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Cytology

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FIGURE: Drugs work at the cellular level where a delicate chemical balance is maintained. A thorough knowledge of cellular structure is imperative to understand cellular physiology and drug therapy.

Clinical Case Study

A 46-year-old inebriated male is brought to the emergency room by paramedics after his girlfriend called 911 reporting that he was experiencing a seizure. Over the next hour, the patient becomes increasingly somnolent (sleepy). While the emergency room staff initiates gastric lavage for presumed drug ingestion, you seek more medical history from the man's girlfriend. She reports that she found him amidst several empty bottles of antifreeze. Upon hearing this, you immediately order a 10% ethanol solution to be given to the man intravenously.

How do enzymes promote metabolism of chemicals? What is meant by "competitive inhibition" and how does this relate to therapy for ethylene glycol poisoning? As you read this chapter, pay attention to other enzyme reactions and recognize that these are important targets for therapeutic medications.

INTRODUCTION TO CYTOLOGY

The cell is the fundamental structural and functional unit of the body. Although cells vary widely in size and shape, they have basic structural similarities, and all cells metabolize to stay alive.

Objective 1 Define the terms *cell, metabolism,* and *cytology.*

Objective 2 Using examples, explain how cells differ from one another and how the structure of a cell determines its function.

Cells as Functional Units

Human anatomy is concerned with the structure of the human body and the relationship of its parts. The body is a masterpiece of organization for which the **cell** provides the basis. For this reason, the cell is called the functional unit. As discussed in chapter 2, cellular organization forms tissues, whose organization in turn forms the organs, which in turn form systems. If the organs and systems are to function properly, cells must function properly. Cellular function is referred to as **metabolism.** In order for cells to remain alive and metabolize, certain requirements must be met. Each cell must have access to nutrients and oxygen and be able to eliminate wastes. In addition, a constant, protective environment must be maintained. All of these requirements are achieved through organization.

Cells were first observed more than 300 years ago by the English scientist Robert Hooke. Using his crude microscope to examine a thin slice of cork, he saw a network of cell walls and boxlike cavities. He called them "little boxes or cells," after the barren cubicles of a monastery. As better microscopes were developed, the intriguing architectural details of cellular structure were gradually revealed. The improved lenses resulted in a series of developments that culminated in the formulation of the **cell theory** in 1838 and 1839 by two German biologists, Matthias Schleiden and Theodor Schwann. This theory states that all living organisms are composed of one or more cells and that the cell is the basic unit of structure for all organisms. The work of Schleiden and Schwann laid the groundwork for a new science called **cytology,** which is concerned with the structure and function of cells.

A knowledge of the cellular level of organization is important for understanding the basic body processes of cellular respiration, protein synthesis, mitosis, and meiosis. An understanding of cellular structure gives meaning to the concept of tissue, organ, and system levels of functional body organization. Furthermore, many dysfunctions and diseases of the body originate in the cells. Although cellular structure and function have been investigated for many years, we still have much to learn about cells. The *etiologies*, or causes, of a number of complex diseases are as yet unknown. Scientists are seeking why and how the body ages. The answers will come only through a better understanding of cellular structure and function.

Advancements in microscopy have revolutionized the science of cytology. In a new process called *microtomography,* the capabilities of electron microscopy are combined with those of CT scanning to produce high-magnification, three-dimensional, microtomographic images of living cells. With this technology, living cells can be observed as they move, grow, and divide. The clinical applications are immense, as scientists can observe the response of diseased cells (including cancer cells) to various drug treatments.

Cellular Diversity

It is amazing that from a single cell, the fertilized egg, hundreds of kinds of cells arise, producing the estimated 60 trillion to 100 trillion cells that make up an adult human. Cells vary greatly in size and shape. The smallest cells are visible only through a high-powered microscope. Even the largest, an egg cell (ovum), is barely visible to the unaided eye. The sizes of cells are measured in micrometers (μm)—one micrometer equals 1/1,000th of a millimeter. Using this basis of comparison, an ovum is about 140 μm in diameter and a red blood cell is about 7.5 μm in diameter. The most common type of white blood cell varies in size from 10 to 12 μm in diameter. Although still microscopic, some cells can be extremely long. A nerve cell (neuron), for example, may extend the entire length of a limb and be over a meter long.

Although a typical diagram of a cell depicts it as round or cube-shaped, the shapes of cells are actually highly variable. They can be flat, oval, elongate, stellate, columnar, and so on (fig. 3.1). The shape of a cell is frequently an indication of its function. A disc-shaped red blood cell is adapted to transport oxygen. Thin, flattened cells may be bound together to form selectively permeable membranes. An irregularly shaped cell, such as a neuron, has a tremendous ratio of surface area to volume, which is ideal for receiving and transmitting stimuli.

The surfaces of some cells are smooth, so that substances pass over them easily. Other cells have distinct depressions and elevations on their cell membranes to facilitate absorption. Some cell surfaces support such structures as cilia, flagella, and gelatinous coats, which assist movement and provide adhesion. Regardless of the sizes and shapes of cells, they all have structural modifications that serve functional purposes.

Knowledge Check

1. Why is the cell considered the basic structural and functional unit of the body?
2. What conditions are necessary for metabolism to occur?
3. Give some examples of structural modifications that allow cells to perform specific functions?

metabolism: Gk. *metabole*, change
cytology: L. *cella*, small room; Gk. *logos*, study of
etiology: L. *aitia*, cause; Gk. *logos*, study of

CHAPTER 3

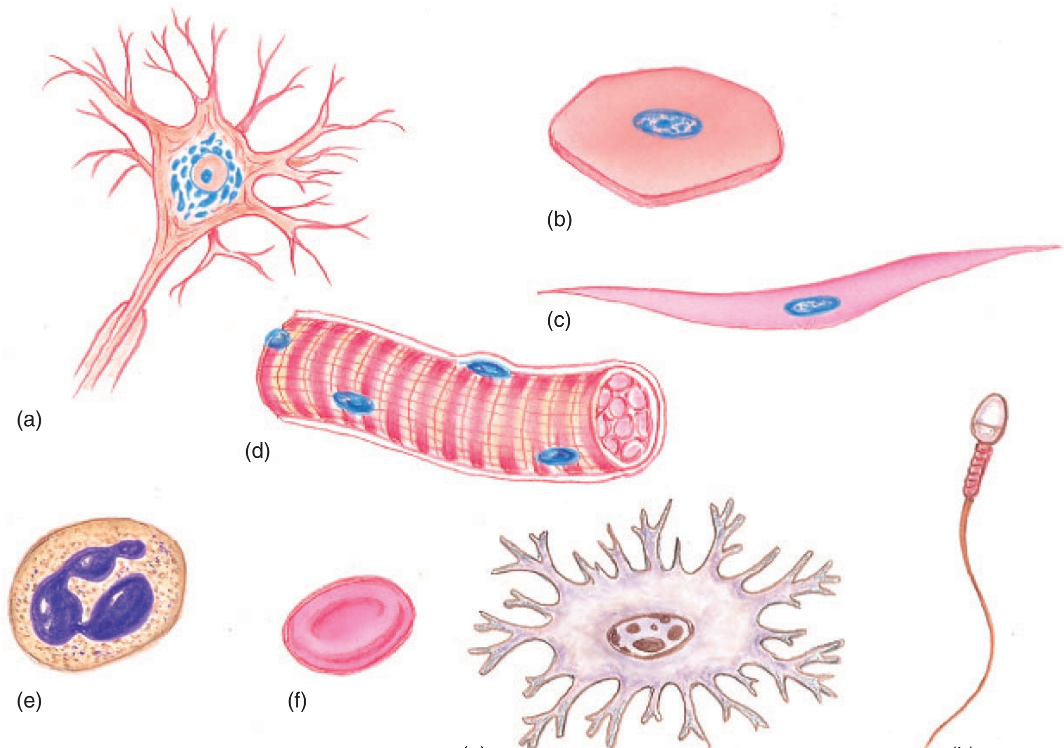


FIGURE 3.1 Examples of the various shapes of cells within the body. (The cells are not drawn to scale.) (*a*) A neuron (nerve cell) showing the cell body surrounded by numerous dendritic extensions and a portion of the axon extending below, (*b*) a squamous epithelial cell from the lining of a blood vessel, (*c*) a smooth muscle cell from the intestinal wall, (*d*) a skeletal muscle cell, (*e*) a leukocyte (white blood cell), (*f*) an erythrocyte (red blood cell), (*g*) an osteocyte (bone cell), and (*h*) a spermatozoon (sperm cell).

CELLULAR CHEMISTRY

All tissues and organs are composed of cellular structures that have basically the same chemical components. The most important inorganic substances in the body include water, acids, bases, and salts. The most important organic substances in the body include proteins, carbohydrates, and lipids.

Objective 3 List the common chemical elements found within cells.

Objective 4 Differentiate between inorganic and organic compounds and give examples of each.

Objective 5 Explain the importance of water in maintaining body homeostasis.

Objective 6 Differentiate between proteins, carbohydrates, and lipids.

To understand cellular structure and function, one must have a knowledge of basic cellular and general body chemistry. All of the processes that occur in the body comply with principles of chemistry. Furthermore, many of the dysfunctions of the body have a chemical basis.

Elements, Molecules, and Compounds

Elements are the simplest chemical substances. Four elements compose over 95% of the body's mass. These elements and their percentages of body weight are oxygen (O) 65%, carbon (C) 18%, hydrogen (H) 10%, and nitrogen (N) 3%. Additional common elements found in the body include calcium (Ca), potassium (K), sodium (Na), phosphorus (P), magnesium (Mg), and sulfur (S).

A few elements exist separately in the body, but most are chemically bound to others to form **molecules.** Some molecules are composed of like elements—an oxygen molecule (O_2), for example. Others, such as water (H_2O), are composed of different kinds of elements. **Compounds** are molecules composed of two or more different elements. Thus, the chemical structure of water may be referred to as both a molecule and a compound.

Organic compounds are those that are composed of carbon, hydrogen, and oxygen. They include common body substances such as proteins, carbohydrates, and lipids. **Inorganic compounds** generally lack carbon and include common body substances such as water and *electrolytes* (acids, bases, and salts). The percentages of organic and inorganic compounds found in adult males and females are compared in table 3.1.

TABLE 3.1 Compounds Found in Adult Males and Females (Expressed as Percentage of Body Weight)

Substance	Male	Female
Water	62	59
Protein	18	15
Lipid	14	20
Carbohydrates	1	1
Other (electrolytes, nucleic acids)	5	5

TABLE 3.2 Kinds of Electrolytes

	Characteristic	Examples
Acid	Ionizes to release hydrogen ions (H^+)	Carbonic acid, hydrochloric acid, acetic acid, phosphoric acid
Base	Ionizes to release hydroxyl ions (OH^-) that combine with hydrogen ions	Sodium hydroxide, potassium hydroxide, magnesium hydroxide, aluminum hydroxide
Salt	Substance formed by the reaction between an acid and a base	Sodium chloride, aluminum chloride, magnesium sulfate

The disparity of proteins, lipids, and water in adult males and females can be explained by relative amounts of sex hormones. Male sex hormones promote the development of proteins, especially in skeletal muscle tissue. Female sex hormones promote the retention of fats, which are an important food resource for nursing a child. Because proteins contain more water than lipids, there is a disparity between the percent of body fluids between males and females.

Water

Water is by far the most abundant compound found within cells and in the extracellular environment. Water generally occurs within the body as a homogeneous mixture of two or more compounds called a *solution*. In this condition, the water is the *solvent*, or the liquid portion of the solution, and the *solutes* are substances dissolved in the solution. Water is an almost universal solvent, meaning that almost all chemical compounds dissolve in it. In addition, it is also used to transport many solutes through the cell membrane of a cell or from one part of the cell to another. Water is also important in maintaining a constant cellular temperature, and thus a constant body temperature, because it absorbs and releases heat slowly. Evaporative cooling (sweating) through the skin also involves water. Another function of water is as a *reactant* in the breakdown (*hydrolysis*) of food material in digestion.

Dehydration is a condition in which fluid loss exceeds fluid intake, with a resultant decrease in the volume of intracellular and extracellular fluids. Rapid dehydration through vomiting, diarrhea, or excessive sweating can lead to serious medical problems by impairing cellular function. Infants are especially vulnerable because their fluid volume is so small. They can die from dehydration resulting from diarrhea within a matter of hours.

solution: L. *solvere*, loosen or dissolve
hydrolysis: Gk. *hydor*, water; *lysis*, a loosening

Electrolytes

Electrolytes are inorganic compounds that break down into ions when dissolved in water, forming a solution capable of conducting electricity. An electrolyte is classified according to the ions it yields when dissolved in water. The three classes of electrolytes are *acids*, *bases*, and *salts*, all of which are important for normal cellular function. The functions of ions include the control of water movement through cells and the maintenance of normal acid-base (*pH*) balance. Ions are also essential for nerve and muscle function, and some ions serve as cofactors that are needed for optimal activity of enzymes. Symptoms of electrolyte imbalances range from muscle cramps and brittle bones to coma and cardiac arrest. The three kinds of electrolytes are summarized in table 3.2.

Proteins

Proteins are nitrogen-containing organic compounds composed of amino acid subunits. An *amino acid* is an organic compound that contains an amino group ($—NH_2$) and a carboxyl group ($—COOH$). There are 20 different types of amino acids that can contribute to a given protein. This variety allows each type of protein to be constructed to function in very specific ways.

Proteins are the most abundant of the organic compounds. They may exist by themselves or be *conjugated* (joined) with other compounds; for example, with nucleic acids (RNA or DNA) to form nucleoproteins, with carbohydrates to form glycoproteins, or with lipids to form lipoproteins.

Proteins may be categorized according to their role in the body as structural or functional. **Structural proteins** contribute significantly to the structure of different tissues. Examples include *collagen* in connective tissue and *keratin* in the epidermis of

electrolyte: L. *electrum*, amber; Gk. *lysis*, a loosening
acid: L. *acidus*, sour
protein: Gk. *proteios*, of the first quality

TABLE 3.3 Chemical Substances of Cells: Location and Function

Substance	Location in Cell	Functions
Water	Throughout	Dissolves, suspends, and ionizes materials; helps regulate temperature
Electrolytes	Throughout	Establish osmotic gradients, pH, and membrane potentials
Proteins	Membranes, cytoskeleton, ribosomes, enzymes	Provide structure, strength, and contractility; catalyze; buffer
Lipids	Membranes, Golgi complex, inclusions	Provide reserve energy source; shape, protect, and insulate
Carbohydrates	Inclusions	Preferred fuel for metabolic activity
Nucleic acids		
DNA	Nucleus, in chromosomes and genes	Controls cell activity
RNA	Nucleolus, cytoplasm	Transmits genetic information; transports amino acids
Trace materials		
Vitamins	Cytoplasm, nucleus	Work with enzymes in metabolism
Minerals	Cytoplasm, nucleus	Essential for normal metabolism; involved in osmotic balance; add strength; buffer

the skin. **Functional proteins** assume a more active role in the body, exerting some form of control of metabolism. Examples include *enzymes* and *antibodies*. Many *hormones* belong to a specialized group of messenger and regulator proteins produced by endocrine glands. Cellular growth, repair, and division depend on the availability of functional proteins. Proteins, under certain conditions, may even be metabolized to supply cellular energy.

Carbohydrates

Carbohydrates are organic compounds that contain carbon, hydrogen, and oxygen, with a 2:1 ratio of hydrogen to oxygen. Carbohydrates include *monosaccharides*, or simple sugars, *disaccharides*, or double sugars, and *polysaccharides*, or long-chained sugars. Carbohydrates are the body's most readily available energy source and also may be used as a fuel reserve. Excessive carbohydrate intake is converted to *glycogen* (animal starch) or to *fat* for storage in adipose tissue.

If a person is deprived of food, the body uses the glycogen and fat reserves first and then metabolizes the protein within the cells. The gradual destruction of cellular protein accounts for the lethargy, extreme emaciation, and ultimate death of starvation victims.

Lipids

Lipids are a third group of important organic compounds found in cells. They are insoluble in water and include both fats and fat-related substances, such as phospholipids and cholesterol. Fats are important in building cell parts and supplying metabolic energy. They also protect and insulate various parts of the body. Phospholipids and protein molecules make up the cell membrane and play an important role in regulating which substances enter or leave a cell.

Lipids, like carbohydrates, are composed of carbon, hydrogen, and oxygen. Lipids, however, contain a smaller proportion of oxygen than do carbohydrates.

The locations and functions of inorganic and organic substances within cells are summarized in table 3.3.

