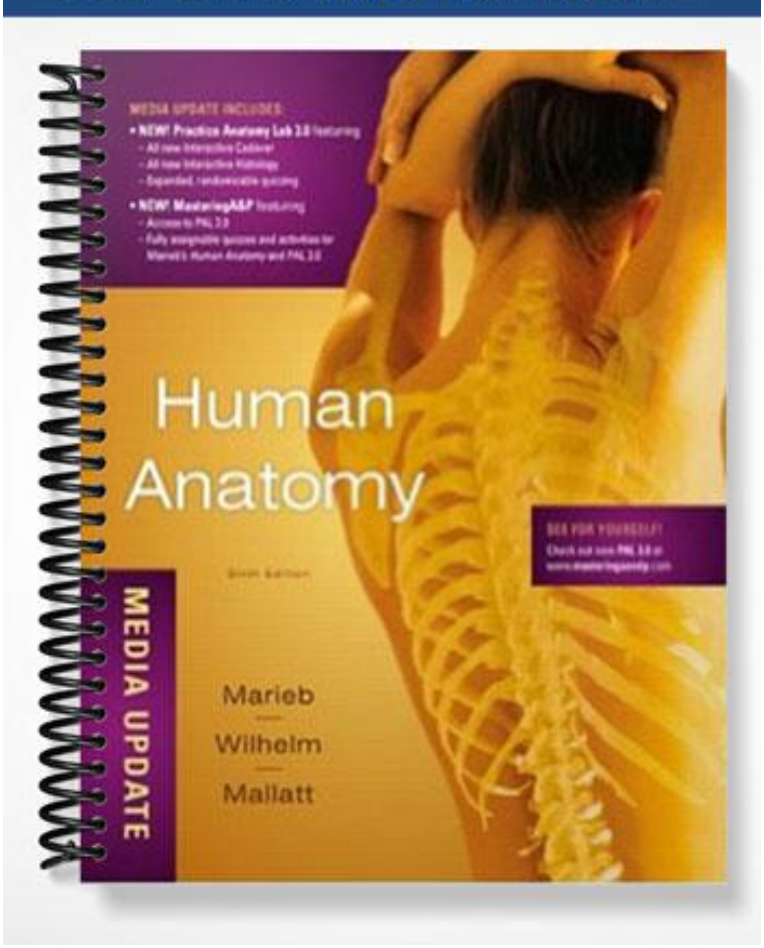
SOLUTIONS MANUAL



2: Cells: The Living Units

LECTURE AND DEMONSTRATION

Objectives

1. Describe the important contributions of Robert Hooke, Matthias Schleiden and Theodor Schwann, and Rudolf Virchow to cell biology.
2. Define cell, and comment on the differences between an actual animal cell and the generalized cell depicted in Figure 2.1.
3. Describe the basic cellular activities required to sustain life.
4. Identify and describe the structure and function of the three main regions of a cell: plasma membrane, cytoplasm, and nucleus.
5. Explain how molecules move across the plasma membrane.
6. Describe the cytosol.
7. Compare the structure and function of ribosomes and endoplasmic reticulum.
8. Explain the relationship between the Golgi apparatus and rough endoplasmic reticulum.
9. Describe the unique structure of mitochondria and the roles the mitochondria play in the cell.
10. Compare and contrast lysosomes with peroxisomes.
11. Describe the structure and function of the cytoskeleton.
12. Explain how microtubules relate to the centrosome and centrioles.
13. Explain the structure of glycosomes and lipid droplets.
14. Describe the structure and function of the nucleus and nuclear envelope.
15. Identify the relationship between chromatin and chromosomes.
16. Explain the function of nucleoli.
17. Identify some specific cell types, and explain the relationship of cell shape to cell function.
18. Explain the cyclic relationship between interphase and cell division.
19. Define and describe interphase and its subphases. Include a key event for each subphase.
20. Define and describe mitosis and its stages, including key events for each stage.
21. Discuss cell differentiation and explain the major theories of aging.

