CHAPTER 3

LECTURE OUTLINE

I. INTRODUCTION

A. A cell is the basic, living, structural, and functional unit of the body.

B. Cell biology or cytology is the study of cell structure and function.

II. PARTS OF A CELL

A. A generalized view of the cell is a composite of many different cells in the body as seen in Figure 3.1. No single cell includes all of the features seen in the generalized cell.

B. The cell can be divided into three principal parts for ease of study.

1. Plasma (cell) membrane
2. Cytoplasm
    a. Cytosol
    b. Organelles (except for the nucleus)
3. Nucleus
    a. chromosomes
    b. genes

III. THE PLASMA MEMBRANE

A. The plasma membrane is a flexible, sturdy barrier that surrounds and contains the cytoplasm of the cell.

1. The fluid mosaic model describes its structure (Figure 3.2).
2. The membrane consists of proteins in a sea of lipids.

B. The Lipid Bilayer

1. The lipid bilayer is the basic framework of the plasma membrane and is made up of three types of lipid molecules: phospholipids, cholesterol, and glycolipids (Figure 3.2).
2. The bilayer arrangement occurs because the lipids are amphipathic molecules. They have both polar (charged) and nonpolar (uncharged) parts with the polar "head" of the phospholipid pointing out and the nonpolar "tail" pointing toward the center of the membrane.
    a. cholesterol molecules are weakly amphipathic

C. Arrangement of Membrane Proteins

1. The membrane proteins are divided into integral and peripheral proteins (Figure 3.2)

a. Integral proteins extend into or across (transmembrane) the entire lipid bilayer among the fatty acid tails of the phospholipid molecules.
b. Peripheral proteins are found at the inner or outer surface of the membrane and can be stripped away from the membrane without disturbing membrane integrity.

2. Integral membrane proteins are amphipathic.
    a. Those that stretch across the entire bilayer and project on both sides of the membrane are termed transmembrane proteins.
    b. Many integral proteins are glycoproteins.
        1. Glycocalyx: formed by the carbohydrate portions of glycolipids and glycoproteins
3. The combined glycoproteins and glycolipids form the glycocalyx which helps cells recognize one another, adhere to one another, and be protected from digestion by enzymes in the extracellular fluid.

D. Functions of Membrane Proteins
    1. Membrane proteins vary in different cells and functions as ion channels, carriers (transporters), receptors, enzymes, linkers, and cell-identity markers (Figure 3.3).
    2. The different proteins help to determine many of the functions of the plasma membrane.

E. Membrane Fluidity
    1. Membranes are fluid structures, rather like cooking oil, because most of the membrane lipids and many of the membrane proteins easily move in the bilayer.
    2. Membrane lipids and proteins are mobile in their own half of the bilayer.
    3. Cholesterol serves to stabilize the membrane and reduce membrane fluidity (figure 2.18).

F. Membrane Permeability
    1. Plasma membranes are *selectively permeable*, meaning that some things can pass through and others cannot.
    2. The lipid bilayer portion of the membrane is permeable to small, nonpolar, uncharged molecules but impermeable to ions and charged or polar molecules. Although thought to be slightly permeable to water, the observed permeability to water is most likely the result of aquaporin channels or proteins imbedded within the plasma membrane that are selective for water molecules.

3. Transmembrane proteins that act as channels or transporters increase the permeability of the membrane to molecules that cannot cross the lipid bilayer.
4. Macromolecules are unable to pass through the plasma membrane except by vesicular transport.

G. Gradients Across the Plasma Membrane
   1. A concentration gradient is the difference in the concentration of a chemical between one side of the plasma membrane and the other.
      a. Oxygen and sodium ions are more concentrated outside the cell membrane with carbon dioxide and potassium ions more concentrated inside the cell membrane.
      b. The inner surface of the membrane is more negatively charged and the outer surface is more positively charged. This sets up an electrical gradient, also called the *membrane potential.*
   2. Maintaining the concentration and electrical gradients are important to the life of the cell.
   3. The combined concentration and electrical gradients are called the electrochemical gradient.

IV. TRANSPORT ACROSS THE PLASMA MEMBRANE

A. Processes to move substances across the cell membrane are essential to the life of the cell.
   1. Some substances cross the lipid bilayer while others cross through ion channels.
   2. Transport processes that mover substances across the cell membrane are either active or passive.
      a. Passive processes include simple diffusion facilitated diffusion and osmosis and are driven by concentration gradients
      b. Active processes include active transport and vesicular transport and these require cellular energy.

