **exocrine**[29] (EC-so-crin) **glands,** they usually maintain their contact with the surface by way of a **duct,** an epithelial tube that conveys their secretion to the surface. The secretion may be released to the body surface, as in the case of sweat, mammary, and tear glands, but more often it is released into the cavity (lumen) of another organ such as the mouth or intestine. **Endocrine**[30] (EN-doe-crin) **glands** lose their contact with the surface and have no ducts. They do, however, have a high density of blood capillaries and secrete their products directly into the blood. The secretions of endocrine glands, called *hormones,* function as chemical messengers to stimulate cells elsewhere in the body. Endocrine glands are the subject of chapter 17 and are not further considered here.

The exocrine-endocrine distinction is not always clear. The liver is an exocrine gland that secretes one of its

[29] *exo* = out + *crin* = to separate, secrete
[30] *endo* = in, into

products, bile, through a system of ducts but secretes hormones, albumin, and other products directly into the bloodstream. Several glands have both exocrine and endocrine components, such as the pancreas, testis, ovary, and kidney. And nearly all of the viscera have at least some cells that secrete hormones, even though most of these organs are not usually thought of as glands (for example, the brain and heart).

Unicellular glands are exocrine cells found in an epithelium that is predominantly nonsecretory. For example, the respiratory tract, which is lined mainly by ciliated cells, also has a liberal scattering of nonciliated, mucus-secreting goblet cells (see figs. 5.6 and 5.7).

Exocrine Gland Structure

Figure 5.30 shows a generalized multicellular exocrine gland—a structural arrangement found in such organs as the mammary gland, pancreas, and salivary glands. Most glands are enclosed in a fibrous **capsule.** The capsule often gives off extensions called **septa,** or **trabeculae** (trah-BEC-you-lee), that divide the interior of the gland into compartments called **lobes,** which are visible to the naked eye. Finer connective tissue septa may further subdivide each lobe into microscopic **lobules** (LOB-yools). Blood vessels, nerves, and the gland's own ducts generally travel through these septa. The connective tissue framework of the gland, called its **stroma,** supports and organizes the glandular tissue. The cells that perform the tasks of synthesis and secretion are collectively called the **parenchyma** (pa-REN-kih-muh). This is typically simple cuboidal or simple columnar epithelium.

Exocrine glands are classified as **simple** if they have a single unbranched duct and **compound** if they have a branched duct. If the duct and secretory portion are of uniform diameter, the gland is called **tubular.** If the secretory cells form a dilated sac, the gland is called **acinar** and the sac is an **acinus**[31] (ASS-ih-nus), or **alveolus**[32] (AL-vee-OH-lus). A gland with secretory cells in both the tubular and acinar portions is called a **tubuloacinar gland** (fig. 5.31).

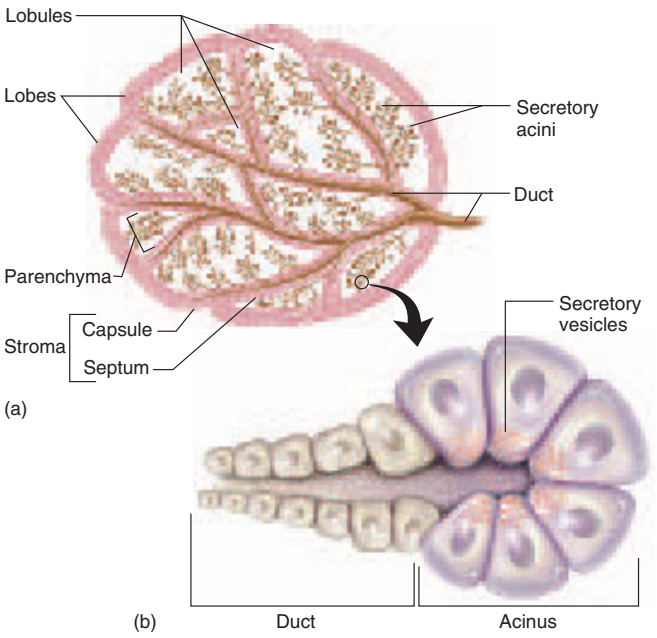


Figure 5.30 General Structure of an Exocrine Gland. (*a*) The gland duct branches repeatedly, following the connective tissue septa, until its finest divisions end on saccular acini of secretory cells. (*b*) Detail of an acinus and the beginning of a duct.

Types of Secretions

Glands are classified not only by their structure but also by the nature of their secretions. **Serous** (SEER-us) **glands** produce relatively thin, watery fluids such as perspiration, milk, tears, and digestive juices. **Mucous glands,** found in the tongue and roof of the mouth among other places, secrete a glycoprotein called *mucin* (MEW-sin). After it is secreted, mucin absorbs water and forms the sticky product *mucus.* (Note that *mucus,* the secretion, is spelled differently from *mucous,* the adjective form of the word.) **Mixed glands,** such as the two pairs of salivary glands in the chin, contain both serous and mucous cells and produce a mixture of the two types of secretions. **Cytogenic**[33] **glands** release whole cells. The only examples of these are the testes and ovaries, which produce sperm and egg cells.

Methods of Secretion

Glands are classified as merocrine or holocrine depending on how they produce their secretions. **Merocrine**[34] (MERR-oh-crin) **glands,** also called **eccrine**[35] (EC-rin) **glands,** have vesicles that release their secretion by exocytosis, as described in chapter 3 (fig. 5.32*a*). These include the tear glands, pancreas, gastric glands, and many others. In **holocrine**[36] **glands,** cells accumulate a product and then the entire cell disintegrates, so the secretion is a mixture of cell fragments and the substance the cell had synthesized prior to its disintegration (fig. 5.32*b*). The oil-producing glands of the scalp are an example. Holocrine secretions tend to be thicker than merocrine secretions.

