CHAPTER 3

Cells and Tissues

YOUR GOALS

After completing this chapter, you will have a working knowledge of the functions of cells and tissues and will have mastered the objectives listed below.

FUNCTION PREVIEW

- Cells carry out all the chemical activities needed to sustain life.
- Tissues provide for a division of labor among body cells.

OBJECTIVE CHECKLIST

PART I: CELLS

Overview of the Cellular Basis of Life (pp. 65–66)

- Name the four elements that make up the bulk of living matter, and list several trace elements.

Anatomy of a Generalized Cell (pp. 66–76)

- Define *cell, organelle,* and *inclusion.*
- Identify on a cell model or diagram the three major cell regions (nucleus, cytoplasm, and plasma membrane).
- List the structures of the nucleus, and explain the function of chromatin and nucleoli.
- Identify the organelles on a cell model or describe them, and indicate the major function of each.

Cell Physiology (pp. 76–88)

- Define *selective permeability, diffusion* (including *simple* and *facilitated diffusion* and *osmosis*), *active transport, passive transport, solute pumping, exocytosis, endocytosis, phagocytosis, pinocytosis, hypertonic, hypotonic,* and *isotonic.*
- Describe plasma membrane structure and explain how the various transport processes account for the directional movements of specific substances across the plasma membrane.
- Describe briefly the process of DNA replication and of mitosis. Explain the importance of mitotic cell division.
- Describe the roles of DNA and of the three major varieties of RNA in protein synthesis.
- Name some cell types, and relate their overall shape and internal structure to their special functions.

PART II: BODY TISSUES (pp. 88–101)

- Name the four major tissue types and their chief subcategories. Explain how the four major tissue types differ structurally and functionally.
- Give the chief locations of the various tissue types in the body.
- Describe the process of tissue repair (wound healing).

PART III: DEVELOPMENTAL ASPECTS OF CELLS AND TISSUES (pp. 101, 104)

- Define *neoplasm,* and distinguish between benign and malignant neoplasms.
- Explain the significance of the fact that some tissue types (muscle and nerve) are largely amitotic after the growth stages are over.

PART I: CELLS

In the late 1600s, Robert Hooke was looking through a crude microscope at some plant tissue—cork. He saw some cubelike structures that reminded him of the long rows of monk's rooms (or cells) at the monastery, so he named these structures **cells.** The living cells that had formed the cork were long since dead. However, the name stuck and is still used to describe the smallest unit, or the building block, of all living things, plants and animals alike. Whatever its form, however it behaves, the cell contains all the parts necessary to survive in a changing world. The human body has trillions of these microscopic building blocks.

Overview of the Cellular Basis of Life

Perhaps the most striking thing about a cell is its organization. If we chemically analyze cells, we find that they are made up primarily of four elements—carbon, oxygen, hydrogen, and nitrogen—plus much smaller amounts of several other elements. Although the four major elements build most of the cell's structure (which is largely protein), the trace elements are very important for certain cell functions. For example, calcium is needed for blood clotting (among other things), and iron is necessary to make hemoglobin, which carries oxygen in the blood. Iodine is required to make the thyroid hormone that controls metabolism. In their ionic form, many of the metals (such as calcium, sodium, and potassium) can carry an electrical charge; when they do they are called *electrolytes* (e-lek'tro-līts). Sodium and potassium ions are essential if nerve impulses are to be transmitted and muscles are to contract. (A more detailed account of body chemistry appears in Chapter 2.)

Strange as it may seem, especially when we feel our firm muscles, living cells are about 60 percent water, which is one of the reasons water is

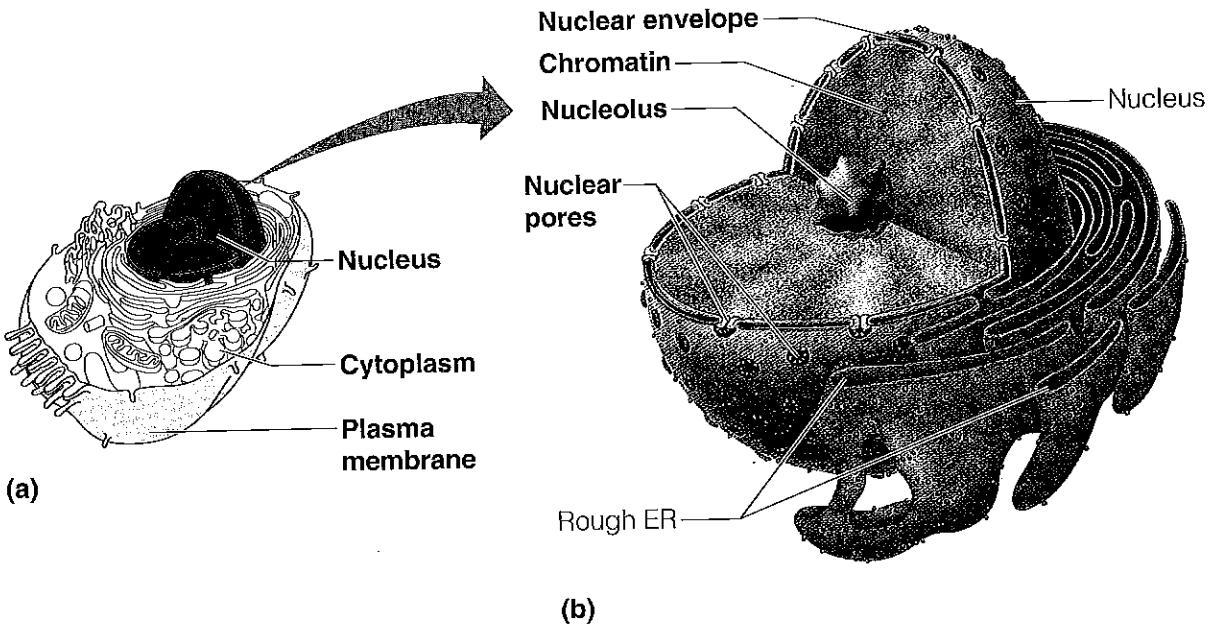


FIGURE 3.1 Anatomy of the generalized animal cell nucleus.
(a) Orientation diagram: The three main regions of the generalized cell.
(b) Structure of the nucleus.

essential for life. In addition to containing large amounts of water, all the body cells are constantly bathed in a dilute saltwater solution (something like seawater) called *interstitial fluid,* which is derived from the blood. All exchanges between cells and blood are made through this fluid.

Cells vary tremendously in length—ranging from 2 micrometers (1/12,000th of an inch) in the smallest cells to over a meter (3 feet) or more in the nerve cells that cause you to wiggle your toes. Furthermore, a cell's structure often reflects its function; this will become clear later in this chapter. Cells can have amazingly different shapes. Some are disk-shaped (red blood cells), some have threadlike extensions (nerve cells), others are like toothpicks pointed at each end (smooth muscle cells).

Cells also vary dramatically in the functions, or roles, they play in the body. For example, white blood cells wander freely through the body tissues and protect the body by destroying bacteria and other foreign substances. Some cells make hormones or chemicals that regulate other body cells. Still others take part in gas exchanges in the lungs or cleanse the blood (kidney tubule cells).

DID YOU GET IT?

1. Hydrogen and nitrogen are two of the four elements that make up the bulk of cell structure. What are the other two?
2. Why are electrocytes, particularly Na^+ and K^+ ions, so important to body function?

For answers, see Appendix D.

Anatomy of a Generalized Cell

Although no one cell type is exactly like all others, cells *do* have the same basic parts, and there are certain functions common to *all* cells. Here we will talk about the **generalized cell,** which demonstrates these many typical features.

In general, all cells have three main regions or parts—a *nucleus* (nu'kle-us), *cytoplasm* (si'to-plazm″), and a *plasma membrane* (Figure 3.1a). The nucleus is usually located near the center of the cell. It is surrounded by the semifluid cytoplasm, which in turn is enclosed by the plasma membrane, which forms the outer cell boundary. (Figure 3.4 on p. 70

shows the more detailed structure of the generalized cell as revealed by the electron microscope.)

The Nucleus

Anything that works, works best when it is controlled. For cells, "headquarters," or the control center, is the gene-containing **nucleus** (*nucle* = kernal). The genetic material, or *deoxyribonucleic acid (DNA),* is much like a blueprint that contains all the instructions needed for building the whole body; so, as one might expect, human DNA differs from that of a frog. More specifically, DNA has the instructions for building *proteins.* DNA is also absolutely necessary for cell reproduction. A cell that has lost or ejected its nucleus (for whatever reason) is programmed only to die.

Although it is most often oval or spherical, the shape of the nucleus usually conforms to the shape of the cell. For example, if the cell is elongated, the nucleus is usually elongated as well. The nucleus has three recognizable regions or structures: the *nuclear envelope, nucleoli,* and *chromatin.*

Nuclear Envelope

The nucleus is bound by a double membrane barrier called the **nuclear envelope,** or **nuclear membrane** (see Figure 3.1b). Between the two membranes is a fluid-filled "moat," or space. At various points, the two layers of the nuclear envelope fuse, and **nuclear pores** penetrate through the fused regions. Like other cellular membranes, the nuclear envelope is selectively permeable, but substances pass through it much more freely than elsewhere because of its relatively large pores. The nuclear membrane encloses a jellylike fluid called *nucleoplasm* (nu'kle-o-plazm") in which other nuclear elements are suspended.

Nucleoli

The nucleus contains one or more small, dark-staining, essentially round bodies called **nucleoli** (nu-kle'o-li; "little nuclei"). Nucleoli are sites where ribosomes are assembled. The *ribosomes,* most of which eventually migrate into the cytoplasm, serve as the actual sites of protein synthesis, as described shortly.

Chromatin

When a cell is not dividing, its DNA is combined with protein and forms a loose network of bumpy threads called **chromatin** (kro'mah-tin) that is scattered throughout the nucleus. When a cell is dividing to form two daughter cells, the chromatin threads coil and condense to form dense, rodlike bodies called **chromosomes**—much the way a stretched spring becomes shorter and thicker when allowed to relax. The functions of DNA and the mechanism of cell division are discussed in the Cell Physiology section beginning on p. 76.

DID YOU GET IT?

3. How would you explain the meaning of the term *generalized cell* to a classmate?
4. What is the general function of the cell nucleus?
5. What is the nuclear envelope?

For answers, see Appendix D.

The Plasma Membrane

The flexible **plasma membrane** is a fragile, transparent barrier that contains the cell contents and separates them from the surrounding environment. (The term *cell membrane* is often used instead, but because nearly all cellular organelles are composed of membranes, we will specifically refer to the cell's surface or outer limiting membrane as the plasma membrane.) Although the plasma membrane is important in defining the limits of the cell, it is much more than a passive envelope, or "baggie." As you will see, its unique structure allows it to play a dynamic role in many cellular activities.

The structure of the plasma membrane consists of two lipid (fat) layers arranged "tail to tail" in which protein molecules float (Figure 3.2). Most of the lipid portion is *phospholipids* (some with attached sugar groups), but a substantial amount of *cholesterol* is also found in plasma membranes. (The characteristics of these specialized lipids are described in Chapter 2.) The olive oil–like lipid bilayer forms the basic "fabric" of the membrane. The polar "heads" of the lollipop-shaped phospholipid molecules are *hydrophilic* ("water loving") and are attracted to water, the main component of both the intercellular and extracellular fluids, and so they lie on both the inner and outer surfaces of the membrane. Their nonpolar "tails," being *hydrophobic* ("water hating"), avoid water, and line up in the center of the membrane. The self-orienting property of the phospholipids allows biological membranes to reseal themselves quickly when

Q *Some proteins float freely in the lipid phase of the membrane whereas others are anchored in specific locations. What could serve as anchoring structures in the latter case?*

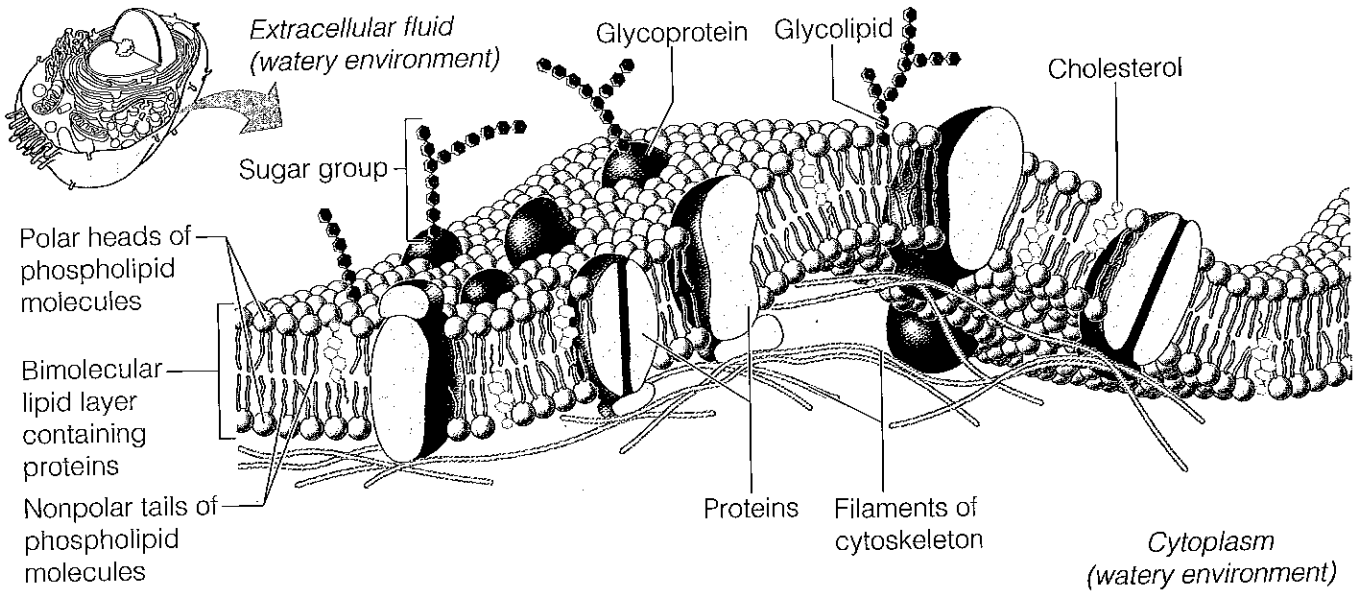


FIGURE 3.2 Structure of the plasma membrane.

torn. The hydrophobic makeup of the membrane interior makes the plasma membrane relatively impermeable to most water-soluble molecules. The cholesterol helps keep the membrane fluid.

The proteins scattered in the lipid bilayer are responsible for most of the specialized functions of the membrane. Some proteins are enzymes. Many of the proteins protruding from the cell exterior are receptors for hormones or other chemical messengers or are binding sites for anchoring the cell to fibers or to other structures inside or outside the cell. Most proteins that span the membrane are involved in transport functions. For example, some cluster together to form protein channels (tiny *pores*) through which water and small water-soluble molecules or ions can move; others act as *carriers* that bind to a substance and move it through the membrane. Branching sugar groups are attached to most of the proteins abutting the extracellular space. Such "sugar-proteins" are called *glycoproteins,* and because of their presence, the cell surface is a fuzzy, sticky, sugar-rich area called the *glycocalyx* (gli-co-ka'liks). (You can think of your cells as being sugar-coated.) Among other things, these glycoproteins determine your blood type, act as receptors that certain bacteria, viruses, or toxins can bind to, and play a role in cell-to-cell interactions. Definite changes in glycoproteins occur in cells that are being transformed into cancer cells. (Cancer is discussed in "A Closer Look" on pp. 102–103.)

A *Filaments of the cytoskeleton attached to membrane proteins.*

Specializations of the Plasma Membrane

Specializations of the plasma membrane—such as *microvilli* and *membrane junctions*—are commonly displayed by the (epithelial) cells that form the linings of hollow body organs, such as the small intestine (Figure 3.3). **Microvilli** (mi"kro-vil'i; "little shaggy hairs") are tiny fingerlike projections that greatly increase the cell's surface area for absorption so that the process occurs more quickly.

Membrane junctions vary structurally depending on their roles.

- **Tight junctions** are impermeable junctions that bind cells together into leakproof sheets that prevent substances from passing through the

extracellular space between cells. In tight junctions, adjacent plasma membranes fuse together tightly like a zipper. In the small intestine, for example, these junctions prevent digestive enzymes from seeping into the bloodstream.

- **Desmosomes** (des'mo-somz) are anchoring junctions that prevent cells subjected to mechanical stress (such as skin cells) from being pulled apart. Structurally, these junctions are buttonlike thickenings of adjacent plasma membranes (plaques), which are connected by fine protein filaments. Thicker protein filaments extend from the plaques inside the cells to the plaques on the cells' opposite sides, thus forming an internal system of strong guy wires.
- **Gap junctions,** commonly seen in the heart and between embryonic cells, function mainly to allow communication. Chemical molecules, such as nutrients or ions, can pass directly from one cell to another through them. In gap junctions, the neighboring cells are connected by **connexons,** which are hollow cylinders composed of proteins that span the entire width of the abutting membranes.

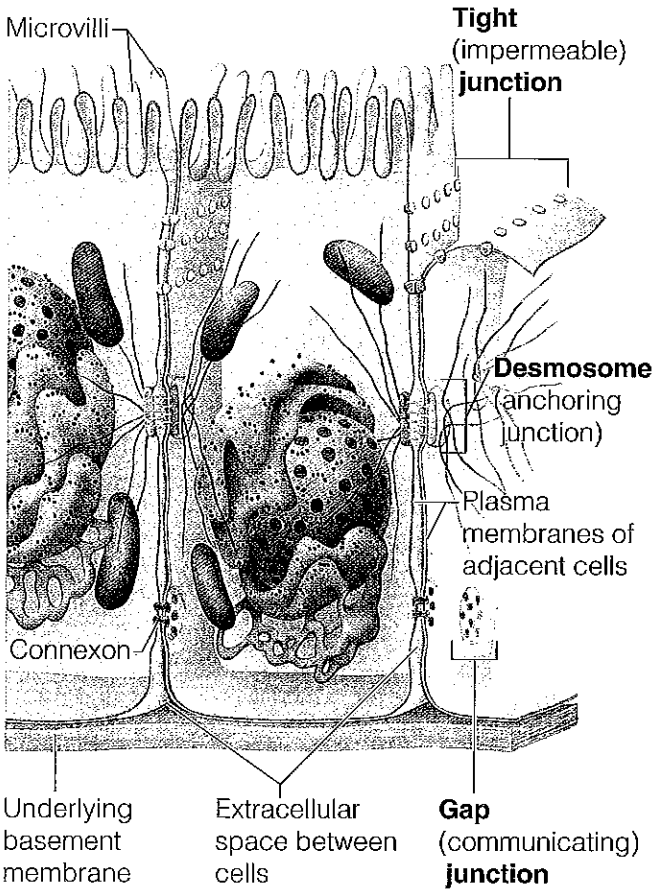


FIGURE 3.3 Cell junctions. An epithelial cell is shown joined to adjacent cells by the three common types of cell junctions: tight junctions, desmosomes, and gap junctions. Also illustrated are microvilli (seen projecting from the free cell surface).

DID YOU GET IT?

6. Why do phospholipids (which form the bulk of cell membranes) organize into a bilayer, tail to tail, in an aqueous environment?
7. The external faces of some membrane proteins have sugar groups attached to them. What are three roles these sugar-coated proteins play in the life of a cell?
8. What is the special function of gap junctions? Of tight junctions?

For answers, see Appendix D.

The Cytoplasm

The **cytoplasm** is the cellular material outside the nucleus and inside the plasma membrane. It is the site of most cellular activities, so you might think of the cytoplasm as the "factory area" of the cell. Although early scientists believed that the cytoplasm was a structureless gel, the electron microscope has revealed that it has three major elements: the *cytosol, organelles,* and *inclusions.* The **cytosol** is semitransparent fluid that suspends the other elements. Dissolved in the cytosol, which is largely water, are nutrients and a variety of other solutes (dissolved substances).

The **organelles** (or"gah-nelz'), described in detail shortly, are the metabolic machinery of the cell. Each type of organelle is specialized to carry out a specific function for the cell as a whole. Some synthesize proteins, others package those proteins, and so on.

Inclusions are chemical substances that may or may not be present, depending on the specific cell type. Most inclusions are stored nutrients or cell products. They include the lipid droplets common in fat cells, glycogen granules abundant in liver and muscle cells, pigments such as melanin in skin and hair cells, mucus and other secretory products, and various kinds of crystals.