Knowledge Check

4. List the four most abundant elements in the body and state their relative percentages of body weight.
5. Define *molecule* and *compound*. What are the two kinds of compounds that exist in the body? On what basis are they distinguished?
6. List some of the functions of water relative to cells and define *solvent* and *solute*.
7. Discuss the importance of electrolytes in maintaining homeostasis within cells.
8. Define *protein* and describe how proteins function within cells. Explain how proteins differ from carbohydrates and lipids.

CELLULAR STRUCTURE

The cell membrane separates the interior of a cell from the extracellular environment. The passage of substances into and out of the cell is regulated by the cell membrane. Most of the metabolic activities of a cell occur within the cytoplasmic organelles. The nucleus functions in protein synthesis and cell reproduction.

Objective 7 Describe the components of a cell.

Objective 8 Describe the composition and structure of the cell membrane and relate its structure to the functions it performs.

Objective 9 Distinguish between passive and active transport and describe the different ways in which each is accomplished.

hormone: Gk. *hormon*, setting in motion
lipid: Gk. *lipos*, fat

TABLE 3.4 Cellular Components: Structure and Function

Component	Structure	Functions
Cell (plasma) membrane	Membrane composed of a double layer of phospholipids in which proteins are embedded	Gives form to cell and controls passage of materials in and out of cell
Cytoplasm	Fluid, jellylike substance between the cell membrane and the nucleus in which organelles are suspended	Serves as matrix substance in which chemical reactions occur
Endoplasmic reticulum	System of interconnected membrane-forming canals and tubules	Provides supporting framework within cytoplasm; transports materials and provides attachment for ribosomes
Ribosomes	Granular particles composed of protein and RNA	Synthesize proteins
Golgi complex	Cluster of flattened membranous sacs	Synthesizes carbohydrates and packages molecules for secretion; secretes lipids and glycoproteins
Mitochondria	Double-walled membranous sacs with folded inner partitions	Release energy from food molecules and transform energy into usable ATP
Lysosomes	Single-walled membranous sacs	Digest foreign molecules and worn and damaged cells
Peroxisomes	Spherical membranous vesicles	Contain enzymes that detoxify harmful molecules and break down hydrogen peroxide
Centrosome	Nonmembranous mass of two rodlike centrioles	Helps organize spindle fibers and distribute chromosomes during mitosis of a cell cycle
Vacuoles	Membranous sacs	Store and release various substances within the cytoplasm
Fibrils and microtubules	Thin, hollow tubes	Support cytoplasm and transport materials within the cytoplasm
Cilia and flagella	Minute cytoplasmic projections that extend from the cell surface	Move particles along cell surface or move the cell
Nuclear membrane (envelope)	Double-walled membrane composed of protein and lipid molecules that surrounds the nucleus	Supports nucleus and controls passage of materials between nucleus and cytoplasm
Nucleolus	Dense nonmembranous mass composed of protein and RNA molecules	Forms ribosomes
Chromatin	Fibrous strands composed of protein and DNA molecules	Contains genetic code that determines which proteins (especially enzymes) will be manufactured by the cell

Objective 10 Describe the structure and function of the endoplasmic reticulum, ribosomes, Golgi complex, lysosomes, and mitochondria.

Objective 11 Describe the structure and function of the nucleus.

As the basic functional unit of the body, the cell is a highly organized molecular factory. As previously discussed, cells come in a great variety of shapes and sizes. This variation, which is also apparent in subcellular structures (organelles), reflects the diversity of function of different cells in the body. All cells, however, have certain features in common—a cell membrane, for example, and most of the other structures listed in table 3.4. Thus, although no one cell can be considered "typical," the general structure of cells can be indicated by a single illustration (fig. 3.2).

For descriptive purposes, a cell can be divided into three principal parts:

1. **Cell (plasma) membrane.** The selectively permeable cell membrane gives form to the cell. It controls the passage of molecules into and out of the cell and separates the cell's internal structures from the extracellular environment.
2. **Cytoplasm** and **organelles.** The cytoplasm (*si′tŏ-plaz″em*) is the cellular material between the nucleus and the cell membrane. Organelles (*or″gă-nelz′*) are the specialized structures suspended within the cytoplasm of the cell that perform specific functions.
3. **Nucleus.** The nucleus (*noo′kle-us*) is the large spheroid or oval body usually located near the center of the cell. It contains the DNA, or genetic material, that directs the activities of the cell. Within the nucleus, one or more dense bodies called **nucleoli** (singular, *nucleolus*) may be seen. The nucleolus contains the subunits for ribosomes, the structures that serve as sites for protein synthesis.

Cell Membrane

The extremely thin **cell (plasma) membrane** is composed primarily of phospholipid and protein molecules. Its thickness ranges from 65 to 100 angstroms (Å); that is, it is less than a millionth of an inch thick. The structure of the cell membrane is not fully understood, but most cytologists believe that it consists of a double layer of phospholipids in which larger globular

plasma: Gk. *plasma*, to form or mold

nucleus: L. *nucleus*, kernel or nut

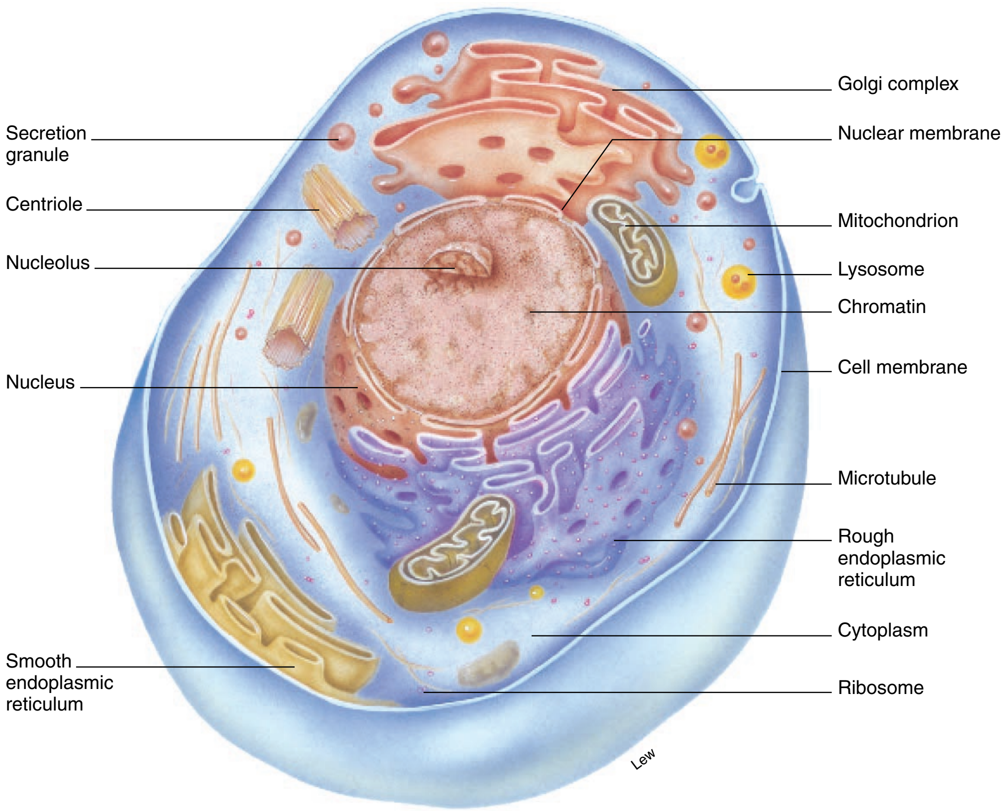


FIGURE 3.2 Structural features of a generalized cell.

proteins are embedded (fig. 3.3). The proteins are free to move within the membrane. As a result, they are not uniformly distributed, but rather form a constantly changing mosaic. Minute openings, or pores, ranging between 7 and 10 Å in diameter extend through the membrane.

The two most important functions of the cell membrane are to enclose the components of the cell and to regulate the passage of substances into and out of the cell. A highly selective exchange of substances occurs across the membrane boundary, involving several types of passive and active processes. The various kinds of movement across a cell membrane are summarized in table 3.5 and illustrated in figure 3.4.

The permeability of the cell membrane depends on the following factors:

- **Structure of the cell membrane.** Although cell membranes of all cells are composed of phospholipids, there is evidence that their thickness and structural arrangement—both of which could affect permeability—vary considerably.
- **Size of the molecules.** Macromolecules, such as certain proteins, are not allowed into the cell. Water and amino acids are small molecules and can readily pass through the cell membrane.
- **Ionic charge.** The protein portion of the cell membrane carries a positive or negative ionic charge. Ions with an opposite charge are attracted to and readily pass through the membrane, whereas those with a similar charge are repelled.
- **Lipid solubility.** Substances that are easily dissolved in lipids pass into the cell with no problem, since a portion of the cell membrane is composed of lipid material.
- **Presence of carrier molecules.** Specialized carrier molecules within the cell membrane are capable of attracting and transporting substances across the membrane, regardless of size, ionic charge, or lipid solubility.
- **Pressure differences.** The pressure difference on the two sides of a cell membrane may greatly aid movement of molecules either into or out of a cell.

Cell membranes of certain cells are highly specialized to facilitate specific functions (fig. 3.5). The columnar cells lining the lumen (hollow portion) of the intestinal tract, for example, have numerous fine projections, or **microvilli** (*mi″kro-vil′i*), that aid in

microvilli: Gk. *mikros*, small; *villus*, tuft of hair

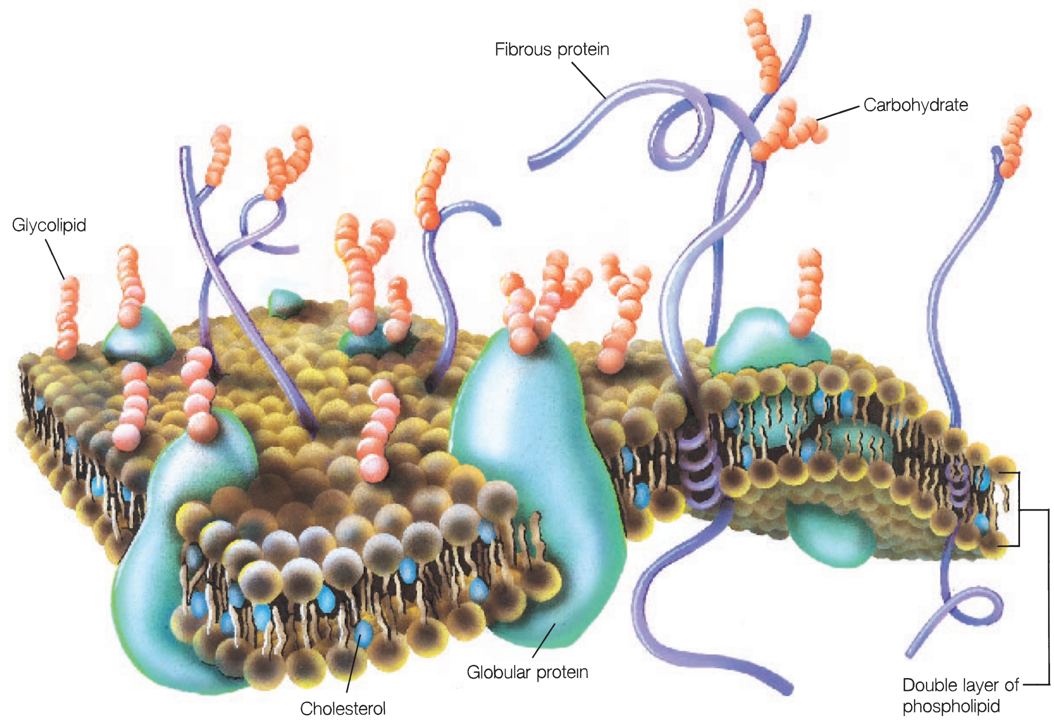


FIGURE 3.3 The cell membrane consists of a double layer of phospholipids, with the phosphates (shown by spheres) oriented outward and the hydrophobic hydrocarbons (wavy lines) oriented toward the center. Proteins may completely or partially span the membrane. Carbohydrates are attached to the outer surface.

TABLE 3.5 Movement through Cell Membranes

Processes	Characteristics	Energy Source	Example
Simple diffusion	Tendency of molecules to move from regions of high concentration to regions of lower concentration	Molecular motion	Respiratory gases are exchanged in lungs
Facilitated diffusion	Diffusion of molecules through semipermeable membrane with the aid of membrane carriers	Carrier energy and molecular motion	Glucose enters cell attached to carrier protein
Osmosis	Passive movement of water molecules through semipermeable membrane from regions of high water concentration to regions of lower water concentration	Molecular motion	Water moves through cell membrane to maintain constant turgidity of cell
Filtration	Movement of molecules from regions of high pressure to regions of lower pressure as a result of hydrostatic pressure	Blood pressure	Wastes are removed from blood within kidneys
Active transport	Carrier-mediated transport of solutes from regions of their low concentration to regions of their higher concentration (against their concentration gradient)	Cellular energy (ATP)	Glucose and amino acids move through membranes
Endocytosis			
Pinocytosis	Process in which membrane engulfs minute droplets of fluid from extracellular environment	Cellular energy	Membrane forms vacuoles containing solute and solvent
Phagocytosis	Process in which membrane engulfs solid particles from extracellular environment	Cellular energy	White blood cell membrane engulfs bacterial cell
Exocytosis	Release of molecules from cell as vesicles rupture	Cellular energy	Hormones and mucus are secreted out of cell; neurotransmitters are released at synapse

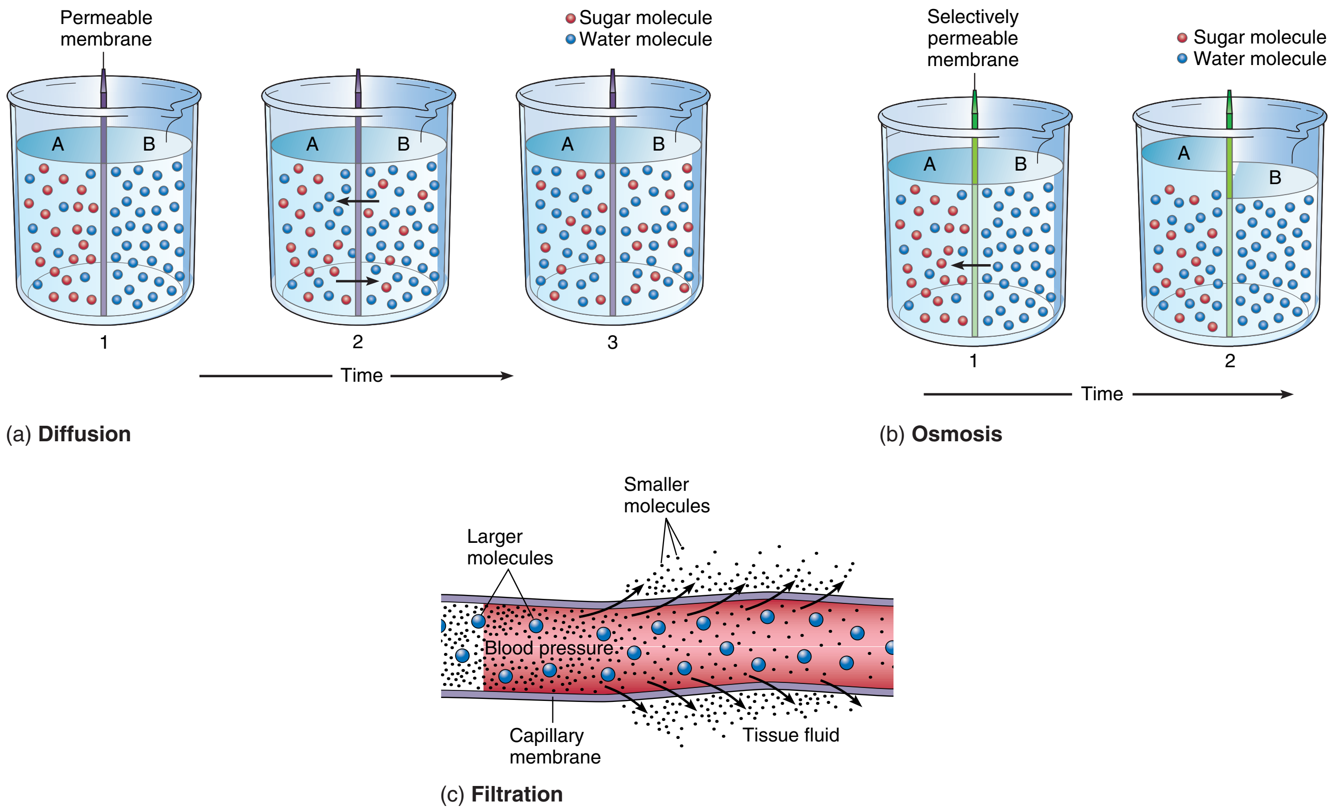


FIGURE 3.4 Examples of various kinds of movements through membranes. (*a*) Sugar molecules diffuse from compartment A to compartment B until equilibrium is achieved in 3. (*b*) Osmosis occurs as a selectively permeable membrane allows only water to diffuse through the membrane between compartments A and B, causing the level of the liquid to rise in A. (*c*) Filtration occurs as small molecules are forced through a membrane by blood pressure, leaving the larger molecules behind.