[31] *acinus* = berry
[32] *alveol* = cavity, pit
[33] *cyto* = cell + *genic* = producing
[34] *mero* = part + *crin* = to separate, secrete
[35] *ec* = *ex* = out
[36] *holo* = whole, entire

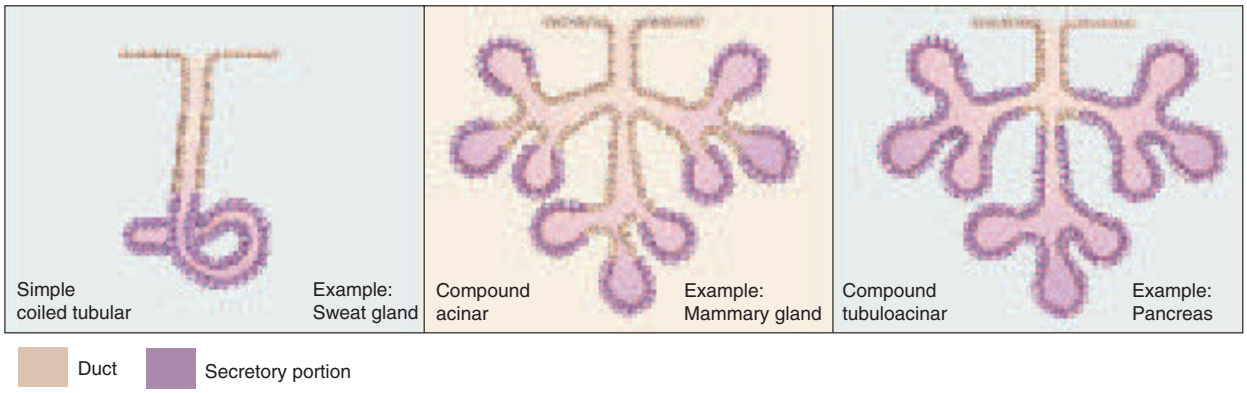


Figure 5.31 **Some Types of Exocrine Glands.** Glands are simple if their ducts do not branch and compound if they do; they are tubular if they have a uniform diameter, acinar if their secretory cells are limited to saccular acini, and tubuloacinar if they have secretory cells in both the acinar and tubular regions.
Predict and sketch the appearance of a simple acinar gland.

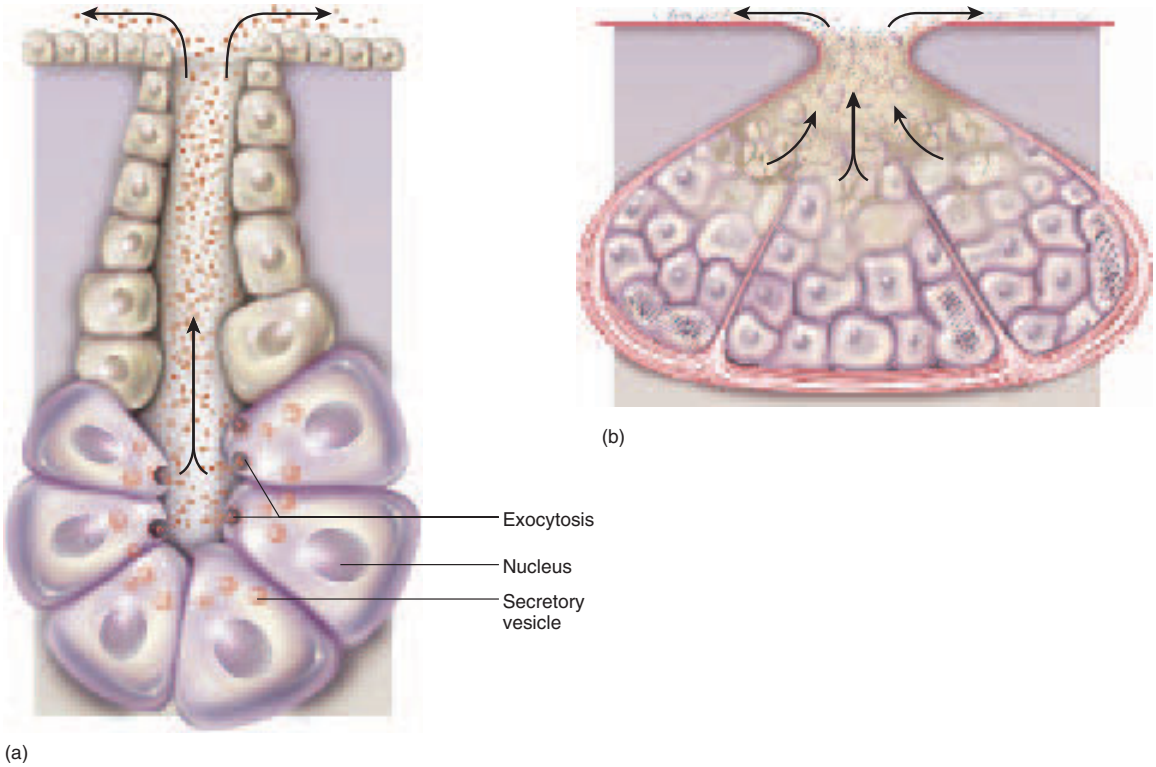


Figure 5.32 **Modes of Exocrine Secretion.** (*a*) A merocrine gland, which secretes its product by means of exocytosis at the apical surfaces of the secretory cells. (*b*) A holocrine gland, whose secretion is composed of disintegrated secretory cells.
Which of these glands would require a higher rate of mitosis in its parenchymal cells?

Some glands, such as the axillary (armpit) sweat glands and mammary glands, are named **apocrine**[37] **glands** from a former belief that the secretion was composed of bits of apical cytoplasm that broke away from the cell surface. Closer study showed this to be untrue; these glands are primarily merocrine in their mode of secretion. These glands are nevertheless different from other merocrine glands in function and histological appearance, and they are still referred to as apocrine glands even though their mode of secretion is not unique.

Membranes

In atlas A, the major cavities of the body were described, as well as some of the membranes that line them and cover their viscera. We now consider some histological aspects of the major body membranes.

The largest membrane of the body is the **cutaneous** (cue-TAY-nee-us) **membrane**—or more simply, the skin (detailed in chapter 6). It consists of a stratified squamous epithelium (epidermis) resting on a layer of connective tissue (dermis). Unlike the other membranes to be considered, it is relatively dry. It retards dehydration of the body and provides an inhospitable environment for the growth of infectious organisms.