Q *Which nuclear component contains your genes?*

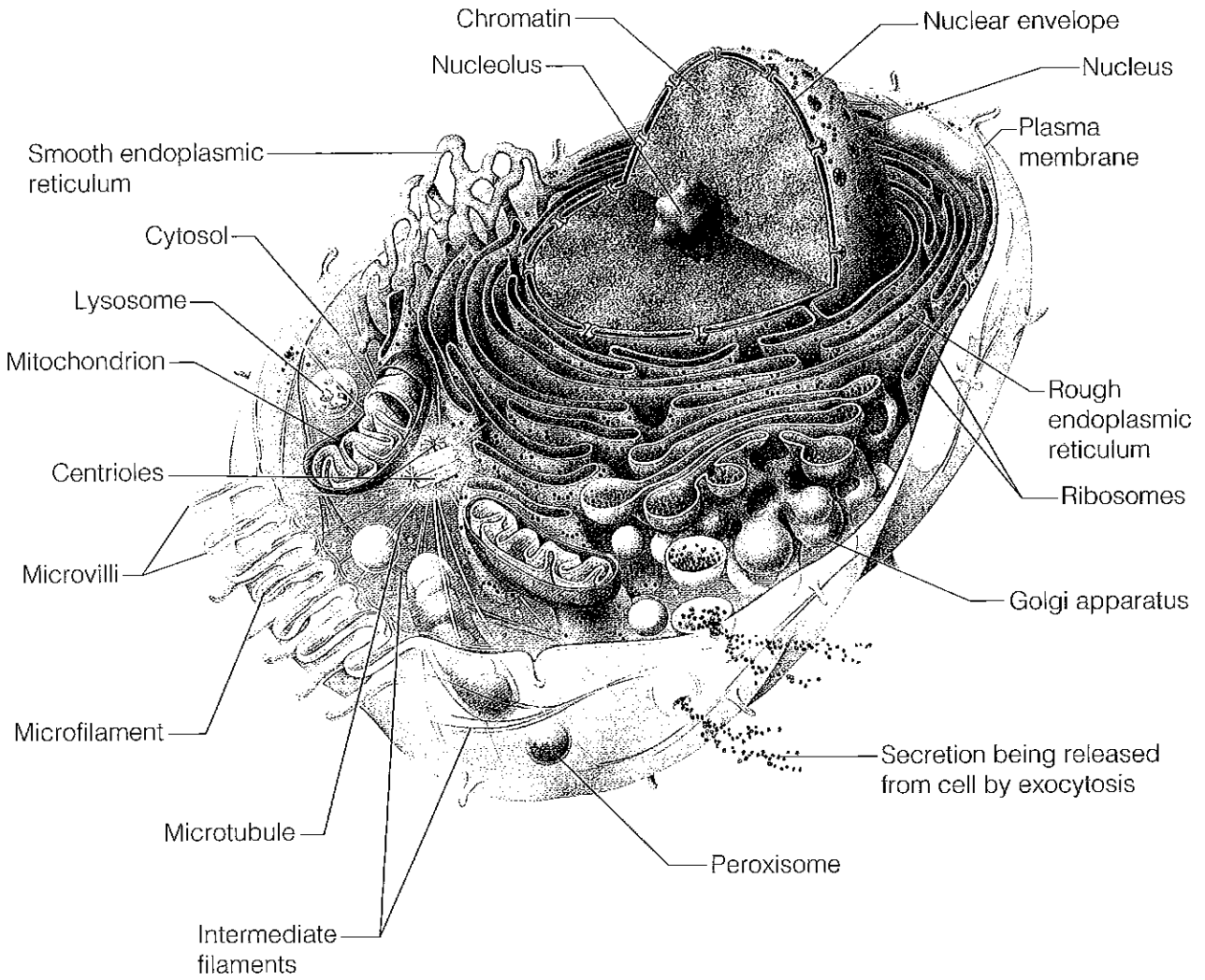


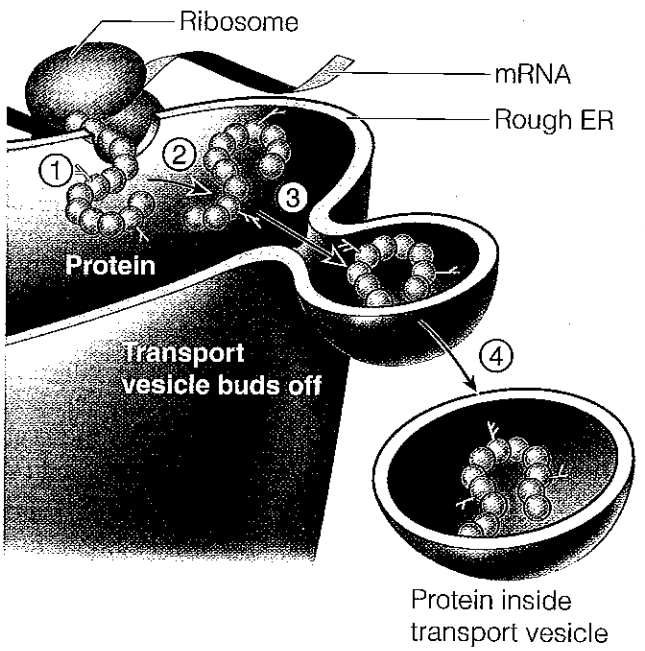
FIGURE 3.4 Structure of the generalized cell. No cell is exactly like this one, but this generalized cell drawing illustrates features common to many human cells.

Cytoplasmic Organelles

The cytoplasmic organelles, literally "little organs," are specialized cellular compartments (Figure 3.4), each performing its own job to maintain the life of the cell. Many organelles are bounded by a membrane similar to the plasma membrane. The membrane boundaries of such organelles allow them to maintain an internal environment quite different from that of the surrounding cytosol. This compartmentalization is crucial to their ability to perform their specialized functions for the cell. Let us consider what goes on in each of the workshops of our cellular factory.

Mitochondria **Mitochondria** (mi″to-kon′dre-ah) are usually depicted as tiny threadlike (*mitos* = thread) or sausage-shaped organelles (see Figure 3.4), but in living cells they squirm, lengthen, and

A *Chromatin.*



1. As the protein is synthesized on the ribosome, it migrates into the rough ER cistern.
2. In the cistern, the protein folds into its functional shape. Short sugar chains may be attached to the protein (forming a glycoprotein).
3. The protein is packaged in a tiny membranous sac called a transport vesicle.
4. The transport vesicle buds from the rough ER and travels to the Golgi apparatus for further processing or goes directly to the plasma membrane where its contents are secreted.

FIGURE 3.5 Synthesis and export of a protein by the rough ER.

change shape almost continuously. The mitochondrial wall consists of a double membrane, equal to *two* plasma membranes, placed side by side. The outer membrane is smooth and featureless, but the inner membrane has shelflike protrusions called *cristae* (kris′te; "crests"). Enzymes dissolved in the fluid within the mitochondria, as well as enzymes that form part of the cristae membranes, carry out the reactions in which oxygen is used to break down foods. As the foods are broken down, energy is released. Much of this energy escapes as heat, but some is captured and used to form *ATP molecules.* ATP provides the energy for all cellular work, and every living cell requires a constant supply of ATP for its many activities. Because the mitochondria supply most of this ATP, they are referred to as the "powerhouses" of the cell.

Metabolically "busy" cells, like liver and muscle cells, use huge amounts of ATP and have hundreds of mitochondria. By contrast, cells that are relatively inactive (an unfertilized egg, for instance) have just a few.

Ribosomes **Ribosomes** (ri′bo-sōmz) are tiny, bilobed, dark bodies made of proteins and one variety of RNA called *ribosomal RNA.* Ribosomes are the actual sites of protein synthesis in the cell. Some ribosomes float free in the cytoplasm, where they manufacture proteins that function in the cytoplasm. Others attach to membranes, and the whole ribosome-membrane combination is called the *rough endoplasmic reticulum.*

Endoplasmic Reticulum The **endoplasmic reticulum** (en″do-plas′mik rĕ-tik′u-lum; "network within the cytoplasm") **(ER)** is a system of fluid-filled cisterns (tubules, or canals) that coil and twist through the cytoplasm. It accounts for about half of a cell's membranes. It serves as a minicirculatory system for the cell because it provides a network of channels for carrying substances (primarily proteins) from one part of the cell to another. There are two forms of ER; a particular cell may have both forms or only one, depending on its specific functions.

The **rough ER** is so called because it is studded with ribosomes. Because essentially all of the building materials of cellular membranes are formed either in it or on it, the rough ER can be thought of as the cell's membrane factory. The proteins made on its ribosomes migrate into the tubules of the rough ER, where they fold into their functional three-dimensional shapes and then are dispatched to other areas of the cell in **transport vesicles** (Figure 3.5). Rough ER is especially abundant in cells that make

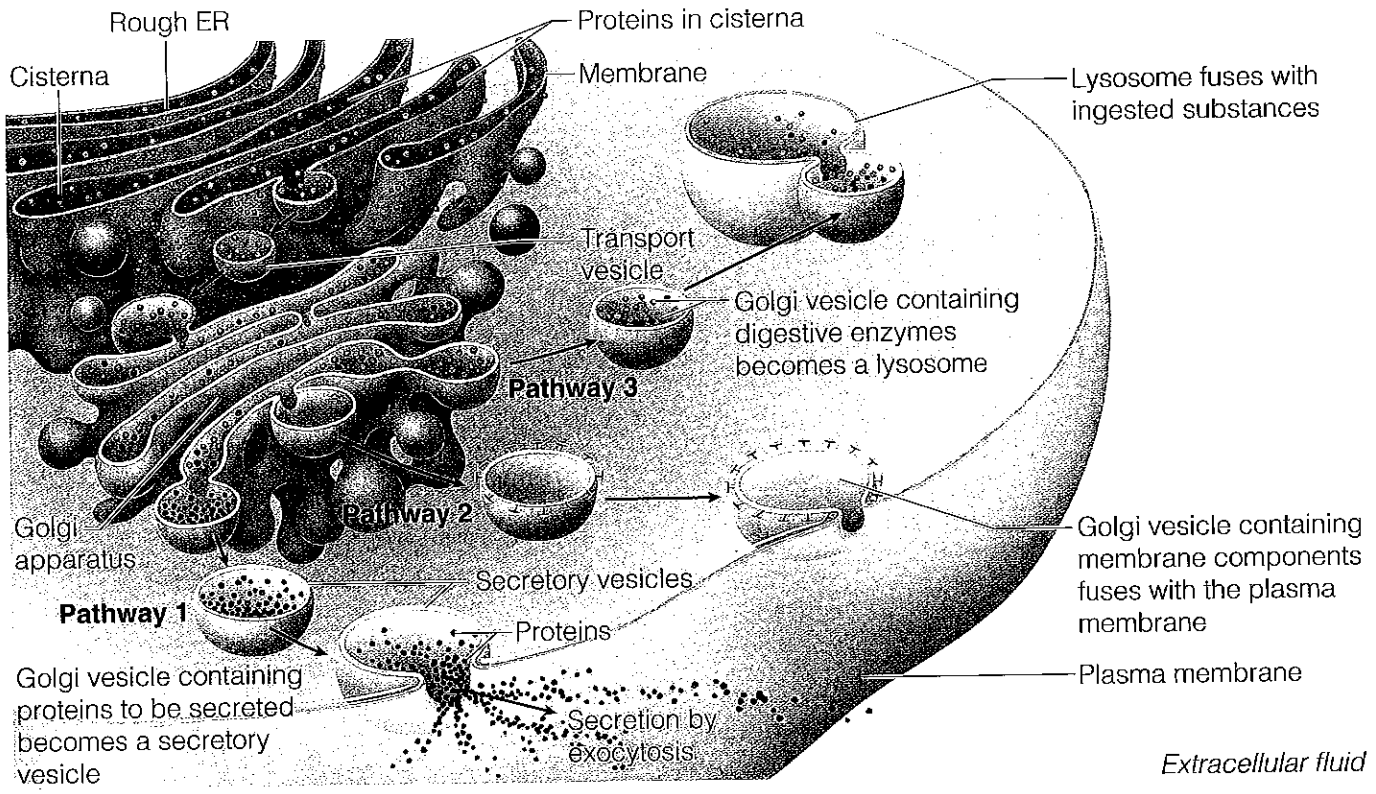


FIGURE 3.6 Role of the Golgi apparatus in packaging the products of the rough ER. Protein-containing transport vesicles pinch off the rough ER and migrate to fuse with the Golgi apparatus. As it passes through the Golgi apparatus, the protein product is sorted (and slightly modified). The product is then packaged within vesicles, which leave the Golgi apparatus and head for various destinations (pathways 1–3), as shown.

and export protein products—for example, pancreas cells, which produce digestive enzymes to be delivered to the small intestine. The enzymes that catalyze the synthesis of membrane lipids reside on the external face of the rough ER, where the needed building blocks are readily available.

Although the **smooth ER** communicates with the rough variety, it plays no role in protein synthesis. Instead it functions in lipid metabolism (cholesterol and fat synthesis and breakdown), and detoxification of drugs and pesticides. Hence it is not surprising that the liver cells are chock-full of smooth ER. So too are body cells that produce steroid-based hormones—for instance, cells of the male testes that manufacture testosterone.

Golgi Apparatus The **Golgi** (gol'je) **apparatus** appears as a stack of flattened membranous sacs, associated with swarms of tiny vesicles. It is generally found close to the nucleus and is the principal "traffic director" for cellular proteins. Its major function is to modify and package proteins (sent to it by the rough ER via transport vesicles) in specific ways, depending on their final destination (Figure 3.6).

As proteins "tagged" for export accumulate in the Golgi apparatus, the sacs swell. Then their swollen ends, filled with protein, pinch off and form **secretory vesicles** (ves'ĭ-kuls), which travel to the plasma membrane. When the vesicles reach the plasma membrane, they fuse with it, the membrane ruptures, and the contents of the sac are ejected to the outside of the cell (pathway 1 in Figure 3.6). Mucus is packaged this way, as are digestive enzymes made by pancreas cells.

In addition to its packaging-for-release functions, the Golgi apparatus pinches off sacs containing proteins and phospholipids destined for a "home" in the plasma membrane (pathway 2 in Figure 3.6) or other cellular membranes. It also packages hydrolytic enzymes into membranous sacs called *lysosomes* that remain in the cell (pathway 3 in Figure 3.6 and discussed next).

Lysosomes **Lysosomes** (lī'so-sōmz; "breakdown bodies"), which appear in different sizes, are membranous "bags" containing powerful digestive enzymes. Because lysosomal enzymes are capable of digesting worn-out or nonusable cell structures and most foreign substances that enter the cell, lysosomes function as the cell's demolition sites. Lysosomes are especially abundant in phagocytes, the cells that dispose of bacteria and cell debris. As described above, the enzymes they contain are formed by ribosomes and packaged by the Golgi apparatus.

HOMEOSTATIC IMBALANCE

The lysosomal membrane is ordinarily quite stable, but it becomes fragile when the cell is injured or deprived of oxygen and when excessive amounts of vitamin A are present. Lysosomal rupture results in self-digestion of the cell. ▲

Peroxisomes **Peroxisomes** (per-ok'sih-sōmz) are membranous sacs containing powerful oxidase (ok'sĭ-dāz) enzymes that use molecular oxygen (O_2) to detoxify a number of harmful or poisonous substances, including alcohol and formaldehyde. However, their most important function is to "disarm" dangerous free radicals. **Free radicals** are highly reactive chemicals with unpaired electrons that can scramble the structure of proteins and nucleic acids. Although free radicals are normal byproducts of cellular metabolism, if allowed to accumulate, they can have devastating effects on cells. Peroxisomes convert free radicals to hydrogen peroxide (H_2O_2), a function indicated in their naming (*peroxisomes* = "peroxide bodies"). The enzyme *catalase* (kat'ah-lās) then converts excess hydrogen peroxide to water. Peroxisomes are especially numerous in liver and kidney cells, which are very active in detoxification.

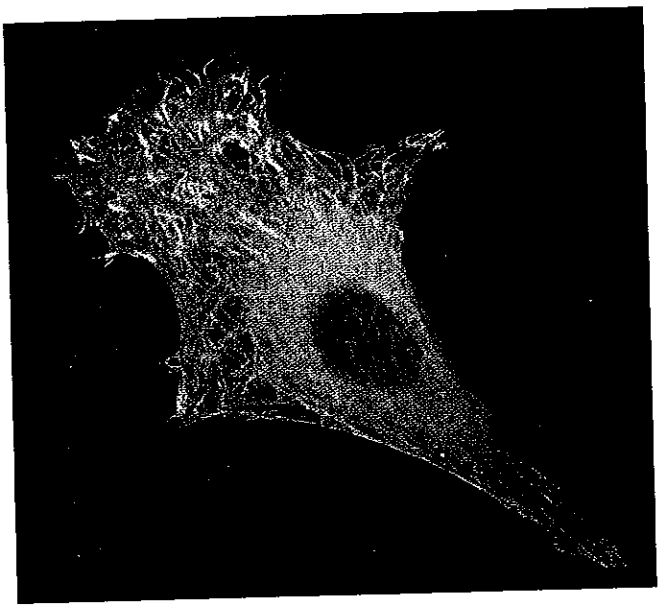
Although peroxisomes look like small lysosomes (see Figure 3.4), they do not arise by budding from the Golgi apparatus. Instead, they appear to replicate themselves by simply pinching in half, as do mitochondria.

Cytoskeleton An elaborate network of protein structures extends throughout the cytoplasm. This network, or **cytoskeleton,** acts as a cell's "bones and muscles" by furnishing an internal framework that determines cell shape, supports other organelles, and provides the machinery needed for intracellular transport and various types of cellular movements. From its largest to its smallest elements, the cytoskeleton is made up of microtubules, intermediate filaments, and microfilaments (Figures 3.4 and 3.7). Although there is some overlap in roles, generally speaking the strong, stable ropelike **intermediate filaments** help form desmosomes (see Figure 3.3) and provide internal guy wires to resist pulling forces on the cell. **Microfilaments** (such as *actin* and *myosin*) are most involved in cell motility and in producing changes in cell shape. You could say that cells move when they get their act(in) together. The tubelike **microtubules** determine the overall shape of a cell and the distribution of organelles. They are very important during cell division, as described on pp. 83–85.

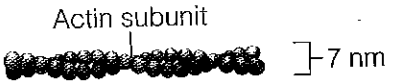
Centrioles The paired **centrioles** (sen'tre-ōlz) lie close to the nucleus (see Figure 3.4). They are rod-shaped bodies that lie at right angles to each other; internally they are made up of fine microtubules. Centrioles are best known for their role in generating microtubules, and during cell division, the centrioles direct the formation of the *mitotic spindle* (see Figure 3.15, p. 85).

In addition to the cell structures described above, some cells have projections called **cilia** (sil'e-ah; "eyelashes"), whiplike cellular extensions that move substances along the cell surface. For example, the ciliated cells of the respiratory system lining move mucus up and away from the lungs. Where cilia appear, there are usually many of them projecting from the exposed cell surface.

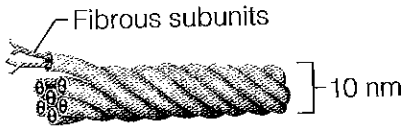
When a cell is about to make cilia, its centrioles multiply and then line up beneath the plasma membrane at the free cell surface. Microtubules then begin to "sprout" from the centrioles and put pressure on the membrane, forming the projections. If the projections formed by the centrioles are substantially longer, they are called **flagella** (flah-jel'ah). The only example of a flagellated cell in the human body is the sperm, which has a single propulsive flagellum called its *tail* (Figure 3.8g). *Notice that cilia propel other substances across a cell's surface, whereas a flagellum propels the cell itself.*



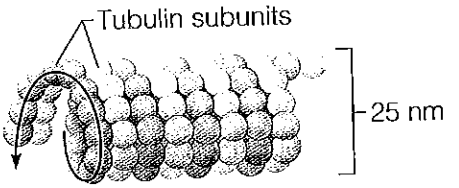
(a)



(b) Microfilament



(c) Intermediate filament



(d) Microtubule

FIGURE 3.7 The cytoskeleton. (a) In this light micrograph of the cytoskeleton of a nerve cell, the microtubules appear green; the microfilaments are blue. Intermediate filaments form most of the rest of the network. **(b–d)** Diagrammatic views of cytoskeletal elements.

DID YOU GET IT?

9. How do the cytosol and the cytoplasm differ?
10. Which two organelles are sacs of enzymes and what is the function of each of these organelles?
11. Which organelle is the major site of ATP synthesis?
12. Name the three types of protein structures that make up the cytoskeleton. Which type helps form desmosomes? Which type is involved in cell motility?

For answers, see Appendix D.

Cell Diversity

So far in this chapter, we have focused on an average human cell. However, the trillions of cells in the human body are made up of some 200 different cell types that vary greatly in size, shape, and function. They include sphere-shaped fat cells, disk-shaped red blood cells, branching nerve cells, and cube-shaped cells of kidney tubules. Figure 3.8 illustrates how the shapes of cells and the relative numbers of the various organelles they contain relate to specialized cell functions. Let's take a look at some of these cell specialists.

1. **Cells that connect body parts:**
   - *Fibroblast.* The elongated shape of this cell lies along the cable-like fibers that it secretes. It has an abundant rough ER and a large Golgi apparatus to make and secrete the protein building blocks of these fibers.
   - *Erythrocyte (red blood cell).* This cell carries oxygen in the bloodstream. Its concave disk shape provides extra surface area for the uptake of oxygen and streamlines the cell so it flows easily through the bloodstream. So much oxygen-carrying pigment is packed in erythrocytes that all other organelles have been shed to make room.
2. **Cell that covers and lines body organs:**
   - *Epithelial cell.* The hexagonal shape of this cell is exactly like a "cell" in a honeycomb of a beehive. This shape allows epithelial

cells to pack together in sheets. An epithelial cell has abundant intermediate filaments that resist tearing when the epithelium is rubbed or pulled.

3. **Cells that move organs and body parts:**
   - *Skeletal muscle and smooth muscle cells.* These cells are elongated and filled with abundant contractile filaments, so they can shorten forcefully and move the bones or change the size of internal organs.
4. **Cell that stores nutrients:**
   - *Fat cell.* The huge spherical shape of a fat cell is produced by a large lipid droplet in its cytoplasm.
5. **Cell that fights disease:**
   - *Macrophage (a phagocytic cell).* This cell extends long pseudopods ("false feet") to crawl through tissue to reach infection sites. The many lysosomes within the cell digest the infectious microorganisms it takes up.
6. **Cell that gathers information and controls body functions:**
   - *Nerve cell (neuron).* This cell has long processes for receiving messages and transmitting them to other structures in the body. The processes are covered with an extensive plasma membrane, and a plentiful rough ER is present to synthesize membrane components.
7. **Cells of reproduction:**
   - *Oocyte (female).* The largest cell in the body, this egg cell contains several copies of all organelles, for distribution to the daughter cells that arise when the fertilized egg divides to become an embryo.
   - *Sperm (male).* This cell is long and streamlined, built for swimming to the egg for fertilization. Its flagellum acts as a motile whip to propel the sperm.

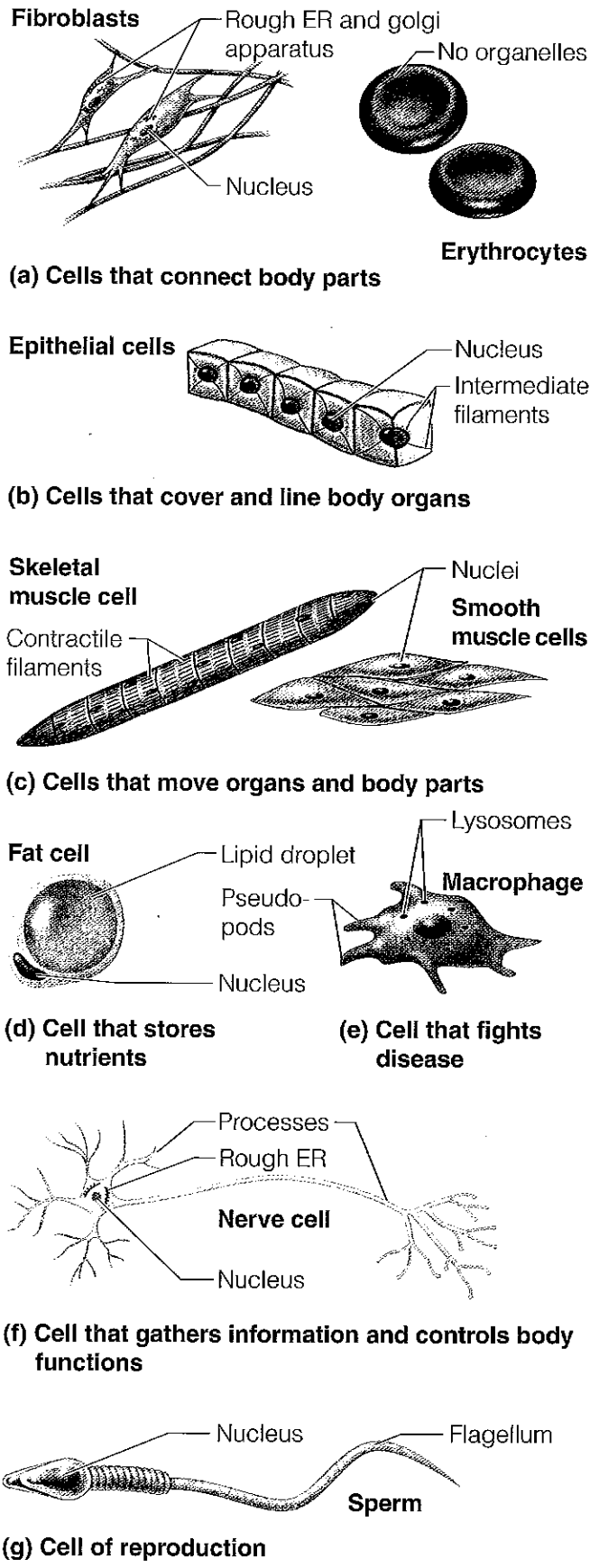


FIGURE 3.8 Cell diversity. The shape of human cells and the relative abundances of their various organelles relate to their function in the body.

