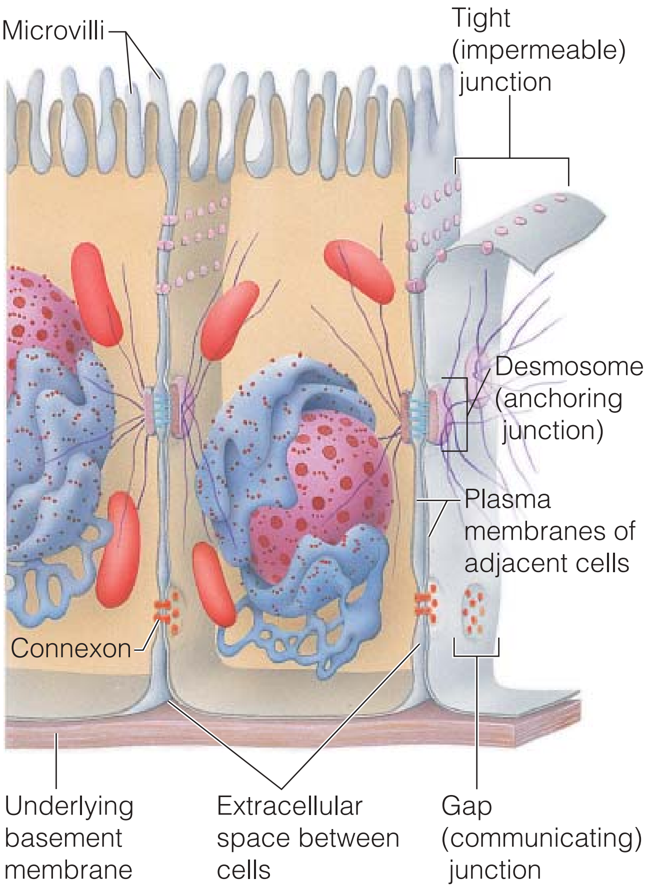

FIGURE 3.3 **Cell junctions.** An epithelial cell is shown joined to adjacent cells by the three common types of cell junctions: tight junctions, desmosomes, and gap junctions. Also illustrated are microvilli (seen projecting from the free cell surface).

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 plaques, buttonlike thickenings of adjacent plasma membranes, 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.

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 it can be thought of 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 not functioning units, but instead 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 seen in skin and hair cells, mucus and other secretory products, and various kinds of crystals.