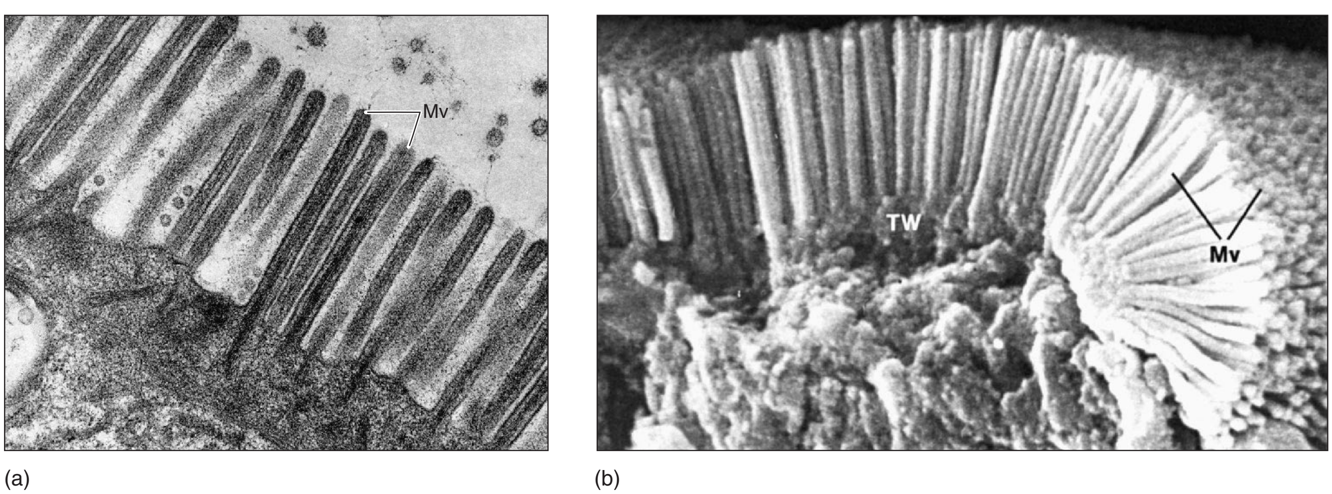


FIGURE 3.5 Microvilli in the small intestine. The microvilli (Mv), are seen here with (*a*) the transmission and (*b*) the scanning electron microscope. (TW is the terminal web, a protein mesh to which the microvilli are anchored.)
Reproduced from R. G. Kessel and R. H. Kardon, *Tissues and Organs: A Text Atlas of Scanning Electron Microscopy,* W. H. Freeman and Co., 1979.

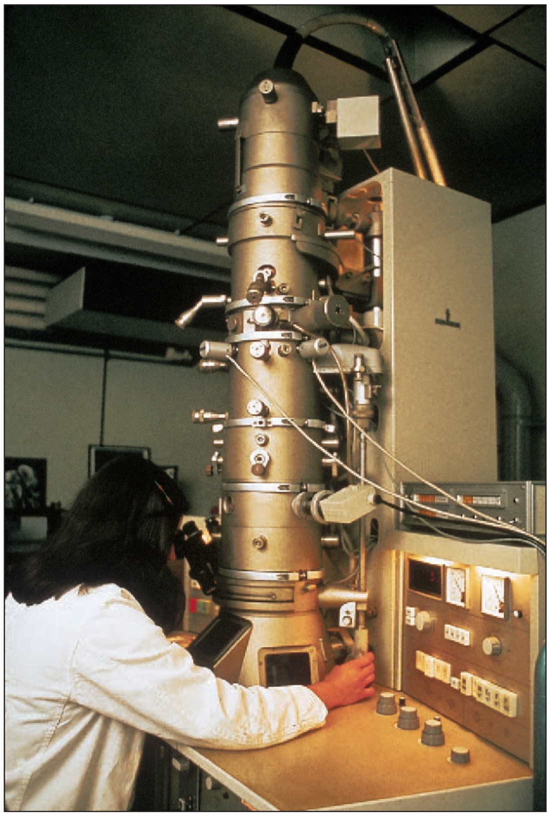


FIGURE 3.6 A transmission electron microscope (TEM) like this one is used to observe and photograph organelles within the cytoplasm of a cell.

the absorptive process of digestion. A single columnar cell may have as many as 3,000 microvilli on the exposed portion of the cell membrane, and a square millimeter of surface area may contain over 200 million microvilli.

Certain sensory organs contain cells that have specialized cell membranes. The photoreceptors, or light-responding rods and cones of the eye, have double-layered, disc-shaped membranes called **sacs.** These structures contain pigments associated with vision. Within the spiral organ (organ of Corti) in the inner ear are **hair cells.** These tactile (touch) receptors are stimulated through mechanical vibration. Hair cells are so named because of the fine hairlike processes that extend from their cell membranes.

Cytoplasm and Organelles

Cytoplasm refers to the material located within the cell membrane but outside the nucleus. The material within the nucleus is frequently called the **nucleoplasm.** The term **protoplasm** is sometimes used to refer to the cytoplasm and nucleoplasm collectively.

When observed through an electron microscope (fig. 3.6), distinct cellular components called **organelles** can be seen in the highly structured cytoplasm. The matrix of the cytoplasm is a jellylike substance that is 80% to 90% water. The organelles and inorganic *colloid substances* (suspended particles) are dispersed throughout the cytoplasm. Colloid substances have similar ionic charges that space them uniformly.

Metabolic activity occurs within the organelles of the cytoplasm. Specific roles such as heat production, cellular maintenance, repair, storage, and protein synthesis are carried out within the organelles.

The structure and functions of each of the major organelles are discussed in the following paragraphs and summarized in table 3.4.

Endoplasmic Reticulum

Often abbreviated **ER,** the endoplasmic reticulum (*en″do-plaz′mik rĕ-tik′yŭ-lum*) is widely distributed throughout the cytoplasm as a complex network of interconnected membranes (fig. 3.7). Although the name sounds complicated, *endoplasmic* simply means "within the plasm" (cytoplasm of the cell) and *reticulum* means "network." Between the interconnected membranes are minute spaces, or **cisterna,** that are connected at one end to the cell membranes. The tubules may also be connected to other organelles or to the outer nuclear envelope.

The ER provides a pathway for transportation of substances within the cell and a storage area for synthesized molecules. There are two distinct varieties, either of which may predominate in a given cell:

1. a **rough,** or **granular, endoplasmic reticulum** (*rough ER*), characterized by numerous small granules called **ribosomes** that are attached to the outer surface of the membranous wall; and
2. a **smooth endoplasmic reticulum** (*smooth ER*) that lacks ribosomes.

The membranous wall of rough ER provides a site for protein synthesis within ribosomes. Smooth ER manufactures certain lipid molecules. Also, enzymes within the smooth ER of liver cells inactivate or detoxify a variety of chemicals.

A person who repeatedly uses certain drugs, such as alcohol or phenobarbital, develops a tolerance to them, so that greater quantities are required to achieve the effect they had originally. The cytological explanation for this is that repeated use causes the smooth endoplasmic reticulum to proliferate in an effort to detoxify these drugs and protect the cell. With increased amounts of smooth endoplasmic reticulum, cells can handle an increased concentration of drugs.

Ribosomes

Ribosomes (*ri′bŏ-somz*) may occur as free particles suspended within the cytoplasm, or they may be attached to the membranous wall of the rough endoplasmic reticulum. Ribosomes are small, granular organelles (fig. 3.7) composed of protein and RNA molecules. They synthesize protein molecules that may be used to build cell structures or to function as enzymes. Some of the proteins synthesized by ribosomes are secreted by the cell to be used elsewhere in the body.

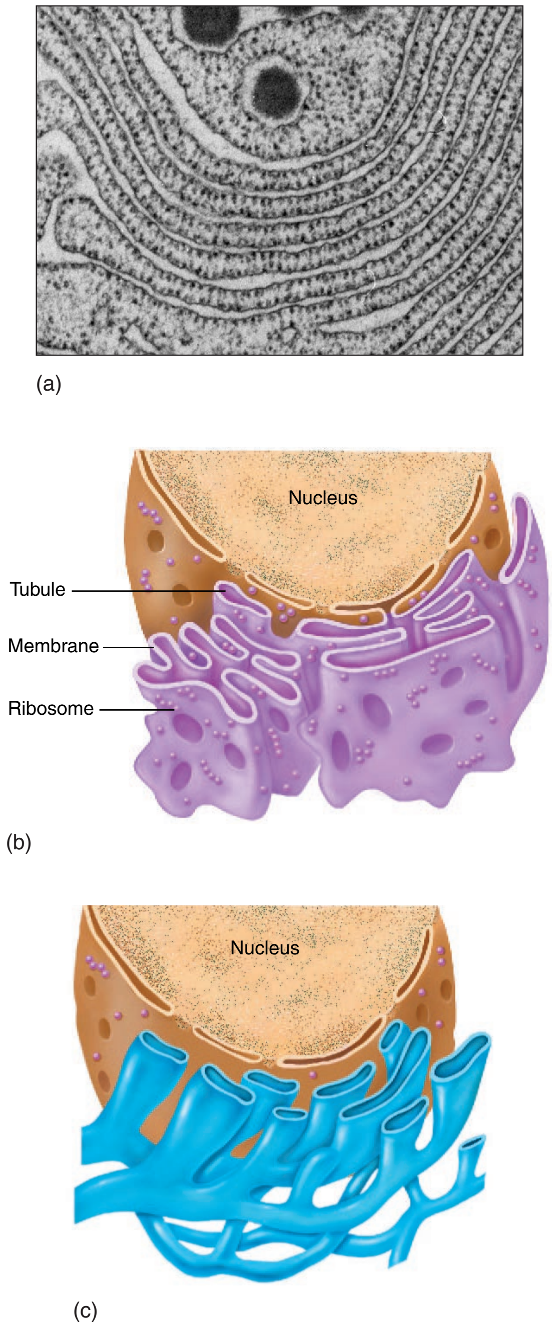


FIGURE 3.7 The endoplasmic reticulum. (*a*) An electron micrograph of the endoplasmic reticulum (about 100,000×). The rough endoplasmic reticulum (*b*) has ribosomes attached to its surface, whereas the smooth endoplasmic reticulum (*c*) lacks ribosomes.

Golgi Complex

The Golgi (*gol′je*) complex (*Golgi apparatus*) consists of several tiny membranous sacs located near the nucleus (fig. 3.8*a*).

The Golgi complex is involved in the synthesis of carbohydrates and cellular secretions. As large carbohydrate molecules are synthesized, they combine with proteins to form compounds called *glycoproteins* that accumulate in the channels of the Golgi complex. When a critical volume is reached, the vesicles break off from the complex and are carried to the cell membrane and released as a secretion (fig. 3.8*b*). Once the vesicle has fused with the cell membrane, it ruptures to release its contents, thus completing the process known as *exocytosis*.

The Golgi complex is prominent in cells of certain secretory organs of the digestive system, including the pancreas and the salivary glands. Pancreatic cells, for example, produce digestive enzymes that are packaged in the Golgi complex and secreted as droplets that flow into the pancreatic duct and are transported to the gastrointestinal (GI) tract.

Mitochondria

Mitochondria (*mi″tŏ-kon′dre-ă*) are double-membraned saclike organelles. They are found in all cells in the body, with the exception of mature red blood cells. The outer mitochondrial membrane is smooth, whereas the inner membrane is arranged in intricate folds called **cristae** (*kris′te*) (fig. 3.9). The cristae create a enormous surface area for chemical reactions.

Mitochondria vary in size and shape. They can migrate through the cytoplasm and can reproduce themselves by budding or cleavage. They are often called the "powerhouses" of cells because of their role in producing metabolic energy. Enzymes connected to the cristae control the chemical reactions that form ATP. Metabolically active cells, such as muscle cells, liver cells, and kidney cells, have a large number of mitochondria because of their high energy requirements.

The darker color of some cuts of meat (a chicken thigh, for example, as compared to a breast) is due to larger amounts of *myoglobin,* a pigmented compound in muscle tissue that acts to store oxygen. Mitochondria are likewise more abundant in red meat. Both mitochondria and myoglobin are important for the high level of metabolic activity in red muscle tissue.

Because mitochondria are contained within ova (egg cells) but not within the heads of sperm cells, all of the mitochondria in a fertilized egg are derived from the mother. As cells divide during the developmental process, the mitochondria likewise replicate themselves; thus, all of the mitochondria in a fetus are genetically identical to those in the original ovum. This accounts for a unique form of inheritance that is passed only from mother to child. A rare cause of blindness—*Leber's hereditary optic neuropathy*—and perhaps some genetically based neuromuscular disorders, are believed to be inherited in this manner.

Golgi complex: from Camillo Golgi, Italian histologist, 1843–1926

mitochondrion: Gk. *mitos*, a thread; *chondros*, lump, grain

cristae: L. *crista*, crest

Leber's hereditary optic neuropathy: from Theodor Leber, German ophthalmologist, 1840–1917

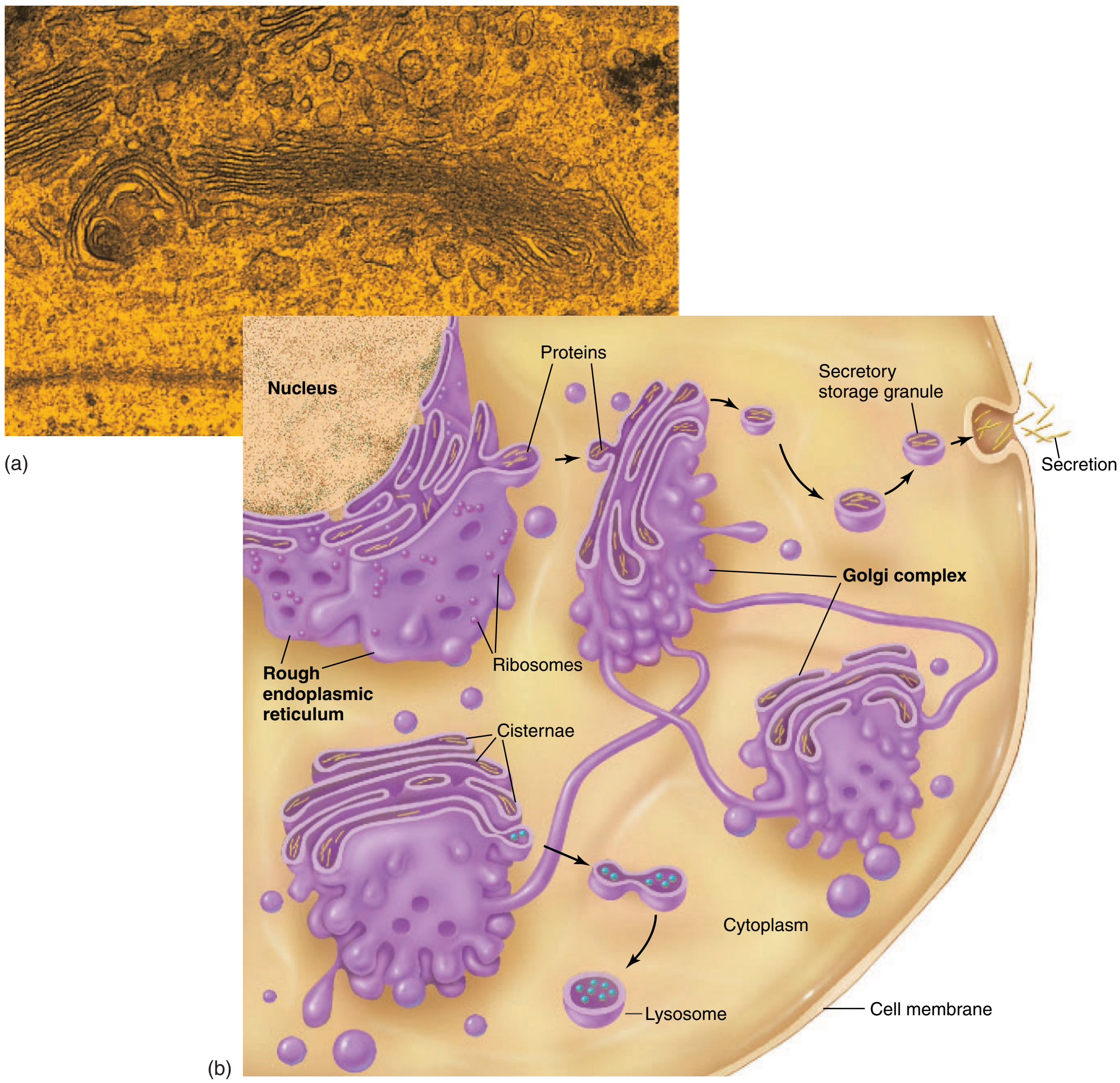


FIGURE 3.8 The Golgi complex. (*a*) An electron micrograph of a Golgi complex. Notice the formation of vesicles at the ends of some of the flattened sacs. (*b*) An illustration of the processing of proteins by the rough endoplasmic reticulum and Golgi complex.