DID YOU GET IT?

13. Name the two cell types involved in connecting body parts or regions.
14. What is the main function of a neuron?

For answers, see Appendix D.

Cell Physiology

As mentioned earlier, each of the cell's internal parts is designed to perform a specific function for the cell. Most cells have the ability to *metabolize* (use nutrients to build new cell material, break down substances, and make ATP), *digest foods, dispose of wastes, reproduce, grow, move,* and *respond to a stimulus* (irritability). Most of these functions are considered in detail in later chapters. For example, metabolism is covered in Chapter 14, and the ability to react to a stimulus is covered in Chapter 7. Here, we will consider only the functions of membrane transport (the means by which substances get through plasma membranes), protein synthesis, and cell reproduction (cell division).

Membrane Transport

The fluid environment on both sides of the plasma membrane is an example of a solution. It is important that you really understand solutions before we dive into an explanation of membrane transport. In the most basic sense, a **solution** is a homogeneous mixture of two or more components. Examples include the air we breathe (a mixture of gases), seawater (a mixture of water and salts), and rubbing alcohol (a mixture of water and alcohol). The substance present in the largest amount in a solution is called the **solvent** (or dissolving medium). Water is the body's chief solvent. Components or substances present in smaller amounts are called **solutes.** The solutes in a solution are so tiny; they do not settle out.

Intracellular fluid (collectively, the nucleoplasm and the cytosol) is a solution containing small amounts of gases (oxygen and carbon dioxide), nutrients, and salts, dissolved in water. So too is **interstitial fluid,** the fluid that continuously bathes the exterior of our cells. Interstitial fluid can be thought of as a rich, nutritious, and rather unusual "soup." It contains thousands of ingredients, including nutrients (amino acids, sugars, fatty acids, vitamins), regulatory substances such as hormones and neurotransmitters, salts, and waste products. To remain healthy, each cell must extract from this soup the exact amounts of the substances it needs at specific times and reject the rest.

The plasma membrane is a selectively permeable barrier. **Selective permeability** means that a barrier allows some substances to pass through it while excluding others. Thus, it allows nutrients to enter the cell but keeps many undesirable substances out. At the same time, valuable cell proteins and other substances are kept within the cell, and wastes are allowed to pass out of it.

HOMEOSTATIC IMBALANCE

The property of selective permeability is typical only of healthy, unharmed cells. When a cell dies or is badly damaged, its plasma membrane can no longer be selective and becomes permeable to nearly everything. This phenomenon is evident when someone has been severely burned. Precious fluids, proteins, and ions "weep" (leak out) from the dead and damaged cells. ▲

Movement of substances through the plasma membrane happens in basically two ways—passively or actively. In **passive transport** processes, substances are transported across the membrane without any energy input from the cell. In **active transport** processes, the cell provides the metabolic energy (ATP) that drives the transport process.

Passive Transport Processes: Diffusion and Filtration

Diffusion (dĭ-fu′zhun) is an important means of passive membrane transport for every cell of the body. The other passive transport process, *filtration,* generally occurs only across capillary walls. Let us examine how these two types of passive transport differ.

Diffusion **Diffusion** is the process by which molecules (and ions) move away from a region where they are more concentrated (more numerous) to a region where they are less concentrated (fewer of them). All molecules possess *kinetic energy* (energy of motion), as described in Chapter 2, and as the molecules move about randomly at high speeds, they collide and change direction with each collision. The overall effect of this erratic

movement is that molecules move *down* their **concentration gradient.** Because the driving force (source of energy) is the kinetic energy of the molecules themselves, the speed of diffusion is affected by the size of the molecules (the smaller the faster) and temperature (the warmer the faster).

An example should help you understand diffusion. Picture yourself pouring a cup of coffee and then adding a cube of sugar (but not stirring the cup). After you add the sugar, the phone rings, and you are called in to work. You never do get to drink the coffee. Upon returning that evening, you find that the coffee tastes sweet even though it was never stirred. The reason is that the sugar molecules moved around all day and eventually, as a result of their activity, became sufficiently distributed throughout the coffee to sweeten the entire cup. A laboratory example that might be familiar to some students is illustrated in Figure 3.9.

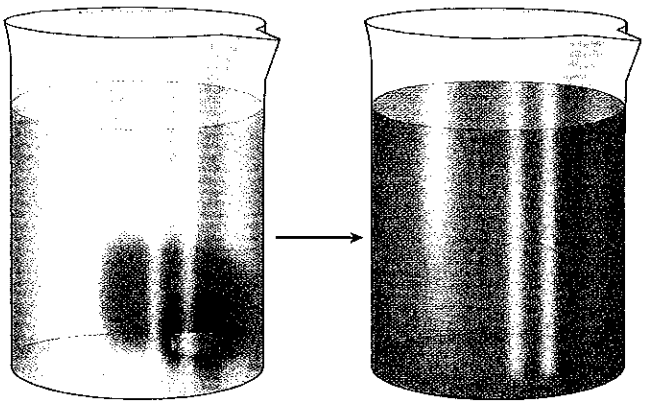


FIGURE 3.9 Diffusion. Particles in solution move continuously and collide constantly with other particles. As a result, particles tend to move away from areas where they are most highly concentrated and to become evenly distributed, as illustrated by the diffusion of dye molecules in a beaker of water.

The hydrophobic core of the plasma membrane is a physical barrier to diffusion. However, molecules will diffuse through the plasma membrane if (1) they are small enough to pass through its pores (channels formed by membrane proteins), (2) they can dissolve in the fatty portion of the membrane, or (3) they are assisted by a membrane carrier. The unassisted diffusion of solutes through the plasma membrane (or any selectively permeable membrane) is called **simple diffusion** (Figure 3.10a). Solutes transported this way are either lipid-soluble (fats, fat-soluble vitamins, oxygen, carbon dioxide) or small enough to pass through the membrane pores (some small ions such as chloride ions, for example).

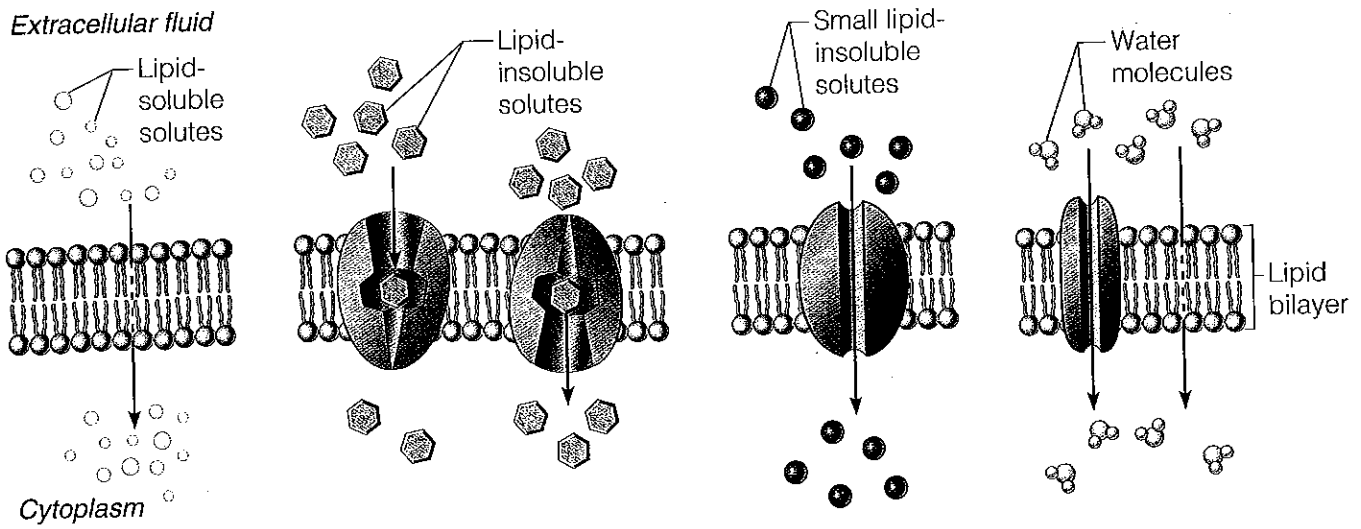
Diffusion of water through a selectively permeable membrane such as the plasma membrane is specifically called **osmosis** (oz-mo'sis). Because water is highly polar, it is repelled by the (nonpolar) lipid core of the plasma membrane, but it can and does pass easily through special pores called *aquaporins* ("water pores") created by the proteins in the membrane (Figure 3.10d). Osmosis into and out of cells is occurring all the time as water moves down its concentration gradient.

Still another example of diffusion is **facilitated diffusion.** Facilitated diffusion provides passage for certain needed substances (notably glucose) that are both lipid-insoluble and too large to pass through the membrane pores. Although facilitated diffusion follows the laws of diffusion—that is, the substances move down their own concentration gradient—a protein membrane channel is used (Figure 3.10c), or a protein molecule that acts as a carrier is needed as a transport vehicle (Figure 3.10b). Hence, some of the proteins in the plasma membrane form channels or act as carriers to move glucose and certain other solutes passively across the membrane and make it available for cell use.

Substances that pass into and out of cells by diffusion save the cell a great deal of energy. When you consider how vitally important water, glucose, and oxygen are to cells, it becomes apparent just how necessary these passive transport processes really are. Glucose and oxygen continually move into the cells (where they are in lower concentration because the cells keep using them up), and carbon dioxide (a waste product of cellular activity) continually moves out of the cells into the blood (where it is in lower concentration).

Filtration **Filtration** is the process by which water and solutes are forced through a membrane (or capillary wall) by *fluid,* or *hydrostatic, pressure.* In the body, hydrostatic pressure is usually exerted by the blood. Like diffusion, filtration is a passive process, and a gradient is involved. In filtration, however, the gradient is a **pressure gradient** that actually pushes solute-containing fluid *(filtrate)* from the higher-pressure area to the lower-pressure area. Filtration is necessary for the kidneys to do their job properly. In the kidneys, water and small

What "facilitates" facilitated diffusion?



(a) Simple diffusion directly through the phospholipid bilayer

(b) Carrier-mediated facilitated diffusion via protein carrier specific for one chemical; binding of substrate causes shape change in transport protein

(c) Channel-mediated facilitated diffusion through a channel protein; mostly ions selected on basis of size and charge

(d) Osmosis, diffusion of water through a specific channel protein (aquaporin) or through the lipid bilayer

FIGURE 3.10 Diffusion through the plasma membrane. (a) In simple diffusion, fat-soluble molecules diffuse directly through the lipid bilayer of the plasma membrane, in which they can dissolve. **(b)** In facilitated diffusion using protein carriers, large, lipid-insoluble molecules (e.g., glucose) are moved across the membrane via a transport protein. **(c)** In facilitated diffusion via membrane channels, small polar or charged particles diffuse through membrane channels constructed by channel proteins. **(d)** In osmosis, water moves across the plasma membrane via specific channels (aquaporins) or diffuses directly through the lipid portion of the membrane.

solutes filter out of the capillaries into the kidney tubules because the blood pressure in the capillaries is greater than the fluid pressure in the tubules. Part of the filtrate formed in this way eventually becomes urine. Filtration is not very selective. For the most part, only blood cells and protein molecules too large to pass through the membrane pores are held back.

Active Transport Processes

Whenever a cell uses some of its ATP supply to move substances across the membrane, the process is referred to as *active*. Substances moved actively are usually unable to pass in the desired direction by diffusion. They may be too large to pass through membrane channels, the membrane may lack special protein carriers for their transport, they may not be able to dissolve in the fat core, or they may have to move "uphill" *against* their concentration gradients. The two most important mechanisms of active membrane transport are active transport and vesicular transport.

Active Transport Sometimes called *solute pumping*, **active transport** is similar to the carrier-mediated facilitated diffusion described earlier in that both processes require protein carriers that combine reversibly with the substances to be transported

Carrier proteins or protein channels.

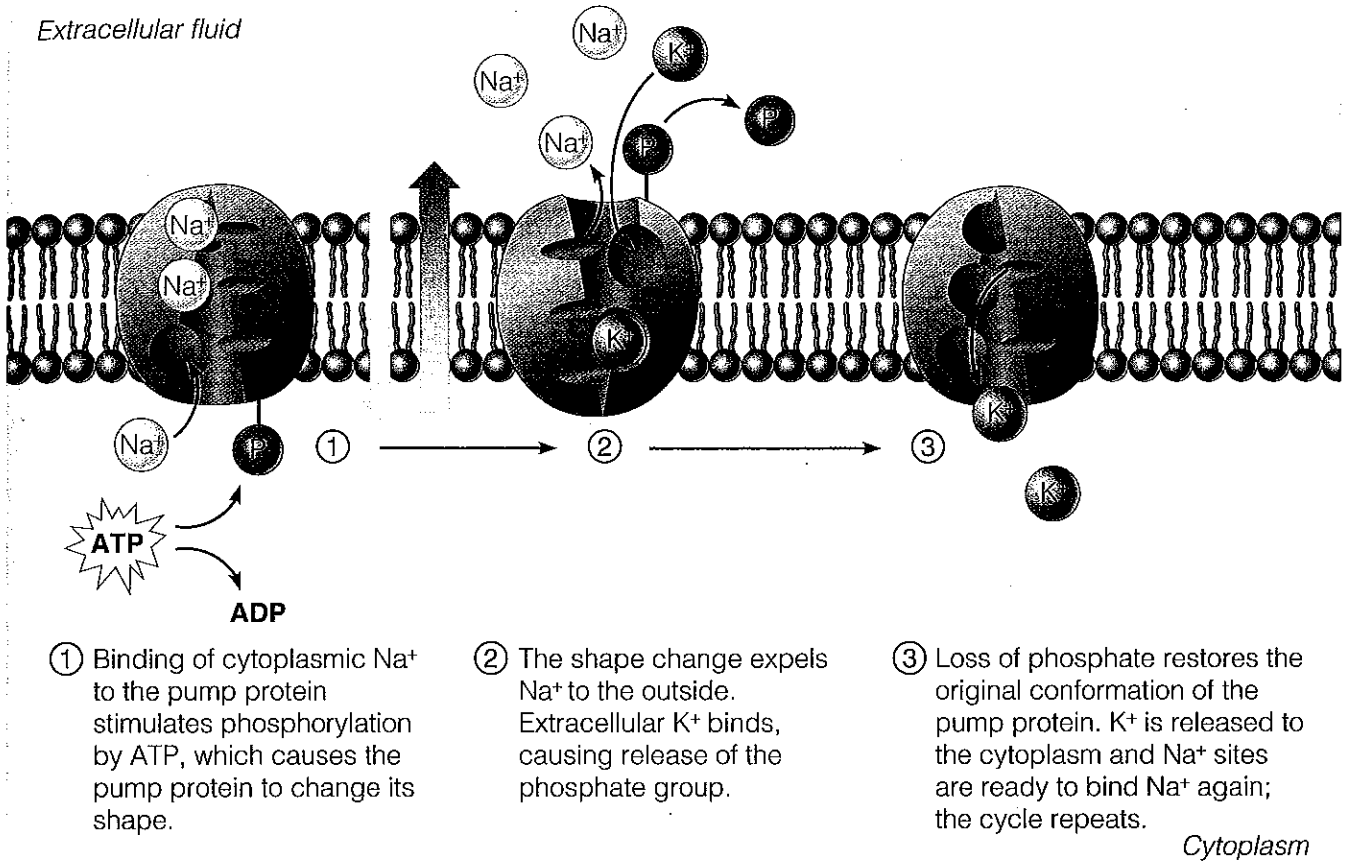
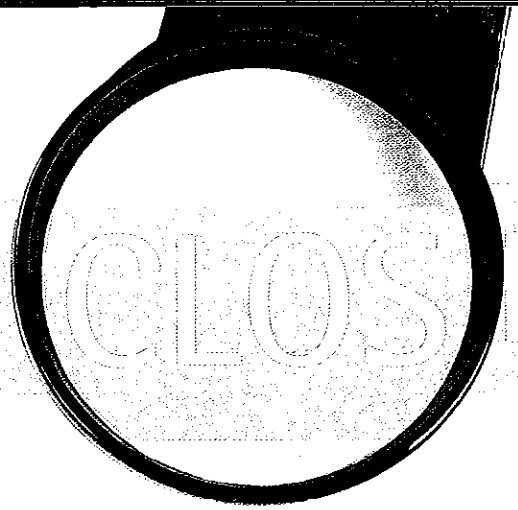


FIGURE 3.11 Operation of the sodium-potassium pump, a solute pump. ATP provides the energy for a "pump" protein to move three sodium ions out of the cell and two potassium ions into the cell. Both ions are moved against their concentration gradients.

across the membrane. However, facilitated diffusion is driven by the kinetic energy of the diffusing molecules, whereas active transport uses ATP to energize its protein carriers, which are called **solute pumps.** Amino acids, some sugars, and most ions are transported by solute pumps, and in most cases these substances move *against* concentration (or electrical) gradients. This is opposite to the direction in which substances would naturally flow by diffusion, which explains the need for energy in the form of ATP. Amino acids are needed to build cellular proteins but are too large to pass through the membrane channels and are not lipid-soluble. The **sodium-potassium pump** that simultaneously carries sodium ions (Na^+) out of and potassium ions into the cell is absolutely necessary for normal transmission of impulses by nerve cells (Figure 3.11). There are more sodium ions outside the cells than inside, so they tend to remain in the cell unless the cell uses ATP to force, or "pump," them out. Likewise, there are relatively more potassium ions inside cells than in the interstitial (extracellular) fluid, and potassium ions that leak out of cells must be actively pumped back inside. Because each of the pumps in the plasma membrane transports only specific substances, active transport provides a way for the cell to be very selective in cases where substances cannot pass by diffusion. (No pump—no transport.)

Vesicular Transport Some substances cannot get through the plasma membrane by passive transport or by active transport. **Vesicular transport,** which involves help from ATP, moves substances



A CLOSER LOOK

IV THERAPY AND CELLULAR "TONICS"

Why is it essential that medical personnel give only the proper *intravenous (IV)*, or into-the-vein, *solutions* to patients?

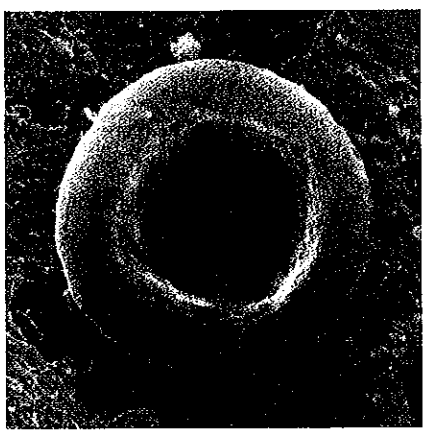
Consider that there is a steady traffic of small molecules across the plasma membrane. Although diffusion of solutes across the membrane is rather slow, osmosis, which moves water across the membrane, occurs very quickly. Anyone administering an IV must use the correct solution to protect the patient's cells from life-threatening dehydration or rupture due to rapid and excessive water entry.

The tendency of a solution to hold water or "pull" water into it is called osmotic pressure. Osmotic pressure is directly related to the concentration of solutes in the solution. The higher the solute concentration, the greater the osmotic pressure and the greater the tendency of water to move into the solution. Many molecules, particularly proteins and some ions, are prevented from diffusing through the plasma membrane. Consequently, any change in their concentration on one side of the membrane forces water to move from one side of the membrane to the other, causing cells to lose or gain water. The ability of a solution to change the size and shape of cells by altering the amount of water they contain is called *tonicity* (ton-is'i-te; *ton* = strength).

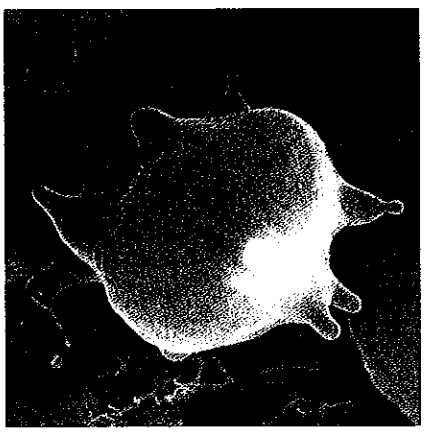
> *"Cells placed in hypotonic solutions plump up rapidly."*

Isotonic (i"so-ton'ik; "same tonicity") solutions (such as Ringer's lactate, 5 percent dextrose, and 0.9 percent saline) have the same solute and water concentrations as cells do. Isotonic solutions cause no visible changes in cells, and when such solutions are infused into the bloodstream, red blood cells (RBCs) retain their normal size and disclike shape (Photo a). As you might guess, interstitial fluid and most intravenous solutions are isotonic solutions.