B. Passive processes
   1. The principle of diffusion
      a. *Diffusion* is the random mixing of particles that occurs in a solution as a result of the kinetic energy of the particles. (Figure 3.4)
      b. Diffusion rate across plasma membranes is influenced by several factors: steepness of the concentration gradient, temperature, mass of the diffusing substance, surface area, and diffusion distance.

2. Simple Diffusion
    a. Nonpolar, hydrophobic molecules such as respiratory gases, some lipids, small alcohols, and ammonia can diffuse across the lipid bilayer without the help of transport proteins (Figure 3.5)
    b. It is important for gas exchange, absorption of some nutrients, and excretion of some wastes.
3. Facilitated Diffusion

    Solutes that are too polar or highly charged to move through the lipid bilayer by simple diffusion can cross the plasma membrane by a passive process called facilitated diffusion. In this process, an integral membrane protein assists a specific substance across the membrane. The integral membrane protein can be either a membrane channel or a carrier.

    a. channel mediated facilitated diffusion: a solute moves down its concentration gradient across the lipid bilayer through a membrane channel. (Figure 3.6)
        1) Most membrane channels are ion channels
        2) Some membrane channels are gated
    b. carrier-mediated facilitated diffusion: a solute binds to a specific transporter on one side of the membrane and is released on the other side after the transporter undergoes a conformational change. (Figure 3.7)
    c. Substances that move across the plasma membrane by carrier mediated facilitated diffusion include glucose, fructose, galactose, and some vitamins
4. *Osmosis*
    a. Osmosis is the net movement of a solvent through a selectively permeable membrane, or in living systems, the movement of water (the solute) from an area of higher concentration to an area of lower concentration across the membrane (Figure 3.8a).
    b. Water molecules penetrate the membrane by diffusion through the lipid bilayer or through aquaporins, transmembrane proteins that function as water channels.
    c. Water moves from an area of lower solute concentration to an area of higher solute concentration. Movement of water can generate hydrostatic pressure (figure 3.8b).

d. Osmosis occurs only when the membrane is permeable to water but not to certain solutes.
e. *Tonicity* of a solution relates to how the solution influences the shape of body cells (Figure 3.9)
    i. In an *isotonic* solution, red blood cells maintain their normal shape.
    ii. In a *hypotonic* solution, red blood cells undergo hemolysis.
    iii. In a *hypertonic* solution, red blood cells undergo cremation.
    iv. There are important medical uses of isotonic, hypotonic, and hypertonic solutions.
f. Clinical Connection: Medical Uses of Isotonic, Hypertonic, and Hypotonic Solutions

C. Active Processes

Active Transport: energy is required for the carrier proteins to move solutes across the membrane against the concentration gradient.

1. Primary Active Transport
    a. In *primary active transport*, energy derived from ATP changes the shape of a transporter protein, which pumps a substance across a plasma membrane against its concentration gradient.
    b. The most prevalent primary active transport mechanism is the sodium ion/potassium ion pump (Figure 3.10).
    c. Clinical Connection: Digitalis slows the sodium ion-calcium ion antiporters, allowing more calcium to stay inside heart muscle cells, which increases the force of their contraction and thus strengthens the heartbeat.
2. Secondary Active Transport
    a. In *secondary active transport*, the energy stored in the form of a sodium or hydrogen ion concentration gradient is used to drive other substances against their own concentration gradients.
    b. Plasma membranes contain several antiporters and symporters powered by the sodium ion gradient (Figure 3.11).
3. Transport in Vesicles
    a. Endocytosis
        1) In *endocytosis*, materials move into a cell in a vesicle formed from the plasma membrane.

2) *Receptor-mediated endocytosis* is the selective uptake of large molecules and particles by cells (Fig 3.12).
    a) The steps of receptor-mediated endocytosis includes binding, vesicle formation, uncoating, fusion and endosome formation, recycling of receptors, degradation in lysosomes, and transcytosis.
    b) Viruses can take advantage of this mechanism to enter cells.
    c) Clinical connection: Viruses and Receptor-Mediated Endocytosis
3) *Phagocytosis* is the ingestion of solid particles (Figure 3.13).
    a) Only a few body cells, termed phagocytes, are able to carry out phagocytosis
        1. macrophages and neutrophils,
4) *Pinocytosis* is the ingestion of extracellular fluid (Figure 3.14). Also called bulk phase endocytosis

b. Exocytosis
1) In exocytosis membrane-enclosed structures called secretory vesicles that form inside the cell fuse with the plasma membrane and release their contents into the extracellular fluid
2) Transcytosis is a transport process that includes both endocytosis and exocytosis.