Mitochondrial diseases may soon be treatable with mitochondria replacement. The treatment will require extraction of the cytoplasm and its organelles from an afflicted egg and replacing it with healthy material from another woman's donar egg. A potential ethical problem to this procedure is that some scientists regard mitochondrial DNA as part of the human genome.

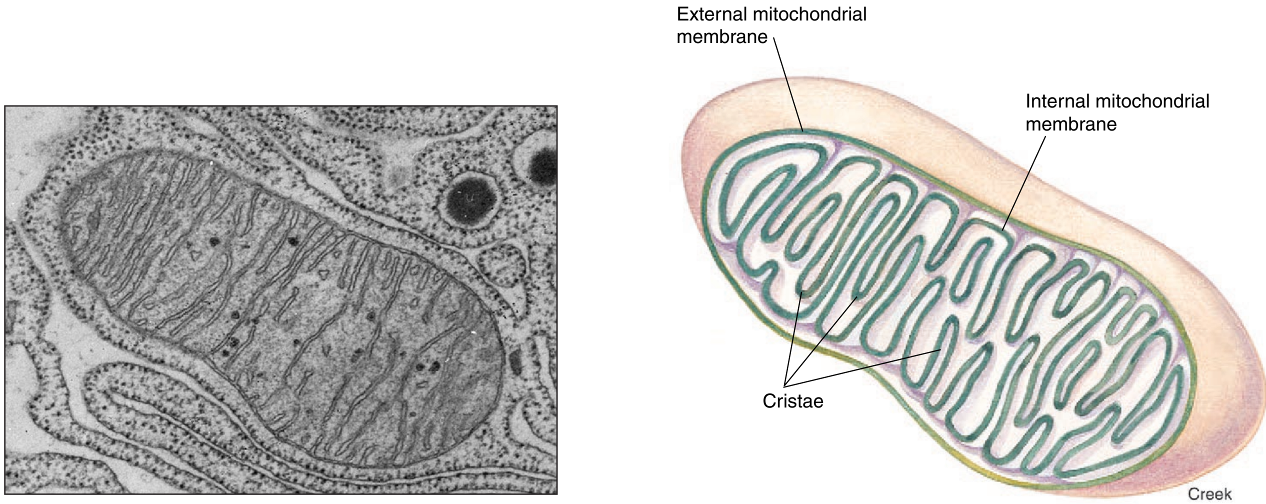
Lysosomes

Lysosomes (*li'sŏ-sōmz*) vary in appearance from granular bodies to small vesicles to membranous spheres (fig. 3.10). They are scattered throughout the cytoplasm. Powerful digestive enzymes enclosed within lysosomes are capable of breaking down protein and carbohydrate molecules. White blood cells contain large numbers of lysosomes and are said to be *phagocytic*, meaning that they will ingest, kill, and digest bacteria through the enzymatic activity of their lysosomes.

The normal atrophy, or decrease in size, of the uterus following the birth of a baby is due to lysosomal digestive activity. Likewise, the secretions of lysosomes are responsible for the regression of the mammary tissue of the breasts after the weaning of an infant.

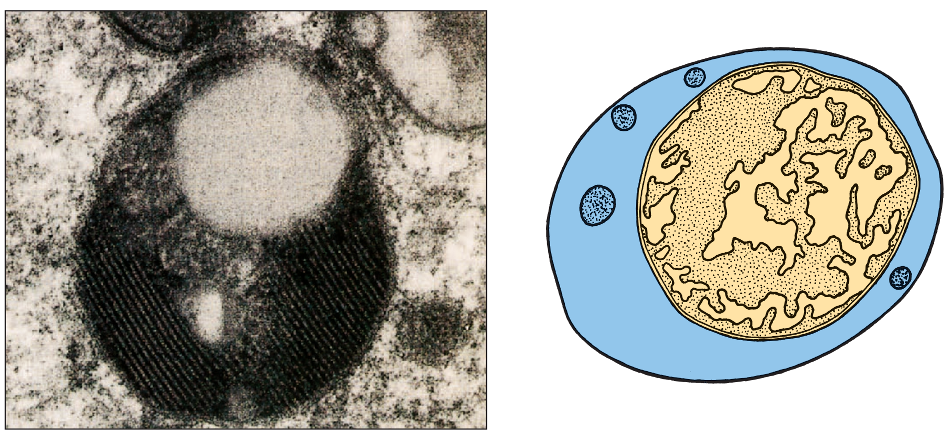
lysosome: Gk. *lysis*, a loosening; *somo*, body

phagocytic: Gk. *phagein*, to eat; *kytos*, a cell



(a) (b)

FIGURE 3.9 (*a*) An electron micrograph of a mitochondrion (about 40,000×). The external mitochondrial membrane and the infoldings (cristae) of the internal mitochondrial membrane are clearly seen. (b) A diagram of a mitochondrion.



(a) (b)

FIGURE 3.10 (*a*) An electron micrograph of a lysosome (about 30,000×). (*b*) A diagram of a lysosome.

Lysosomes also digest worn-out cell parts, and if their membranes are ruptured they destroy the entire cell within which they reside. For this reason, lysosomes are frequently called "suicide packets."

Several diseases arise from abnormalities in lysosome function. The painful inflammation of *rheumatoid arthritis,* for example, occurs when enzymes from lysosomes are released into the joint capsule and initiate digestion of the surrounding tissue.

Lysosomes were not discovered until the early 1950s, but their existence and functions had been predicted before these organelles were actually observed in cells. Such was not the case with other organelles, whose structures generally were observed and described before their functional roles in the cell were understood.

Peroxisomes

Peroxisomes (*pĕ-roks'ĭ-sōmz*) are membranous sacs that resemble lysosomes structurally and they too contain enzymes. Peroxisomes occur in most cells but are particularly abundant in the kidney and liver. Some of the enzymes in peroxisomes promote the breakdown of fats, producing hydrogen peroxide—a highly toxic substance—as a by-product. Hydrogen peroxide is an important compound in white blood cells, which phagocytize diseased or

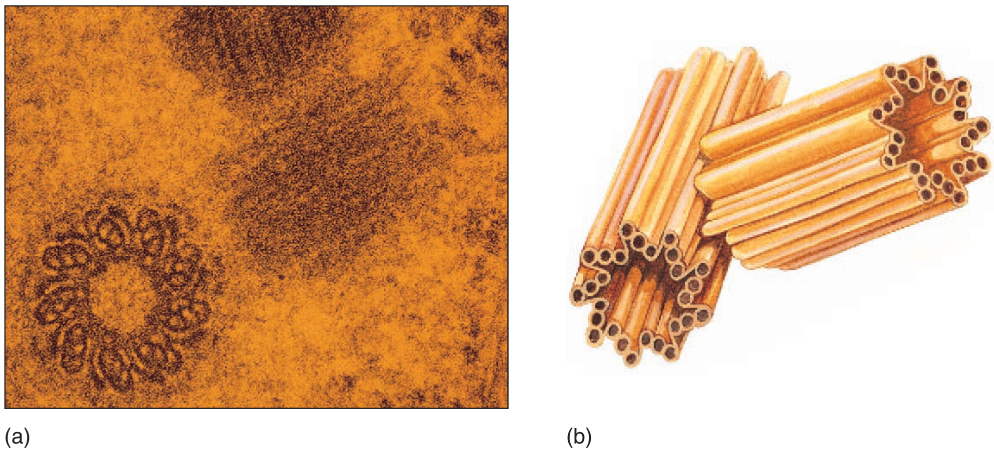


FIGURE 3.11 (*a*) An electron micrograph of centrioles in a centrosome (about 14,200×). (*b*) A diagram showing that the centrioles are positioned at right angles to each other.

worn-out cells. Peroxisomes also contain the enzyme *catalase,* which breaks down excess hydrogen peroxide into water and oxygen so that there is no toxic effect on other organelles within the cytoplasm.

Centrosome and Centrioles

The **centrosome** (central body) is a nonmembranous spherical mass positioned near the nucleus. Within the centrosome, a pair of rodlike structures called **centrioles** (*sen′tre-ōlz*) (fig. 3.11) are positioned at right angles to each other. The wall of each centriole is composed of nine evenly spaced bundles, and each bundle contains three microtubules.

Centrosomes are found only in those cells that can divide. During the mitotic (replication) process, the centrioles move away from each other and take positions on either side of the nucleus. They are then involved in the distribution of the chromosomes during cellular reproduction. Mature muscle and nerve cells lack centrosomes, and thus cannot divide.

Vacuoles

Vacuoles (*vak′yoo-ōlz*) are membranous sacs of various sizes that usually function as storage chambers. They are formed when a portion of the cell membrane invaginates and pinches off during endocytosis. Vacuolation is initiated either by *pinocytosis (pin″ŏ-si-to′sis)*, in which cells take in minute droplets of liquid through the cell membrane, or by *phagocytosis (fag″ŏ-si-to′sis)*, in which the cell membrane engulfs solid particles (fig. 3.12). Vacuoles may contain liquid or solid materials that were previously outside the cell.

vacuole: L. *vacuus,* empty

Fibrils and Microtubules

Both fibrils and microtubules are found throughout the cytoplasm. The **fibrils** are minute rodlike structures, whereas the **microtubules** are fine, threadlike tubular structures of varying lengths (fig. 3.13). Both provide the cell with support by forming a type of cytoskeleton. Specialized fibrils called *myofilaments* are particularly abundant in muscle cells, where they aid in the contraction of these cells. Microtubules are also involved in the transportation of macromolecules throughout the cytoplasm. They are especially abundant in the cells of endocrine organs, where they aid the movement of hormones to be secreted into the blood. Microtubules in certain cells provide flexible support for cilia and flagella.

Cilia and Flagella

Although cilia and flagella appear to be extensions of the cell membrane, they are actually cytoplasmic projections from the interior of the cell. These projections contain cytoplasm and supportive microtubules bounded by the cell membrane (fig. 3.14). Cilia and flagella should not be confused with microvilli or with stereocilia, both of which are specializations of cell membranes.

Cilia (*sil′e-ă*) are numerous short projections from the exposed border of certain cells (fig. 3.15). Ciliated cells are interspersed with mucus-secreting **goblet cells.** There is always a film of mucus on the free surface of ciliated cells. Ciliated cells line the lumina (hollow portions) of sections of the respiratory and reproductive tracts. The function of the cilia is to move the mucus and any adherent material toward the exterior of the body.

Flagella (*flă-jel′ă*) are similar to cilia in basic microtubular structure (see fig. 3.14), but they are somewhat longer than cilia. The only example of a flagellated cell in humans is the sperm cell, which uses the single structure for locomotion.

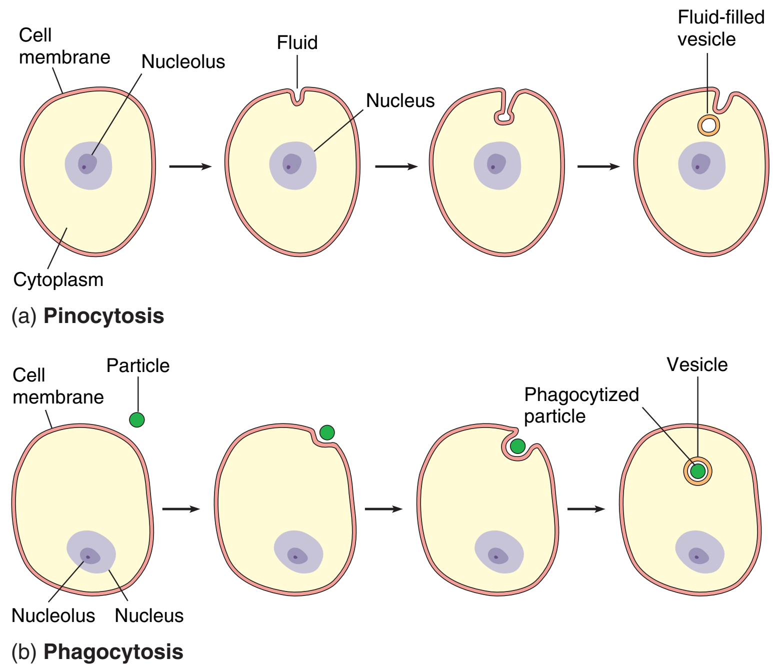


FIGURE 3.12 Pinocytosis and phagocytosis compared. (*a*) During pinocytosis, the cell takes in a minute droplet of fluid from its surroundings. (*b*) During phagocytosis, a solid particle is engulfed and ingested through the cell membrane.

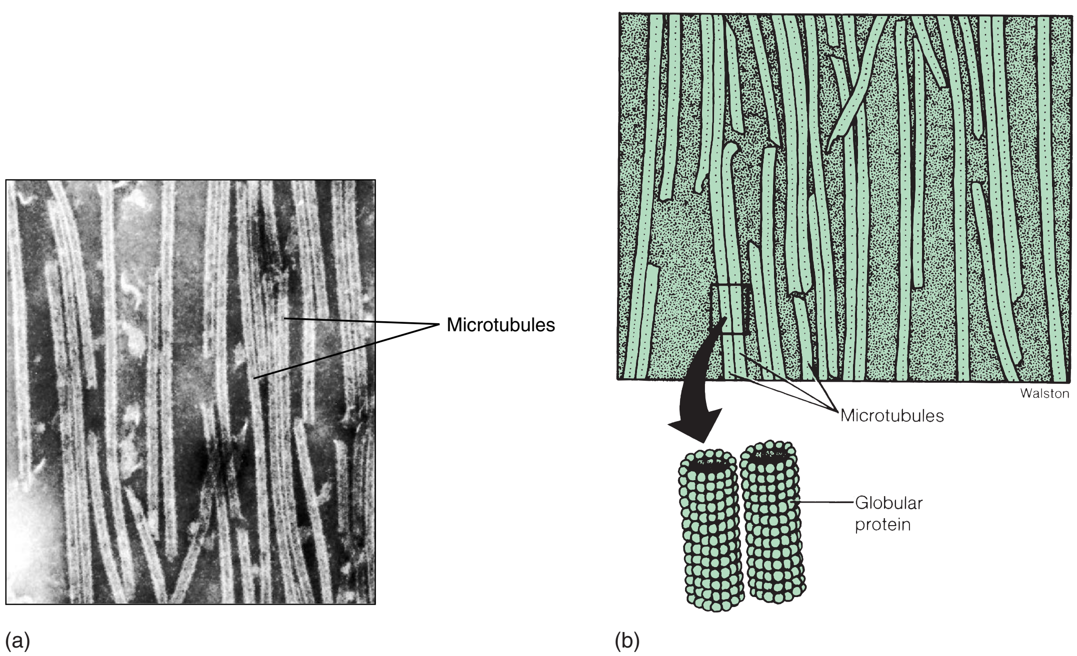


FIGURE 3.13 (*a*) An electron micrograph showing microtubules forming a type of cytoskeleton (about 30,000×). (*b*) A diagram of a microtubule showing the precisely arranged globular proteins of which they are composed.