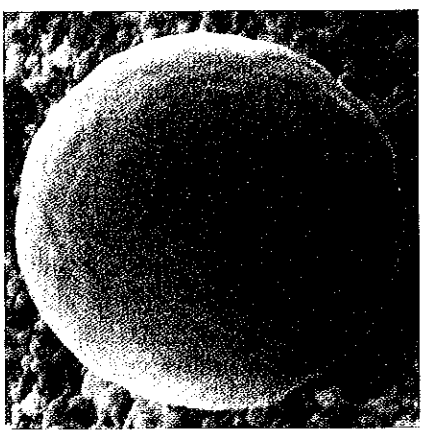
If red blood cells are exposed to a *hypertonic* (hi"per-ton'ik) solution—a solution that contains more solutes, or dissolved substances, than there are inside the cells—the cells will



(a) RBC in isotonic solution



(b) RBC in hypertonic solution



(c) RBC in hypotonic solution

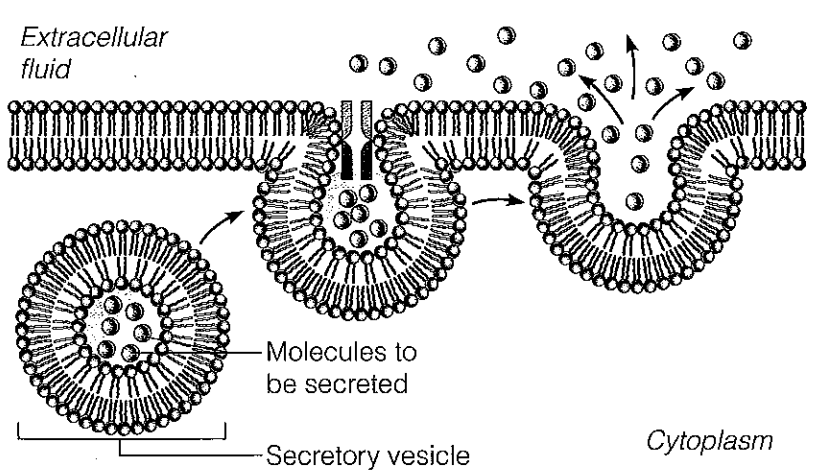
begin to shrink, or *crenate* (kre'nāt). This is because water is in higher concentration inside the cell than outside, so it follows its concentration gradient and leaves the cell (Photo b). Hypertonic solutions are sometimes given to patients who have *edema* (swelling of the feet and hands due to fluid retention). Such solutions draw water out of the tissue spaces into the bloodstream so that the kidneys can eliminate excess fluid.

When a solution contains fewer solutes (and therefore more water) than the cell does, it is said to be *hypotonic* (hi"po-ton'ik) to the cell. Cells placed in hypotonic solutions plump up rapidly as water rushes into them (Photo c). Distilled water represents the most extreme example of a hypotonic fluid. Because it contains no solutes at all, water will enter cells until they finally burst, or *lyse*. Hypotonic solutions are sometimes infused intravenously (slowly and with care) to rehydrate the tissues of extremely dehydrated patients. In less extreme cases, drinking hypotonic fluids usually does the trick. (Many fluids that we tend to drink regularly, such as tea, colas, and sport drinks, are hypotonic.)

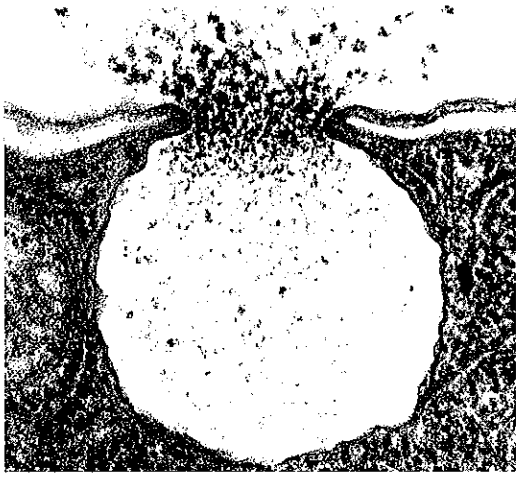
into or out of cells without their actually crossing the plasma membrane. The two types of vesicular transport are *exocytosis* and *endocytosis*.

Exocytosis (ek"so-si-to'sis; "out of the cell") moves substances out of cells (Figure 3.12). It is the means by which cells actively secrete hormones, mucus, and other cell products or eject certain cellular wastes. The product to be released is first "packaged" (typically by the efforts of the Golgi apparatus) into a small membranous vesicle or sac. The sac migrates to the plasma membrane and fuses with it. The fused area then ruptures, spilling the sac contents out of the cell (also see Figure 3.6).

Endocytosis (en"do-si-to'sis; "into the cell") includes those ATP-requiring processes that take up, or engulf, extracellular substances by enclosing them in a small membranous vesicle (Figure



(a)



(b)

FIGURE 3.12 Exocytosis. (a) A secretory vesicle migrates to the plasma membrane, and the two membranes fuse. The fused site opens and releases the contents to the outside of the cell. **(b)** Electron micrograph of a vesicle in exocytosis (60,000×).

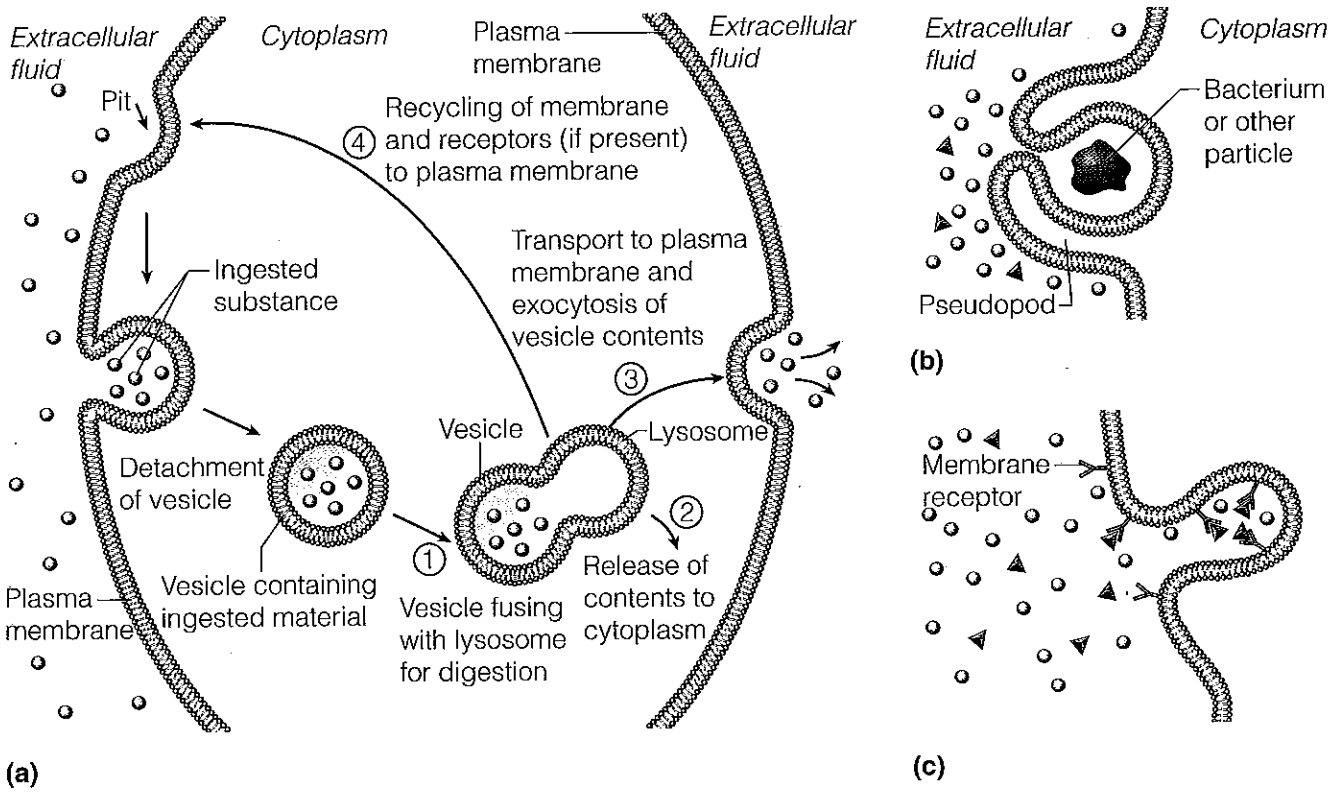


FIGURE 3.13 Events and types of endocytosis. (a) Sequence of events in endocytosis. Once the vesicle detaches from the plasma membrane, its contents may be digested within a lysosome and then released to the cytoplasm (its membrane components, and receptors if present, are recycled to the plasma membrane); or, alternatively, the vesicle may be transported across the cell intact and then released to the cell exterior by exocytosis. The type illustrated is pinocytosis. **(b)** Phagocytosis. **(c)** Receptor-mediated endocytosis.

3.13). Once the vesicle, or sac, is formed, it detaches from the plasma membrane and moves into the cytoplasm, where it fuses with a lysosome and its contents are digested (by lysosomal enzymes).

If the engulfed substances are relatively large particles such as bacteria or dead body cells, which are separated from the external environment by flowing cytoplasmic extensions called *pseudopods,* the endocytosis process is more specifically called **phagocytosis** (fag″o-si-to′sis), a term that means "cell eating" (Figure 3.13b). Certain white blood cells and other "professional" phagocytes of the body act as scavenger cells that police and protect the body by ingesting bacteria and other foreign debris. Hence, phagocytosis is a protective mechanism, not a means of getting nutrients.

If we say that cells can eat, we can also say that they can drink. In this form of endocytosis, called **pinocytosis** (pi″no-si-to′sis; "cell drinking"), the cell "gulps" droplets of extracellular fluid. The plasma membrane invaginates to form a tiny pit, and then its edges fuse around the droplet of extracellular fluid containing dissolved proteins or fats (Figure 3.13a). Unlike phagocytosis, pinocytosis is a routine activity of most cells. It is especially important in cells that function in absorption (for example, cells forming the lining of the small intestine).

Receptor-mediated endocytosis is the main cellular mechanism for taking up specific target molecules (Figure 3.13c). In this process, plasma membrane receptor proteins bind only with certain substances. Both the receptors and

high concentrations of the attached target molecules are internalized in a vesicle, and then the contents of the vesicle are dealt with in one of the ways shown in Figure 3.13a. Although phagocytosis and pinocytosis are important, compared to receptor-mediated endocytosis, they are pretty unselective. Substances encytosed by receptor-mediated endocytosis include enzymes, some hormones, cholesterol, and iron. Unfortunately, flu viruses also use this route to enter and attack our cells.

DID YOU GET IT?

15. What determines whether a membrane transport process is active or passive? How are concentration gradients involved in passive transport processes?
16. Which vesicular transport process moves large particles into the cell?
17. Which process is more selective—pinocytosis or receptor-mediated endocytosis?

For answers, see Appendix D.

Cell Division

The **cell life cycle** is the series of changes a cell goes through from the time it is formed until it divides. The cycle has two major periods: **interphase,** in which the cell grows and carries on its usual metabolic activities, and **cell division,** during which it reproduces itself. Although the term *interphase* leads one to believe that it is merely a resting time between the phases of cell division, this is not the case. During interphase, which is by far the longer phase of the cell cycle, the cell is very active and is resting *only* from division. A more accurate name for interphase would be *metabolic phase.*

Preparations: DNA Replication

The function of cell division is to produce more cells for growth and repair processes. Because it is essential that all body cells have the same genetic material, an important event *always precedes* cell division: the genetic material (the DNA molecules that form part of the chromatin) is duplicated exactly. This occurs toward the end of the cell's interphase period.

You will recall from Chapter 2 that DNA is a very complex molecule. It is composed of building blocks called *nucleotides,* each consisting of deoxyribose sugar, a phosphate group, and a nitrogen-containing base. Essentially DNA is a *double helix,* a ladderlike molecule that is coiled into a spiral staircase shape. The upright parts of the DNA "ladder" are alternating phosphate and sugar units, and the rungs of the ladder are made of pairs of nitrogen-containing bases.

The precise trigger for DNA synthesis is unknown, but once it starts, it continues until all the DNA has been replicated. The process begins as the DNA helix uncoils and gradually separates into its two nucleotide chains (Figure 3.14). Each nucleotide strand then serves as a *template,* or set of instructions, for building a new nucleotide strand.

Remember that nucleotides join in a *complementary* way: adenine (A) always bonds to thymine (T), and guanine (G) always bonds to cytosine (C). Hence, the order of the nucleotides on the template strand also determines the order on the new strand. For example, a TACTGC sequence on a template strand would bond to new nucleotides with the order ATGACG. The end result is that two DNA molecules are formed that are identical to the original DNA helix, and each consists of one old and one newly assembled nucleotide strand.

Events of Cell Division

In all cells other than bacteria and some cells of the reproductive system, cell division consists of two events. **Mitosis** (mi-to″sis), or division of the nucleus, occurs first. The second event is division of the cytoplasm, **cytokinesis** (si′to-kĭ-ne″sis), which begins when mitosis is nearly completed.

Mitosis Mitosis results in the formation of two daughter nuclei with exactly the same genes as the mother nucleus. As explained above, DNA replication precedes mitosis, so that for a short time the cell nucleus contains a double dose of genes. When the nucleus divides, each *daughter cell* ends up with *exactly* the same genetic information as the original mother cell and the original fertilized egg from which it came.

The stages of mitosis, diagrammed in Figure 3.15, include the following events:

- **Prophase** (pro′faz). As cell division begins, the chromatin threads coil and shorten so that

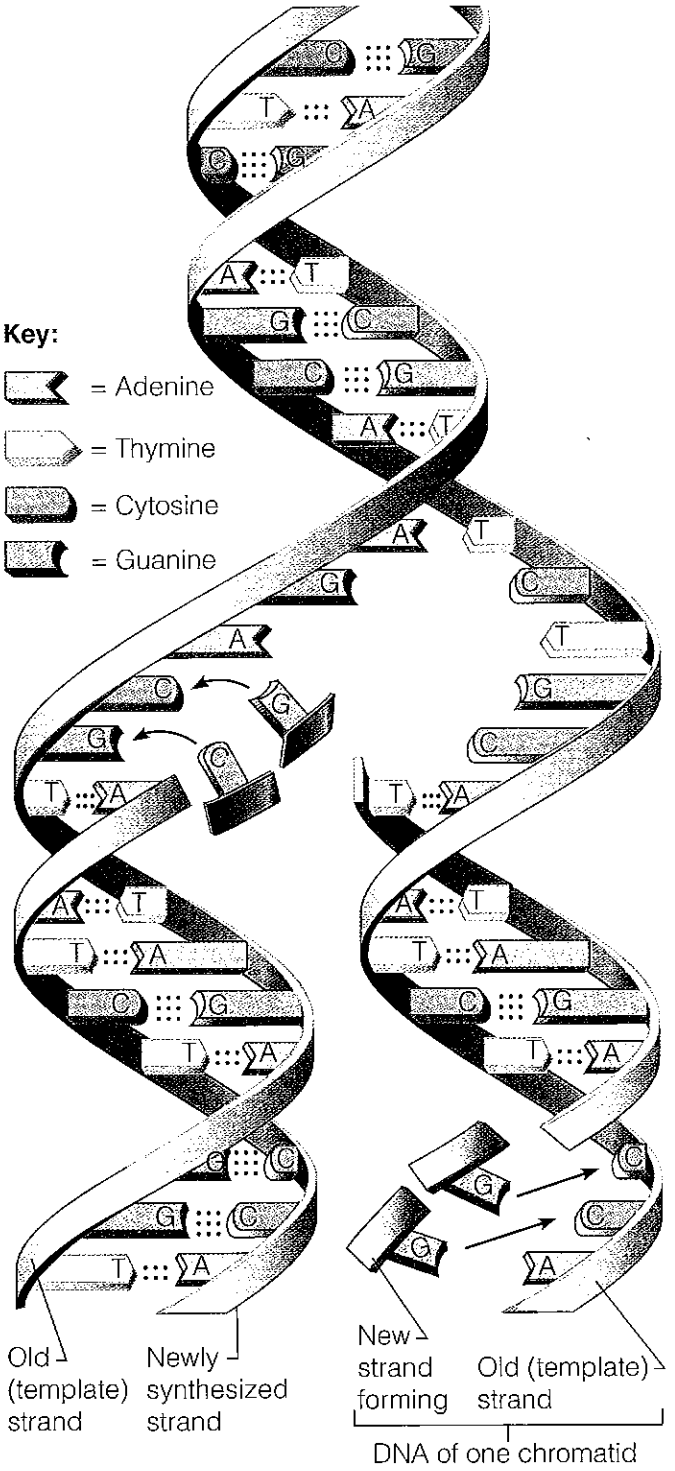


FIGURE 3.14 Replication of the DNA molecule during interphase. The DNA helix unwinds (center), and its nucleotide strands are separated. Each strand then acts as a template for building a new complementary strand. As a result, two helixes, each identical to the original DNA helix, are formed.

visible barlike bodies called **chromosomes** (*chromo* = colored; *soma* = body) appear. Because DNA has already been replicated, each chromosome is actually made up of two strands, each called a **chromatid** (kro'mah-tid), held together by a small buttonlike body called a **centromere** (sen'tro-mēr). The centrioles separate from each other and begin to move toward opposite sides of the cell, directing the assembly of a **mitotic spindle** (composed of microtubules) between them as they move. The spindle provides a scaffolding for the attachment and movement of the chromosomes during the later mitotic stages. By the end of prophase, the nuclear envelope and the nucleoli have broken down and disappeared, and the chromosomes have attached randomly to the spindle fibers by their centromeres.

- **Metaphase** (met'ah-faz). In this short stage, the chromosomes cluster and become aligned at the *metaphase plate* (the center of the spindle midway between the centrioles) so that a straight line of chromosomes is seen.
- **Anaphase** (an'ah-faz). During anaphase, the centromeres that have held the chromatids together split. The chromatids (now called chromosomes again) begin to move slowly apart, drawn toward opposite ends of the cell. The chromosomes seem to be pulled by their half-centromeres, with their "arms" dangling behind them. Anaphase is over when chromosome movement ends.
- **Telophase** (tel'o-faz). Telophase is essentially prophase in reverse. The chromosomes at opposite ends of the cell uncoil to become threadlike chromatin again. The spindle breaks down and disappears, a nuclear envelope forms around each chromatin mass, and nucleoli appear in each of the daughter nuclei.

Mitosis is basically the same in all animal cells. Depending on the type of tissue, it takes from 5 minutes to several hours to complete, but typically it lasts about 2 hours. Centriole replication is deferred until late interphase of the next cell cycle, when DNA replication begins before the onset of mitosis.

Cytokinesis Cytokinesis, or the division of the cytoplasm, usually begins during late anaphase and completes during telophase. A contractile ring made of microfilaments forms a **cleavage furrow** over the

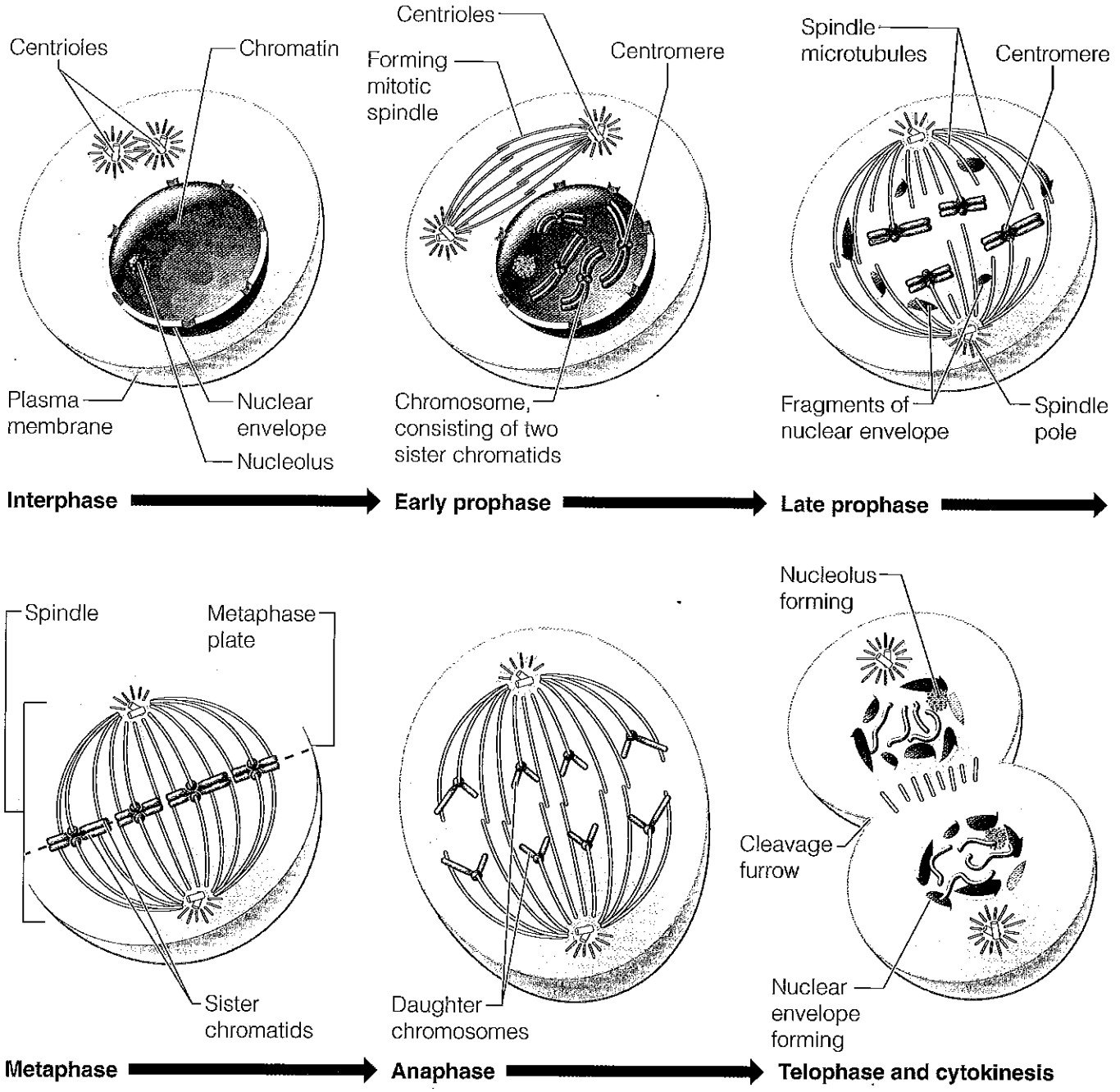


FIGURE 3.15 Stages of mitosis.

midline of the spindle, and it eventually squeezes or pinches the original cytoplasmic mass into two parts. Thus, at the end of cell division, two daughter cells exist. Each is smaller and has less cytoplasm than the mother cell, but it is genetically identical to it. The daughter cells grow and carry out normal cell activities until it is their turn to divide.

Mitosis and division of the cytoplasm usually go hand in hand, but in some cases the cytoplasm is not divided. This condition leads to the formation of *binucleate* (two nuclei) or *multinucleate* cells. This is fairly common in the liver.

As mentioned earlier, mitosis provides the "new" cells for body growth in youth and is

necessary to repair body tissue all through life. Mitosis gone wild is the basis for tumors and cancers.

Protein Synthesis

Genes: The Blueprint for Protein Structure

In addition to replicating itself for cell division, DNA serves as the master blueprint for protein syntheses. Traditionally, a **gene** is defined as a DNA segment that carries the information for building one protein or polypeptide chain.

