Chapter 3 - Cells: The Living Units

Objectives

Overview of the Cellular Basis of Life

1. Define cell. Discuss cell diversity.
2. Discuss a generalized cell. List the three main parts of a cell and their functions.

The Plasma Membrane: Structure

3. Discuss the fluid mosaic model of membrane structure.
4. List and describe the plasma membrane specializations.

The Plasma Membrane: Functions

5. Discuss membrane transport. Differentiate between active and passive transport.
6. Compare and contrast simple diffusion, facilitated diffusion, osmosis, and filtration.
7. Compare and contrast primary and secondary active transport.
8. Discuss the differences and similarities between the vesicular transport processes.
9. Define the resting membrane potential. How is it created and maintained?
10. Identify the different ways a cell interacts with its environment. Discuss cell adhesion molecules and the roles of membrane receptors.

The Cytoplasm

11. Discuss the cytoplasm and its components.
12. Discuss the functions of the cytoplasmic organelles. What conditions lead to a greater prevalence of a specific organelle?

The Nucleus

13. Define the characteristics and functions of the nucleus, nuclear envelope, and nucleoli.
14. Discuss chromatin structure and function.

Cell Growth and Reproduction

15. Identify the phases of cell growth and division, and describe what specific events occur within each phase.
16. Name the factors that influence cell division.
17. Define protein synthesis and the processes of transcription and translation.
18. Describe the types of RNA that are used in protein synthesis and their specific roles.
19. Discuss how proteins are degraded within the cytosol.

Extracellular Material

20. Define extracellular material and list its components.

Developmental Aspects of Cells

21. Discuss how cell development progresses, and what signals stimulate these changes.
22. Discuss the various theories of cell aging.

Lecture Outline

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

A. The four concepts of the cell theory state (p. 65):
1. Cells are the basic structural and functional units of life.
2. The activity of an organism depends on the activities of its cells.
3. The biochemical activities of a cell are dictated by their organelles.
4. The continuity of life has a cellular basis.

B. Characteristics of Cells (pp. 65–66; Fig. 3.1-3.2)
1. Cells vary greatly in their size, shape, and function.
2. All cells are composed primarily of carbon, hydrogen, nitrogen, and oxygen.
3. All cells have the same basic parts and some common functions.
4. A generalized human cell contains the plasma membrane, the cytoplasm, and the nucleus (Fig. 3.2).

II. The Plasma Membrane: Structure (pp. 67–69)

A. The Fluid Mosaic Model (pp. 67–68; Figs. 3.3–3.4)
1. The plasma membrane is composed of a double layer of phospholipids embedded with small amounts of cholesterol and proteins.
2. The phospolipid bilayer is composed of two layers of phospholipids lying tail to tail, with their polar heads exposed to water inside and outside the cell.
3. The inward-facing and outward-facing surfaces of the plasma membrane differ in the kinds and amounts of lipids they contain.
   a. Glycolipids are found only in the outer membrane.
   b. Lipid rafts are also found only in the outer membrane, and are assumed to function in cell signaling.
4. Integral proteins are firmly inserted into the plasma membrane.
   a. Most integral proteins are transmembrane proteins that span the entire width of the membrane and are involved with transport as channels or carriers.
5. Peripheral proteins are not embedded in the plasma membrane, but attach to integral proteins or to phospolipids.
   a. Peripheral proteins may function as enzymes or in mechanical functions of the cell.
6. The glycocalyx is the fuzzy, sticky, carbohydrate-rich area surrounding the cell.

B. Specializations of the Plasma Membrane (p. 69; Fig. 3.5)
1. Microvilli are fingerlike extensions of the plasma membrane that increase the surface area of the cell.
2. Most body cells are bound together using glycolipids, specialized interlocking regions, or specialized membrane junctions.

a. Tight junctions are a type of membrane junction in which integral proteins on adjacent cells fuse together to form an impermeable junction in order to prevent molecules from passing through the extracellular space between cells.
b. Desmosomes are mechanical couplings that are scattered along the sides of adjoining cells that prevent their separation and reduce the chance of tearing when a tissue is stressed.
c. Gap junctions are a communication junction between cells that allows substances to pass between adjacent cells.