Suggested Lecture Outline

I. Overview of Cells (pp. 24–25, Fig. 2.1)

A. Revolutionary discoveries in the 1800s overturned the theory of spontaneous generation. Scientists assert that organisms are composed of cells that arise from other cells. (p. 24)

B. The cell is the basic structural and functional unit of all living things. (pp. 24–25)

1. Major cellular regions are the plasma membrane, the cytoplasm, and the nucleus.

2. Most cell types contain each of the requisite organelles, but in differing abundances based on the cell's type and its function.

II. The Plasma Membrane (Plasmalemma) (pp. 25–28, Figs. 2.2–2.5)

A. Structure (pp. 25–26, Fig. 2.2)
   1. Double layer, or bilayer, of lipid molecules (phospholipids, cholesterol, and glycolipids) with protein molecules dispersed within it.

B. Functions (pp. 26–27, Fig. 2.2)
   1. Separates two major fluid compartments: the intercellular fluid within the cells and the extracellular fluid, which lies outside and between cells.
   2. Some membrane proteins act as receptors and are part of the body's cellular communication system.
   3. Substances that enter and leave the cell are determined by the plasma membrane.

C. Membrane Transport (p. 27, Fig. 2.3)
   1. Small uncharged molecules pass through the lipid bilayer by diffusion.
   2. Osmosis is the diffusion of water molecules across a selectively permeable membrane.
   3. Faciliatated diffusion is the movement of molecules down their concentration gradient, diffusing through the plasma membrane by moving through specific integral proteins.
   4. Moving molecules across the plasma membrane against their concentration gradient is an energy-requiring process called active transport.

D. Movement of Large Macromolecules (pp. 27–28, Figs. 2.4, 2.5)
   1. Two types of vesicular transport, called endocytosis and exocytosis, move the largest macromolecules.
   2. Three types of endocytosis occur in cells: phagocytosis, pinocytosis, and receptor-mediated endocytosis.
      a. Hormones, low-density lipoproteins (LDLs), viruses, and some toxins enter cells by receptor-mediated endocytosis.
   3. Exocytosis is the process by which substances move from the cytoplasm to the outside of a cell.

III. The Cytoplasm (pp. 30–35, Figs. 2.6–2.12)

A. The three major elements of the cytoplasm are the cytosol, organelles, and inclusions. (p. 30)

B. Cytosol (also termed cytoplasmic matrix) is the jelly-like fluid that suspends cytoplasmic elements. (p. 30)

C. Cytoplasmic organelles perform different cellular survival functions. (pp. 30–35, Figs. 2.6–2.12, Table 2.1)
   1. Ribosomes are the sites of protein synthesis.
   2. Endoplasmic reticulum makes proteins (rough ER) and is the site of lipid and steroid synthesis (smooth ER).
   3. Golgi apparatus packages and modifies proteins.
   4. Mitochondria synthesize ATP.
   5. Lysosomes are the sites of intracellular digestion.
   6. Peroxisomes detoxify toxic substances.
   7. Cytoskeleton supports cellular structures.
   8. Centrioles act in forming cilia and flagella, and organize microtubule networks during mitosis.

D. Inclusions are not permanent structures in cells; examples are food storage units for fats and sugars, as well as pigments. (p. 35)

IV. The Nucleus (pp. 35–38, Figs. 2.13–2.15)

A. The nucleus is the control center of the cell; it contains the DNA that directs protein synthesis. (pp. 35–36)

B. Two parallel membranes separated by a fluid-filled space form the nuclear envelope that surrounds the nucleus. (pp. 36–37)

C. Nucleoli contain parts of several chromosomes and assist in assembling ribosomal subunits. (p. 37)

D. Chromatin is composed of DNA and histones located in the nucleus. (pp. 37–38, Figs. 2.14, 2.15)

1. The DNA molecule is a double helix made up of four types of nucleotides with bases of adenine, thymine, guanine, and cytosine.