Proteins are key substances for all aspects of cell life. As described in Chapter 2, *fibrous (structural) proteins* are the major building materials for cells. Other proteins, the *globular (functional) proteins,* do things other than build structures. For example, all **enzymes,** biological catalysts that regulate chemical reactions in the cells, are functional proteins. The importance of enzymes cannot be overstated. Every chemical reaction that goes on in the body requires an enzyme. It follows that DNA regulates cell activities largely by specifying the structure of enzymes, which in turn control or direct the chemical reactions in which carbohydrates, fats, other proteins, and even DNA itself are made and broken down.

How does DNA bring about its miracles? It appears that DNA's information is encoded in the sequence of bases along each side of the ladder-like DNA molecules. Each sequence of *three* bases (a *triplet*) calls for a particular *amino acid* (Figure 3.16). (Amino acids are the building blocks of proteins that are joined during protein synthesis.) For example, a DNA base sequence of AAA specifies an amino acid called phenylalanine, whereas CCT calls for glycine. Just as different arrangements of notes on sheet music are played as different melodies, variations in the arrangements of A, C, T, and G in each gene allow cells to make all the different kinds of proteins needed. It has been estimated that a single gene has between 300 and 3,000 base pairs in sequence.

The Role of RNA

By itself, DNA is rather like a strip of magnetic recording tape; its information is not useful until it is decoded. Furthermore, most ribosomes—the manufacturing sites for proteins—are in the cytoplasm, but in interphase cells DNA never leaves the nucleus. Thus, DNA requires not only a decoder but also a messenger to achieve its task of specifying the structure of proteins to be built at the ribosomes. These messenger and decoder functions are carried out by a second type of nucleic acid, called **ribonucleic** (ri"bo-nu-kle'ik) **acid,** or **RNA.**

As you learned in Chapter 2, RNA differs from DNA in being single-stranded and in having ribose sugar instead of deoxyribose and a uracil (U) base instead of thymine (T). Three varieties of RNA play a special role in protein synthesis. **Transfer RNA (tRNA) molecules** are small cloverleaf-shaped molecules. **Ribosomal RNA (rRNA)** helps form the ribosomes, where proteins are built. **Messenger RNA (mRNA) molecules** are long, single nucleotide strands that resemble half of a DNA molecule and carry the "message" containing instructions for protein synthesis from the DNA gene in the nucleus to the ribosomes in the cytoplasm.

Protein synthesis involves two major phases: *transcription,* when complementary mRNA is made at the DNA gene, and *translation,* when the information carried in mRNA molecules is "decoded" and used to assemble proteins. These steps are summarized simply in Figure 3.16 and described in more detail next.

Transcription

The word *transcription* often refers to one of the jobs done by a secretary—converting notes from one form (shorthand notes or an audiotape recording) into another form (a typewritten letter, for example). In other words, the same information is transformed from one form or format to another. In cells, **transcription** involves the transfer of information from DNA's base sequence into the *complementary* base sequence of mRNA (Figure 3.16, step 1). Only DNA and mRNA are involved in transcription. Whereas each three-base sequence specifying a particular amino acid on the DNA gene is called a **triplet,** the corresponding three-base sequences on mRNA are called **codons.** The form is different, but the same information is being conveyed. Thus, if the (partial) sequence of DNA triplets is AAT-CGT-TCG, the related codons on mRNA would be UUA-GCA-AGC.

Translation

A translator takes words in one language and restates them in another language. In the **translation phase** of protein synthesis, the language of nucleic

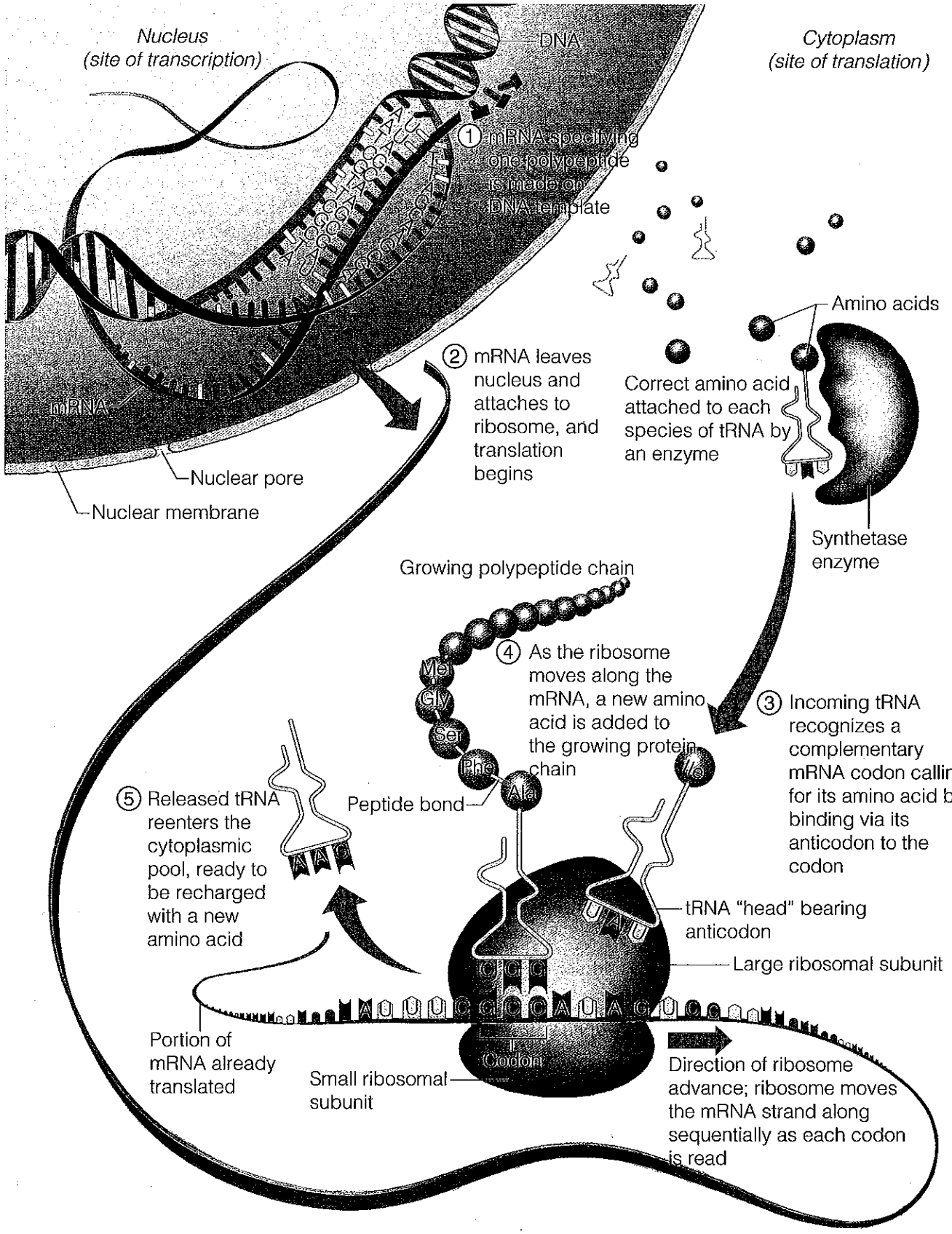


FIGURE 3.16 Protein synthesis. (①) Transcription. (②–⑤) Translation.

acids (base sequence) is "translated" into the language of proteins (amino acid sequence). Translation occurs in the cytoplasm and involves three major varieties of RNA. As illustrated in Figure 3.16, steps 2–5, translation consists of the following events. Once the mRNA attaches to the ribosome (step 2), tRNA comes into the picture. Its job is to transfer, or ferry, amino acids to the ribosome, where they are bound together by enzymes in the exact sequence specified by the gene (and its mRNA). There are about 45 common types of tRNAs, each capable of carrying one of the 20 or so common types of amino acid to the protein synthesis sites. But that is not the only job of the tiny tRNAs. They also have to recognize the mRNA codons "calling for" the amino acid they are toting. They can do this because they have a special three-base sequence called an **anticodon** on their "head" that can bind to the complementary codons (step 3).

Once the first tRNA has maneuvered itself into the correct position at the beginning of the mRNA message, the ribosome moves the mRNA strand along, bringing the next codon into position to be read by another tRNA. As amino acids are brought to their proper positions along the length of mRNA, they are joined together by enzymes (step 4). As an amino acid bonds to the chain, its tRNA is released and moves away from the ribosome to pick up another amino acid (step 5). When the last codon (the termination, or "stop," codon) is read, the protein is released.

DID YOU GET IT?

18. How do the terms *template strand* and *complementary* relate to DNA synthesis?
19. What results if cytokinesis does not happen?
20. What is the role of mRNA in protein synthesis?
21. What are the two stages of protein synthesis, and in which stage are proteins actually synthesized?

For answers, see Appendix D.

PART II: BODY TISSUES

The human body, complex as it is, starts out as a single cell, the fertilized egg, which divides almost endlessly. The millions of cells that result become specialized for particular functions. Some become muscle cells, others the transparent lens of the eye, still others skin cells, and so on. Thus, there is a division of labor in the body, with certain groups of highly specialized cells performing functions that benefit the organism as a whole.

Cell specialization carries with it certain hazards. When a small group of cells is indispensable, its loss can disable or even destroy the body. For example, the action of the heart depends on a very specialized cell group in the heart muscle that controls its contractions. If those particular cells are damaged or stop functioning, the heart will no longer work efficiently, and the whole body will suffer or die from lack of oxygen.

Groups of cells that are similar in structure and function are called **tissues.** The four primary tissue types—epithelium, connective tissue, nervous tissue, and muscle—interweave to form the fabric of the body. If we had to assign a single term to each primary tissue type that would best describe its overall role, the terms would most likely be *covering* (epithelium), *support* (connective), *movement* (muscle), and *control* (nervous). However, these terms reflect only a tiny fraction of the functions that each of these tissues performs.

As explained in Chapter 1, tissues are organized into *organs* such as the heart, kidneys, and lungs. Most organs contain several tissue types, and the arrangement of the tissues determines each organ's structure and what it is able to do. Thus, a study of tissues should be helpful in your later study of the body's organs and how they work.

For now, we want to become familiar with the major similarities and differences in the primary tissues. Because epithelium and some types of connective tissue will not be considered again, they are emphasized more in this section than are muscle, nervous tissues, and bone (a connective tissue), which are covered in more depth in later chapters.

Epithelial Tissue

Epithelial tissue, or **epithelium** (ep″ĭ-the′le-um; *epithe* = laid on, covering) is the *lining, covering,* and *glandular tissue* of the body. Glandular epithelium forms various glands in the body. Covering and lining epithelium covers all free body surfaces and contains versatile cells. One type forms the outer layer of the skin. Others dip into the body to line its cavities. Because epithelium

forms the boundaries that separate us from the outside world, nearly all substances that the body gives off or receives must pass through epithelium.

Epithelial functions include *protection, absorption, filtration,* and *secretion.* For example, the epithelium of the skin protects against bacterial and chemical damage, and the epithelium lining the respiratory tract has cilia, which sweep dust and other debris away from the lungs. Epithelium specialized to absorb substances lines some digestive system organs such as the stomach and small intestine, which absorb food nutrients into the body. In the kidneys, epithelium both absorbs and filters. Secretion is a specialty of the glands, which produce such substances as perspiration, oil, digestive enzymes, and mucus.

Special Characteristics of Epithelium

Epithelium generally has the characteristics listed below:

- Except for glandular epithelium (described on p. 93), epithelial cells fit closely together to form continuous sheets. Neighboring cells are bound together at many points by specialized cell junctions, including desmosomes and tight junctions (see p. 69).
- The membranes always have one free (unattached) surface or edge. This so-called **apical surface** is exposed to the body's exterior or to the cavity of an internal organ. The exposed surfaces of some epithelia are slick and smooth, but others exhibit cell surface modifications, such as microvilli or cilia.
- The lower surface of an epithelium rests on a **basement membrane,** a structureless material secreted by both the epithelial cells and the connective tissue cells that abut the epithelium.
- Epithelial tissues have no blood supply of their own (that is, they are *avascular*) and depend on diffusion from the capillaries in the underlying connective tissue for food and oxygen.
- If well nourished, epithelial cells regenerate themselves easily.

Classification of Epithelium

Each epithelium is given two names. The first indicates the relative number of cell layers it has (Figure 3.17a). The classifications by cell arrangement (layers) are **simple epithelium** (one layer of cells)

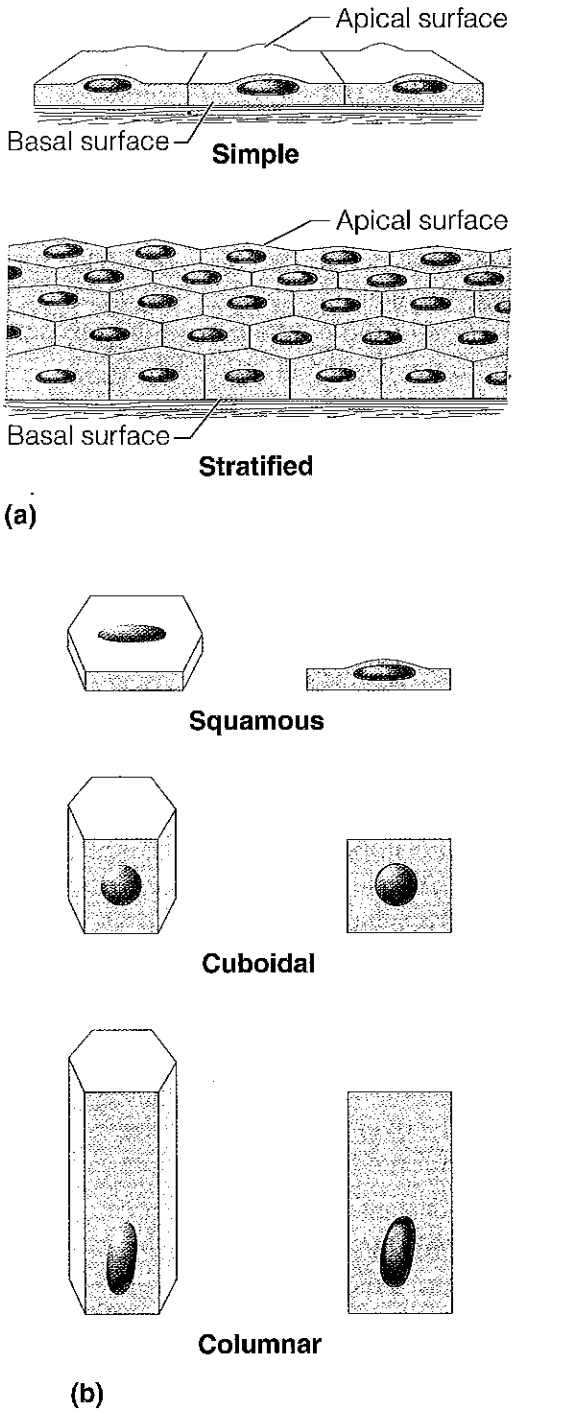


FIGURE 3.17 Classification of epithelia. **(a)** Classification on the basis of arrangement (layers). **(b)** Classification on the basis of cell shape; for each category, a whole cell is shown on the left and a longitudinal section is shown on the right.

and **stratified epithelium** (more than one cell layer). The second describes the shape of its cells (Figure 3.17b). There are *squamous* (skwa′mus) *cells,* flattened like fish scales (*squam* = scale), *cuboidal* (ku-boi′dal) *cells,* which are cube-shaped like dice, and *columnar cells,* shaped like columns. The terms describing the shape and arrangement are then combined to describe the epithelium fully. Stratified epithelia are named for the cells at the *free surface* of the epithelial membrane, not those resting on the basement membrane.

Simple Epithelia

The simple epithelia are most concerned with absorption, secretion, and filtration. Because simple epithelia are usually very thin, protection is not one of their specialties.

Simple Squamous Epithelium **Simple squamous epithelium** is a single layer of thin squamous cells resting on a basement membrane. The cells fit closely together, much like floor tiles. This type of epithelium usually forms membranes where filtration or exchange of substances by rapid diffusion occurs. Simple squamous epithelium is in the air sacs of the lungs, where oxygen and carbon dioxide are exchanged (Figure 3.18a), and it forms the walls of capillaries, where nutrients and gases pass between the tissue cells and the blood in the capillaries. Simple squamous epithelium also forms **serous membranes,** or **serosae** (se-ro′se), the slick membranes that line the ventral body cavity and cover the organs in that cavity. The serous membranes are described in more detail in Chapter 4.

Simple Cuboidal Epithelium **Simple cuboidal epithelium,** which is one layer of cuboidal cells resting on a basement membrane, is common in glands and their ducts (for example, the salivary glands and pancreas). It also forms the walls of the kidney tubules and covers the surface of the ovaries (Figure 3.18b).

Simple Columnar Epithelium **Simple columnar epithelium** is made up of a single layer of tall cells that fit closely together. **Goblet cells,** which produce a lubricating mucus, are often seen in this type of epithelium. Simple columnar epithelium lines the entire length of the digestive tract from the stomach to the anus (Figure 3.18c). Epithelial membranes that line body cavities open to the body exterior are called **mucosae** (mu-ko′se) or **mucous membranes.**

Pseudostratified Columnar Epithelium All of the cells of **pseudostratified** (soo″do-străʹtī-fīd) **columnar epithelium** rest on a basement membrane. However, some of its cells are shorter than others, and their nuclei appear at different heights above the basement membrane. As a result, this epithelium gives the false (*pseudo*) impression that it is stratified; hence its name. Like simple columnar epithelium, this variety mainly functions in absorption and secretion. A ciliated variety (more precisely called *pseudostratified ciliated columnar epithelium*) lines most of the respiratory tract (Figure 3.18d). The mucus produced by the goblet cells in this epithelium traps dust and other debris, and the cilia propel the mucus upward and away from the lungs.

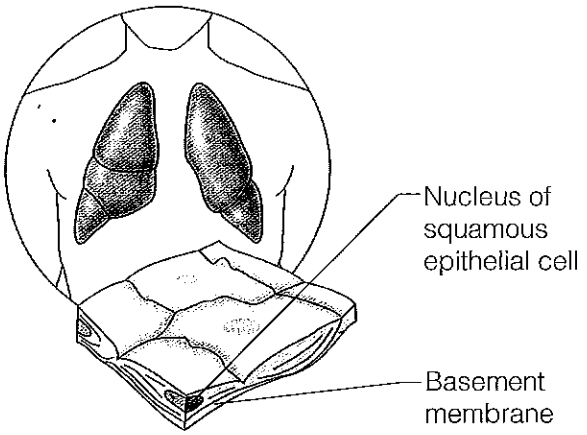
Stratified Epithelia

Stratified epithelia consist of two or more cell layers. Being considerably more durable than the simple epithelia, these epithelia function primarily to protect.

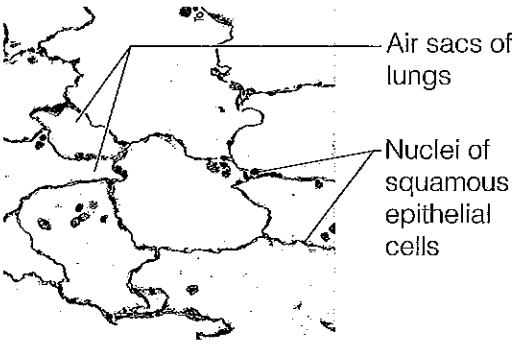
Stratified Squamous Epithelium **Stratified squamous epithelium** is the most common stratified epithelium in the body. It usually consists of several layers of cells. The cells at the free edge are squamous cells, whereas those close to the basement membrane are cuboidal or columnar. Stratified squamous epithelium is found in sites that receive a good deal of abuse or friction, such as the esophagus, the mouth, and the outer portion of the skin (Figure 3.18e).

Stratified Cuboidal and Stratified Columnar Epithelia **Stratified cuboidal epithelium** typically has just two cell layers with (at least) the surface cells being cuboidal in shape. The surface cells of **stratified columnar epithelium** are columnar cells, but its basal cells vary in size and shape. Both of these epithelia are fairly rare in the body, found mainly in the ducts of large glands. (Because the distribution of these two epithelia is extremely limited, they are not illustrated in Figure 3.18. They are described here only to provide a complete listing of the epithelial tissues.)

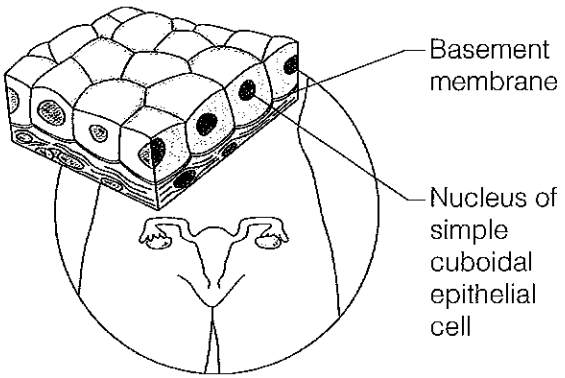
Transitional Epithelium **Transitional epithelium** is a highly modified, stratified squamous epithelium



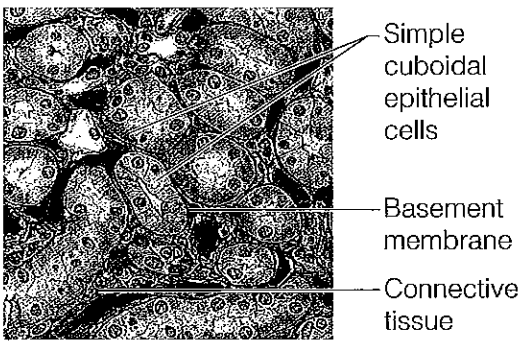
(a) Diagram: Simple squamous



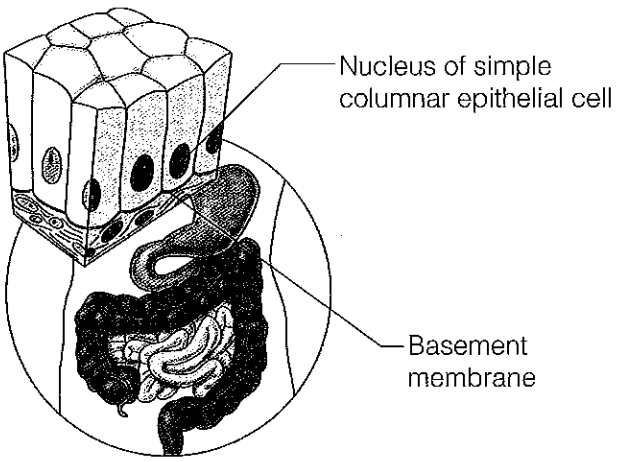
Photomicrograph: Simple squamous epithelium forming part of the alveolar (air sac) walls (100x).