The two principal kinds of internal membranes are mucous and serous membranes. A **mucous membrane (mucosa)** (fig. 5.33), lines passageways that open to the exterior environment: the digestive, respiratory, urinary, and reproductive tracts. A mucosa consists of two to three layers: (1) an epithelium, (2) an areolar connective tissue layer called the **lamina propria**[38] (LAM-ih-nuh PRO-pree-uh), and sometimes, (3) a layer of smooth muscle called the **muscularis** (MUSK-you-LAIR-iss) **mucosae.** Mucous membranes have absorptive, secretory, and protective functions. They are often covered with mucus secreted by goblet cells, multicellular mucous glands, or both. The mucus traps bacteria and foreign particles, which keeps them from invading the tissues and aids in their removal from the body. The epithelium of a mucous membrane may also include absorptive, ciliated, and other types of cells.

A **serous membrane (serosa)** is composed of a simple squamous epithelium resting on a thin layer of areolar connective tissue. Serous membranes produce watery **serous** (SEER-us) **fluid,** which arises from the blood and derives its name from the fact that it is similar to blood serum in composition. Serous membranes line the insides of some body cavities and form a smooth outer surface on some of the viscera, such as the digestive tract. The pleurae, pericardium, and peritoneum described in atlas A are serous membranes.

The circulatory system is lined with a simple squamous epithelium called **endothelium,** derived from mesoderm. The endothelium rests on a thin layer of areolar tissue, which often rests in turn on an elastic sheet. Collectively, these tissues make up a membrane called the *tunica interna* of the blood vessels and *endocardium* of

[37] *apo* = from, off, away

[38] *lamina* = layer + *propria* = of one's own

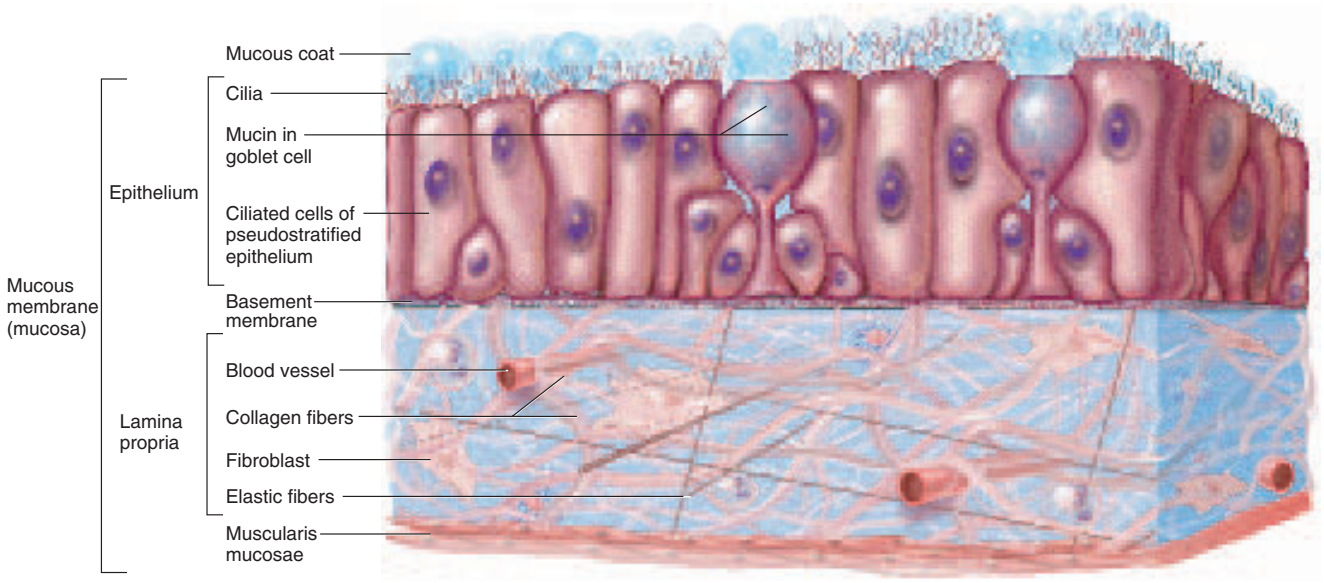


Figure 5.33 **Histology of a Mucous Membrane.**

the heart. The simple squamous epithelium that lines the pleural, pericardial, and peritoneal cavities is called **mesothelium.**

Some joints of the skeletal system are lined by fibrous **synovial** (sih-NO-vee-ul) **membranes,** made only of connective tissue. These membranes span the gap from one bone to the next and secrete slippery *synovial fluid* (rich in hyaluronic acid) into the joint.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

19. Compare the structure of tight junctions and gap junctions. Relate their structural differences to their functional differences.
20. Distinguish between a simple gland and a compound gland, and give an example of each. Distinguish between a tubular gland and an acinar gland, and give an example of each.
21. Contrast the merocrine and holocrine methods of secretion, and name a gland product produced by each method.
22. Describe the differences between a mucous and a serous membrane.
23. Name the layers of a mucous membrane, and state which of the four primary tissue classes composes each layer.

Tissue Growth, Development, Death, and Repair

Objectives

When you have completed this section, you should be able to

- name and describe the ways that a tissue can change from one type to another;
- name and describe the modes of tissue growth;
- name and describe the modes and causes of tissue shrinkage and death; and
- name and describe the ways the body repairs damaged tissues.

Changes in Tissue Type

You have studied the form and function of more than two dozen discrete types of human tissue in this chapter. You should not leave this subject, however, with the impression that once these tissue types are established in the adult, they never change. Tissues are, in fact, capable of changing from one type to another within certain limits. Most obviously, unspecialized tissues of the embryo develop into more diverse and specialized types of mature tissue—mesenchyme to muscle, for example. This development of a more specialized form and function is called **differentiation.**

Epithelia often exhibit **metaplasia,**[39] a change from one type of mature tissue to another. For example, the vagina of a young girl is lined with a simple cuboidal epithelium. At puberty, it changes to a stratified squamous epithelium, better adapted to the future demands of intercourse and childbirth. The nasal cavity is lined with ciliated pseudostratified columnar epithelium. However, if we block one nostril and breathe through the other one for several days, the epithelium in the unblocked passage changes to stratified squamous. In smokers, the pseudostratified columnar epithelium of the bronchi may transform into a stratified squamous epithelium.