V. The Cell Life Cycle (pp. 38–39 and 40–41, Figs. 2.16, 2.17)

A. The two major divisions of the cell cycle are interphase and cell division (mitotic phase). Cytokinesis occurs at the end of the M (mitotic) phase of the cell life cycle. (p. 38, Fig. 2.16)

B. Interphase is divided into G_1, S, and G_2 subphases. DNA replication occurrs during the S subphase. (pp. 38–39, Fig. 2.16)

C. During G_1 and G_2 of interphase, "checkpoints" evaluate cellular activity. G_1 checkpoint assesses cell size and G_2 checkpoint verifies accuracy of replication. (pp. 38–39, Fig. 2.16)

D. Nuclear material divides during mitosis. (pp. 39–41, Fig. 2.17)

E. During cytokinesis, an entire cell is divided into two daughter cells. (pp. 39–41, Fig. 2.17)

VI. Developmental Aspects of Cells (pp. 39 and 42–43, Fig. 2.18)

A. Cell differentiation is the development of specific and distinctive features of human body cells. (p. 39)

B. Evidence supports the theory that aging occurs because mitochondria are damaged by free radicals and/or genetically influenced processes. (pp. 42–43)

Lecture Hints

1. Explain why the cell in Figure 2.1 is described as a "generalized" cell. Emphasize that many body cells have a different structure, and relate shape to function. (Example: Mature red blood cells are anucleate, and skeletal muscle cells are multinucleate. RBCs are biconcave discs that lack organelles and are packed with hemoglobin for oxygen transport.)
2. Display slides of electron micrographs to augment text diagrams. Comment on preparation of animal tissues for microscopy and on different types of microscopes.
3. Relate the function of the plasma membrane to its location at the interface between the cell's interior and exterior.
4. Describe the structure and functions of integral and peripheral proteins.
5. Explain diffusion and osmosis. Comment on how diffusion and osmosis differ from active transport mechanisms, such as exocytosis, endocytosis, and phagocytosis.
6. Describe the roles of *v*-SNARES and *t*-SNARES in exocytosis. Note that SNARE is an acronym for a group of proteins known as "*s*oluble *N*SF *a*ttachment *r*eceptors."
7. Explain the characteristics and content of cytoplasm, and distinguish it from cytosol.
8. Discuss the specific roles of cytoplasmic organelles and inclusions.
9. Present a summary list of cellular organelles organized as membranous, microtubular, or "other," and briefly comment on functions of each organelle.
10. Explain the role of mitochondria as the source of most cellular energy. Refer to Figure 2.10.
11. Relate a molecule of glucose (food energy) to ATP production.
12. Using specific cellular examples, comment on why some cells have larger numbers of mitochondria and some have fewer mitochondria.
13. Discuss protein synthesis within cells.
14. Correlate the role of the nucleus as the source of information for protein synthesis, with the ribosome as the site of protein synthesis and the Golgi apparatus as the site of packaging and delivery of proteins within cells.

15. Explain why the rough ER is considered the cell's "membrane factory" by tracing the flow of membrane components from the rough ER to the plasma membrane.
16. List components of the cytoskeleton.
17. Explain how the various elements of the cell's skeleton differ from each other in structure and function.
18. Discuss the role of the nucleus as the control center of the cell.
19. Explain the importance of DNA, and describe the design of the double helix. Tell students they will not confuse complementary base pairing if they simply remember "A-T" as the only word possible from the base symbols, G, C, A, and T.
20. Describe the relationship of the nuclear envelope to rough ER.
21. Explain differences between chromatin and chromosomes.
22. Describe the structures and functions of the nucleus and nucleolus. Stress that the two are different entities within the cell.
23. Introduce the concept of cellular diversity by relating the shape of a cell to its function. Figure 2.18 is excellent for this concept.
24. Emphasize the cell cycle as a continuous process using the stages as discrete events.
25. Contrast cellular changes during interphase with changes during mitosis.
26. Describe the functions of "checkpoints" during interphase of the cell cycle.
27. Ask students why telophase is the reverse of prophase.
28. Explain cytokinesis, and clearly distinguish it from mitosis.
29. Point out that mitosis is possible without cytokinesis, using multinucleated skeletal muscle cells for an example.
30. Make sure students can distinguish genes, chromatin, chromosomes, DNA, and proteins.
31. Discuss the free-radical and mitochondrial theories of aging in relation to environmental pollution and the current craze for ingesting antioxidants such as vitamins C and E.
32. Discuss telomeres and telomerase in reference to the genetic theory of aging.
33. Distinguish apoptosis from senescence.