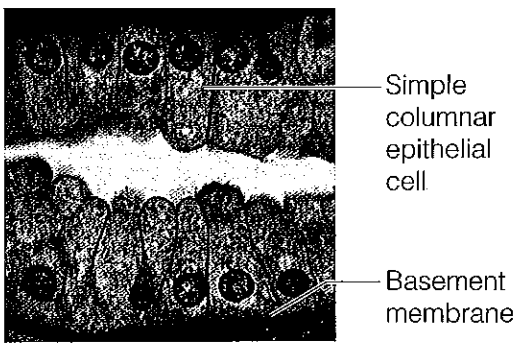
(b) Diagram: Simple cuboidal



Photomicrograph: Simple cuboidal epithelium in kidney tubules (400x).

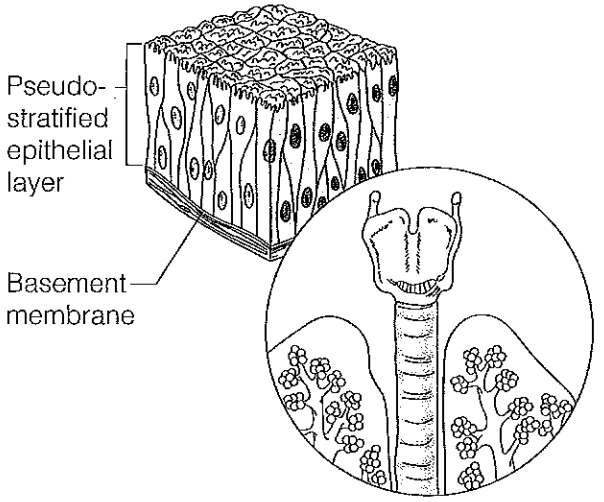


(c) Diagram: Simple columnar

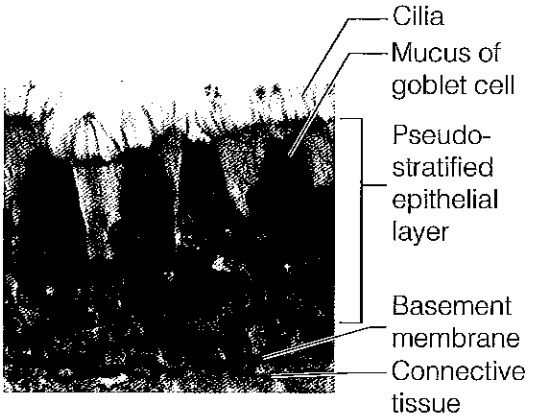


Photomicrograph: Simple columnar epithelium of the stomach lining (900x).

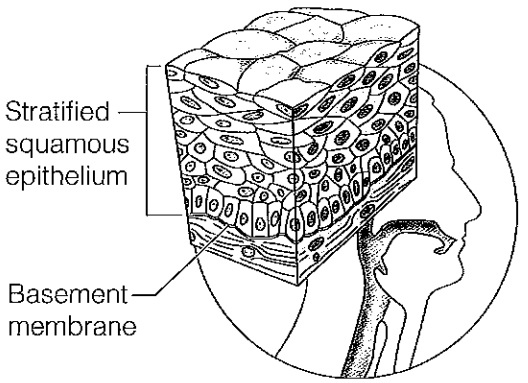
FIGURE 3.18 Types of epithelia and their common locations in the body. *(Continued on page 92.)*



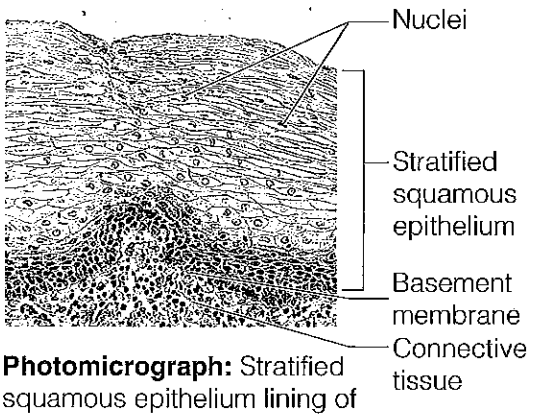
(d) Diagram: Pseudostratified (ciliated) columnar



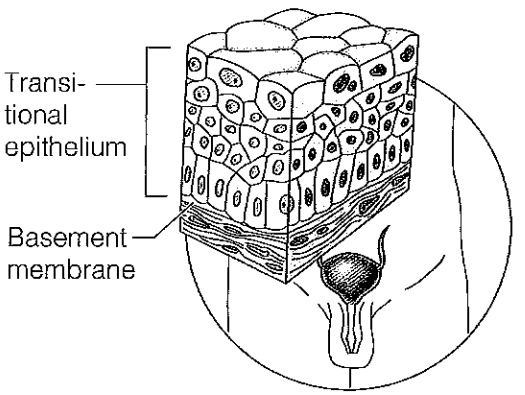
Photomicrograph: Pseudostratified ciliated columnar epithelium lining the human trachea (700x).



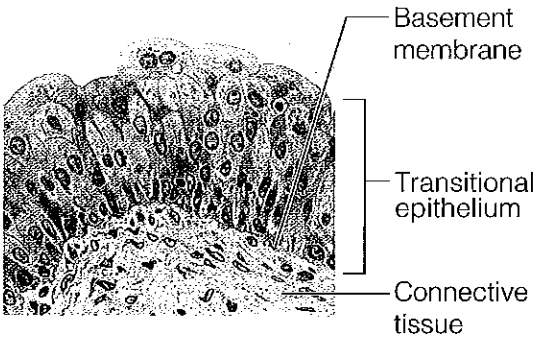
(e) Diagram: Stratified squamous



Photomicrograph: Stratified squamous epithelium lining of the esophagus (200x).



(f) Diagram: Transitional



Photomicrograph: Transitional epithelium lining of the bladder, relaxed state (300x); note the rounded appearance of the cells at the surface; these cells flatten and elongate when the bladder fills with urine.

FIGURE 3.18 ***(continued)*** **Types of epithelia and their common locations in the body.**

that forms the lining of only a few organs—the urinary bladder, the ureters, and part of the urethra. *All* these organs are part of the urinary system and are subject to considerable stretching (Figure 3.18f). Cells of the basal layer are cuboidal or columnar; those at the free surface vary in appearance. When the organ is not stretched, the membrane is many-layered, and the superficial cells are rounded and domelike. When the organ is distended with urine, the epithelium thins, and the surface cells flatten and become squamouslike. This ability of transitional cells to slide past one another and change their shape (undergo "transitions") allows the ureter wall to stretch as a greater volume of urine flows through that tubelike organ. In the bladder, it allows more urine to be stored.

Glandular Epithelium

A **gland** consists of one or more cells that make and secrete a particular product. This product, called a **secretion,** typically contains protein molecules in an aqueous (water-based) fluid. The term *secretion* also indicates an active *process* in which the glandular cells obtain needed materials from the blood and use them to make their secretion, which they then discharge.

Two major types of glands develop from epithelial sheets. **Endocrine** (en′do-krin) **glands** lose their connection to the surface (duct); thus they are often called *ductless* glands. Their secretions (all hormones) diffuse directly into the blood vessels that weave through the glands. Examples of endocrine glands include the thyroid, adrenals, and pituitary.

Exocrine (ek′so-krin) **glands** retain their ducts, and their secretions empty through the ducts to the epithelial surface. Exocrine glands, which include the sweat and oil glands, liver, and pancreas, are both internal and external. They are discussed with the organ systems to which their products are related.

Connective Tissue

Connective tissue, as its name suggests, connects body parts. It is found everywhere in the body. It is the most abundant and widely distributed of the tissue types. Connective tissues perform many functions but they are primarily involved in *protecting, supporting,* and *binding together* other body tissues.

Common Characteristics of Connective Tissue

The characteristics of connective tissue include the following:

- **Variations in blood supply.** Most connective tissues are well *vascularized* (that is, they have a good blood supply), but there are exceptions. Tendons and ligaments have a poor blood supply, and cartilages are avascular. Consequently, all these structures heal very slowly when injured. (This is why some people say that, given a choice, they would rather have a broken bone than a torn ligament.)
- **Extracellular matrix.** Connective tissues are made up of many different types of cells plus varying amounts of a nonliving substance found outside the cells, called the extracellular matrix.

Extracellular Matrix

The **extracellular matrix** deserves a bit more explanation because it is what makes connective tissue so different from the other tissue types. The matrix, which is produced by the connective tissue cells and then secreted to their exterior, has two main elements, a structureless ground substance and fibers. The *ground substance* of the matrix is composed largely of water plus some adhesion proteins and large, charged polysaccharide molecules. The cell adhesion proteins serve as a glue that allows the connective tissue cells to attach themselves to the matrix fibers embedded in the ground substance. The charged polysaccharide molecules trap water as they intertwine. As the relative abundance of these polysaccharides increases, they cause the matrix to vary from fluid to gel-like to firm to rock-hard in its consistency. The ability of the ground substance to absorb large amounts of water allow it to serve as a water reservoir for the body.

Various types and amounts of fibers are deposited in the matrix and form part of it. These include collagen (white) fibers distinguished by their high tensile strength, elastic (yellow) fibers (the key characteristic of which is an ability to be stretched and then recoil), and reticular fibers (fine collagen fibers that form the internal "skeleton" of soft organs such as the spleen), depending on the connective tissue type. The building blocks, or

monomers, of these fibers are made by the connective tissue cells and secreted into the ground substance in the extracellular space, where they join together to form the various fiber types.

Because of its extracellular matrix, connective tissue is able to form a soft packing tissue around other organs, to bear weight, and to withstand stretching and other abuses, such as abrasion, that no other tissue could endure. But there is variation. At one extreme, fat tissue is composed mostly of cells, and the matrix is soft. At the opposite extreme, bone and cartilage have very few cells and large amounts of hard matrix, which makes them extremely strong. Find the various types of connective tissues in Figure 3.19 as you read their descriptions, which follow.

Types of Connective Tissue

As noted above, all connective tissues consist of living cells surrounded by a matrix. Their major differences reflect fiber type and the number of fibers in the matrix. From most rigid to softest, the major connective tissue classes are *bone, cartilage, dense connective tissue, loose connective tissue,* and *blood.*

Bone

Bone, sometimes called *osseous* (os′e-us) *tissue,* is composed of bone cells sitting in cavities called *lacunae* (lah-ku′ne; "pits") and surrounded by layers of a very hard matrix that contains calcium salts in addition to large numbers of collagen fibers (Figure 3.19a). Because of its rocklike hardness, bone has an exceptional ability to protect and support other body organs (for example, the skull protects the brain).

Cartilage

Cartilage is less hard and more flexible than bone. It is found in only a few places in the body. Most widespread is **hyaline** (hi′ah-lin) **cartilage,** which has abundant collagen fibers hidden by a rubbery matrix with a glassy (*hyalin* = glass), blue-white appearance (Figure 3.19b). It forms the supporting structures of the larynx, or voice box, attaches the ribs to the breastbone, and covers the ends of many bones, where they form joints. The skeleton of a fetus is made largely of hyaline cartilage; but, by the time the baby is born, most of that cartilage has been replaced by bone.

Although hyaline cartilage is the most abundant type of cartilage in the body, there are others. Highly compressible **fibrocartilage** forms the cushionlike disks between the vertebrae of the spinal column (Figure 3.19c). **Elastic cartilage** is found where a structure with elasticity is desired. For example, it supports the external ear. (Elastic cartilage is not illustrated in Figure 3.19.)

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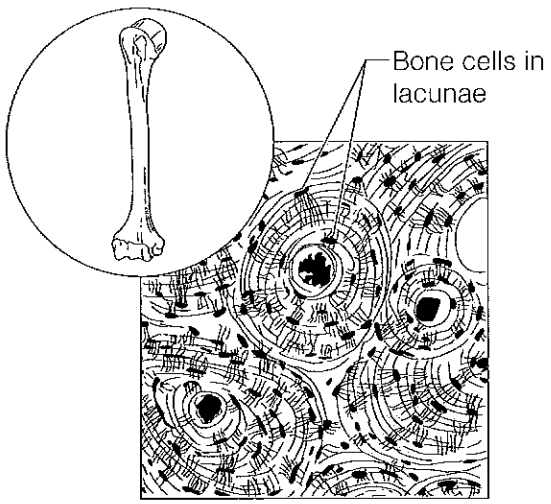
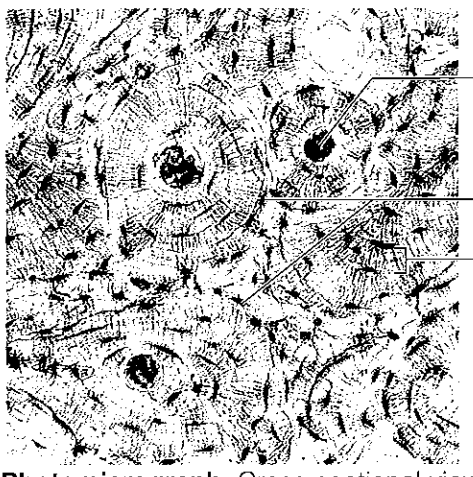
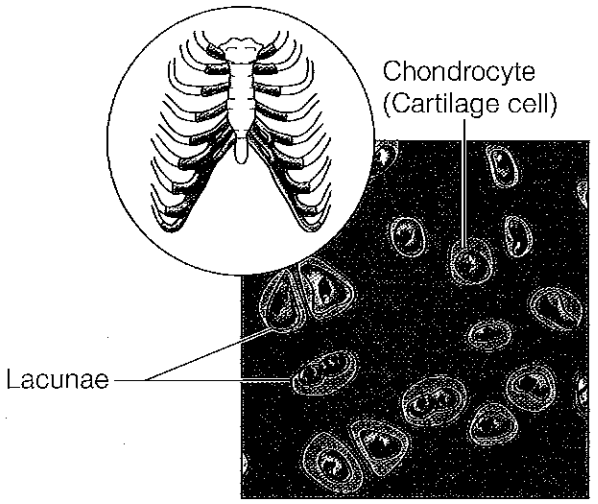


(a) Diagram: Bone

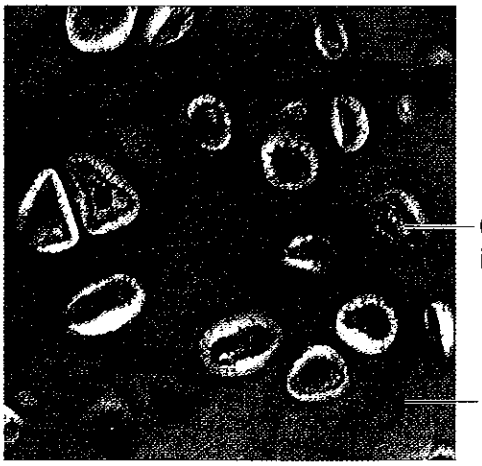


Photomicrograph: Cross-sectional view of ground bone (250x).

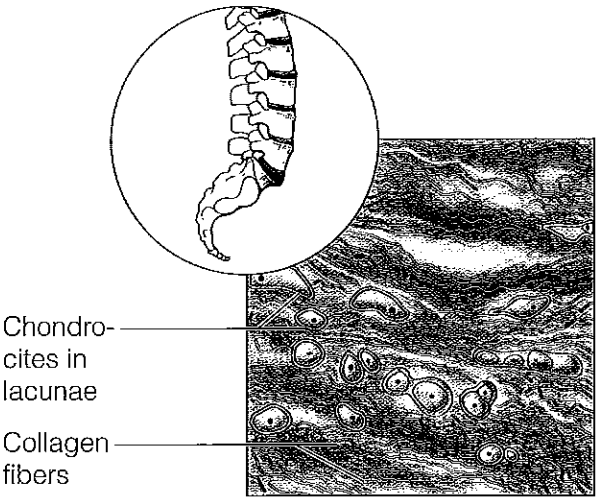
FIGURE 3.19 **Connective tissues and their common body locations.**



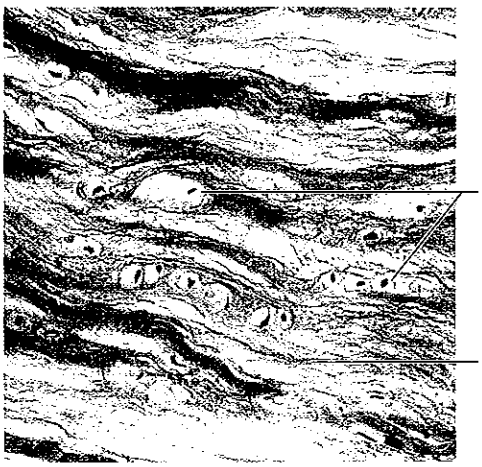
(b) Diagram: Hyaline cartilage



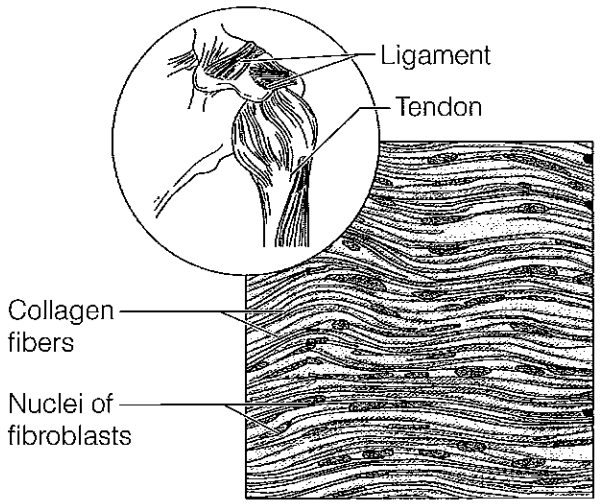
Photomicrograph: Hyaline cartilage from the trachea (400x).



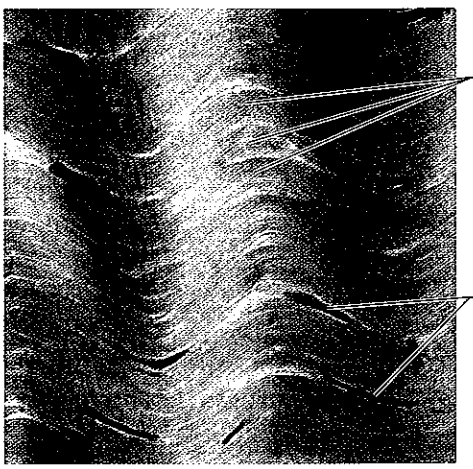
(c) Diagram: Fibrocartilage



Photomicrograph: Fibrocartilage of an intervertebral disc (200x).

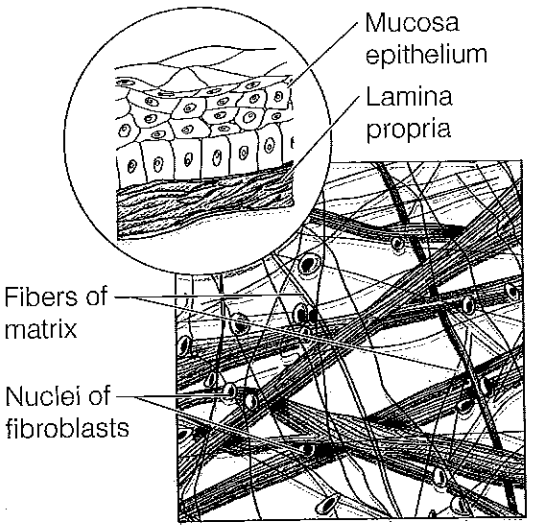


(d) Diagram: Dense fibrous

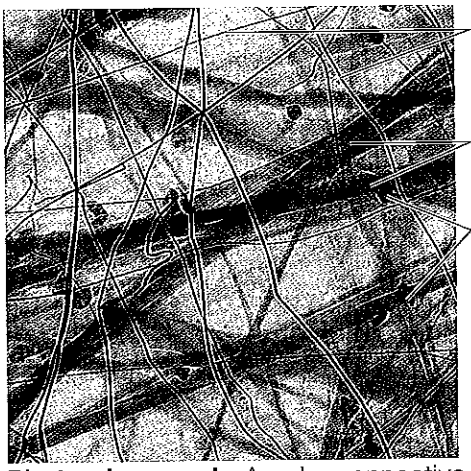


Photomicrograph: Dense fibrous connective tissue from a tendon (500x).

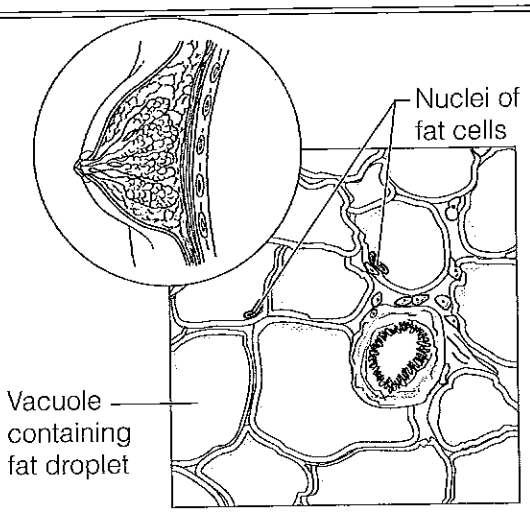
(Continues on page 96)



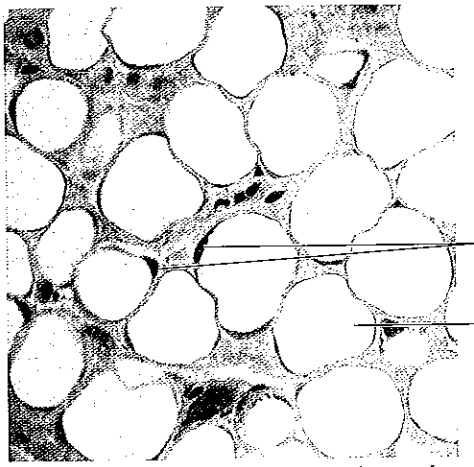
(e) Diagram: Areolar



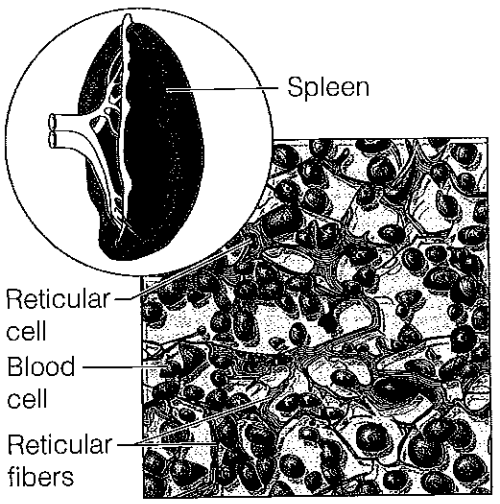
Photomicrograph: Areolar connective tissue, a soft packaging tissue of the body (330x).