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

Q *Which nuclear component contains your genes?*

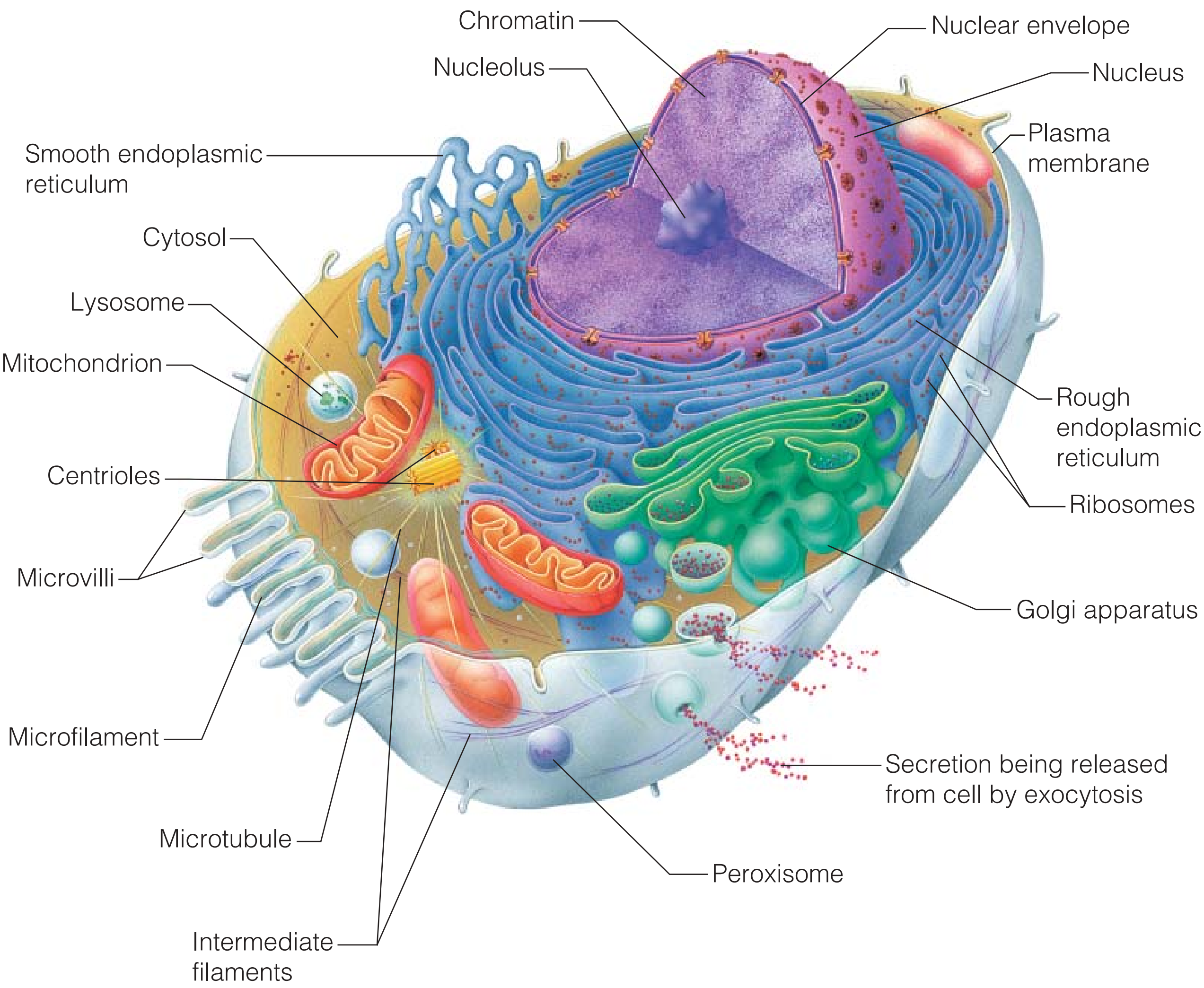

FIGURE 3.4 **Structure of the generalized cell.** No cell is exactly like this one, but this generalized cell drawing illustrates features common to many human cells.

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 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

A *The nucleus.*

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). In general the amount of rough ER a cell has is a good clue to the amount of protein that cell makes. Rough ER is especially abundant in cells that 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.

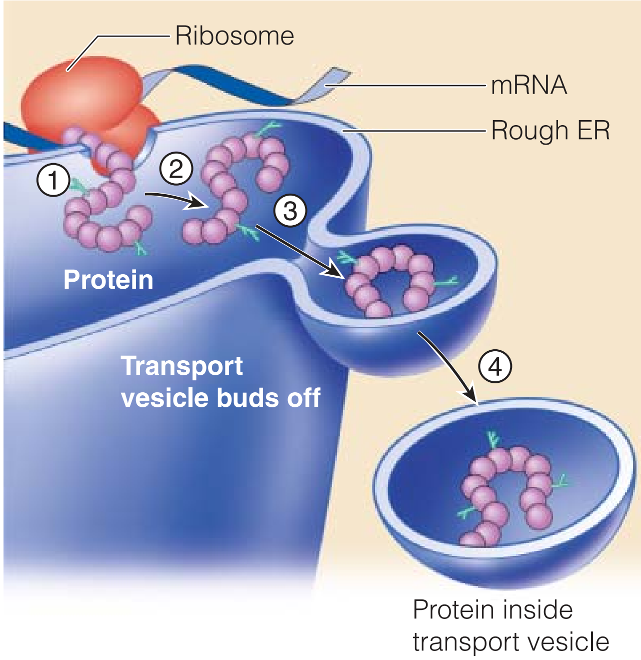

FIGURE 3.5 Synthesis and export of a protein by the rough ER. ① As the protein is synthesized on the ribosome, it migrates into the rough ER cisterna. ② In the cisterna, short sugar chains may be attached to the protein (forming a glycoprotein) and the protein folds into its functional shape. ③ The protein is then 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 directly to the plasma membrane where its contents are secreted.

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).