Think About It

What functions of a pseudostratified columnar epithelium could not be served by a stratified squamous epithelium? In light of this, what might be some consequences of bronchial metaplasia in heavy smokers?

Tissue Growth

Tissues grow either because their cells increase in number or because the existing cells grow larger. Most embryonic and childhood growth occurs by **hyperplasia**[40] (HY-pur-PLAY-zhuh), tissue growth through cell multiplication. Exercised muscles grow, however, through **hypertrophy**[41] (hy-PUR-truh-fee), the enlargement of preexisting cells. **Neoplasia**[42] (NEE-oh-PLAY-zhuh) is the development of a tumor (neoplasm)—whether benign or malignant—composed of abnormal, nonfunctional tissue.

Tissue Shrinkage and Death

The shrinkage of a tissue through a loss in cell size or number is called **atrophy**[43] (AT-ruh-fee). Atrophy results from both normal aging *(senile atrophy)* and lack of use of an organ *(disuse atrophy)*. Muscles that are not exercised exhibit disuse atrophy as their cells become smaller. This was a serious problem for the first astronauts who participated in prolonged microgravity space flights. Upon return to normal gravity, they were sometimes too weak from muscular atrophy to walk. Space stations and shuttles now include exercise equipment to maintain the crews' muscular condition. Disuse atrophy also occurs when a limb is immobilized, as in a cast.

Necrosis[44] (neh-CRO-sis) is the premature, pathological death of tissue due to trauma, toxins, infection, and so forth. **Gangrene** is any tissue necrosis resulting from an insufficient blood supply. *Gas gangrene* is necrosis of a

[39] *meta* = change + *plas* = form, growth

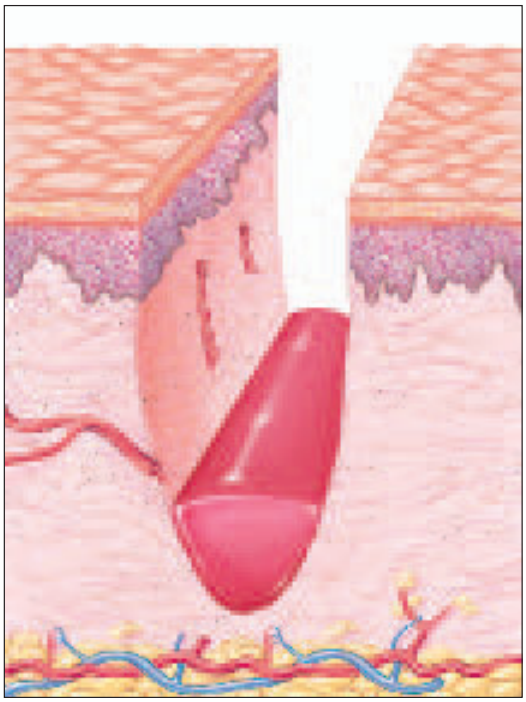
[40] *hyper* = excessive + *plas* = growth