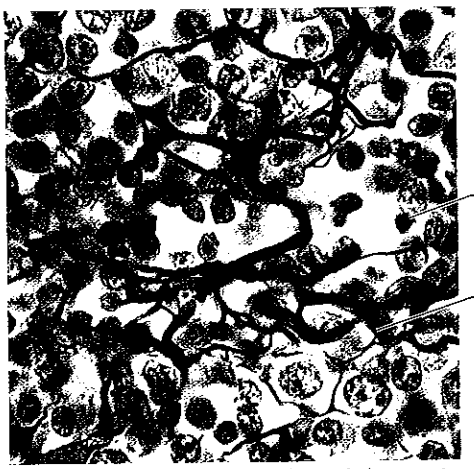
(f) Diagram: Adipose



Photomicrograph: Adipose tissue from the subcutaneous layer beneath the skin (330x).

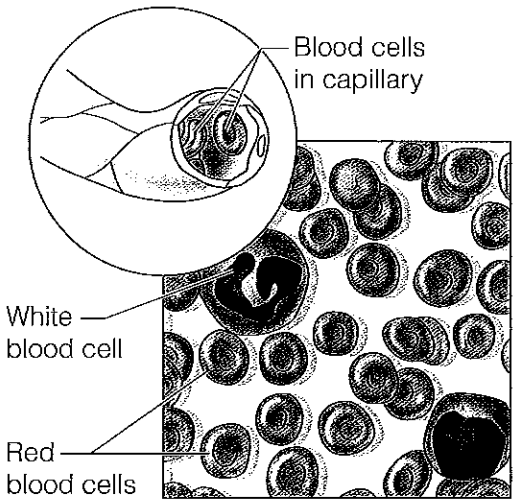


(g) Diagram: Reticular

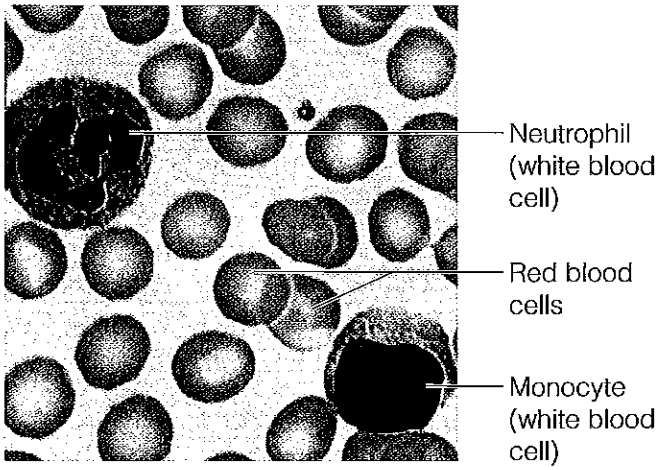


Photomicrograph: Dark-staining network of reticular connective tissue (400x).

FIGURE 3.19 ***(continued)*** **Connective tissues and their common body locations.** (**e, f,** and **g** are subclasses of loose connective tissues.)



(h) Diagram: Blood



Photomicrograph: Smear of human blood (1300x)

FIGURE 3.19 ***(continued)***

Dense Connective Tissue

Dense connective tissue, also called **dense fibrous tissue,** has collagen fibers as its main matrix element (Figure 3.19d). Crowded between the collagen fibers are rows of *fibroblasts* (fiber-forming cells) that manufacture the building blocks of the fibers. Dense connective tissue forms strong, ropelike structures such as tendons and ligaments. **Tendons** attach skeletal muscles to bones; **ligaments** connect bones to bones at joints. Ligaments are more stretchy and contain more elastic fibers than tendons. Dense connective tissue also makes up the lower layers of the skin (dermis), where it is arranged in sheets.

Loose Connective Tissue

Relatively speaking, **loose connective tissues** are softer and have more cells and fewer fibers than any other connective tissue type except blood.

Areolar Tissue **Areolar** (ah-re′o-lar) **tissue,** the most widely distributed connective tissue variety in the body, is a soft, pliable, "cobwebby" tissue that cushions and protects the body organs it wraps (Figure 3.19e). It functions as a universal packing tissue and connective tissue "glue" because it helps to hold the internal organs together and in their proper positions. A soft layer of areolar connective tissue called the *lamina propria* (lah′mĭ-nah pro′pre-ah) underlies all mucous membranes. Its fluid matrix contains all types of fibers, which form a loose network. In fact, when viewed through a microscope, most of the matrix appears to be empty space, which explains the name of this tissue type (*areola* = small open space). Because of its loose and fluid nature, areolar connective tissue provides a reservoir of water and salts for the surrounding tissues, and essentially all body cells obtain their nutrients from and release their wastes into this "tissue fluid." When a body region is inflamed, the areolar tissue in the area soaks up the excess fluid like a sponge, and the area swells and becomes puffy, a condition called **edema.** Many types of *phagocytes* wander through this tissue, scavenging for bacteria, dead cells, and other debris, which they destroy.

Adipose Tissue **Adipose** (ad′ĭ-pŏs) **tissue** is commonly called *fat.* Basically, it is an areolar tissue in which fat cells predominate (Figure 3.19f). A glistening droplet of oil occupies most of a fat cell's volume and compresses the nucleus, displacing it to one side. Because the oil-containing region looks empty and the thin rim of cytoplasm containing the bulging nucleus looks like a ring with a seal, fat cells are sometimes called *signet ring cells.*

Adipose tissue forms the subcutaneous tissue beneath the skin, where it insulates the body and protects it from bumps and extremes of both heat and cold. Adipose tissue also protects some organs

individually—the kidneys are surrounded by a capsule of fat, and adipose tissue cushions the eyeballs in their sockets. There are also fat "depots" in the body, such as the hips and breasts, where fat is stored and available for fuel if needed.

Reticular Connective Tissue **Reticular connective tissue** consists of a delicate network of interwoven reticular fibers associated with *reticular cells,* which resemble fibroblasts (Figure 3.19g). Reticular tissue is limited to certain sites: it forms the **stroma** (literally, "bed" or "mattress"), or internal framework, which can support many free blood cells (largely lymphocytes) in lymphoid organs such as lymph nodes, the spleen, and bone marrow.

Blood

Blood, or *vascular tissue,* is considered a connective tissue because it consists of *blood cells* surrounded by a nonliving, fluid matrix called *blood plasma* (Figure 3.19h). The "fibers" of blood are soluble protein molecules that become visible only during blood clotting. Still, we must recognize that blood is quite atypical as connective tissues go. Blood is the transport vehicle for the cardiovascular system, carrying nutrients, wastes, respiratory gases, and many other substances throughout the body. Blood is considered in detail in Chapter 10.

Muscle Tissue

Muscle tissues are highly specialized to *contract,* or *shorten,* to produce movement.

Types of Muscle Tissue

The three types of muscle tissue are illustrated in Figure 3.20. Notice their similarities and differences as you read through their descriptions.

Skeletal Muscle

Skeletal muscle tissue is packaged by connective tissue sheets into organs called *skeletal muscles,* which are attached to the skeleton. These muscles, which can be controlled *voluntarily* (or consciously), form the flesh of the body, the so-called muscular system (see Chapter 6). When the skeletal muscles contract, they pull on bones or skin. The result of their action is gross body movements or changes in our facial expressions. The cells of skeletal muscle are long, cylindrical, multinucleate, and they have obvious *striations* (stripes). Because skeletal muscle cells are elongated to provide a long axis for contraction, they are often called *muscle fibers.*

Cardiac Muscle

Cardiac muscle, covered in more detail in Chapter 11, is found only in the heart. As it contracts, the heart acts as a pump and propels blood through the blood vessels. Like skeletal muscle, cardiac muscle has striations, but cardiac cells are uninucleate, relatively short, branching cells that fit tightly together (like clasped fingers) at junctions called **intercalated disks.** These intercalated disks contain gap junctions that allow ions to pass freely from cell to cell, resulting in rapid conduction of the exciting electrical impulse across the heart. Cardiac muscle is under *involuntary control,* which means that we cannot consciously control the activity of the heart. (There are, however, rare individuals who claim they have such an ability.)

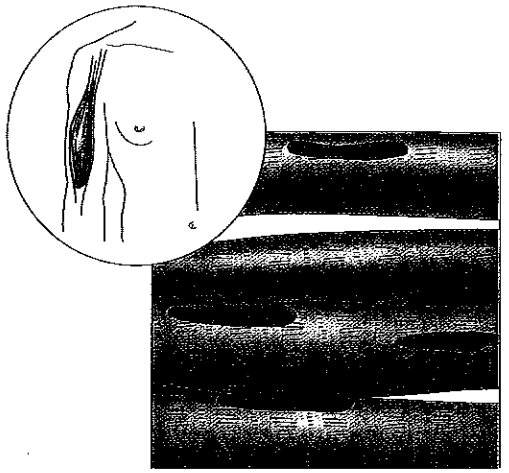
Smooth Muscle

Smooth, or **visceral, muscle** is so called because no striations are visible. The individual cells have a single nucleus and are spindle-shaped (pointed at each end). Smooth muscle is found in the walls of hollow organs such as the stomach, uterus, and blood vessels. As smooth muscle in its walls contracts, the cavity of an organ alternately becomes smaller (constricts on smooth muscle contraction) or enlarges (dilates on smooth muscle relaxation) so that substances are propelled through the organ along a specific pathway. Smooth muscle contracts much more slowly than the other two muscle types. *Peristalsis* (per″ĭ-stal′sis), a wavelike motion that keeps food moving through the small intestine, is typical of its activity.

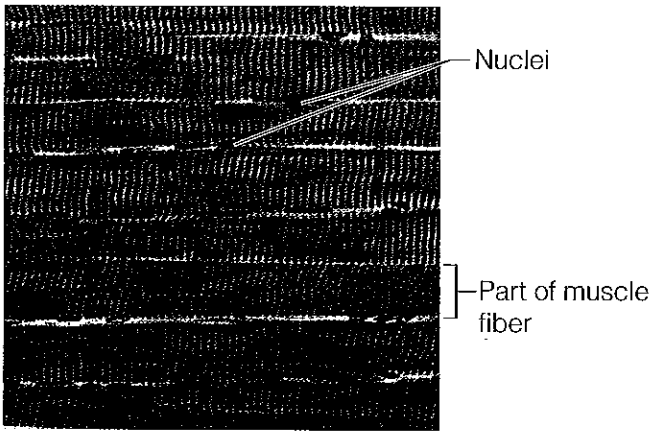
Nervous Tissue

When we think of **nervous tissue,** we think of cells called **neurons.** All neurons receive and conduct electrochemical impulses from one part of the body to another; thus, *irritability* and *conductivity* are their two major functional characteristics. The structure of neurons is unique (Figure 3.21). Their cytoplasm is drawn out into long processes (extensions), as much as 3 feet or more in the leg, which allows a single neuron to conduct an impulse over long distances in the body. Neurons, along with a special group of **supporting cells** that insulate, support, and protect the delicate neurons, make up the structures of the nervous system—the brain, spinal cord, and nerves.

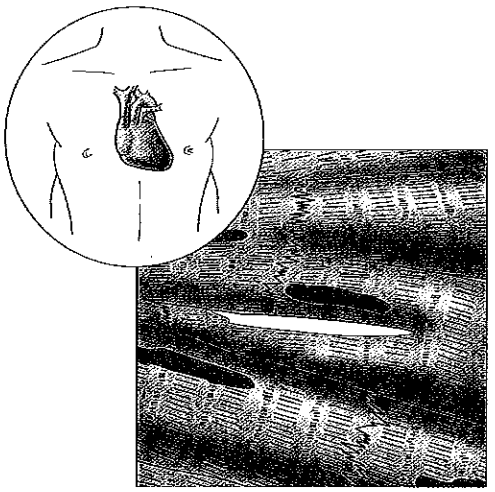
Cell division typically yields two daughter cells, each with one nucleus. How is the multinuclear condition of skeletal muscle explained?



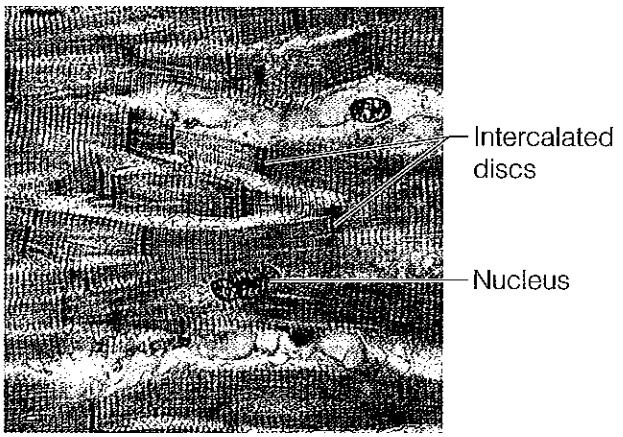
(a) Diagram: Skeletal muscle



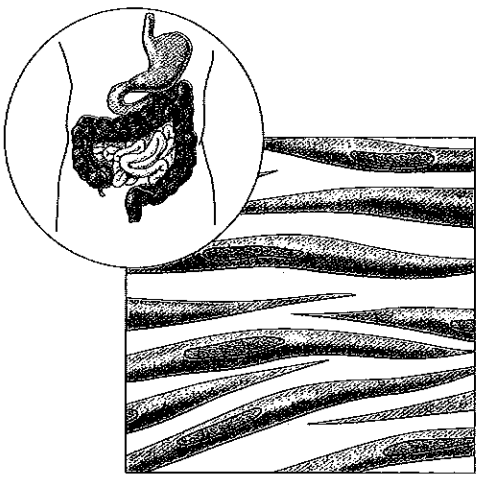
Photomicrograph: Skeletal muscle (approx. 250x).



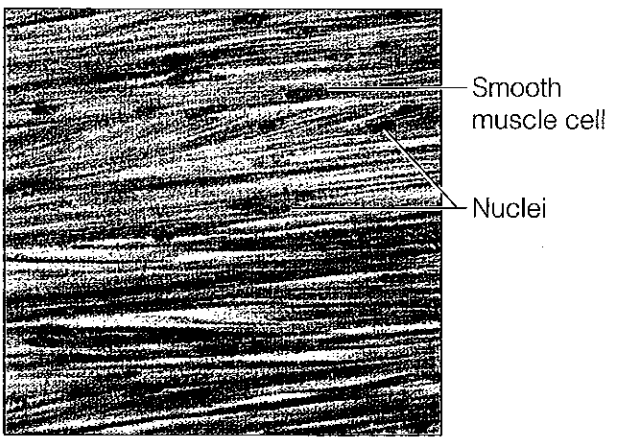
(b) Diagram: Cardiac muscle



Photomicrograph: Cardiac muscle (800x).



(c) Diagram: Smooth muscle



Photomicrograph: Sheet of smooth muscle (approx. 250x).

FIGURE 3.20 Types of muscle tissue and their common locations in the body.

Skeletal muscle cells repeatedly undergo mitosis unaccompanied by cytokinesis.

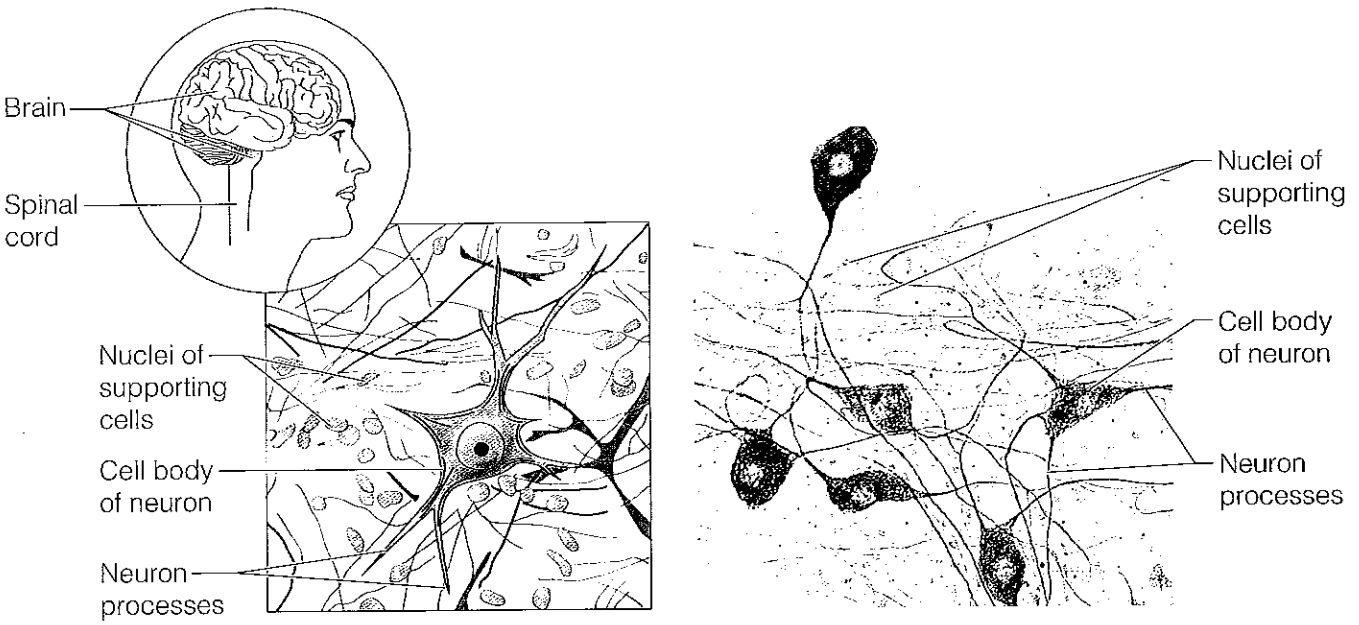


Diagram: Nervous tissue

Photomicrograph: Neurons (200x)

FIGURE 3.21 **Nervous tissue.** Neurons and supporting cells form the brain, spinal cord, and nerves.

Tissue Repair (Wound Healing)

The body has many techniques for protecting itself from uninvited guests or injury. Intact physical barriers such as the skin and mucous membranes, cilia, and the strong acid produced by stomach glands are just three examples of body defenses exerted at the local tissue level. When tissue injury does occur, it stimulates the body's inflammatory and immune responses, and the healing process begins almost immediately. Inflammation is a generalized (nonspecific) body response that attempts to prevent further injury. The immune response, in contrast, is extremely specific and mounts a vigorous attack against recognized invaders (bacteria, viruses, toxins). These protective responses are considered in detail in Chapter 12. Here we will concentrate on the process of tissue repair itself.

Tissue repair, or wound healing, occurs in two major ways: by regeneration and by fibrosis. **Regeneration** is the replacement of destroyed tissue by the same kind of cells, whereas **fibrosis** involves repair by dense (fibrous) connective tissue, that is, by the formation of *scar tissue.* Which occurs depends on (1) the type of tissue damaged and (2) the severity of the injury. Generally speaking, clean cuts (incisions) heal much more successfully than ragged tears of the tissue.

Tissue injury sets a series of events into motion:

- **The capillaries become very permeable.** This allows fluid rich in clotting proteins and other substances to seep into the injured area from the bloodstream. Then leaked clotting proteins construct a clot, which stops the loss of blood, holds the edges of the wound together, and walls off the injured area, preventing bacteria or other harmful substances from spreading to surrounding tissues. Where the clot is exposed to air, it quickly dries and hardens, forming a scab.
- **Granulation tissue forms.** *Granulation tissue* is a delicate pink tissue composed largely of new capillaries that grow into the damaged area from undamaged blood vessels nearby. These capillaries are fragile and bleed freely, as when a scab is picked away from a skin wound. Granulation tissue also contains phagocytes that eventually dispose of the blood clot and connective tissue cells (fibroblasts) that synthesize the building blocks of collagen fibers (scar tissue) to permanently bridge the gap.

- **The surface epithelium regenerates.** As the surface epithelium begins to regenerate, it makes its way across the granulation tissue just beneath the scab. The scab soon detaches, and the final result is a fully regenerated surface epithelium that covers an underlying area of fibrosis (the scar). The scar is either invisible or visible as a thin white line, depending on the severity of the wound.

The ability of the different tissue types to regenerate varies widely. Epithelial tissues such as the skin epidermis and mucous membranes regenerate beautifully. So, too, do most of the fibrous connective tissues and bone. Skeletal muscle regenerates poorly, if at all, and cardiac muscle and nervous tissue within the brain and spinal cord are replaced largely by scar tissue.

HOMEOSTATIC IMBALANCE

Scar tissue is strong, but it lacks the flexibility of most normal tissues. Perhaps even more important is its inability to perform the normal functions of the tissue it replaces. Thus, if scar tissue forms in the wall of the bladder, heart, or another muscular organ, it may severely hamper the functioning of that organ. ▲

DID YOU GET IT?

22. What two criteria are used to classify epithelial tissues?
23. How do endocrine and exocrine glands differ in structure and function?
24. How do connective tissues differ significantly from other tissues?
25. Which of the three types of muscle tissue is striated? Which is voluntary?

For answers, see Appendix D.

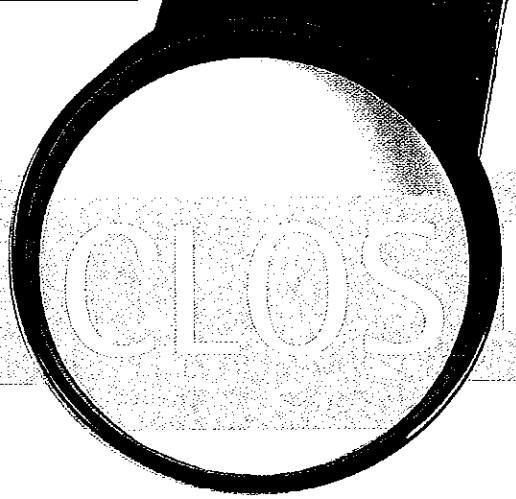
PART III: DEVELOPMENTAL ASPECTS OF CELLS AND TISSUES

We all begin life as a single cell, which divides thousands of times to form our multicellular embryonic body. Very early in embryonic development, the cells begin to specialize to form the primary tissues, and by birth, most organs are well formed and functioning. The body continues to grow and enlarge by forming new tissue throughout childhood and adolescence.

Cell division is extremely important during the body's growth period. Most cells (except neurons) undergo mitosis until the end of puberty, when adult body size is reached and overall body growth ends. After this time, only certain cells routinely divide (are mitotic)—for example, cells exposed to abrasion that continually wear away, such as skin and intestinal cells. Liver cells stop dividing; but they retain this ability should some of them die or become damaged and need to be replaced. Still other cell groups (for example, heart muscle and nervous tissue) almost completely lose their ability to divide when they are fully mature; that is, they become *amitotic* (am″ĭ-tot′ik). Amitotic tissues are severely handicapped by injury because the lost cells cannot be replaced by the same type of cells. This is why the heart of an individual who has had several severe heart attacks becomes weaker and weaker. Damaged cardiac muscle does not regenerate and is replaced by scar tissue that cannot contract, so the heart becomes less and less capable of acting as an efficient blood pump.