Classroom Discussion Topics and Activities

1. Using Plastilene™ (a reusable modeling clay available in many colors) and contrasting paper, organize students into groups of three with instructions to model the plasma membrane. Using text Figure 2.2, p. 25, instruct students to include phospholipids, cholesterol, glycocalyx, and one membrane protein. Then have brief group presentations covering the structure and functions of the chosen proteins.
2. Illustrate a cell by using a hypothetical Jell-O® fruit salad. The Jell-O® is the cytosol; an orange is the nucleus; and nuts, raisins, and other fruits are the organelles.
3. Ask students to name common examples of diffusion, osmosis, and filtration.
4. Use a model of an animal cell to demonstrate the various organelles and other cell features.
5. Instruct students to list all parts of a generalized cell that are involved in the following functions: respiration, digestion, excretion, transportation, reproduction, food acquirement, energy production, protein formation, and internal support.
6. Instruct the students to construct a chart that lists the membrane-bound organelles in one column, and in another column, the organelles that are not membrane-bound.
7. Use a Slinky™ to demonstrate the helical nature of DNA. Demonstrate the relationship between chromatin and the chromosome states by stretching or tightly coiling the Slinky™.
8. Beginning with a typical diploid human body cell containing 46 chromosomes, have students identify the number of chromosomes and chromatids present in each stage of mitosis.
9. Use models of chromosomes with detachable chromatids to illustrate mitotic phases. (Make simple models using strands of colored yarn with sewn-on snaps or colored pipe cleaners.)

10. Assign the following questions to be answered at the next class meeting:
    a. Why is damage to the heart or brain more damaging than injury to the liver?
    b. Why is precise division of the chromosomes during metaphase of mitosis so important?
    c. Is mitosis without cytokinesis possible? What would be the result?
11. Discuss why certain body cells (e.g., muscle and nerve cells) "lost" their ability to divide.
12. Ask students why they survive even though they lose billions of cells daily.
13. Ask students to consider possibilities of growing organs from "scratch." What ethical issues of tissue engineering and regenerative medicine are involved? Supplemental video: *Spare Parts: Growing Human Organs* (FHS; 28 min., 1999)
14. Pique students' interest by discussing topics such as the cell biology of cancer or theories on aging.
15. Describe telomeres as "pencil erasers"; once the "eraser" is gone, the cell undergoes senescence.

Clinical Questions

1. A patient receiving treatment for testicular cancer was told that the chemotherapy drug he received inhibits the division of cancer cells. What could the drug be, and how would it stop cell division?
   Answer: One chemotherapy drug considered in this chapter, vinblastine, inhibits the formation of microtubules and mitotic spindles required for cell division. Because cancer cells divide rapidly, the drug will preferentially affect these cells. Unfortunately, normal cells that divide rapidly will also be affected.
2. A small boy received a cut on his arm, and his mother applied hydrogen peroxide to the wound. The wound bubbled! Why?
   Answer: The hydrogen peroxide was degraded to water and oxygen (which bubbled off) by the action of the intracellular enzymes in peroxisomes. (Bacteria in the cut produce a similar enzyme.)

ART RESOURCES

Transparencies Index/Instructor Resource DVD

Figure 2.1	Structure of a generalized cell.
Figure 2.2	The plasma membrane according to the fluid mosaic model.
Figure 2.3	Membrane transport mechanisms.
Figure 2.4	The three types of endocytosis.
Figure 2.5	Exocytosis.
Figure 2.6	The endoplasmic reticulum (ER) and ribosomes.
Figure 2.7	Golgi apparatus.
Figure 2.8	The sequence of events from protein synthesis on the rough ER to the final distribution of these proteins.
Figure 2.9	Electron micrograph of a cell containing lysosomes (93,000X).
Figure 2.10	Mitochondria.
Figure 2.11	Cytoskeletal elements.
Figure 2.12	Centrosome and centrioles.
Figure 2.13	The nucleus.
Figure 2.14	Molecular structure of DNA.
Figure 2.15	Chromatin and chromosome structure.
Figure 2.16	The cell cycle.
Figure 2.17	Focus on mitosis.
Figure 2.18	Cellular diversity.