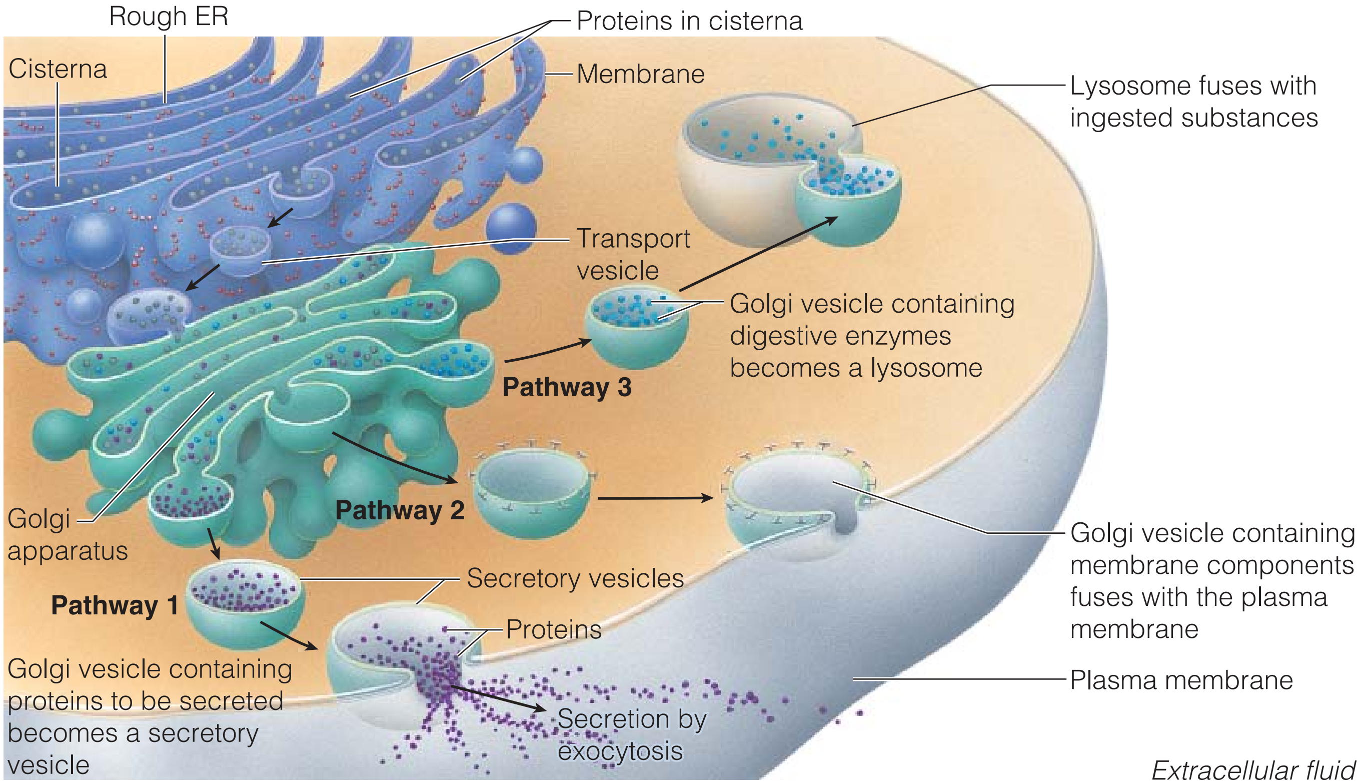

FIGURE 3.6 Role of the Golgi apparatus in packaging the products of the rough ER. Protein-containing transport vesicles pinch off the rough ER and migrate to fuse with the Golgi apparatus. As it passes through the Golgi apparatus, the protein product is sorted (and slightly modified). The product is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

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 to become part of the plasma membrane (pathway 2 in Figure 3.6) and packages hydrolytic enzymes into membranous sacs called *lysosomes* that remain in the cell (pathway 3 in Figure 3.6).

Lysosomes **Lysosomes** (li′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 white blood cells that engulf bacteria and other potentially harmful substances because they digest and rid the body of such foreign invaders. 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.