[41] *trophy* = nourishment

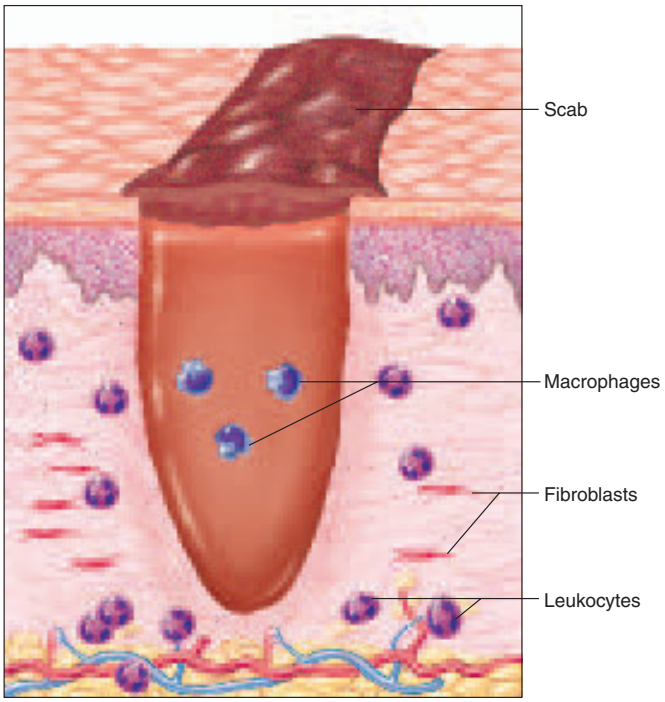
[42] *neo* = new

[43] *a* = without

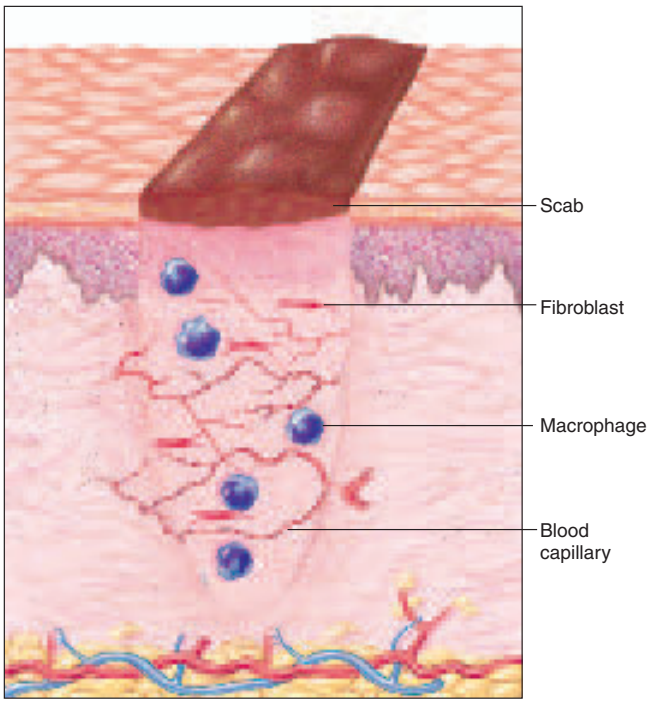
[44] *necr* = death + *osis* = process



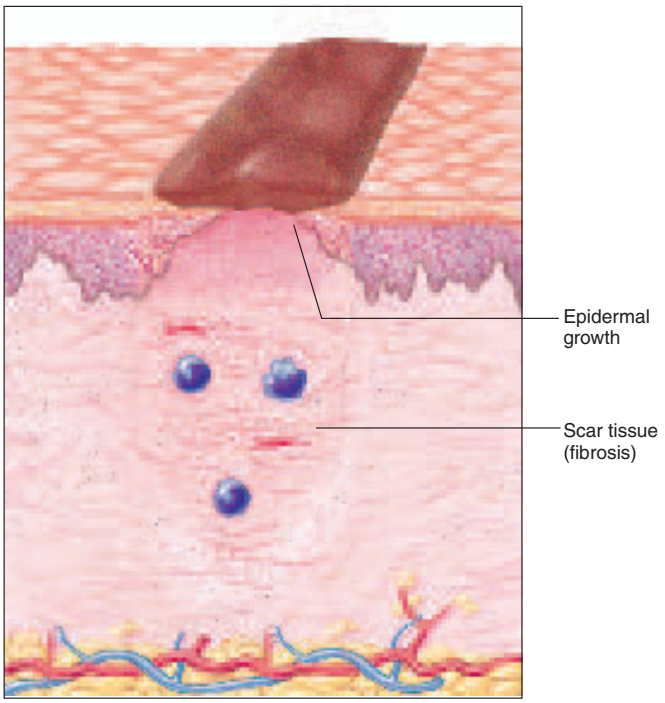
1. Bleeding into the wound



2. Scab formation and macrophage activity



3. Formation of granulation tissue



4. Epithelial regeneration and connective tissue fibrosis

Figure 5.34 **Stages in the Healing of a Wound to the Skin.**

wound resulting from infection with certain bacteria. **Infarction** is the sudden death of tissue, such as heart muscle *(myocardial infarction)*, which occurs when its blood supply is cut off. A *decubitus ulcer* (bed sore) is tissue necrosis that occurs when immobilized persons, such as those confined to a hospital bed or wheelchair, are unable to move, and continual pressure on the skin cuts off blood flow to an area. Cells dying by necrosis usually swell, exhibit *blebbing* (bubbling) of their plasma membranes, and then rupture. The cell contents released into the tissues trigger an inflammatory response in which macrophages phagocytize the cellular debris.

Apoptosis[45] (AP-oh-TOE-sis), or **programmed cell death,** is the normal death of cells that have completed their function and best serve the body by dying and getting out of the way. Cells undergoing apoptosis shrink and are quickly phagocytized by macrophages and other cells. The cell contents never escape the cell, so there is no inflammatory response. Although billions of cells die every hour by apoptosis, they are engulfed so quickly that they are almost never seen except within macrophages. For this reason, apoptosis was not discovered until recently.

Apparently every cell has a built-in "suicide program" that enables the body to dispose of it when necessary. In some cases, a receptor protein in the plasma membrane called *Fas* binds to an extracellular suicide signal. *Fas* then activates intracellular enzymes that destroy the cell, including an *endonuclease* that chops up its DNA and a *protease* that destroys cellular proteins. In other cases, cells seem to undergo apoptosis automatically if they stop receiving growth factors from other cells. For example, in embryonic development we produce about twice as many neurons as we need. Those that make connections with target cells survive, while the excess 50% die for lack of *nerve growth factor.* Apoptosis also "dissolves" the webbing between the fingers and toes during embryonic development; it frees the earlobe from the side of the head in people with the genotype for detached earlobes (see chapter 4); and it causes shrinkage of the uterus after pregnancy and of the breasts after lactation ceases.

Tissue Repair

Damaged tissues can be repaired in two ways: *regeneration* or *fibrosis.* **Regeneration** is the replacement of dead or damaged cells by the same type of cells as before. Regeneration restores normal function to the organ. Most skin injuries (cuts, scrapes, and minor burns) heal by regeneration. The liver also regenerates remarkably well. **Fibrosis** is the replacement of damaged tissue with scar tissue, composed mainly of collagen produced by fibroblasts. Scar tissue helps to hold an organ together, but it does not restore normal function. Examples include the healing of severe cuts and burns, the healing of muscle injuries, and scarring of the lungs in tuberculosis.

[45] *apo* = away + *ptosis* = falling

Insight 5.3 Clinical Application

Keloids

In some people, especially dark-skinned adults, healing skin wounds exhibit excessive fibrosis, producing raised, shiny scars called *keloids* (fig. 5.35). Keloids extend beyond the boundaries of the original wound and tend to return even if they are surgically removed. Keloids may result from the excessive secretion of a fibroblast-stimulating growth factor by macrophages and platelets. They occur most often on the upper trunk and earlobes. Some tribespeople practice *scarification*—scratching or cutting the skin to induce keloid formation as a way of decorating the body.

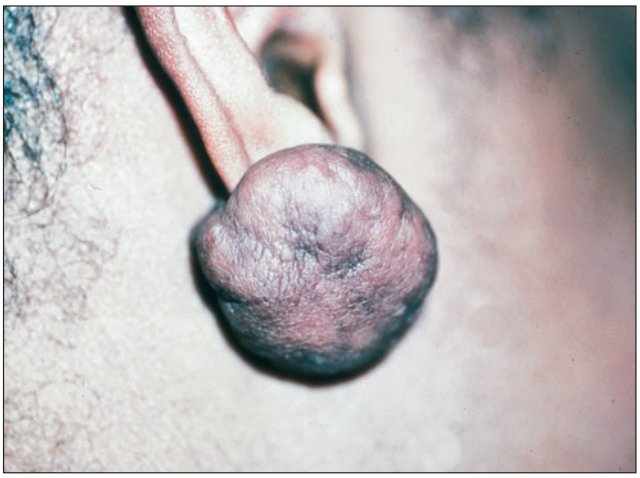


Figure 5.35 A Keloid of the Earlobe. This scar resulted from piercing the ear for earrings.