Table 2.1 Parts of the Cell: Structure and Function

Teaching with Art

Figure 2.2 The plasma membrane.

Figure 2.4 The three types of endocytosis.

Figure 2.5 Exocytosis.

Textbook pp. 25–28; transparencies; Instructor Resource DVD.

Checklist of Key Points in the Figure

- Explain the "fluid" nature of the fluid mosaic model.
- Explain why the fluid mosaic model is a "mosaic."
- Define intracellular fluid and extracellular fluid.
- Correlate Figures 2.2–2.5 to differentiate bulk transport concepts, exocytosis, and endocytosis. Students often do not understand the important point that endocytosis involves taking in the dissolved solutes in the fluid, not just the solvent itself.
- Explain the terms cell-eating and cell-drinking.
- Describe the difference between nonselective pinocytosis and highly selective receptor-mediated endocytosis.
- Illustrate the importance of phagocytosis using white blood cells.
- Illustrate exocytosis with the production of salty, protein-containing solution by cells in tear glands when weeping occurs.

Common Conceptual Difficulties Interpreting the Art

- Remind students that Figure 2.2 focuses on the molecular level.
- Cellular components are recycled and reused.
- Energy is required. Where does it come from?
- Point out relationship of plasma membrane to vesicle formation during endocytosis and exocytosis.
- Point out that because the membrane is "highly selective" in receptor-mediated endocytosis, this does not mean harmful substances such as toxins and viruses are kept out of the cell.

Art Exercise

Using Figure 2.4 for reference, instruct students to represent phagocytosis with a simple drawing. Follow a highlighted segment of plasma membrane to its incorporation into a phagosome. Add lysosomes to the drawing. Ask students where the highlighted membrane finally ends up. A similar demonstration is possible using Figure 2.4 with an overlay and colored marker.

Critical Reasoning

Ask students why lymph nodes become swollen and tender when there is an infection in the body.

Answer: Lymphocytes are white blood cells that fight infections in the body. A swollen node means a proliferation of lymphocytes and is evidence of the body's fight against infection.

SUPPLEMENTAL COURSE MATERIALS

Library Research Topics

1. Can protein molecules move within the cell membrane? What research supports your findings?
2. Receptor-mediated endocytosis is a highly selective mechanism to ingest molecules. How can it be used to kill cancer cells?
3. Do chemical carcinogens cause all cancers? What other things cause cancer?
4. Review the evidence for and against the theory that mitochondria evolved from bacteria that came to live within primitive eukaryotic cells.
5. Read about the newest research on aging.
6. Research current use of tissue engineering and regenerative medicine.

Media

See Appendix A of the Instructor Resource Guide for Key to Audiovisual Distributors.

Slides

1. *Cell Structure Set* (CBS)
2. *Onion Mitosis 35mm Slides Set* (CBS)

Video

1. *The Aging Process* (FHS; 19 min.). This program explains the effects of aging on the mind and body and explores the theories about why cells wear out.
2. *Cancer* (FHS; 23 min.). Provides a look at how cancers form and some of the weapons used in the fight against them. Some of the treatments demonstrated include chemotherapy, radiation therapy, surgery, photochemotherapy, and monoclonal antibodies.
3. *Exploring the Living Cell* (GP; 180 min., 2007). This DVD includes high-resolution animations and electron microscopy images. Also included are narrations about each organelle and imagery of cellular organelles.
4. *An Introduction to the Living Cell* (CBS; 30 min.). This program takes students on a visual tour of a cell. Subcellular organelles are shown working together. Computer animation and microscopic images are used to visualize the complexities of the cell.
5. *A Journey Through the Cell* (IM; 25 min. each, 1997). Contains computer graphics and animations, and includes presentations by scientists introducing ideas central to understanding cells.
6. *Living Cells: Structure and Function* (CBS; 36 min., 1996). This DVD shows both real-time and time-lapsed video of cellular components, mitosis, cell division, and structure and function of cells.