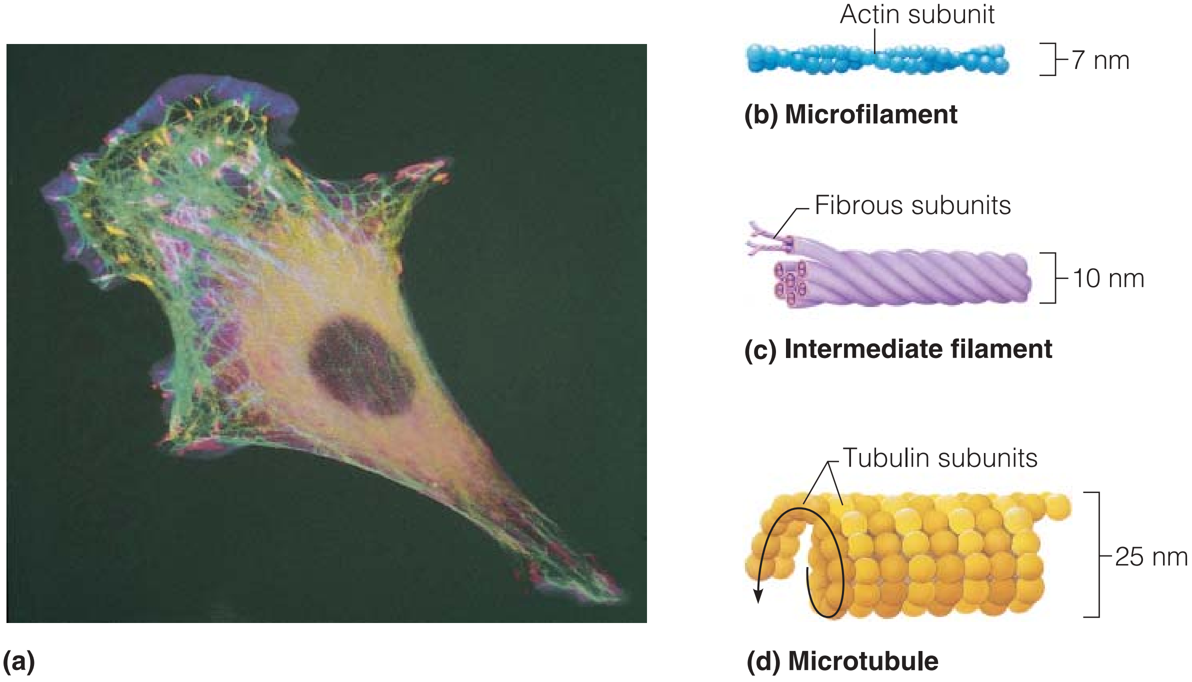

FIGURE 3.7 **The cytoskeleton. (a)** In this light micrograph of the cytoskeleton of a nerve cell, the microtubules appear green; the microfilaments are blue. Intermediate filaments form most of the rest of the network. **(b–d)** Diagrammatic views of the three types of cytoskeletal elements.

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 by-products 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 (see Figure 3.2). 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. 80–81 and 83.

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. During cell division, the centrioles direct the formation of the *mitotic spindle* (see Figure 3.15, p. 81).

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.*

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 also has an abundant rough ER and

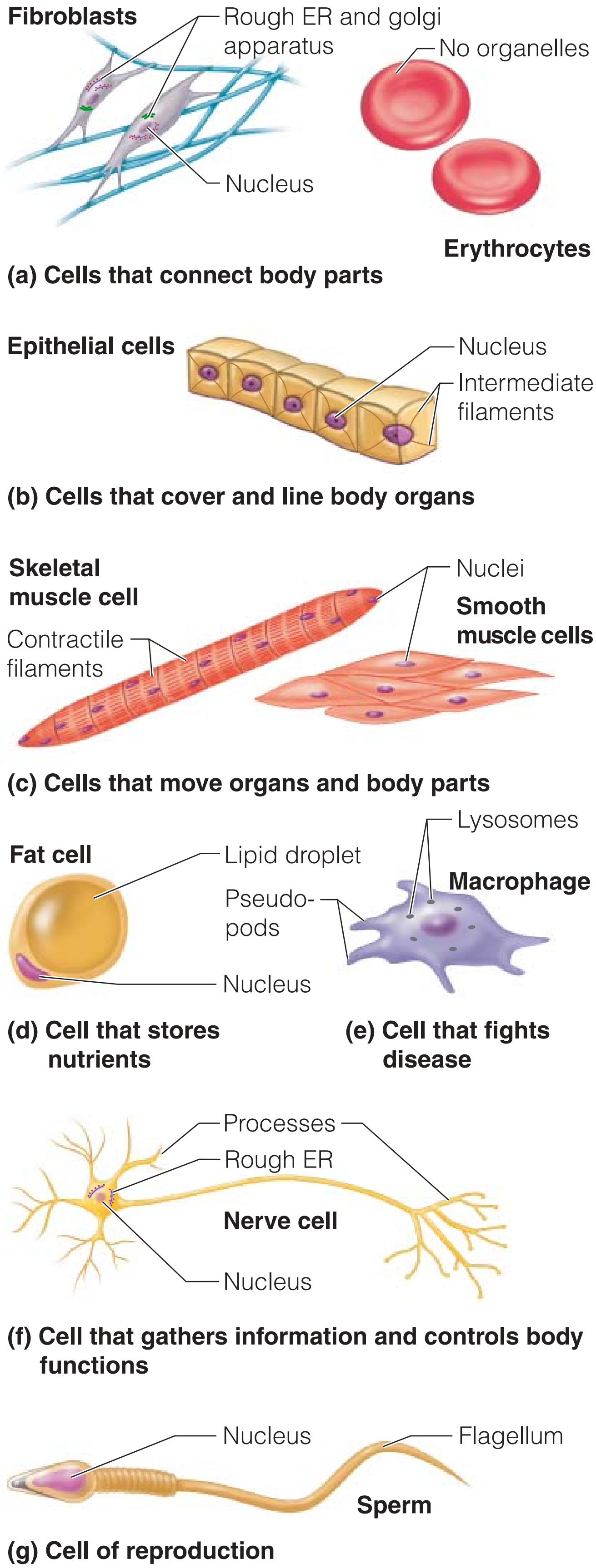

FIGURE 3.8 Cell diversity. The shape of human cells and the relative abundances of their various organelles relate to their function in the body.