III. The Plasma Membrane: Functions (pp. 70–83)

A. Membrane Transport (pp. 69–81; Tables 3.1–3.2; Figs. 3.6–3.14)

1. The plasma membrane is a selectively permeable barrier, regulating how substances pass into and out of the cell.
2. Passive processes do not use energy and move substances down a concentration gradient.
   a. Diffusion is a process in which substances move directly through the plasma membrane from an area of higher concentration to an area of lower concentration (Fig. 3.6).
   b. In facilitated diffusion substances are moved through the plasma membrane by binding to protein carriers in the membrane or by moving through channels (Fig. 3.7).
   c. Osmosis is the diffusion of water through a selectively permeable membrane. (Fig. 3.8, 3.9)
   d. Filtration is a pressure-driven process that forces water and solutes through a membrane or capillary wall.
3. Active processes use energy (ATP) to move substances across a membrane (Fig. 3.10).
   a. Active transport uses solute pumps to move substances against a concentration gradient. The two kinds of active transport are primary active transport and secondary active transport (Fig. 3.11).
   b. Vesicular transport is the means by which large particles, macromolecules, and fluids are transported across the plasma membrane, or within the cell.
      i. Exocytosis is a process used to move substances from inside the cell to the extracellular environment (Fig. 3.12).
   c. Endocytosis, transcytosis, and vesicular traffiking are vesicular transport processes that move molecules using protein-coated vesicles (Fig. 3.13–3.14).
   d. Clathrin-coated vesicles are the main route for endocytosis and transcytosis of bulk solids.
   e. Non-clathrin-coated vesicles, or caveolae, are inpocketings of the cell membrane that capture specific molecules in vesicles lined with caveolin, not clathrin.

B. Generating and Maintaining a Resting Membrane Potential (pp. 81–83; Fig. 3.15)

1. A membrane potential is a voltage across the cell membrane that occurs due to a separation of oppositely charged particles (ions).
2. The resting membrane potential is a condition in which the inside of the cell membrane is negatively charged compared to the outside, and ranges in voltage from 25 to 2100 millivolts.
   a. The resting membrane potential is determined mainly by the concentration gradient of potassium (K^+).
   b. Active transport pumps ensure that passive ion movement does not lead to an electrochemical equilibrium across the membrane, thus maintaining the resting membrane potential.

C. Cell-Environmental Interactions (pp. 83–84)

1. Cells can interact directly with other cells, respond to extracellular chemicals, and interact with molecules that direct migration.
2. Roles of Cell Adhesion Molecules
    a. Cell adhesion molecules (CAMs) are glycoproteins that play roles in embryonic development, wound repair, and immunity.
3. Roles of Membrane Receptors (Fig. 3.16)
    a. Membrane receptors are integral proteins and glycoproteins that serve as binding sites.
    b. Some membrane receptors function in contact signaling, electrical signaling, and chemical signaling.
4. Nitric oxide, consisting of one atom of oxygen and one atom of nitrogen, is the first known gas to act as a biological messenger.

IV. The Cytoplasm (pp. 84–95)

A. The cytoplasm is the cellular material between the cell membrane and the nucleus, and is the site of most cellular activity (p. 84).
1. There are three major elements of the cytoplasm: cytosol, cytoplasmic organelles, and cytoplasmic inclusions.

B. Cytoplasmic Organelles (pp. 84–95; Table 3.3; Fig. 3.17–3.27)
1. Mitochondria are sausage-shaped membranous organelles that are the power plants of the cell, producing most of its ATP.
2. Ribosomes are small staining granules consisting of protein and ribosomal RNA that are the site of protein synthesis.
3. The endoplasmic reticulum is an extensive system of tubes and membranes enclosing fluid-filled cavities, called cisternae, that extend throughout the cytosol.
    a. The rough endoplasmic reticulum has ribosomes that manufacture all proteins that are secreted from cells.
    b. Smooth ER is a continuation of rough ER, consisting of a looping network of tubules. Its enzymes catalyze reactions involved in several processes.
4. The Golgi apparatus is a series of stacked, flattened, membranous sacs associated with groups of membranous vesicles.
    a. The main function of the Golgi apparatus is to modify, concentrate, and package the proteins and lipids made at the rough ER.
    b. The Golgi apparatus creates vesicles containing lipids and transmembrane proteins for incorporation into the cell membrane.
    c. The Golgi apparatus packages digestive enzymes into lysosomes.
5. Lysosomes are spherical membranous organelles that contain digestive enzymes.
    a. Lysosomes function best in acidic environments, can digest almost any kind of biological molecule, and are abundant in phagocytes.
    b. The membrane of the lysosome functions to allow products of digestion to be released to the cytosol, yet contain the acid hydrolases used to digest molecules.
6. The endomembrane system includes the ER, Golgi apparatus, secretory vesicles, lysosomes, and nuclear membrane.
    a. The endomembrane system functions together to produce, store, and export biological molecules, as well as degrade potentially harmful substances.
7. Peroxisomes are membranous sacs containing enzymes, such as oxidases and catalases, which are used to detoxify harmful substances such as alcohol, formaldehyde, and free radicals.