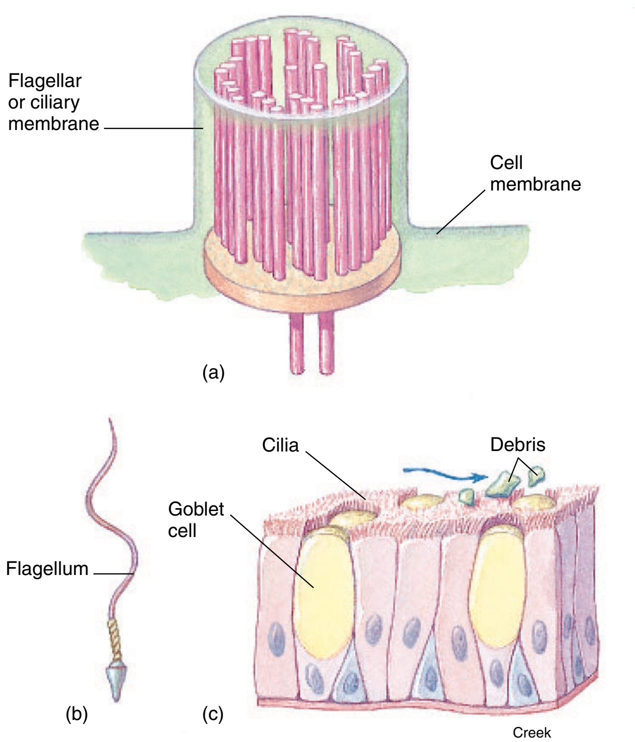


FIGURE 3.14 (*a*) Cilia and flagella are similar in the structural arrangement of their microtubules. (*b*) A sperm cell (spermatozoon) has a single flagellum for propulsion. (*c*) Cilia produce a wavelike motion to move particles toward the outside of the body.

Cell Nucleus

The spherical **nucleus** is usually located near the center of the cell (fig. 3.16). It is the largest structure of the cell and contains the genetic material that determines cellular structure and controls cellular activity.

Most cells contain a single nucleus. Certain cells, however, such as skeletal muscle cells, are multinucleated. The long skeletal muscle fibers contain so much cytoplasm that several governing centers are necessary. Other cells, such as mature red blood cells, lack nuclei. These cells are limited to certain types of chemical activities and are not capable of cell division.

The nucleus is enclosed by a bilayered **nuclear membrane** (*nuclear envelope*) (fig. 3.16). The narrow space between the inner and outer layers of the nuclear membrane is called the **nucleolemma cisterna** (*sis-ter′na*). Minute **nuclear pores** are located along the nuclear membrane. These openings are lined with proteins that act as selective gates, allowing certain molecules, such as proteins, RNA, and protein-RNA complexes, to move between the nucleoplasm and the cytoplasm.

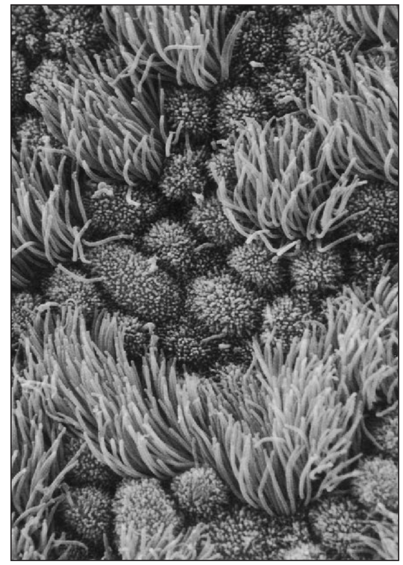


FIGURE 3.15 An electron micrograph of ciliated cells that line the lumen of the uterine tube (640×).

Two important structures within the nucleoplasm of the nucleus determine what a cell will look like and what functions it will perform:

1. **Nucleoli.** Nucleoli (*noo-kle′ŏ-li*) are small, nonmembranous spherical bodies composed largely of protein and RNA. It is thought that they function in the production of ribosomes. As ribosomes are formed, they migrate through the nuclear membrane into the cytoplasm.
2. **Chromatin.** Chromatin (*kro′mă-tin*) is a coiled, threadlike mass. It is the genetic material of the cell and consists principally of protein and DNA molecules. When a cell begins to divide, the chromatin shortens and thickens into rod-shaped structures called *chromosomes* (*kro′mŏ-sōmz*) (figs. 3.17 and 3.18). Each chromosome carries thousands of genes that determine the structure and function of a cell.

Knowledge Check

9. Describe the composition and specializations of the cell membrane. Discuss the importance of the selective permeability of the cell membrane.
10. Describe the various kinds of movements across the cell membrane. Which are passive and which are active?
11. Describe the structure and function of the following cytoplasmic organelles: rough endoplasmic reticulum, Golgi complex, lysosomes, and mitochondria.
12. Distinguish between the nucleus and nucleoli.
13. Distinguish between chromatin and chromosomes.

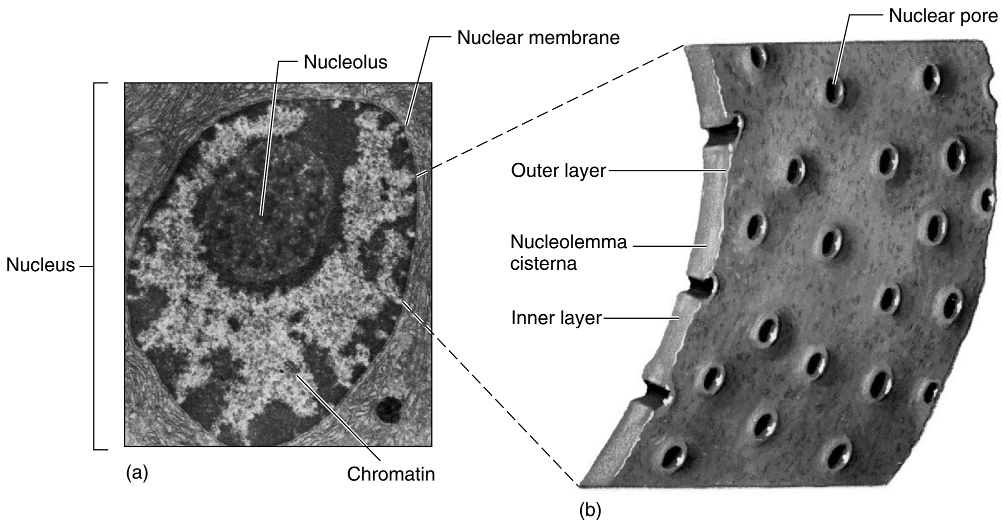


FIGURE 3.16 (*a*) An electron micrograph of the cell nucleus (about 20,000×). The nucleus contains a nucleolus and masses of chromatin. (*b*) The double-layered nuclear membrane has pores that permit substances to pass between nucleus and cytoplasm.

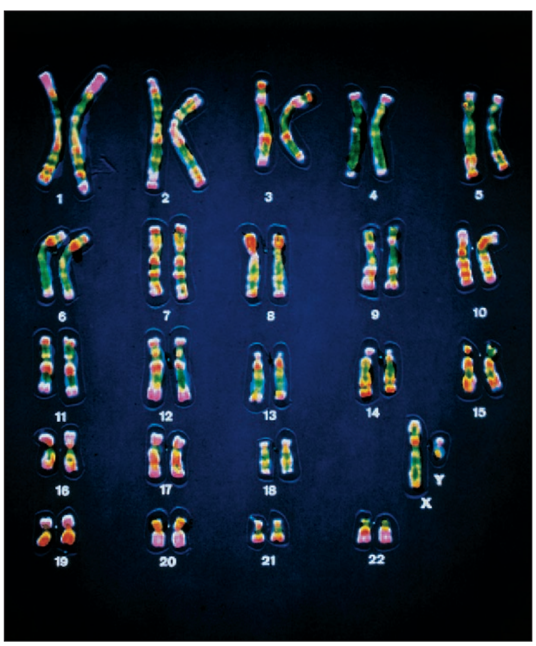


FIGURE 3.17 A color-enhanced light micrograph showing the full complement of male chromosomes arranged in numbered homologous pairs.

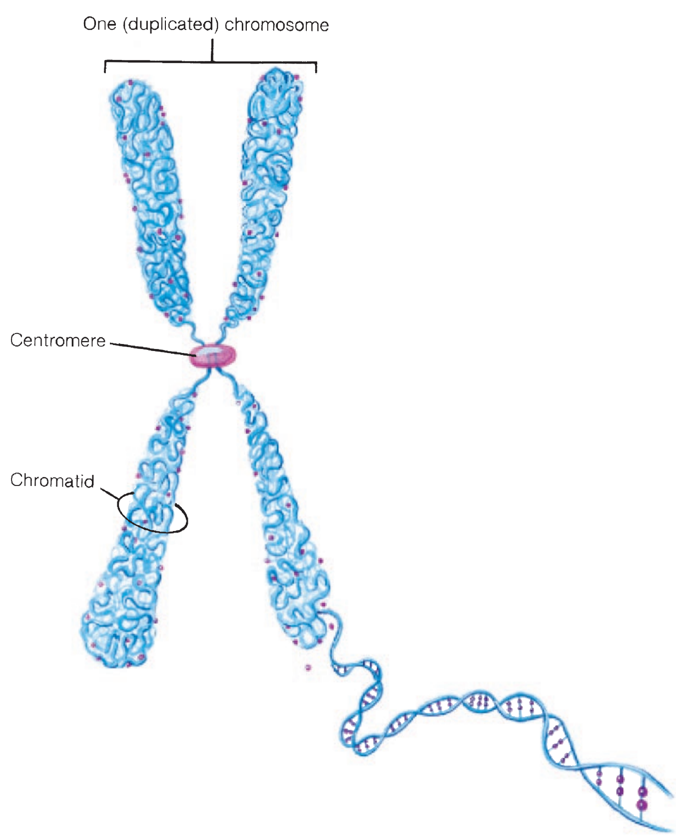


FIGURE 3.18 The structure of a chromosome after DNA replication, in which it consists of two identical strands, or chromatids.

CELL CYCLE

A cell cycle consists of growth, synthesis, and mitosis. Growth is the increase in cellular mass resulting from metabolism. Synthesis is the production of DNA and RNA to regulate cellular activity. Mitosis is the division of the nucleus and cytoplasm of a cell that results in the formation of two daughter cells.

Objective 12 Describe the structure of DNA and RNA molecules.

Objective 13 Discuss genetic transcription and protein synthesis.

Objective 14 List the stages of mitosis and discuss the events of each stage.

Objective 15 Discuss the significance of mitosis.

Cellular replication is one of the principal concepts of biology. Through the process of cellular division called **mitosis** (*mi-to'sis*), a multicellular organism can develop and be maintained. Mitosis enables body growth and the replacement of damaged, diseased, or worn-out cells. The process ensures that each daughter cell will have the same number and kind of chromosomes as the original parent cell.

In an average healthy adult, over 100 billion cells will die and be mitotically replaced during a 24-hour period. This represents a replacement of about 2% of the body mass each day. Some of the most mitotically active sites are the outer layer of skin, the bone marrow, the internal lining of the digestive tract, and the liver.

Before a cell can divide, it must first duplicate its chromosomes so that the genetic traits can be passed to the succeeding generations of cells. A chromosome consists of a coiled deoxyribonucleic acid (DNA) molecule that is complexed with protein. As mentioned previously, chromosomes are formed by the shortening and thickening of the chromatin within the nucleus when the cell begins to divide, at which time they are clearly visible under the compound microscope. There are 23 pairs of chromosomes in each human body (somatic) cell and approximately 20,000 genes are positioned on each chromosome.

Chromosomes are of varied lengths and shapes—some twisted, some rodlike. During mitosis, they shorten and condense, each pair assuming a characteristic shape (see fig. 3.17). On the chromosome is a small, buttonlike body called a **centromere** to which are attached the **spindle fibers** that direct the chromosome toward the pole of the cell during mitosis.

Structure of DNA

The DNA molecule is frequently called a *double helix* because of its resemblance to a spiral ladder (fig. 3.19). The sides of the DNA molecule are formed by alternating units of the sugar *deoxyribose* and phosphoric acid called the *phosphate group*. The rungs of the molecule are composed of pairs of *nitrogenous bases*. The ends of each nitrogenous base are attached to the deoxyribose-phosphate units. There are only four types of nitrogenous bases in a DNA molecule: adenine (A), thymine (T), cytosine (C), and guanine (G).

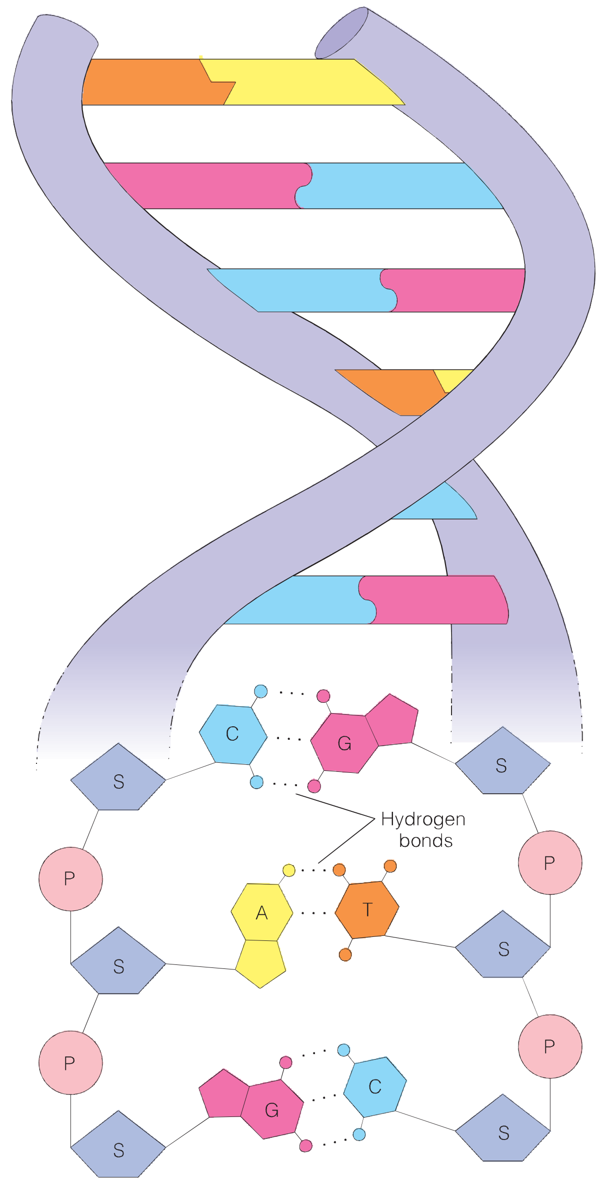


FIGURE 3.19 The double-helix structure of DNA. Each strand of the helix contains only four kinds of organic bases (A, T, C, and G).

The basic structural units of the DNA molecule are called **nucleotides.** Each nucleotide consists of a molecule of deoxyribose, a phosphate group, and one of the four nitrogenous bases. Thus, there is a nucleotide type for each of the four bases.

mitosis: Gk. *mitos*, thread

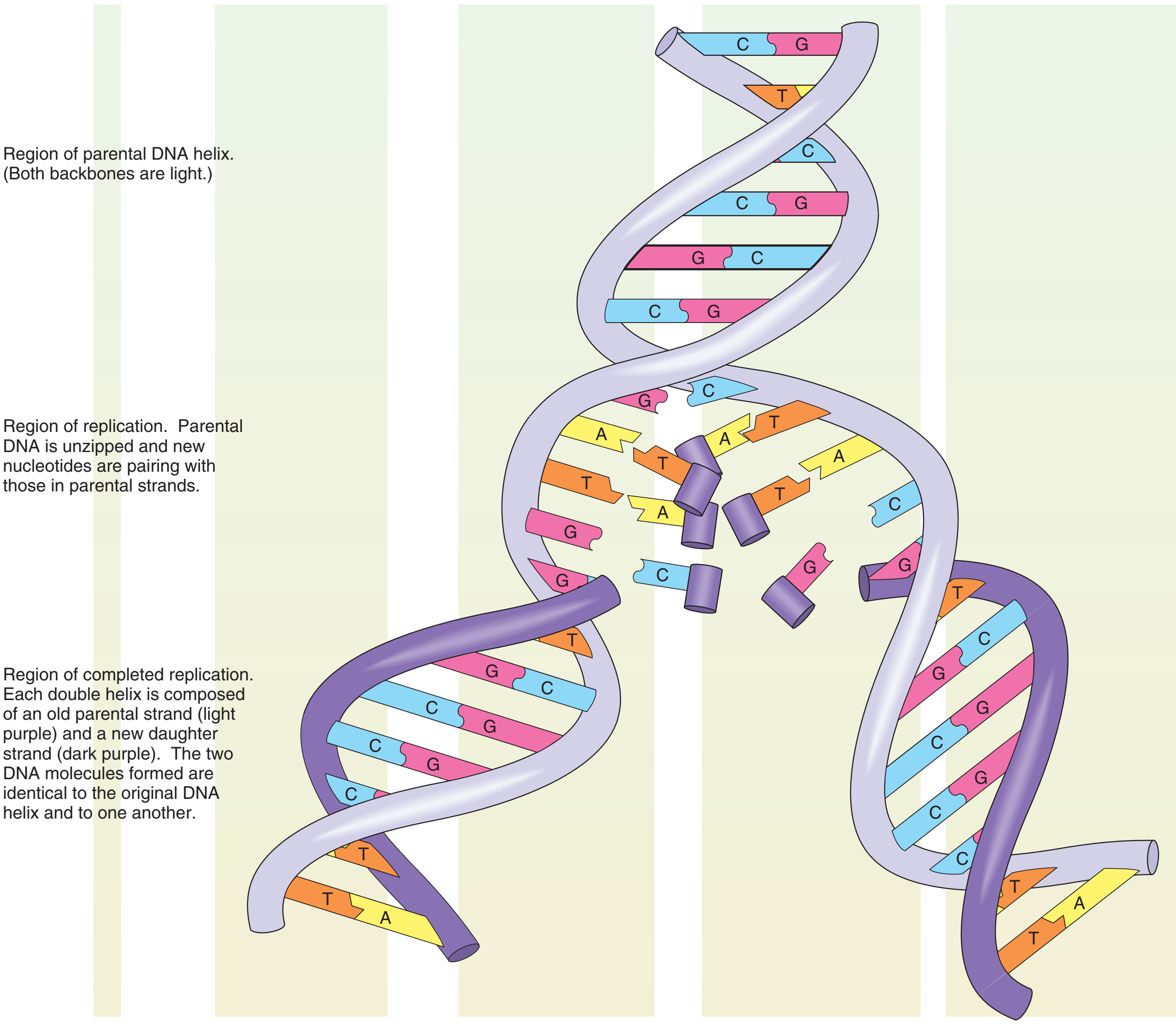


FIGURE 3.20 The replication of DNA. Each new double helix is composed of one old and one new strand. The sequence of bases of each of the new molecules is identical to that of the parent DNA because of complementary base pairing.