Figure 5.34 illustrates the following stages in the healing of a cut in the skin, where both regeneration and fibrosis are involved:

1. Severed blood vessels bleed into the cut. Mast cells and cells damaged by the cut release histamine, which dilates blood vessels, increases blood flow to the area, and makes blood capillaries more permeable. Blood plasma seeps into the wound, carrying antibodies, clotting proteins, and blood cells.
2. A blood clot forms in the tissue, loosely knitting the edges of the cut together and interfering with the spread of pathogens from the site of injury into healthy tissues. The surface of the blood clot dries and hardens in the air, forming a scab that temporarily seals the wound and blocks infection.

Beneath the scab, macrophages begin to clean up tissue debris by phagocytizing and digesting it.

3. New blood capillaries sprout from nearby vessels and grow into the wound. The deeper portions of the clot become infiltrated by capillaries and fibroblasts and transform into a soft mass called **granulation tissue.** Macrophages remove the blood clot while fibroblasts deposit new collagen to replace it. This *fibroblastic (reconstructive) phase* of repair begins 3 to 4 days after the injury and lasts up to 2 weeks.
4. Surface epithelial cells around the wound multiply and migrate into the wounded area, beneath the scab. The scab loosens and eventually falls off, and the epithelium grows thicker. Thus, the epithelium *regenerates* while the underlying connective tissue undergoes *fibrosis,* or scarring. Capillaries withdraw from the area as fibrosis progresses. The scar tissue may or may not show through the epithelium, depending on the severity of the wound. The wound may exhibit a depressed area at first, but this is often filled in by continued fibrosis and remodeling from below, until the scar becomes unnoticeable. This *remodeling (maturation) phase* of tissue repair begins several weeks after injury and may last as long as 2 years.

Before You Go On

Answer the following questions to test your understanding of the preceding section:

24. Distinguish between *differentiation* and *metaplasia.*
25. Tissues can grow through an increase in cell size or cell number. What are the respective terms for these two kinds of growth?
26. Distinguish between *atrophy, necrosis,* and *apoptosis,* and describe a circumstance under which each of these forms of tissue loss may occur.
27. Distinguish between regeneration and fibrosis. Which process restores normal cellular function? What good is the other process if it does not restore function?

Insight 5.4 Clinical Application

The Stem Cell Controversy

One of the most controversial scientific issues at the dawn of the twenty-first century has been stem cell research. At least 18 countries have recently debated or enacted laws to regulate stem cell research, with politicians, scientists, bioethicists, and religious leaders joining in the debate, and legions of lay citizens contributing their opinions to newspaper editorial pages. What are stem cells and why is this subject so controversial?

Stem cells are immature cells with the ability to develop into one or more types of mature, functional cells. *Adult stem (AS) cells* sparsely populate most of the body's organs and retain the ability to differentiate into mature, functional cells. When an adult stem cell divides, one daughter cell remains a stem cell and the other differentiates into a mature tissue cell. The latter replaces a cell lost to damage or to normal cellular turnover. Some stem cells are *unipotent,* able to develop into only one mature cell type, such as sperm or epidermal squamous cells. Others are *multipotent,* able to produce multiple mature cell types, as when bone marrow stem cells differentiate into red and white blood cells.

Not surprisingly, biologists see stem cells as a possible treatment for diseases that result from the loss of functional cells. Skin and bone marrow stem cells have been used in therapy for many years. Scientists hope that with a little coaxing, stem cells might replace cardiac muscle damaged by heart attack; restore function to an injured spinal cord; cure parkinsonism by replacing lost brain cells; or cure diabetes mellitus by replacing lost insulin-secreting cells. But adult stem cells have limited developmental potential, and probably cannot make all the cell types needed to treat a broad range of degenerative diseases. In addition, they are present in very small numbers, and difficult to harvest and culture in the quantities needed for therapy.

Embryonic stem (ES) cells, however, may hold greater potential. ES cells harvested from week-old human embryos composed of 100 to 150 cells are *pluripotent*—able to develop into any type of embryonic or adult cell. New laboratory methods have made ES cells easier to culture than AS cells and have greatly accelerated stem cell research in recent years.

The road to therapy with ES cells remains full of technical, ethical, and legal speed bumps. Will ES cells be rejected by the recipient's immune system? Can the ES cells or the growth media in which they are cultured introduce viruses or other pathogens into the recipient? How can the ES cells be made to lodge and grow in the right place in the patient's body? Could they grow into tumors instead of healthy tissue? Can ES cell therapy ever be economical enough to be affordable to any but the very rich? Scientists can scarcely begin to tackle these problems, however, unless and until a bioethical question is resolved: Can we balance the benefits of stem cell therapy against the destruction of early human embryos from which the ES cells are harvested?

Where do these embryos come from? Most are donated by couples using *in vitro fertilization (IVF)* to conceive a child. IVF entails collecting numerous eggs from the prospective mother, fertilizing them in glassware with the father's sperm, letting them develop into embryos (technically, pre-embryos) of about 8 to 16 cells, and then transplanting *some* of these into the mother's uterus (see Insight 29.4). To overcome the low odds of success, excess embryos are always produced and some are always left over. The excess embryos are often destroyed, but many couples choose instead to donate them for research that may ultimately benefit other patients. It would seem sensible to use the embryos for beneficial purposes rather than to simply destroy and discard them. Opponents of stem cell research argue, however, that potential medical benefits cannot justify the destruction of a human embryo. Understandably, this has aroused an intense debate that is likely to restrain stem cell research for some time to come.