The aging process begins once maturity has been reached. (Some believe it begins at birth.) No one has been able to explain just *what* causes aging, but there have been many suggestions. Some believe it is a result of little "chemical insults," which occur continually through life—for example, the presence of toxic chemicals (such as alcohol, certain drugs, or carbon monoxide) in the blood, or the temporary absence of needed substances such as glucose or oxygen. Perhaps the effect of these chemical insults is cumulative and finally succeeds in upsetting the delicate chemical balance of the body cells. Others think that external physical factors such as radiation (X rays or ultraviolet waves) contribute to the aging process. Still another theory is that the aging "clock" is genetically programmed, or built into our genes. We all know of cases like the radiant woman of 50 who looks about 35 or the barely-out-of-adolescence man of 24 who looks 40. It appears that such traits can run in families.

There is no question that certain events are part of the aging process. For example, with age, epithelial membranes thin and are more easily damaged, and the skin loses its elasticity and



A CLOSER LOOK

CANCER—THE INTIMATE ENEMY

The word *cancer* elicits dread in nearly everyone. Why does cancer strike some and not others? Before attempting to answer that question, let's define some terms. An abnormal cell mass that develops when controls of the cell cycle and cell division malfunction is called a **neoplasm** ("new growth") or **tumor.** However, not all neoplasms are cancerous. **Benign** (be-nīn': "kindly") neoplasms are strictly local affairs. They tend to be surrounded by a capsule, grow slowly, and seldom kill their hosts if they are removed before they compress vital organs. In contrast, **malignant** ("bad") neoplasms (cancers) are nonencapsulated masses that grow more relentlessly and may become killers. Their cells resemble immature cells, and they invade their surroundings rather than pushing them aside, as reflected in the name *cancer,* from the Latin word for "crab." Whereas normal cells become fatally "homesick" and die when they lose contact with the surrounding matrix, malignant cells tend to break away from the parent mass and spread via the blood to distant parts of the body, where they form new masses. This last capability is called *metastasis* (mĕ-tas'tă-sis). Additionally, cancer cells consume an exceptional amount of the body's nutrients, leading to weight loss and tissue wasting that contributes to death.

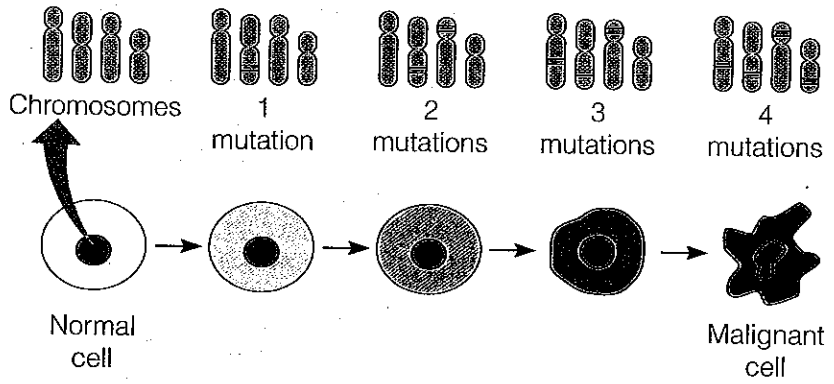
What causes transformation—the changes that convert a normal cell into a cancerous one? It is well known that radiation, mechanical trauma, certain viral infections, and many chemicals (tobacco tars, saccharine) can act as **carcinogens** (cancer-causers). What all of these factors have in common is that they all cause *mutations*—changes in DNA

> *"The seeds of cancer do appear to be in our own genes."*

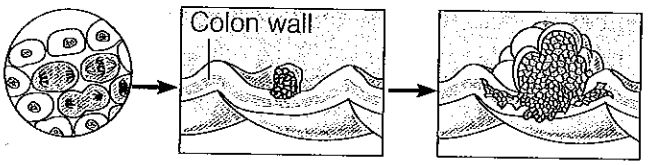
that alter the expression of certain genes. However, most carcinogens are eliminated by peroxisomal or lysosomal enzymes or the immune system. Furthermore, one mutation doesn't do it—apparently it takes a sequence of several genetic changes to change a normal cell to a full-fledged cancer cell. See figure (a).

Clues to the role of genes were provided by the discovery of *oncogenes* (cancer-causing [*onco* = tumor] genes), and then *proto-oncogenes.* Proto-oncogenes code for proteins that are needed for normal cell division and growth. However, many have fragile sites that break when they are exposed to carcinogens, and this event converts them into oncogenes. An example of a problem that might result from this conversion is the switching on of dormant genes that allow cells to become invasive (an ability of embryonic cells—and cancer cells—but not normal adult cells). However, oncogenes have been discovered in only 15 to 20 percent of human cancers, so the more recent discovery of *tumor suppressor genes,* or anti-oncogenes, which work to suppress or prevent cancer, was not too surprising. The tumor suppressor genes (such as *p*53 and *p*16) aid DNA repair, put the "brakes" on cell division, help to inactivate carcinogens, or enhance the ability of the immune system to destroy cancer cells. When the tumor suppressor genes are damaged or changed in some way, the oncogenes are free to "do their thing." One of the best-understood of human cancers, colon cancer illustrates this principle; see figure (b). The first sign of colon cancer is a polyp (benign tumor), which forms when the division rate of apparently normal cells of the colon lining undergoes an unusual increase. In time, a malignant neoplasm makes its appearance at the site. In most cases, these changes parallel cellular changes at the DNA level and include activation of an oncogene and inactivation of two tumor suppressor genes. Whatever the precise genetic factor at work, the seeds of cancer do appear to be in our own genes. Thus, as you can see, cancer is an intimate enemy indeed.

Almost half of all Americans develop cancer in their lifetime, and a fifth of us will die of it. Cancer can arise



(a) Accumulation of mutations in the development of a cancer cell.



Cellular changes:	Increased cell division	Growth of polyp	Growth of malignant tumor (carcinoma)
DNA changes:	Oncogene activated	Tumor-suppressor gene inactivated	Second tumor-suppressor gene inactivated

(b) Stepwise development of a typical colon cancer.

from almost any cell type, but the most common cancers originate in the skin, lung, colon, breast, and male prostate gland. Although incidence of stomach and colon cancer is down, skin and lymphoid cancer rates are up.

Screening procedures, such as self-examination of one's breasts or testicles for lumps and checking fecal samples for blood, aid in early detection of cancers. Unfortunately, most cancers are diagnosed only after symptoms (pain, bloody discharge, lump, etc.) have already appeared. In this case the diagnostic method most used is the biopsy. In a biopsy, a sample of the primary tumor is removed surgically (or by scraping) and examined microscopically for structural changes typical of malignant cells. Increasingly, diagnosis is made by genetic or chemical analysis of the tissue samples, in which cancer cells are typed to determine which genes are switched on or off or which drugs will be most effective. MRI and CT scans can be used to detect large cancers.

The treatment of choice for either type of neoplasm is surgical removal. If surgery is not possible—as in cases where the cancer has spread widely or is inoperable—radiation and drugs (chemotherapy) are used. Anticancer drugs have unpleasant side effects because most target *all* rapidly dividing cells, including normal ones. The side effects include nausea, vomiting, and loss of hair. X rays, even if highly localized, also have side effects because, in passing through the body, they kill healthy cells that lie in their path as well as cancer cells.

Current cancer treatments—"cut, burn, and poison"—are recognized as crude and painful. Promising new methods focus on the following:

- Delivering radiation or anticancer drugs more precisely to the cancer (via monoclonal antibodies that respond to one type of protein on a cancer cell).
- Increasing the immune system's ability to fend off cancer.
- Starving tumors by cutting off their ability to attract a rich blood supply.
- Destroying cancer cells with viruses.

Additionally, a cancer vaccine is in clinical trials. As techniques for diagnosing and treating cancers become more and more specific, curing many types of cancer becomes increasingly probable.

begins to sag. The exocrine glands of the body (epithelial tissue) become less active, and we begin to "dry out" as less oil, mucus, and sweat are produced. Some endocrine glands produce decreasing amounts of hormones, and the body processes that they control (such as metabolism and reproduction) become less efficient or stop altogether.

Connective tissue structures also show changes with age. Bones become porous and weaken, and the repair of tissue injuries slows. Muscles begin to waste away. Although a poor diet may contribute to some of these changes, there is little doubt that decreased efficiency of the circulatory system, which reduces nutrient and oxygen delivery to body tissues, is a major factor.

Besides the tissue changes associated with aging, which accelerate in the later years of life, other modifications of cells and tissues may occur at any time. For example, when cells fail to honor normal controls on cell division and multiply wildly, an abnormal mass of proliferating cells, known as a **neoplasm** (ne′o-plazm″; "new growth"), results. Neoplasms may be benign or malignant (cancerous). See "A Closer Look," pp. 102–103, for more information on cancer.

However, not all increases in cell number involve neoplasms. Certain body tissues (or organs) may enlarge because there is some local irritant or condition that stimulates the cells. This response is called **hyperplasia** (hi″per-pla′ze-ah). For example, a woman's breasts enlarge during pregnancy in response to increased hormones; this is a normal but temporary situation that doesn't have to be treated. In contrast, **atrophy** (at′ro-fe), or decrease in size, can occur in an organ or body area that loses its normal stimulation. For example, muscles that are not used or that have lost their nerve supply begin to atrophy and waste away rapidly.

DID YOU GET IT?

26. Which of the four types of tissue is most likely to remain mitotic throughout life?
27. What is a neoplasm?
28. How does the activity of endocrine glands change as the body ages?

For answers, see Appendix D.

SUMMARY

Media study tools that provide additional review of key topics of Chapter 3 are referenced below.

IP = *InterActive Physiology*
WEB = The A&P Place

PART I: CELLS (pp. 65–88)

Overview of the Cellular Basis of Life (pp. 65–66)

1. A cell is composed primarily of four elements—carbon, hydrogen, oxygen, and nitrogen—plus many trace elements. Living matter is over 60 percent water. The major building material of the cell is protein.
2. Cells vary in size from microscopic to over a meter in length. Shape often reflects function. For example, muscle cells have a long axis to allow shortening.

Anatomy of a Generalized Cell (pp. 66–76)

1. Cells have three major regions—nucleus, cytoplasm, and plasma membrane.
   a. The nucleus, or control center, directs cell activity and is necessary for reproduction. The nucleus contains genetic material (DNA), which carries instructions for synthesis of proteins.
   b. The plasma membrane limits and encloses the cytoplasm and acts as a selective barrier to the movement of substances into and out of the cell. It is composed of a lipid bilayer containing proteins. The water-impermeable lipid portion forms the basic membrane structure. The proteins (many of which are glycoproteins) act as enzymes or carriers in membrane transport, form membrane channels, provide receptor sites for hormones and other chemicals, or play a role in cellular recognition and interactions during development and immune reactions.

Specializations of the plasma membrane include microvilli (which increase the absorptive area) and cell junctions (desmosomes, tight junctions, and gap junctions).

WEB Exercise: Chapter 3, Structure of the Plasma Membrane.

c. The cytoplasm is where most cellular activities occur. Its fluid substance, the cytosol, contains inclusions, stored or inactive materials in the cytoplasm (fat globules, water vacuoles, crystals, and the like) and specialized bodies called organelles, each with a specific function. For example, mitochondria are sites of ATP synthesis, ribosomes are sites of protein synthesis, and the Golgi apparatus packages proteins for export from the cell. Lysosomes carry out intracellular digestion, and peroxisomes disarm dangerous chemicals in the cells. Cytoskeletal elements function in cellular support and motion. The centrioles play a role in cell division and form the bases of cilia and flagella.

WEB Exercise: Chapter 3, Parts of the Cell: Structure.

Cell Physiology (pp. 76–88)

1. All cells exhibit irritability, digest foods, excrete wastes, and are able to reproduce, grow, move, and metabolize.

2. Transport of substances through the cell membrane:

WEB Exercise: Chapter 3, Membrane Transport.

a. Passive transport processes include diffusion and filtration.

(1) Diffusion is the movement of a substance from an area of its higher concentration to an area of its lower concentration. It occurs because of kinetic energy of the molecules themselves. The diffusion of dissolved solutes through the plasma membrane is simple diffusion. The diffusion of water across the plasma membrane is osmosis. Diffusion that requires a protein channel or carrier is facilitated diffusion.

WEB Exercise: Chapter 3, Passive Transport.

(2) Filtration is the movement of substances through a membrane from an area of high hydrostatic pressure to an area of lower fluid pressure. In the body, the driving force of filtration is blood pressure.

b. Active transport and vesicular transport use energy (ATP) provided by the cell.

(1) In active transport, substances are moved across the membrane against an electrical or a concentration gradient by proteins called solute pumps. This accounts for the transport of amino acids, some sugars, and most ions.

(2) The two types of ATP-activated vesicular transport are exocytosis and endocytosis. Exocytosis moves secretions and other substances out of cells; a membrane-bound vesicle fuses with the plasma membrane, ruptures, and ejects its contents to the cell exterior. Endocytosis, in which particles are taken up by enclosure in a plasma membrane sac, includes phagocytosis (uptake of solid particles), pinocytosis (uptake of fluids), and the highly selective receptor-mediated endocytosis. In the latter, membrane receptors bind with and internalize only selected target molecules.

3. Osmotic pressure, which reflects the solute concentration of a solution, determines whether cells gain or lose water. (Discussion in "A Closer Look" on pp. 80–81)

a. Hypertonic solutions contain more solutes (and less water) than do cells. In these solutions, cells lose water by osmosis and crenate.

b. Hypotonic solutions contain fewer solutes (and more water) than do the cells. In these solutions, cells swell and may rupture (lyse) as water rushes in by osmosis.

c. Isotonic solutions, which have the same solute-to-solvent ratio as cells, cause no changes in cell size or shape.

4. Cell division has two phases, mitosis (nuclear division) and cytokinesis (division of the cytoplasm).

a. Mitosis begins after DNA has been replicated (during interphase); it consists of four stages—prophase, metaphase, anaphase, and telophase. The result is two daughter nuclei, each identical to the mother nucleus.

b. Cytokinesis usually begins during anaphase and progressively pinches the cytoplasm in half. Cytokinesis does not always occur; in such cases bi- or multinucleate cells result.

c. Mitotic cell division provides an increased number of cells for growth and repair.

5. Protein synthesis involves both DNA (the genes) and RNA.

a. A gene is a segment of DNA that carries the instructions for building one protein. The information is in the sequence of bases in the nucleotide strands. Each three-base sequence (triplet) specifies one amino acid in the protein.

b. Messenger RNA carries the instructions for protein synthesis from the DNA (gene) to the ribosomes. Transfer RNA transports amino acids to the ribosomes. Ribosomal RNA forms part of the ribosomal structure and helps coordinate the protein building process.

PART II: BODY TISSUES (pp. 88–101)

1. Epithelium is the covering, lining, and glandular tissue. Its functions include protection, absorption, and secretion. Epithelia are named according to arrangement (simple, stratified) and cell shape (squamous, cuboidal, columnar).

2. Connective tissue is the supportive, protective, and binding tissue. It is characterized by the presence of a nonliving, extracellular matrix (ground substance plus fibers) produced and secreted by the cells; it varies in amount and consistency. Fat, ligaments and tendons, bones, and cartilage are all connective tissues or connective tissue structures.

   WEB Exercise: Chapter 3, Identifying Connective Tissue.

3. Muscle tissue is specialized to contract, or shorten, which causes movement. There are three types—skeletal (attached to the skeleton), cardiac (forms the heart), and smooth (in the walls of hollow organs).

4. Nervous tissue is composed of supporting cells and irritable cells called neurons, which are highly specialized to receive and transmit nerve impulses and supporting cells. Neurons are important in control of body processes. Nervous tissue is located in nervous system structures—brain, spinal cord, and nerves.

5. Tissue repair (wound healing) may involve regeneration, fibrosis, or both. In regeneration, the injured tissue is replaced by the same type of cells. In fibrosis, the wound is repaired with scar tissue. Epithelia and connective tissues regenerate well. Mature cardiac muscle and nervous tissue are repaired by fibrosis.

PART III: DEVELOPMENTAL ASPECTS OF CELLS AND TISSUES (pp. 101, 104)

1. Growth through cell division continues through puberty. Cell populations exposed to friction (such as epithelium) replace lost cells throughout life. Connective tissue remains mitotic and forms repair (scar) tissue. With some exceptions, muscle tissue becomes amitotic by the end of puberty, and nervous tissue becomes amitotic shortly after birth. Amitotic tissues are severely handicapped by injury.

2. The cause of aging is unknown, but chemical and physical insults, as well as genetic programming, are suggested.

3. Neoplasms, both benign and cancerous, represent abnormal cell masses in which normal controls on cell division are not working. Hyperplasia (increase in size) of tissue or organ may occur when tissue is strongly stimulated or irritated. Atrophy (decrease in size) of a tissue or organ occurs when the organ is no longer stimulated normally.

REVIEW QUESTIONS

Multiple Choice

More than one choice may apply.

1. Which of the following would you expect to find in or on cells whose main function is absorption?
   a. Microvilli
   b. Cilia
   c. Gap junctions
   d. Secretory vesicles

2. Adult cell types you might expect to have gap junctions include
   a. skeletal muscle.
   b. bone.
   c. heart muscle.
   d. smooth muscle.

3. Which of the following are possible functions of the glycoproteins in the plasma membrane?
   a. Determination of blood groups
   b. Binding sites for toxins or bacteria
   c. Aiding the binding of sperm to egg
   d. Increasing the efficiency of absorption

4. A cell with abundant peroxisomes would most likely be involved in
   a. secretion.
   b. storage of glycogen.
   c. ATP manufacture.
   d. movement.
   e. detoxification activities.

5. A cell stimulated to increase its steroid production will have abundant
   a. ribosomes.
   b. rough ER.
   c. smooth ER.
   d. Golgi apparatus.
   e. secretory vesicles.

6. For diffusion to occur, there must be
   a. a selectively permeable membrane.
   b. equal amounts of solute.
   c. a concentration difference.

d. some sort of carrier system.
e. all of the above.

7. In which of the following tissue types might you expect to find goblet cells?
   a. Simple cuboidal
   b. Simple columnar
   c. Simple squamous
   d. Stratified squamous
   e. Transitional

8. An epithelium "built" to withstand friction is
   a. simple squamous.
   b. stratified squamous.
   c. simple cuboidal.
   d. simple columnar.
   e. pseudostratified.

9. What kind of connective tissue acts as a sponge, soaking up fluid when edema occurs?
   a. Areolar connective
   b. Adipose connective
   c. Dense irregular connective
   d. Reticular connective
   e. Vascular

10. What type of connective tissue prevents muscles from pulling away from bones during contraction?
    a. Dense connective
    b. Areolar
    c. Elastic connective
    d. Hyaline cartilage

11. Which of the following terms describe cardiac muscle?
    a. Striated
    b. Intercalated disks
    c. Multinucleated
    d. Involuntary
    e. Branching

12. Cancer is the same as
    a. all tumor.
    b. all neoplasms.
    c. all malignant neoplasms.
    d. benign tumors.
    e. AIDS.

13. Which of these processes involves specific membrane receptors?
    a. Phagocytosis
    b. Receptor-mediated endocytosis
    c. Exocytosis
    d. Pinocytosis

Short Answer Essay

14. Define *cell* and *organelle*.

15. Although cells have differences that reflect their special functions in the body, what functional abilities do *all* cells exhibit?

16. Describe the special function of DNA found in the nucleus. What nuclear structures contain DNA? Help to form ribosomes?

17. Describe the general structure and function of the plasma membrane.

18. Describe the general composition and function of the cytosol and inclusions of the cytoplasm.

19. Name the cellular organelles, and explain the function of each.

20. Define *diffusion, osmosis, simple diffusion, filtration, solute pumping, exocytosis, endocytosis, phagocytosis, pinocytosis,* and *receptor-mediated endocytosis*.

21. What two structural characteristics of cell membranes determine whether substances can pass through them passively? What determines whether or not a substance can be actively transported through the membrane?

22. Explain the effect of the following solutions on living cells: hypertonic, hypotonic, and isotonic.

23. Briefly describe the process of DNA replication.

24. Define *mitosis*. Why is mitosis important?

25. What is the role of the spindle in mitosis?

26. Why can an organ be permanently damaged if its cells are amitotic?

27. Describe the relative roles of DNA and RNA in protein synthesis.

28. Define *tissue*. List the four major types of tissue. Which of these types is most widely distributed in the body?

29. Describe the general characteristics of epithelial tissue. List the most important functions of epithelial tissues, and give examples of each.

30. Where is ciliated epithelium found, and what role does it play?

31. What are the general structural characteristics of connective tissues? What are the functions of connective tissues? How are their functions reflected in their structures?

32. Name a connective tissue with (1) a soft fluid matrix, and (2) a stony hard matrix.

33. What is the function of muscle tissue?

34. Tell where each of the three types of muscle tissue would be found in the body. What is meant by the statement, "Smooth muscles are involuntary in action"?

35. How does tissue healing by fibrosis differ from healing by regeneration? Which is more desirable and why?

36. Define *atrophy*.

CRITICAL THINKING AND CLINICAL APPLICATION QUESTIONS

37. Two examples of chemotherapeutic drugs (used to treat cancer) and their cellular actions are given below. Explain why each drug could be fatal to a cell.
    - Vincristine: damages the mitotic spindle.
    - Adriamycin: binds to DNA and blocks messenger RNA synthesis.

38. Hydrocortisone is an anti-inflammatory drug that stabilizes lysosomal membranes. Explain how this effect reduces cell damage and inflammation.

39. John has severely injured his knee during football practice. He is told that he has a torn knee cartilage and to expect that recovery and repair will take a long time. Why will it take a long time?

40. Three patients in an intensive care unit are examined by the resident doctor. One patient has brain damage from a stroke, another had a heart attack that severely damaged his heart muscle, and the third has a severely damaged liver (a gland) from a crushing injury in a car accident. All three patients have stabilized and will survive, but only one will have full functional recovery through regeneration. Which one and why?

41. Kareem had a nervous habit of chewing on the inner lining of his lip with his front teeth. The lip grew thicker and thicker from years of continual irritation. Kareem's dentist noticed his greatly thickened lip, then told him to have it checked to see if the thickening was a tumor. A biopsy revealed hyperplasia and scattered areas of dysplasia, but no evidence of neoplasia. What do these terms mean? Did Kareem have cancer of the mouth?