Software

1. *Animal and Plant Mitosis SMARTSlides* (WNSE; Win/Mac). Your classroom computer becomes a microscope with a library of 20 prepared slides. The program presents all phases of plant and animal mitosis.
2. *The Cell: Structure, Function, and Process* (IM; Win/Mac). Introduces the microscopic world of the cell and explores various cell processes.
3. *Exploration of Cell Process* (IM; Win/Mac). Helps students to visualize and understand essential cell processes.
4. *The Plasma Membrane and Cellular Transport* (CBS; Win/Mac). This CD provides a detailed study of membranes and cell motility. Introduces the fluid mosaic model. Students can explore cell biology at their own pace.
5. *Practice Anatomy Lab™ 2.0* (*PAL*) (BC; CD-ROM, Website). An interactive study and lab assessment tool. The cytology module illustrates and tests understanding of mitosis through a series of histology images.

Suggested Readings

Bartek, Jiri, and Jiri Lukas. Order from destruction. *Science* 294 (5540) (Oct. 2001): 66–67.

Biello, D. Genes governing embryonic stem cell "immortality" discovered. *Scientific American* (June 12, 2006).

Cavanee, W., and R. White. The genetic basis of cancer. *Scientific American* (March 1995): 72–79.

Cormack, D.H. *Ham's Histology*. 9th ed. Philadelphia: J.B. Lippincott, 1998.

Finkel, Elizabeth. The mitochondrion: Is it central to apoptosis? *Science* 292 (5516) (April 2001): 624–626.

Graham, S. Studies provide additional insight into abilities of stem cells. *Scientific American* (June 21, 2002).

Glick, B.S., and V. Malhotra. The curious status of the Golgi apparatus. *Cell* 95 (December 23, 1998): 883–889.

Hayflick, L. *How and Why We Age*. New York: Ballantine Books, 1996.

Hentze, Matthias W. Believe it or not—translation in the nucleus. *Science* 293 (5532) (Aug. 2001): 1058–1059.

Hunot, Stephane, and Richard A. Flavell. Death of a monopoly? *Science* 292 (5518) (May 2001): 865–866.

Kipling, D., and R.G. Faragher. Telomeres: Aging hard or hardly aging? *Nature* 398 (March 18, 1999): 191, 193.

Rusting, R. Why do we age? *Scientific American* 267 (December 1992): 131–141.

Scientific American Special Issue. What you need to know about cancer. (September 1996).

Sinclair, D., and L. Guarente. Unlocking the secrets of longevity genes. *Scientific American* (February 20, 2006).

Sprong, H., et al. How proteins move lipids and lipids move proteins. *Nature Reviews: Molecular Cell Biology* 2 (July 2001): 504–513.

Suh, Y.A., et al. Cell transformation by the superoxide-generating oxidase Mox1. *Nature* 401 (September 2, 1999): 79–82.

Thweatt, R., and S. Goldstein. Werner syndrome and biological aging: A molecular genetic hypothesis. *BioEssays* 15 (June 1993): 421–426.

ANSWERS TO TEXTBOOK QUESTIONS

Answers for multiple-choice and matching questions 1–12 are located in Appendix B of the textbook.

Short Answer and Essay Questions

13. Membrane-lined organelles: mitochondria, rough ER (and nuclear envelope), smooth ER, Golgi apparatus, lysosomes, and peroxisomes (nucleus too). Organelles that have no membrane: centrioles and centrosomes, microtubules, microfilaments, and intermediate filaments. (p. 29, Table 2.1)
14. A nucleolus is a dark-staining structure within a nucleus, much smaller than the nucleus itself. Whereas the nucleus contains many chromosomes, the nucleolus consists of parts of several of these chromosomes that work together to manufacture the basic subunits of ribosomes. (pp. 35–37)
15. Mitochondria are the only organelles that have a complex, double-unit membrane and their own DNA and genes. (Although it was not mentioned, mitochondria also contain their own ribosomes and RNA.) (pp. 32–33)
16. A chromosome is one of 46 long, single molecules of DNA (with the associated protein) in the nucleus of typical human cells. When a cell is dividing, its chromosomes are maximally coiled, so they appear as thick rods. In nondividing cells, the chromosomes are partially uncoiled for transcription. (Fig. 2.15)

Critical Reasoning and Clinical Applications Questions

1. Experiments on rats and other animals indicate that slightly underweight and undernourished animals have prolonged life spans. (p. 42) (See "Aging," Chapter 2.)