Chapter Review

Review of Key Concepts

The Study of Tissues (p. 158)

1. *Histology (microscopic anatomy)* is the study of tissues.
2. The body is composed of four *primary tissues: epithelial, connective, nervous,* and *muscular tissue.*
3. Tissues are composed of *cells* and *matrix (extracellular material).* The matrix is composed of *fibers* and *ground substance.*
4. Mature tissues develop from three *primary germ layers* of the embryo: *ectoderm, mesoderm,* and *endoderm.*
5. Most tissues are studied as thin slices called *histological sections* colored with *stains* to show detail. Histological sections of elongated structures can be *longitudinal, cross,* or *oblique sections.*

Epithelial Tissue (p. 160)

1. *Epithelia* are sheets of cells that cover organ surfaces and form glands.
2. Epithelia are composed of one or more layers of closely adhering cells, and lack blood vessels.
3. Epithelia are connected to the underlying connective tissue by a thin *basement membrane.*
4. In a *simple epithelium,* all cells contact the basement membrane. The four kinds of simple epithelium are *simple squamous* (with flat cells), *simple cuboidal* (with cubical to round cells), *simple columnar* (with tall narrow cells), and *pseudostratified columnar* (in which there are basal cells that do not reach the free surface, creating an appearance of stratification) (table 5.2).
5. In a *stratified epithelium,* the cells are multilayered and some rest on top of others, without touching the basement membrane. The four types of stratified epithelium are *stratified squamous, stratified cuboidal, stratified columnar,* and *transitional* (table 5.3).
6. Stratified squamous epithelium has two forms: *keratinized,* in which the surface cells are dead and packed with keratin, and *nonkeratinized,* in which the surface cells are living. The former constitutes the epidermis and the latter is found in internal passages such as the esophagus.

Connective Tissue (p. 166)

1. *Connective tissue* consists mostly of fibers and ground substance, with widely separated cells.
2. Connective tissue binds, supports, and protects organs, and plays diverse roles in immunity, movement, transport, energy storage, and other processes.
3. *Fibrous connective tissue* has especially conspicuous fibers, which are of three kinds: *collagenous, reticular,* and *elastic.*
4. The cells of fibrous connective tissue include *fibroblasts, macrophages, leukocytes, plasma cells, mast cells,* and *adipocytes.*
5. The ground substance of fibrous connective tissue usually has a gelatinous consistency due to glycosaminoglycans, proteoglycans, and adhesive glycoproteins.
6. Fibrous connective tissue includes *areolar, reticular, adipose, dense irregular,* and *dense regular* types (tables 5.4 and 5.5).
7. *Cartilage* is a connective tissue with a rubbery matrix. Its principal cells are *chondrocytes*, housed in cavities called *lacunae.* The three types of cartilage are *hyaline cartilage, elastic cartilage,* and *fibrocartilage* (table 5.6).
8. *Bone (osseous tissue)* has a stony calcified matrix. The two types of bone are *spongy* and *compact* bone.
9. The principal cells of bone are *osteocytes,* housed in lacunae. Much of the matrix of compact bone is deposited in cylindrical layers around a *central canal* occupied by blood vessels and nerves (table 5.7).
10. *Blood* is a fluid connective tissue composed of *erythrocytes, leukocytes,* and *platelets* in a liquid matrix, the *plasma* (table 5.8).

Nervous and Muscular Tissue—Excitable Tissues (p. 175)

1. Nervous and muscular tissue are called *excitable* tissues because they show quick electrical responses to stimuli.
2. *Nervous tissue* is composed of *neurons (nerve cells)* and supporting *glial cells* (table 5.9).
3. Neurons have a *cell body (soma)* and usually one *axon* and *multiple dendrites.*
4. *Muscular tissue* is specialized to contract and move other tissues.
5. There are three kinds of muscle: *skeletal, cardiac,* and *smooth* (table 5.10).

Intercellular Junctions, Glands, and Membranes (p. 178)

1. Intercellular junctions attach cells to each other.
2. Zipperlike *tight junctions* seal off the space between cells; snap- or weldlike *desmosomes* connect cells at patches rather than continuous zones of attachment; and *gap junctions* have pores that allow substances to pass directly from cell to cell.
3. *Glands* are organs that release secretions for use in the body or for waste elimination.
4. *Exocrine glands* release their secretions through a duct onto the surface of an organ. *Endocrine glands* lack ducts and release their secretions *(hormones)* into the bloodstream.
5. The connective tissue framework of a gland is called its *stroma,* and includes a capsule and internal septa. The secretory part is the *parenchyma* and is composed of epithelial secretory cells and ducts.
6. *Simple* glands have a single unbranched duct; *compound* glands have branched ducts. *Tubular* glands have ductile and secretory portions of uniform diameter; *acinar* glands have dilated sacs (acini) of secretory cells at the end of a duct.
7. *Serous* glands secrete thin runny fluids; *mucous* glands secrete viscous

mucus; *mixed* glands secrete both; and *cytogenic* glands produce cells (eggs and sperm) as their products.
8. *Merocrine* gland cells release their secretion by exocytosis; *holocrine* gland cells break down to become the secretion; *apocrine* glands are specialized glands with a merocrine mode of secretion but different histological appearance.
9. Membranes of the body include the relatively dry *cutaneous membrane* (skin), moist *serous membranes* covered with serous fluid; and *mucous* membranes that secrete mucus. Blood vessels are lined with a membrane called the *endothelium;* the ventral body cavity is lined with a membrane called *mesothelium;* and some joints are lined with *synovial* membranes.

Tissue Growth, Development, Death, and Repair (p. 183)
1. *Differentiation* is the development of a mature specialized tissue from an unspecialized one. *Metaplasia* is the normal conversion of one mature tissue type into another.
2. Organs grow through tissue *hyperplasia* (cell multiplication), *hypertrophy* (cell enlargement), or *neoplasia* (abnormal growth of tumors).
3. Organs shrink through tissue *atrophy* (shrinkage due to aging or disuse).
4. Two kinds of tissue death are *necrosis* (pathological death of tissues from such causes as trauma, infection, toxins, and oxygen deprivation) and *apoptosis* (normal, programmed death of cells that have completed their function).
5. Two kinds of tissue repair are *regeneration* (which restores the preexisting tissue type and function) and *fibrosis* (which replaces the previous tissue with fibrous scar tissue).