8. The cytoskeleton is a series of rods running through the cytosol, supporting cellular structures and aiding in cell movement.
    a. There are three types of rods in the cytoskeleton: microtubules, microfilaments, and intermediate filaments.
9. Centrosome and Centrioles
    a. The centrosome is a region near the nucleus in which a group of microtubules is anchored.
    b. The centrosome functions as a microtubule organizing center, and forms the mitotic spindle during cell division.
    c. Centrioles are small, barrel-shaped organelles associated with the centrosome, and also form the bases of cilia and flagella.
10. Cellular Extensions
    a. Cilia are whiplike, motile cellular extensions on the exposed surfaces of some cells.
    b. Flagella are long cellular projections that move the cell through the environment.

V. The Nucleus (pp. 95–97)

A. Basic Characteristics (p. 95; Fig. 3.28)
    1. The nucleus is the control center of the cell and contains the cellular DNA.
    2. Most cells have only one nucleus, but very large cells may be multinucleate.
    3. All body cells except mature red blood cells have nuclei.
    4. The nucleus is larger than the cytoplasmic organelles; it has three regions and protein-containing subcompartments.

B. Nuclear Envelope (p. 95)
    1. The nuclear envelope is a double-membrane barrier surrounding the nucleus.
        a. The outer membrane is continuous with the rough ER.
        b. The inner membrane is lined with a shape-maintaining network of protein filaments, the nuclear lamina.
    2. At various points, nuclear pores penetrate areas where the membranes of the nuclear envelope fuse.
        a. A complex of proteins, called a pore complex, lines each nuclear pore and regulates passage of large particles into and out of the nucleus.
    3. The nuclear envelope encloses the fluid and solutes of the nucleus, the nucleoplasm.

C. Nucleoli (pp. 97)
    1. Nucleoli are dark-staining spherical bodies within the nucleus.
    2. There are typically one or two nucleoli per nucleus.
    3. Nucleoli are the sites of assembly of ribosomal subunits, and are large in actively growing cells.

D. Chromatin (p. 97; Fig. 3.29)
    1. Chromatin is roughly half DNA, the genetic material of the cell, and half histone proteins.
    2. Nucleosomes are the fundamental unit of chromatin, consisting of clusters of eight histone proteins connected by a DNA molecule.
    3. When a cell is preparing to divide, chromatin condenses into dense, rodlike chromosomes.

VI. Cell Growth and Reproduction (pp. 97–111)

A. The Cell Life Cycle (pp. 97–101; Figs. 3.30–3.32)

1. The cell life cycle is a series of changes a cell goes through from the time it is formed to the time it reproduces.
2. Interphase and cell division are the two main periods of the cell cycle.
3. Interphase is the period from cell formation to cell division, and has three subphases.
   a. During G_1, or gap 1, subphase the cell is synthesizing proteins and actively growing.
   b. During the S phase, DNA is replicated.
   c. During the G_2, or gap 2, subphase enzyme and other proteins are synthesized and distributed throughout the cell.
   d. DNA replication takes place when the DNA helix uncoils, and the hydrogen bonds between its base pairs are broken. Then each nucleotide strand of the DNA acts as a template for the construction of a complementary nucleotide strand.
4. Cell division is a process necessary for growth and tissue repair. There are three main events of cell division.
   a. Mitosis is the process of nuclear division in which cells contain all genes.
   b. Meiosis is the process of nuclear division found only in egg and sperm cells in which the cells have half the genes found in other body cells.
   c. Cytokinesis is the process of dividing the cytoplasm.
   d. Control of cell division depends on surface-volume relationships, chemical signaling, and contact inhibition.