The pairing of the nitrogenous bases of the nucleotides is highly specific. The molecular configuration of each base is such that adenine always pairs with thymine and cytosine always pairs with guanine. The hydrogen bonds between these bases are relatively weak and can be easily split during cellular division (fig. 3.20). During division, the sequence of bases along the sides of the DNA molecule serves as a template that determines the sequence along each new strand.

James Watson and Francis Crick, who devised the double-helix model, first described their vision of DNA in 1953, in the journal *Nature* (see table 1.2). The closing sentence of their brief article (a mere 900 words) is a marvel of humility and restraint: "It has not escaped our notice that the specific pairing we have postulated . . . immediately suggests a possible copying mechanism for the genetic material."

Structure of RNA and RNA Synthesis

In the process of protein synthesis, DNA produces a messenger molecule of RNA of complementary structure to transport the genetic information. Like DNA, RNA consists of long chains of nucleotides joined together by sugar-phosphate bonds. However,

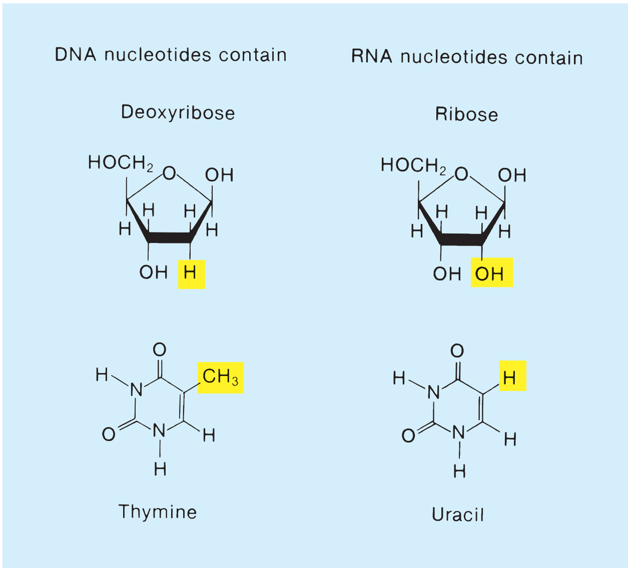


FIGURE 3.21 Differences between the nitrogenous bases and sugars in DNA and RNA.

as shown in Fig. 3.21, nucleotides in RNA differ from those in DNA in the following ways:

- A **ribonucleotide** contains the sugar ribose (instead of deoxyribose).
- The base *uracil* is present in place of thymine.
- RNA is composed of a single polynucleotide strand; it is not double-stranded like DNA.
- RNA is considerably shorter than DNA.

Four types of RNA are produced within the nucleus, each with a different composition and function:

1. **Precursor messenger RNA (pre-mRNA),** which is altered within the nucleus (through cutting and splicing) to form mRNA;
2. **Messenger RNA (mRNA),** which contains the code for the synthesis of specific proteins;
3. **Transfer RNA (tRNA),** which transfers amino acids and which is needed for decoding the genetic message contained in mRNA; and
4. **Ribosomal RNA (rRNA),** which forms part of the structure of ribosomes.

The DNA that codes for rRNA synthesis is located in the nucleolus. Pre-mRNA and tRNA synthesis is controlled by DNA located elsewhere in the nucleus.

Genetic Transcription—RNA Synthesis

During cell division, the chromosomes are inactive packages of DNA. The genes do not become active until the chromosomes unravel. Active DNA directs the metabolism of the cell indirectly through its regulation of RNA and protein synthesis.

One gene codes for one polypeptide chain. Each gene is a strand of DNA that is several thousand nucleotide pairs long. In order for the genetic code to be translated for the synthesis of specific proteins, the DNA code must first be transcribed into an RNA code (fig. 3.22). This is accomplished by DNA-directed RNA synthesis, or **genetic transcription.**

During RNA synthesis, the enzyme *RNA polymerase* breaks the weak hydrogen bonds between paired DNA bases. This does not occur throughout the length of DNA, but only in the regions that are to be transcribed (there are base sequences that code for "start" and "stop"). Double-stranded DNA, therefore, separates in these regions so that the freed bases can pair with the complementary RNA nucleotide bases that are freely available in the nucleus.

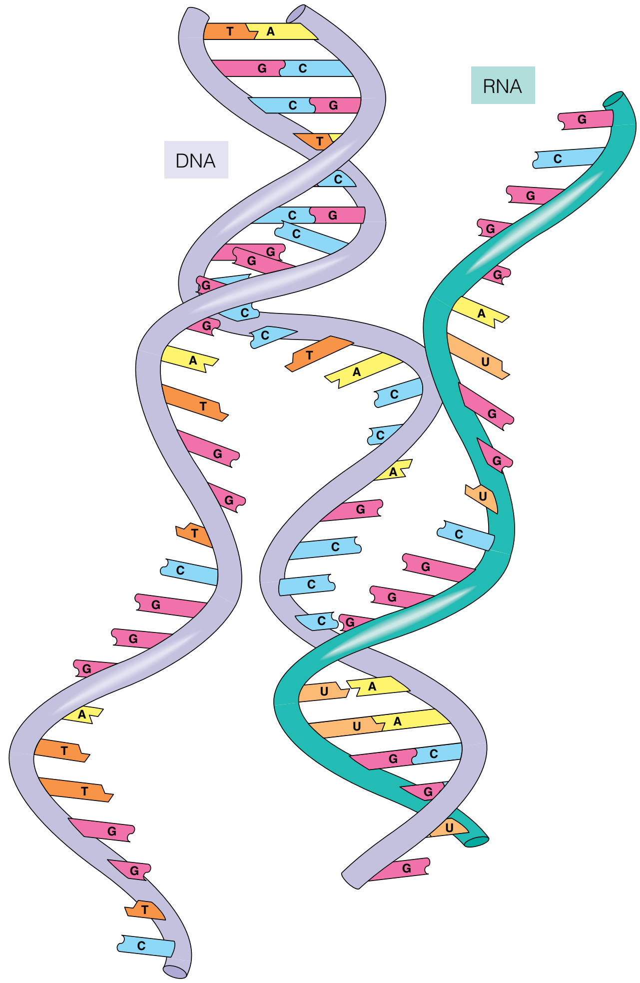


FIGURE 3.22 RNA synthesis (genetic transcription). Notice that only one of the two DNA strands is used to form a single-stranded molecule of RNA.

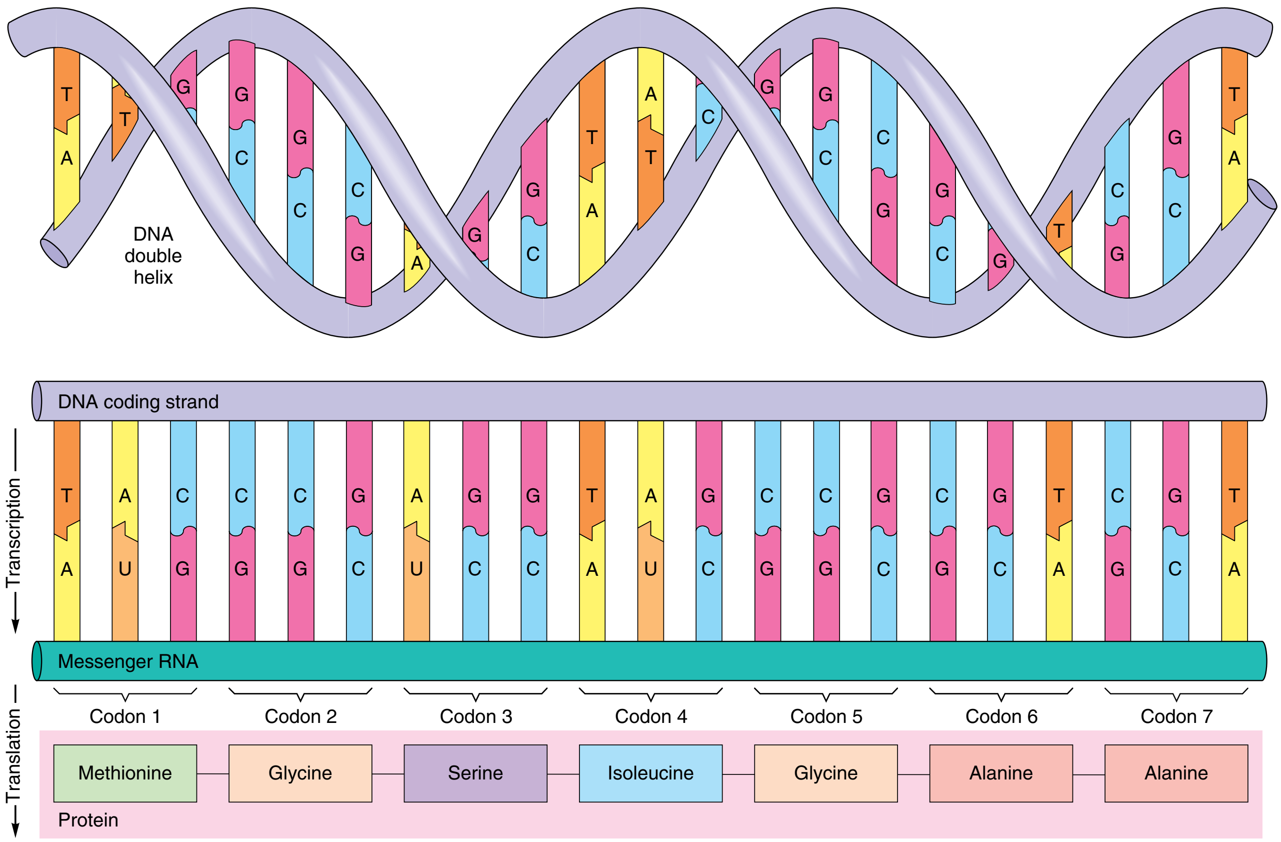


FIGURE 3.23 The genetic code is first transcribed into base triplets (codons) in mRNA and then translated into a specific sequence of amino acids in a protein.

This pairing of bases follows the law of complementary base pairing: guanine bonds with cytosine (and vice versa), and adenine bonds with uracil (because uracil in RNA is equivalent to thymine in DNA). In RNA synthesis, only one of the two freed strands of DNA serves as a guide (see fig. 3.22). Once an RNA molecule has been produced, it detaches from the DNA strand on which it was formed. This process can continue indefinitely, producing many thousands of RNA copies of the DNA strand being transcribed. When the gene is no longer to be transcribed, the separated DNA strands can recoil into their helical form.

In the case of pre-mRNA, the finished molecule is altered after synthesis. Within the pre-mRNA are noncoding regions known as *introns*. The introns are removed through the action of enzymes, and the coding regions are then spliced together so that they can direct the synthesis of a specific protein.

Protein Synthesis

Once produced, mRNA leaves the nucleus and enters the cytoplasm, where it attaches to ribosomes. The mRNA passes through a number of ribosomes to form a polyribosome, or polysome for short. The association of mRNA with ribosomes is needed for **genetic translation**—the production of specific proteins according to the code contained in the mRNA base sequences.

Functions of Codons and Anticodons

Each mRNA molecule contains several hundred or more nucleotides, arranged in the sequence determined by complementary base pairing with DNA during genetic transcription (RNA synthesis). Every three bases, or base triplet, is a "code word"—called a **codon**—for a specific amino acid. Sample codons and their amino acid "translation" are shown in figure 3.23. As mRNA move through the ribosome, the sequence of codons is translated into a sequence of specific amino acids within a growing polypeptide chain.

Translation of the codons is accomplished by transfer RNA (tRNA) and particular enzymes. One end of each tRNA contains the **anticodon.** The anticodon consists of three nucleotides that are complementary to a specific codon in MRNA. Enzymes in the cell cytoplasm join specific amino acids to the ends of tRNA, so that a tRNA with a given anticodon is always bonded to one specific amino acid. There are 20 different varieties of

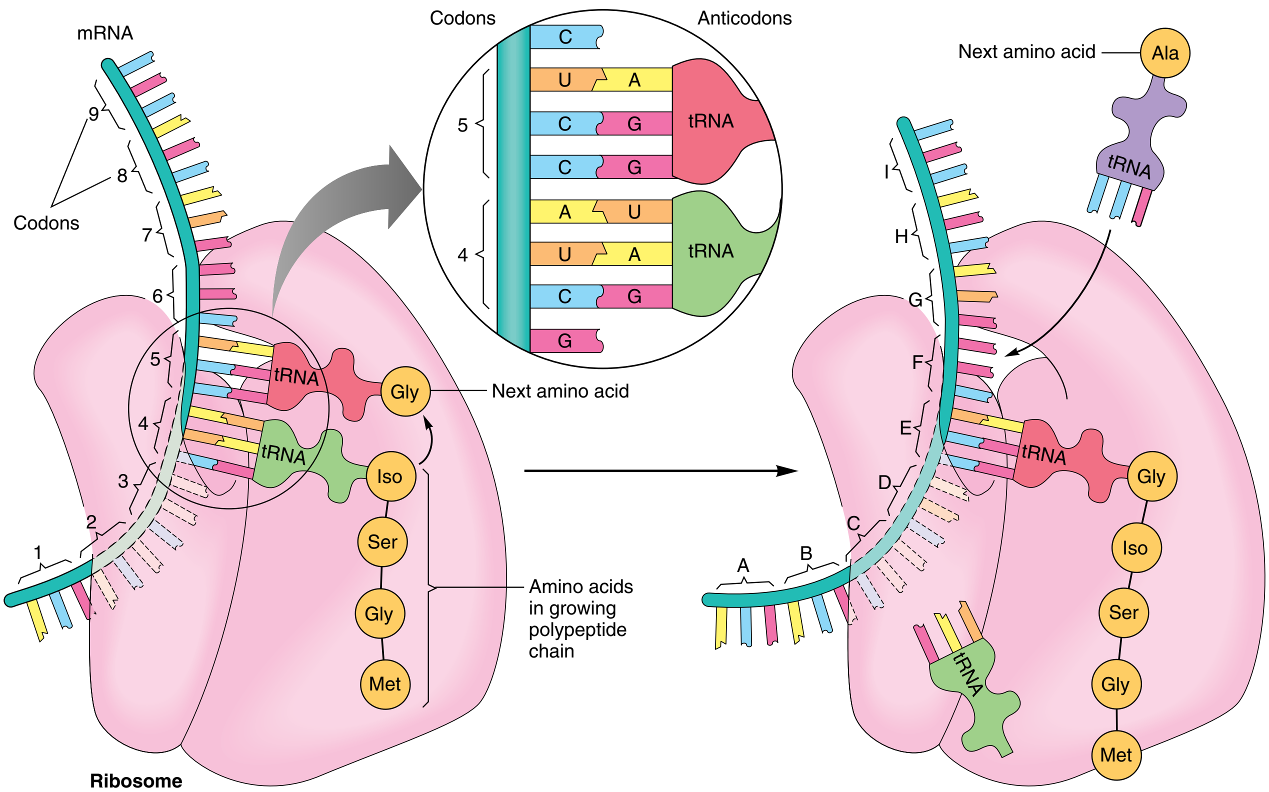


FIGURE 3.24 The actions of mRNA and tRNA in genetic translation. The three-letter abbreviations for the amino acids in the growing polypeptide chain stand for the amino acids indicated in figure 3.23.

synthetase enzymes—one for each type of amino acid. Each synthetase must not only recognize its specific amino acid, it must also be able to attach this amino acid to the particular tRNA that has the correct anticodon for that amino acid. Each of the tRNA molecules in the cytoplasm of a cell is thus bonded to a specific amino acid and is capable of bonding by its anticodon base triplet with a specific codon in mRNA.