2. Hyperplasia means the cells have proliferated into a thick layer of structurally normal cells; dysplasia means that a few of the cells show abnormal size or shape; lack of neoplasia means that the cells were not proliferating uncontrollably (no tumor or cancer was evident). Therefore, Kareem did not have cancer of the mouth. (See "Related Clinical Terms," p. 43.)
3. G_1, S, G_2, and M are all phases of the cell life cycle. (Fig. 2.16) G_1 is a growth phase followed by S, the phase in which DNA is replicated in preparation for cell division. G_2 is when the final preparations for cell division are made, and M is the mitotic phase leading to division of the nucleus. Clearly, the tumor-suppressor genes are halting various phases of the cell life cycle in precancer cells that would otherwise multiply uncontrollably. (pp. 38–39)
4. Peroxisomes. (pp. 33–34)
5. Long-term use of phenobarbital causes proliferation of smooth endoplasmic reticulum in the liver because the smooth ER acts to detoxify poisons and drugs. Proliferation of smooth ER is necessary because, as phenobarbital is repeatedly ingested, the body must manufacture more smooth ER in order to combat the poison. In the user, this is perceived as "tolerance" to the drug and the user needs higher doses of the drug to achieve the original result. (p. 31 and Table 2.1)
6. Without microtubules, the mitotic spindle cannot form, and without the mitotic spindle, mitosis and cell division are impossible. (pp. 34–35)
7. Describing cellular structures in terms of their roles in a "manufacturing factory" gives the following results: (pp. 29–35)
    a. Plasma membrane—allows only specific substances into the factory.
    b. Mitochondria—provides energy for the factory.
    c. Nucleus—the manager/leader of the factory.
    d. Golgi apparatus—shipping and receiving in the factory.
    e. Ribosomes—makes the products in the factory.
    f. Lysosomes—the "demolition crew" of the factory.
    g. Peroxisomes—toxic waste removal system of the factory.

SUPPLEMENTAL STUDENT MATERIALS

to *Human Anatomy,* Sixth Edition

Chapter 2: Cells: The Living Units

To the Student

The cell is the structural and functional unit of all living things. The human body has 50 to 60 trillion cells consisting of some 200 different types that are amazingly diverse in size, shape, and function. Mastery of basic knowledge of the cell leads to fuller understanding and comprehension of tissues, organs, organ systems, and ultimately, the human organism.

Step 1: Learn basic concepts about cells.

__ Define cell.
__ List three major regions of a "generalized" animal cell.
__ Indicate the general function of each region.

Step 2: Correlate plasma membrane structure and function.

__ Describe the composition of the plasma membrane.
__ Relate the composition of the plasma membrane to the movement of substances into and out of the cell.

__ Differentiate passive from active transport mechanisms.
__ Describe transport processes relative to energy source, substances transported, direction of movement, and mechanisms.

Step 3: Summarize basic structural and functional relationships about the cytoplasm.

__ Describe the composition of the cytosol.
__ List ten organelles, including vaults and inclusions, found in the cytosol.
__ Define inclusions, and list several kinds.
__ Explain the structure and function of mitochondria.
__ Explain the structure, function, and interrelationships of ribosomes, the endoplasmic reticulum, and the Golgi apparatus.
__ Compare the functions of lysosomes and peroxisomes.
__ Name and describe the structure and function of cytoskeletal elements.

Step 4: Summarize basic structural and functional relationships about the nucleus.

__ Describe the structure and function of the nuclear envelope.
__ Explain the structure and function of chromatin.
__ Explain the structure and function of a nucleolus.

Step 5: Understand events of cell growth and reproduction.

__ List the phases of the cell cycle.
__ Describe the events of each phase.
__ Explain the significance of interphase.

Step 6: Recognize cell diversity.

__ Name specific cell types.
__ Relate the shapes of different cell types to the functions of the cells.

Step 7: Understand the developmental aspect of cells.

__ Describe how cell differentiation leads to structural and functional variation.
__ Describe how cells differ in function based on specific requirements.
__ Explain the current theories of aging.