B. Protein Synthesis (pp. 101–110; Fig. 3.33–3.38)

1. DNA specifies the structure of protein molecules that act as structural or functional molecules.
2. Proteins are composed of polypeptide chains made up of amino acids.
3. Each gene is a segment of DNA that carries instructions for one polypetide chain, as well as exons that specify amino acid informational sequences and noncoding sequences called introns.
4. Each sequence of three nucleotide bases of DNA is called a triplet, and specifies a particular amino acid.
5. The role of RNA
   a. RNA exists in three forms that decode and carry out the instructions of DNA in protein synthesis: Transfer RNA (tRNA), Ribosomal RNA (rRNA), and Messenger RNA (mRNA).
   b. All three types of RNA are constructed on the DNA in the nucleus, then released from the DNA to migrate to the cytoplasm while the DNA recoils to its original form.
6. There are two main steps of protein synthesis: transcription and translation.
   a. Transcription is the process of transferring information from a gene's base sequence to a complementary mRNA molecule.
      i. To make the mRNA complement, the transcription factor mediates binding of RNA polymerase, an enzyme that directs the synthesis of mRNA.
      ii. The mRNA that initially results from transcription, called primary transcript, contains introns that must be removed.
   b. Translation is the process of converting the language of nucleic acids (nucleotides) to the language of proteins (amino acids).

VII. Extracellular Materials (p. 111)

A. Extracellular materials are substances contributing to body mass that are found outside the cells (p. 111).

B. There are three classes of extracellular materials (p. 111).

1. Body fluids consist mainly of interstitial fluid, blood plasma, and cerebrospinal fluid, and are important to transport and solute dissolution.
2. Cellular secretions include substances aiding in digestion or functioning as lubrication.
3. Extracellular matrix is a jellylike substance consisting of proteins and polysaccharides.

VIII. Developmental Aspects of Cells (pp. 111–112)

A. Embryonic and Fetal Development of Cells (p. 111)

1. Embryonic cells are exposed to different chemical signals that cause them to follow different pathways in development.
2. Chemical signals influence development by switching genes on and off.
3. Cell differentiation is the process of cells developing specific and distinctive features.
4. Apoptosis is the programmed cell death of stressed, surplus developing cells.

B. Development of Cells Through Adolescence (p. 111)

1. Most organ systems are well formed and functional before birth.
2. The body continues to form new cells throughout childhood and adolescence.
3. During young adulthood, cell numbers remain relatively constant, but local changes in the rate of cell division are common.

C. Effect of Aging on Cells (pp. 112)

1. The wear and tear theory considers the cumulative effect of slight chemical damage and the production of free radicals.
2. Cell aging may also be a result of autoimmune responses and progressive weakening of the immune response.
3. The genetic theory of cell aging suggests that cessation of mitosis and cell aging are genetically programmed.

Cross References

Additional information on topics covered in Chapter 3 can be found in the chapters listed below.

1. Chapter 2: Phospholipids; kinetic energy; ions; adenosine triphosphate; protein; enzymes; deoxyribonucleic acid; ribonucleic acid; comparison of DNA and RNA; hydrogen bond
2. Chapter 8: Lysosomal rupture (autolysis) and self-digestion of cells
3. Chapter 9: Role of smooth ER in calcium ion storage and release; microfilaments as contractile elements
4. Chapter 11: Specialized forms of cytoskeletal elements; nervous system membrane potentials
5. Chapter 14: Membrane receptors and functions in the autonomic nervous system
6. Chapter 18: Cell junctions and cardiac function
7. Chapter 19: Cell junctions and movement of substances through capillary walls

8. Chapter 21: Function of lysozyme in protection of the body; function of cilia in innate defense of the body
9. Chapter 22: Diffusion of respiratory gases
10. Chapter 23: Microvilli and increased absorptive surface area in epithelial cells of the small intestine; membrane transport related to absorption of digested substances
11. Chapter 24: Examples of membrane transport
12. Chapter 25: Hydrostatic pressure and movement of fluid through membranes
13. Chapter 26: Membrane transport related to electrolyte and water balance
14. Chapter 27: Reproductive cell division and gamete production; tight junctions and the blood/testis barrier; functions of flagella and cilia; mitrochondria and energy production in sperm cells
15. Chapter 29: Cell division in relation to hereditary process
16. Appendix C: mRNA codons and the amino acids they specify

Laboratory Correlations

1. Marieb, E. N. *Human Anatomy & Physiology Laboratory Manual: Cat and Fetal Pig Versions*. Eighth Edition Updates. Benjamin Cummings, 2006.
   Exercise 3: The Microscope
   Exercise 4: The Cell—Anatomy and Division
   Exercise 5: The Cell—Transport Mechanisms and Cell Permeability
2. Marieb, E. N. *Human Anatomy & Physiology Laboratory Manual: Main Version*. Seventh Edition Update. Benjamin Cummings, 2006.
   Exercise 3: The Microscope
   Exercise 4: The Cell—Anatomy and Division
   Exercise 5: The Cell—Transport Mechanisms and Cell Permeability