Formation of a Polypeptide

The anticodons of tRNA bind to the codons of mRNA as the mRNA moves through the ribosome. Because each tRNA molecule carries a specific amino acid, the joining together of these amino acids by peptide bonds forms a polypeptide whose amino acid sequence has been determined by the sequence of codons in mRNA.

The first and second tRNA bring the first and second amino acids together, and a peptide bond forms between them. The first amino acid then detaches from its tRNA, so that a dipeptide is linked by the second amino acid to the second tRNA. When the third tRNA binds to the third codon, the amino acid it brings forms a peptide bond with the second amino acid (which detaches from its tRNA). A tripeptide is thus attached by the third amino acid to the third tRNA. The polypeptide chain lengthens as new amino acids are added to its growing tip (fig. 3.24). This polypeptide chain is always attached by means of only one tRNA to the strand of mRNA, and this tRNA molecule is always the one that has added the latest amino acid to the growing polypeptide.

As the polypeptide chain becomes longer, interactions between its amino acids cause the chain to twist into a helix (secondary structure) and to fold and bend upon itself (tertiary structure). At the end of this process, the new protein detaches from the tRNA as the last amino acid is added.

Cell Cycle and Cell Division

A **cell cycle** is the series of changes that a cell undergoes from the time it is formed until it has completed a division and reproduced itself. **Interphase** is the first period of the cycle, from cell formation to the start of cell division (fig. 3.25). During interphase, the cell grows, carries on metabolic activities, and prepares itself for division.

Interphase is divided into **G1, S,** and **G2 phases.** During the G1 (first growth) phase, the cell grows rapidly and is metabolically active. The duration of G1 varies considerably in different types of cells. It may last only hours in cells that have rapid

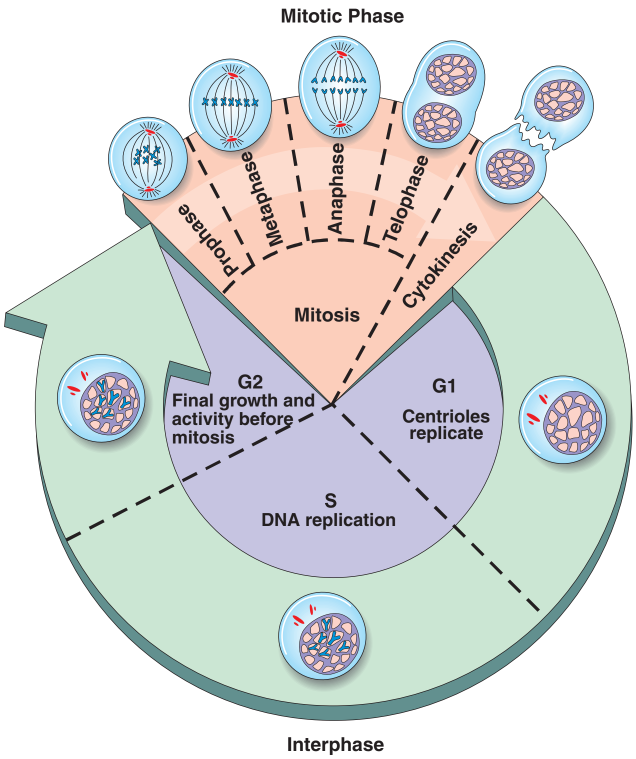


FIGURE 3.25 Interphase and the mitotic phase are the two principal divisions of the cell cycle. During the mitotic phase, nuclear division is followed by cytoplasmic division and the formation of two daughter cells.

division rates, or it may be a matter of days or even years for other cells. At the end of G1, the centrioles replicate in preparation for their role in cell division. During the S (synthetic) phase, the DNA in the nucleus of the cell replicates, so that the two future cells will receive identical copies of the genetic material. During the G2 (second growth) phase, the enzymes and other proteins needed for the division process are synthesized, and the cell continues to grow.

The actual division of a cell is referred to as the **mitotic phase,** or simply **M phase** (fig. 3.25). The mitotic phase is further divided into mitosis and cytokinesis. **Mitosis** is the period of a cell cycle during which there is nuclear division and the duplicated chromosomes separate to form two genetically identical daughter nuclei. The process of mitosis takes place in four successive stages, each stage passing into the next without sharp structural distinctions. These stages are *prophase*, *metaphase*, *anaphase*, and *telophase* (fig. 3.26). **Cytokinesis** (*si″to-kĭnésis*) is division of the cytoplasm, which takes place during telophase.

cytokinesis: Gk. *kytos*, a hollow; *kinesis*, movement

Highly specialized cells, such as muscle and nerve cells, do not replicate after a person is born. If these cells die, as the result of disease, injury, or even disuse, they are not replaced and scar tissue may form. Nerve cells are especially vulnerable to damage from oxygen deprivation, alcohol, and various other drugs.

Knowledge Check

14. Explain why the DNA molecule is described as a double helix.
15. Describe the various forms of RNA, and discuss how RNA directs protein synthesis.
16. List the phases in the life cycle of a cell and describe the principal events that occur during each phase.
17. Explain why mitosis is such an important biological process.

CLINICAL CONSIDERATIONS

Cellular Adaptations

Apparently included within cellular specialization of structure and function is mitotic potential. Certain cells do not require further division once the organ to which they contribute becomes functional. Others, as part of their specialization, require continuous mitosis to keep an organ healthy. Thus, in the adult, it is found that some cells divide continually, some occasionally, and some not at all. For example, epidermal cells, hemopoietic cells within bone marrow, and cells that line the lumen of the GI tract divide continually throughout life. Cells within specialized organs, such as the liver or kidneys, divide as the need becomes apparent. Naturally occurring cellular death, disease, or trauma from surgery or injury may necessitate mitosis in these organs. Still other cells, such as muscle or nerve cells, lose their mitotic ability as they become differentiated. Trauma to these cells frequently causes a permanent loss of function.

Although the factors regulating mitosis are unclear, evidence suggests that mitotic ability is genetically controlled and, for those cells that do divide, even the number of divisions is predetermined. If this is true, it may be a factor in the aging process. Physical stress, nutrition, and hormones definitely have an effect on mitotic activity. It is thought that the replication activity of cells might be controlled through a feedback mechanism involving the release of a *growth-inhibiting substance*. Such a substance might slow or inhibit the cell divisions and growth of particular organs once they had amassed a certain number of cells or had reached a certain size.

Except for cells on exposed surfaces, most cells of the body are located in a fairly homogeneous environment, where continual adaptation to change is not necessary for survival. However, cells do have remarkable adaptability and resilience, enabling them to withstand conditions that might otherwise be lethal. Prolonged exposure to sunlight, for example, stimulates the synthesis of melanin and tanning of the skin. Likewise, mechanical

(a) Interphase
- The chromosomes are in an extended form and seen as chromatin in the electron microscope.
- The nucleus is visible.

(b) Prophase
- The chromosomes are seen to consist of two chromatids joined by a centromere.
- The centrioles move apart toward opposite poles of the cell.
- Spindle fibers are produced and extended from each centrosome.
- The nuclear membrane starts to disappear.
- The nucleolus is no longer visible.

(c) Metaphase
- The chromosomes are lined up at the equator of the cell.
- The spindle fibers from each centriole are attached to the centromeres of the chromosomes.
- The nuclear membrane has disappeared.

(d) Anaphase
- The centromeres split, and the sister chromatids separate as each is pulled to an opposite pole.

(e) Telophase
- The chromosomes become longer, thinner and less distance.
- New nuclear membranes form.
- The nucleolus reappears.
- Cell division is nearly complete.

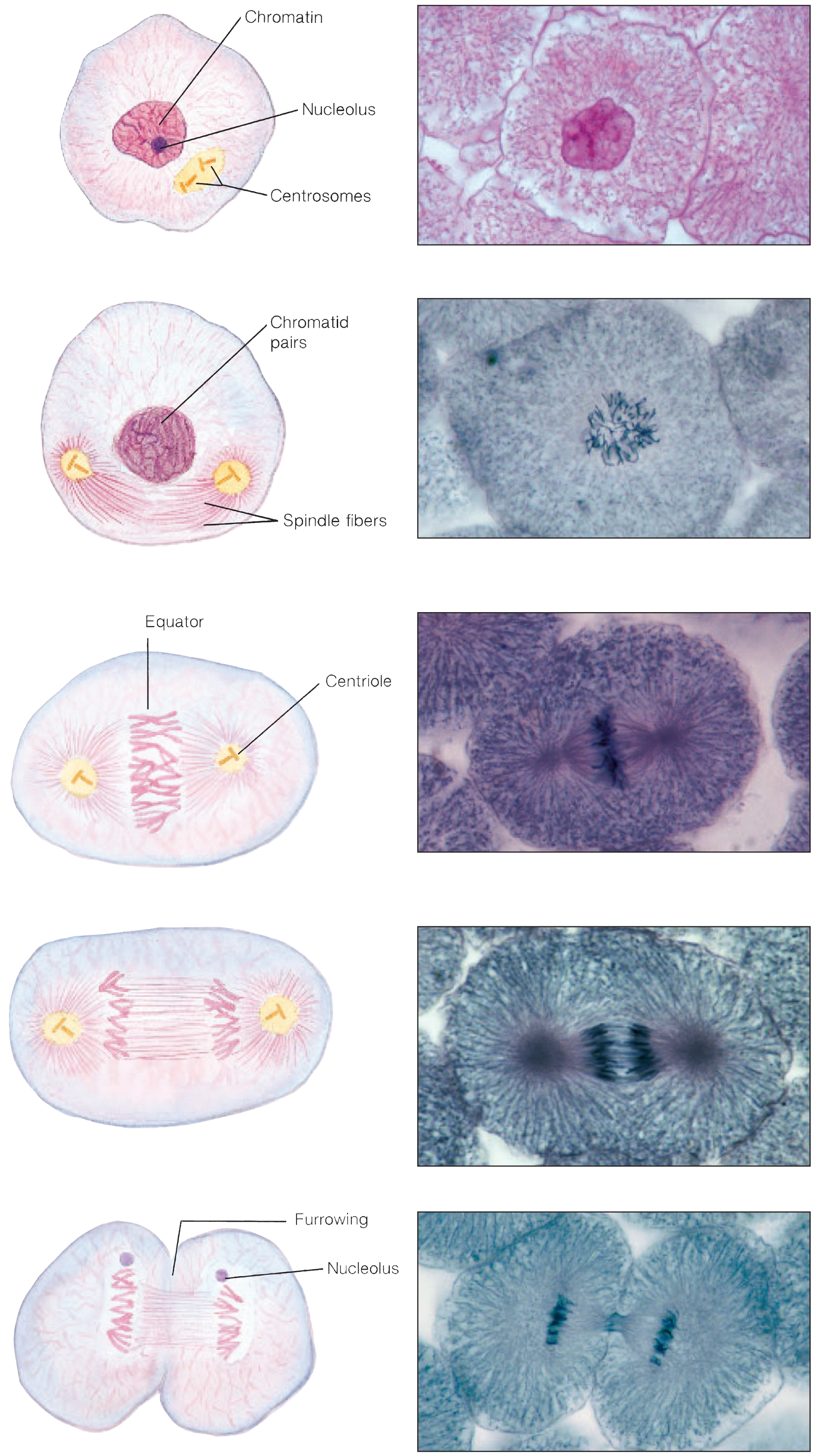


FIGURE 3.26 The stages of mitosis.

friction to the skin stimulates mitotic activity and the synthesis of a fibrous protein, *keratin,* which results in the formation of a protective callus.

Cells adapt to potentially injurious stimuli by several specific mechanisms. **Hypertrophy** (*hi″pe′rtrŏ-fe*) refers to an increase in the size of cells resulting from increased synthesis of protein, nucleic acids, and lipids. Cellular hypertrophy can be either compensatory or hormonal. **Compensatory hypertrophy** occurs when increased metabolic demands on particular cells result in an increase in cellular mass. Examples of compensatory hypertrophy include the enlargement of skeletal muscle fibers as a result of exercise and cardiac (heart) muscle fibers or kidney cells because of an increased work demand. Hypertension (high blood pressure) causes cardiac cells to hypertrophy because they must pump blood against raised pressures. After the removal of a diseased kidney, there is a compensatory increase in the size of the cells of the remaining kidney so that its normal weight is approximately doubled. Examples of **hormonal hypertrophy** are the increased size of the breasts and smooth muscles of the uterus in a pregnant woman.

Hyperplasia (*hi″per-pla′ze-ă*) refers to an increase in the number of cells formed as a result of increased mitotic activity. The removal of a portion of the liver, for example, leads to regeneration, or hyperplasia, of the remaining liver cells to restore the loss. But the triggering mechanism for hyperplasia is not known. In women, a type of hormonally induced hyperplasia occurs in cells of the endometrium of the uterus after menstruation, which restores this layer to a suitable state for possible implantation of an embryo.

Atrophy (*at′rŏ-fe*) refers to a decrease in the size of cells and a corresponding decrease in the size of the affected organ. Atrophy can occur in the cells of any organ and may be classified as **disuse atrophy, disease atrophy,** or **aging (senile) atrophy.**

Metaplasia (*met′ă″-plá ze-ă*) is a specialized cellular change in which one type of cell transforms into another. Generally, it involves the change of highly specialized cells into more generalized, protective cells. For example, excessive exposure to inhaled smoke causes the specialized ciliated columnar epithelial cells lining the bronchial airways to change into stratified squamous epithelium, which is more resistant to injury from smoke.

Trauma to Cells

As adaptable as cells are to environmental changes, they are subject to damage from aging and disease. If a trauma causes extensive cellular death, the condition may become life threatening. A person dies when a vital organ can no longer perform its metabolic role in sustaining the body.

Energy deficit means that more energy is required by a cell than is available. Cells can tolerate certain mild deficits because of various reserves stored within the cytoplasm, but a severe or prolonged deficit will cause cells to die. An energy deficit occurs when the cells do not have enough glucose or oxygen to allow for glucose combustion. Examples of energy deficits are low levels of blood sugar (hypoglycemia) and the impermeability of the cell membrane to glucose (as in diabetes mellitus). Malnutrition also may result in an energy deficit. Few cells can tolerate an interruption in oxygen supply. Cells of the brain and the heart have tremendous oxygen demands, and an interruption of the supply to these organs can cause death in a matter of minutes.

Physical injury to cells, another type of trauma, occurs in a variety of ways. High temperature (**hyperthermia**) is generally less tolerable to cells than low temperature (**hypothermia**). Respiratory rate, heart rate, and metabolism accelerate with hyperthermia. Continued hyperthermia causes protein coagulation within cells, and eventually cellular death. In frostbite, rapid or prolonged chilling causes cellular injury. In severe frostbite, ice crystals form and cause the cells to burst.

Burns are particularly significant if they cause damage to the deeper skin layers, which interferes with the mitotic activity of cells (see fig. 5.20). Of immediate concern with burns, however, is the devastating effect of fluid loss and infection through traumatized cell membranes.

Accidental poisoning and suicide through drug overdose account for large numbers of deaths in the United States and elsewhere. **Drugs** and **poisons** can cause cellular dysfunction by disrupting DNA replication, RNA transcription, enzyme systems, or cell membrane activity.

Radiation causes a type of cell trauma that is cumulative in effect. When X rays are administered for therapeutic purposes (radiotherapy), small doses are focused on a tumorous area over a course of many days to prevent widespread cellular injury. Some cells are more sensitive to radiation than others. Immature or mitotically active cells are highly sensitive, whereas cells that are no longer growing, such as neurons and muscle cells, are not as vulnerable to radiation injury.

Infectious agents, or **pathogens,** also cause cellular dysfunction. Viruses and bacteria are the most common pathogens. Viruses usually invade and destroy cells as they reproduce themselves. Bacteria, on the other hand, do not usually invade cells but will frequently poison cells with their toxic metabolic wastes.