Selected Vocabulary

histology 158
tissue 158
matrix 158
ground substance 158
tissue fluid 158
extracellular fluid 158
epithelial tissue 160
basement membrane 160
goblet cell 161
connective tissue 166
fibroblast 167
collagenous fibers 167
cartilage 172
chondrocyte 172
osseous tissue 172
osteocyte 172
nervous tissue 175
neuron 175
muscular tissue 175
tight junction 178
desmosome 179
gap junction 179
exocrine gland 179
endocrine gland 179
stroma 180
parenchyma 180
acinus 180
merocrine gland 180
holocrine gland 180
apocrine gland 182
mucous membrane 182
serous membrane 182
differentiation 183
hyperplasia 183
hypertrophy 183
atrophy 183
necrosis 183
apoptosis 185
regeneration 185
fibrosis 185

Testing Your Recall

1. Transitional epithelium is found in
   a. the urinary system.
   b. the respiratory system.
   c. the digestive system.
   d. the reproductive system.
   e. all of the above.

2. The external surface of the stomach is covered by
   a. a mucosa.
   b. a serosa.
   c. the parietal peritoneum.
   d. a lamina propria.
   e. a basement membrane.

3. Which of these is a primary germ layer?
   a. epidermis
   b. mucosa
   c. ectoderm
   d. endothelium
   e. epithelium

4. A seminiferous tubule of the testis is lined with ____ epithelium.
   a. simple cuboidal
   b. pseudostratified columnar ciliated
   c. stratified squamous
   d. transitional
   e. stratified cuboidal

5. ____ prevent fluids from seeping between epithelial cells.
   a. Glycosaminoglycans
   b. Hemidesmosomes
   c. Tight junctions
   d. Communicating junctions
   e. Basement membranes

6. A fixative serves to
   a. stop tissue decay.
   b. improve contrast.
   c. repair a damaged tissue.
   d. bind epithelial cells together.
   e. bind cardiac myocytes together.

7. The collagen of areolar tissue is produced by
   a. macrophages.
   b. fibroblasts.
   c. mast cells.
   d. leukocytes.
   e. chondrocytes.

8. Tendons are composed of _____ connective tissue.
   a. skeletal
   b. areolar
   c. dense irregular
   d. yellow elastic
   e. dense regular

9. The shape of the external ear is due to
   a. skeletal muscle.
   b. elastic cartilage.
   c. fibrocartilage.
   d. articular cartilage.
   e. hyaline cartilage.

10. The most abundant formed element(s) of blood is/are
    a. plasma.
    b. erythrocytes.
    c. platelets.
    d. leukocytes.
    e. proteins.

11. Any form of pathological tissue death is called _____.

12. The simple squamous epithelium that lines the peritoneal cavity is called _____.
13. Osteocytes and chondrocytes occupy little cavities called _____.
14. Muscle cells and axons are often called _____ because of their shape.
15. Tendons and ligaments are made mainly of the protein _____.
16. The only type of muscle that lacks gap junctions is _____.
17. An epithelium rests on a layer called the _____ between its deepest cells and the underlying connective tissue.
18. Fibers and ground substance make up the _____ of a connective tissue.
19. Polysaccharide chains bound to a core protein form giant molecules called _____, an important part of the connective tissue matrix.
20. Any epithelium in which every cell touches the basement membrane is called a/an _____ epithelium.

Answers in Appendix B

True or False

Determine which five of the following statements are false, and briefly explain why.

1. The esophagus is protected from abrasion by a keratinized stratified squamous epithelium.
2. All cells of a pseudostratified columnar epithelium contact the basement membrane.
3. Not all skeletal muscle is attached to bones.
4. The stroma of a gland does not secrete anything.
5. In all connective tissues, the matrix occupies more space than the cells do.
6. Adipocytes are limited to adipose tissue.
7. Tight junctions function primarily to prevent cells from pulling apart.
8. Metaplasia is a normal, healthy tissue transformation but neoplasia is not.
9. Nerve and muscle cells are not the body's only electrically excitable cells.
10. Cartilage is always covered by a fibrous perichondrium.

Answers in Appendix B

Testing Your Comprehension

1. A woman in labor is often told to push. In doing so, is she consciously contracting her uterus to expel the baby? Justify your answer based on the muscular composition of the uterus.
2. A major tenet of the cell theory is that all bodily structure and function is based on cells. The structural properties of bone, cartilage, and tendons, however, are due more to their extracellular material than to their cells. Is this an exception to the cell theory? Why or why not?
3. When cartilage is compressed, water is squeezed out of it, and when pressure is taken off, water flows back into the matrix. This being the case, why do you think cartilage at weight-bearing joints such as the knees can degenerate from lack of exercise?
4. The epithelium of the respiratory tract is mostly of the pseudostratified columnar ciliated type, but in the alveoli—the tiny air sacs where oxygen and carbon dioxide are exchanged between the blood and inhaled air—the epithelium is simple squamous. Explain the functional significance of this histological difference. That is, why don't the alveoli have the same kind of epithelium as the rest of the respiratory tract?
5. Which do you think would heal faster, cartilage or bone? Stratified squamous or simple columnar epithelium? Why?

Answers at the Online Learning Center

Answers to Figure Legend Questions

5.2 These are longitudinal sections. In the transverse plane, both the egg white and yolk would be round. In the oblique plane, the egg white would be elliptical but the yolk would be round.

5.12 The epithelia of the tongue, oral cavity, esophagus, and anal canal would look similar to this.

5.29 Gap junctions

5.31 A simple sac opening directly onto an epithelial surface, without a duct

5.32 The holocrine gland, to replace the cells that disintegrate

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The Online Learning Center provides a wealth of information fully organized and integrated by chapter. You will find practice quizzes, interactive activities, labeling exercises, flashcards, and much more that will complement your learning and understanding of anatomy and physiology.