Medical Genetics

Medical genetics is a branch of medicine concerned with diseases that have a genetic origin. Genetic factors include abnormalities in chromosome number or structure and mutant genes. Genetic diseases are a diverse group of disorders, including malformed blood cells (sickle-cell anemia), defective blood clotting (hemophilia), and mental retardation (Down syndrome).

Chromosomal abnormalities occur in approximately 0.6% of live-birth infants. The majority (70%) are subtle, cause no problems, and usually go undetected. Structural changes in the DNA that are passed from parent to offspring by means of sex

hypertrophy: Gk. *hyper,* over; *trophe,* nourishment
hyperplasia: Gk. *hyper,* over; *plasis,* a molding
atrophy: Gk. *a,* without; *trophe,* nourishment
metaplasia: Gk. *meta,* between; *plasis,* a molding

cells are called **mutations** (*myoo-ta'shunz*). Mutations either occur naturally or are environmentally induced through chemicals or radiation. Natural mutations are not well understood. About 12% of all congenital malformations are caused by mutations and probably come about through an interaction of genetic and environmental factors. Many of these problems can be predicted by knowing the genetic pedigree of prospective parents and prevented through genetic counseling. **Teratology** (*ter-ă-tol'ŏ-je*) is the science concerned with developmental defects and the diagnosis, treatment, and prevention of malformations.

Genetic problems are occasionally caused by having too few or too many chromosomes. The absence of an entire chromosome is termed **monosomy** (*mon'o-som"me*). Embryos with monosomy usually die. People with **Turner's syndrome** have only one X chromosome and have a better chance of survival than those who are missing one of the other chromosomes. **Trisomy** (*tri' so-me*), a genetic condition in which an extra chromosome is present, occurs more frequently than monosomy. The best known among the trisomies is **Down syndrome.**

In an attempt to better understand medical genetics, the *Human Genome Project* was launched by Congress in 1988 with the ambitious goal of completely mapping the human genome. Scientists are currently on the verge of determining the exact sequences of bases with which the 3 billion base pairs are arranged to form the 50,000 to 100,000 genes in the haploid human genome of a sperm cell or ovum. Knowing this information will provide the ultimate reference for diagnosis and treatment of the 4000 genetic diseases that are known to be directly caused by particular abnormal genes.

Cancer

Cancer refers to a complex group of diseases characterized by uncontrolled cell replication. The rapid proliferation of cells results in the formation of a **neoplasm,** or new cellular mass. Neoplasms, frequently called *tumors*, are classified as benign or malignant based on their cytological and histological features. **Benign neoplasms** usually grow slowly and are confined to a particular area. These types are usually not life threatening unless they grow to large sizes in vital organs like the brain. **Malignant neoplasms** (fig. 3.27) grow rapidly and **metastasize** (*mĕ-tas'tă-sīz*) (fragment and spread) easily through lymphatic or blood vessels. The original malignant neoplasm is called the *primary growth* and the new tumors, or metastatic tumors, are called *secondary growths*.

Cancer cells resemble undifferentiated or primordial cell types. Generally they do not mature before they divide and are not capable of maintaining normal cell function. Cancer causes death when a vital organ regresses because of competition from cancer cells for space and nutrients. The pain associated with cancer develops when the growing neoplasm affects sensory neurons.

FIGURE 3.27 An electron micrograph of cancer cells from the respiratory tract (59,800×).

The various types of cancers are classified on the basis of the tissue in which they develop. Lymphoma, for example, is a cancer of lymphoid tissue; osteogenic cancer is a type of bone cancer; myeloma is cancer of the bone marrow; and sarcoma is a general term for any cancer arising from cells of connective tissue.

The etiology (cause) of cancers is largely unknown. However, initiating factors, or **carcinogens** (*kar-sin'ŏ-jenz*), such as viruses, chemicals, or irradiation, may provoke cancer to develop. Cigarette smoking, for example, causes various respiratory cancers to develop. The tendency to develop other types of cancers has a genetic basis. Some researchers even think that physiological stress can promote certain types of cancerous activity. Because the causes of cancer are not well understood, emphasis is placed on early detection with prompt treatment.

Aging

Although there are obvious external indicators of aging—graying and loss of hair, wrinkling of skin, loss of teeth, and decreased muscle mass—changes within cells as a result of aging are not as apparent and are not well understood. Certain organelles alter with age. The mitochondria, for example, may change in structure and number, and the Golgi complex may fragment. Also, lipid vacuoles tend to accumulate in the cytoplasm, and the cytoplasmic food stores that contain glycogen decrease.

mutation: L. *mutare*, to change

teratology: Gk. *teras*, monster; *logos*, study

Turner's syndrome: from Henry H. Turner, American endocrinologist, 1892–1970

Down syndrome: from John L. H. Down, English physician, 1828–96

carcinogen: Gk, *karkinos*, cancer

CHAPTER 3

The chromatin and chromosomes within the nucleus show changes with aging, such as clumping, shrinking, or fragmenting with repeated mitotic divisions. There is strong evidence that certain cell types have a predetermined number of mitotic divisions that are genetically controlled, thus determining the overall vitality and longevity of an organ. If this is true, identifying and genetically manipulating the "aging gene" might be possible.

Extracellular substances also change with age. Protein strands of *collagen* and *elastin* change in quality and number in aged tissues. Elastin plays an important role in the walls of arteries, and its deterioration is thought to be associated with such vascular diseases as arteriosclerosis in aged persons.

Clinical Case Study Answer

Giving a substance that competes for the enzyme alcohol dehydrogenase can inhibit the reaction that forms the toxic metabolite of ethylene glycol. Thus, infusing a nearly intoxicating dose of alcohol can spare the kidneys from harm. The ethylene glycol is then excreted harmlessly.

Chapter Summary

Introduction to Cytology (p. 49)

1. Cells are the structural and functional units of the body. Cellular function is referred to as metabolism and the study of cells is referred to as cytology.
2. Cellular function depends on the specific membranes and organelles characteristic of each type of cell.
3. All cells have structural modifications that serve functional purposes.

Cellular Chemistry (pp. 50–52)

1. Four elements (oxygen, carbon, hydrogen, and nitrogen) compose over 95% of the body's mass and are linked together to form inorganic and organic compounds.
2. Water is the most abundant inorganic compound in cells and is an excellent solvent.
   (a) Water is important in temperature control and hydrolysis.
   (b) Dehydration, a condition in which fluid loss exceeds fluid intake, may be a serious problem—especially in infants.
3. Electrolytes are inorganic compounds that form ions when dissolved in water.
   (a) The three classes of electrolytes are acids, bases, and salts.
   (b) Electrolytes are important in maintaining pH, in conducting electrical currents, and in regulating the activity of enzymes.
4. Proteins are organic compounds that may exist by themselves or be conjugated with other compounds.
   (a) Proteins are important structural components of the body and are necessary for cellular growth, repair, and division.
   (b) Enzymes and hormones are examples of specialized proteins.
5. Carbohydrates are organic compounds containing carbon, hydrogen, and oxygen, with a 2:1 ratio of hydrogen to oxygen.
   (a) The carbohydrate group includes the starches and sugars.
   (b) Carbohydrates are the most abundant source of cellular energy.
6. Lipids are organic fats and fat-related substances.
   (a) Lipids are composed primarily of carbon, hydrogen, and oxygen.
   (b) Lipids serve as an important source of energy, form parts of membranes, and protect and insulate various parts of the body.

Cellular Structure (pp. 52–64)

1. A cell is composed of a cell membrane, cytoplasm and organelles, and a nucleus.
2. The cell membrane, composed of phospholipid and protein molecules, encloses the contents of the cell and regulates the passage of substances into and out of the cell.
   (a) The permeability of the cell membrane depends on its structure, the size of the molecules, ionic charge, lipid solubility, and the presence of carrier molecules.
   (b) Cell membranes may be specialized with such structures as microvilli, sacs, and hair cells.
3. Cytoplasm refers to the material between the cell membrane and the nucleus. Nucleoplasm is the material within the nucleus. Protoplasm is a collective term for both the cytoplasm and nucleoplasm.
4. Organelles are specialized components within the cytoplasm of cells.
   (a) Endoplasmic reticulum provides a framework within the cytoplasm and forms a site for the attachment of ribosomes. It functions in the synthesis of lipids and proteins and in cellular transport.
   (b) Ribosomes are particles of protein and RNA that function in protein synthesis. The protein particles may be used within the cell or secreted.
   (c) The Golgi complex consists of membranous vesicles that synthesize glycoproteins and secrete lipids. The Golgi complex is extensive in secretory cells, such as those of the pancreas and salivary glands.
   (d) Mitochondria are membranous sacs that consist of outer and inner mitochondrial layers and folded membranous extensions of the inner layer called cristae. The mitochondria produce ATP and are called the "powerhouses" of a cell. Mitochondria are lacking in sperm cells and red blood cells.
   (e) Lysosomes are spherical bodies that contain digestive enzymes. They are abundant in the phagocytic white blood cells.
   (f) Peroxisomes are enzyme-containing membranous sacs that are abundant in the kidneys and liver. Some of the enzymes in peroxisomes generate hydrogen peroxide, and one of them, catalase, breaks down excess hydrogen peroxide.

(g) The centrosome is the dense area of cytoplasm near the nucleus that contains the centrioles. The paired centrioles play an important role in cell division.
(h) Vacuoles are membranous sacs that function as storage chambers.
(i) Fibrils and microtubules provide support in the form of a cytoskeleton.
(j) Cilia and flagella are projections of the cell that have the same basic structure and that function in producing movement.

5. The cell nucleus is enclosed in a nuclear membrane that controls the movement of substances between the nucleoplasm and the cytoplasm.
   (a) The nucleoli are small bodies of protein and RNA within the nucleus that produce ribosomes.
   (b) Chromatin is a coiled fiber of protein and DNA that shortens to form chromosomes during cell reproduction.
6. The nucleotides in DNA consist of the sugar deoxyribose, phosphate, and one of four nitrogenous bases: adenine, guanine, cytosine, or thymine. According to the law of complementary base pairing, bases are specific in their bonding: adenine bonds with thymine and guanine bonds with cytosine.
7. RNA contains the sugar ribose (instead of deoxyribose) and the base uracil (in place of thymine). The three major forms of RNA are mRNA, tRNA, and rRNA.
8. The genetic code in mRNA consists of three bases called codons. Codons bond to anticodons, which are three bases in tRNA.
9. Each type of tRNA is bonded to a specific type of amino acid, which the tRNA brings to the growing polypeptide chain.

Cell Cycle (pp. 65–70)

1. The cell cycle consists of growth, synthesis, and mitosis.
   (a) Growth is the increase in cellular mass that results from metabolism. Synthesis is the production of DNA and RNA to regulate cellular activity. Mitosis is the splitting of the cell's nucleus and cytoplasm that results in the formation of two diploid cells.
   (b) Mitosis permits an increase in the number of cells (body growth) and allows for the replacement of damaged, diseased, or worn-out cells.
2. A DNA molecule is in the shape of a double helix. The structural unit of the molecule is a nucleotide, which consists of deoxyribose (sugar), phosphate, and a nitrogenous base.
3. Cell division consists of a division of the chromosomes (mitosis) and a division of the cytoplasm (cytokinesis). The stages of mitosis include prophase, metaphase, anaphase, and telophase.

Review Activities

Objective Questions

1. Inorganic compounds that form ions when dissociated in water are
   (a) hydrolites. (d) ionizers.
   (b) metabolites. (e) nucleic acids.
   (c) electrolytes.
2. The four elements that compose over 95% of the body are
   (a) oxygen, potassium, hydrogen, carbon.
   (b) carbon, sodium, nitrogen, oxygen.
   (c) potassium, sodium, magnesium, oxygen.
   (d) carbon, oxygen, nitrogen, hydrogen.
   (e) oxygen, carbon, hydrogen, sulfur.
3. Which organelle contains strong hydrolytic enzymes?
   (a) the lysosome
   (b) the Golgi complex
   (c) the ribosome
   (d) the vacuole
   (e) the mitochondrion
4. Ciliated cells occur in
   (a) the trachea. (c) the bronchioles.
   (b) the ductus deferens. (d) the uterine tubes.
   (e) all of the above.
5. Osmosis deals with the movement of
   (a) gases. (c) oxygen only.
   (b) water only. (d) both a and c.
6. The phase of mitosis in which the chromosomes line up at the equator (equatorial plane) of the cell is called
   (a) interphase. (d) anaphase.
   (b) prophase. (e) telophase.
   (c) metaphase.
7. The phase of mitosis in which the chromatids separate is called
   (a) interphase. (d) anaphase.
   (b) prophase. (e) telophase.
   (c) metaphase.
8. The organelle that combines protein with carbohydrates and packages them within vesicles for secretion is
   (a) the Golgi complex.
   (b) the rough endoplasmic reticulum.
   (c) the smooth endoplasmic reticulum.
   (d) the ribosome.
9. The enlarged skeletal muscle fibers that result from an increased work demand serve to illustrate
   (a) disuse atrophy.
   (b) compensatory hypertrophy.
   (c) metaplasia.
   (d) inertia.
10. Regeneration of liver cells is an example of
    (a) compensatory hypertrophy.
    (b) hyperplasia.
    (c) metaplasia.
    (d) hypertrophy.
11. Which of the following statements about DNA is *false?*
    (a) It is located in the nucleus.
    (b) It is double-stranded.
    (c) The bases adenine and thymine can bond together.
    (d) The bases guanine and adenine can bond together.
12. Which of the following statements about RNA is *true?*
    (a) It is made in the nucleus.
    (b) It contains the sugar deoxyribose.
    (c) It is a complementary copy of the entire DNA molecule.
    (d) It is double-stranded.

Essay Questions

1. Explain why a knowledge of cellular anatomy is necessary for understanding tissue and organ function within the body. How is the study of cells important for the understanding of body dysfunction and disease?
2. Why is water a good fluid medium of the cell?

3. How are proteins, carbohydrates, and lipids similar? How are they different? What are enzymes and hormones?
4. Describe the cell membrane. List the various kinds of movement through the cell membrane and give an example of each.
5. Describe, diagram, and list the functions of the following:
   (a) endoplasmic reticulum,
   (b) ribosome,
   (c) mitochondrion,
   (d) Golgi complex,
   (e) centrioles, and
   (f) cilia.
6. Define *inorganic compound* and *organic compound* and give examples of each.
7. Define the terms *protoplasm*, *cytoplasm*, and *nucleoplasm*. Describe the position of the membranes associated with each of these substances.
8. Describe the structure of the nucleus and the functions of its parts.
9. What is a nucleotide? How does it relate to the overall structure of a DNA molecule?
10. Explain the relationship between DNA, chromosomes, chromatids, and genes.
11. Describe how RNA is produced and list the different forms of RNA.
12. Explain how one DNA strand can serve as a template for the synthesis of another DNA strand.
13. Distinguish between mitosis and cytokinesis. Describe the major events of mitosis and discuss the significance of the mitotic process.
14. Give examples of factors that contribute cellular hypertrophy, hyperplasia, atrophy, and metaplasia.
15. Explain how cells respond to
   (a) energy deficit,
   (b) hyperthermia,
   (c) burns,
   (d) radiation, and
   (e) pathogens.
16. Define the following genetic terms: *teratology*, *monosomy*, *trisomy*, and *mutation*.
17. In what ways do cells of a neoplasm differ from normal cells. How may a malignant neoplasm cause death?
18. Discuss the cellular and extracellular changes that accompany aging.

Critical-Thinking Questions

1. How is the structural organization of its individual cells essential to a multicellular organism?
2. Construct a table comparing the structure and function of several kinds of cells. Indicate which organelles would be of particular importance to each kind of cell.
3. Define *medical genetics* and give some examples of genetic diseases. Is spending the billions of dollars required to complete the Human Genome Project justified? Why or why not?
4. The brain is protected to some extent by the blood-brain barrier—a membrane between circulating blood and the brain that keeps certain damaging substances from reaching brain tissue. However, the brain is still subject to trauma that can cause it to swell, much like an ankle swells with a sprain. Because the cranium is a cavity of fixed size, brain edema (swelling) can rapidly lead to coma and death. Knowing what you do about movement of water across a membrane, can you explain why *mannitol*, a type of sugar that does not cross the blood-brain barrier, is commonly used to treat patients who have suffered head trauma?
5. Your friend knows that you have just reviewed cellular chemistry, and so he asks for your opinion about his new diet. In an attempt to eliminate the lipid content in adipose tissue and thus lose weight, he has completely eliminated fat from his diet. He feels that he is now free to eat as much food as he likes, provided it consists only of carbohydrates and protein. Is your friend's logic flawed? Would you advise him to stick with this diet?

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