D. Table 3.1 summarizes the processes by which materials are transported into and out of cells.

V. CYTOPLASM

1. *Cytosol*, the intracellular fluid, is the semifluid portion of cytoplasm that contains inclusions and dissolved solutes (Figure 3.1).
    1. Cytosol is composed mostly of water, plus proteins, carbohydrates, lipids, and inorganic substances.
    2. The chemicals in cytosol are either in solution or in a colloidal (suspended) form.
    3. Functionally, cytosol is the medium in which many metabolic reactions occur.
    4. The cytoskeleton is a network of protein filaments that extends cytosol
        a. The *cytoskeleton* is a network of several kinds of protein filaments that extend throughout the cytoplasm and provides a structural framework for the cell (Figure 3.15).

b. It consists of microfilaments, intermediate filaments, and microtubules.
    1) Most microfilaments are composed of actin and function in movement and mechanical support.
    2) Intermediate filaments are composed of several different proteins and function in support and to help anchor organelles such as the nucleus (Figure 3.16).
    3) Microtubules are composed of a protein called tubulin and help determine cell shape and function in the intracellular transport of organelles and the migration of chromosome during cell division. (Figure 3.16)

B. Organelles: Organelles are specialized structures that have characteristic shapes and perform specific functions in cellular growth, maintenance, and reproduction.
    1. *Centrosomes* are dense areas of cytoplasm containing the *centrioles*, which are paired cylinders arranged at right angles to one another, and serve as centers for organizing microtubules in interphase cells and the mitotic spindle during cell division. (Figure 3.16a-c)
    2. Cilia and Flagella
        a. *Cilia* are numerous, short, hairlike projections extending from the surface of a cell and functioning to move materials across the surface of the cell (Figure. 3.17).
        b. *Flagella* are similar to cilia but are much longer; usually moving an entire cell. The only example of a flagellum in the human body is the sperm cell tail (Figure 3.17).
    3. Ribosomes
        a. *Ribosomes* are tiny spheres consisting of ribosomal RNA and several ribosomal proteins; they occur free (singly or in clusters) or together with endoplasmic reticulum (Fig 3.18).
        b. Functionally, ribosomes are the sites of protein synthesis.
    4. Endoplasmic Reticulum
        a. The *endoplasmic reticulum* (ER) is a network of membranes that form flattened sacs or tubules called cisterns (Figure 3.19).
        b. *Rough ER* is continuous with the nuclear membrane and has its outer surface studded with ribosomes.

    c. *Smooth ER* extends from the rough ER to form a network of membrane tubules but does not contain ribosomes on its membrane surface.
    d. The ER transports substances, stores newly synthesized molecules, synthesizes and packages molecules, detoxifies chemicals, and releases calcium ions involved in muscle contraction.
    e. *Clinical Connection*: The role of the smooth ER in chemical detoxification has a role in drug tolerance.
5. Golgi Complex
    a. The *Golgi complex* consists of four to six stacked, flattened membranous sacs (cisterns) referred to as cis, medial, and trans (Figure 3.20).
    b. The principal function of the Golgi complex is to process, sort, and deliver proteins and lipids to the plasma membrane, lysosomes, and secretory vesicles (Figure 3.21).
6. Lysosomes
    a. *Lysosomes* are membrane-enclosed vesicles that form in the Golgi complex and contain powerful digestive enzymes (Figure 3.22).
    b. Lysosomes function in intracellular digestion, digestion of worn-out organelles (autophagy), digestion of cellular contents (autolysis) during embryological development, and extracellular digestion.
    c. Clinical connection: Tay-Sachs disease is an example of a disorder caused by faulty lysosomes.
7. Perioxosomes
    a. *Peroxisomes* are similar in structure to lysosomes, but are smaller (figure 3.1).
    b. They contain enzymes (e.g., catalase) that use molecular oxygen to oxidize various organic substances.
8. Proteosomes
    a. Proteosomes are structures that destroy unneeded, damaged, or faulty proteins.
    b. They contain proteases which cut proteins into small peptides.
    c. Clinical Connection: Proteosomes are thought to be a factor in several diseases.
9. Mitochondria

a. The *mitochondrion* is bound by a double membrane. The outer membrane is smooth with the inner membrane arranged in folds called cristae (Figure 3.23).
b. Mitochondria are the site of ATP production in the cell by the catabolism of nutrient molecules.
c. Plays an important role in apoptosis
d. Mitochondria self-replicate using their own DNA.
e. Mitochondrial DNA (genes) are usually inherited only from the mother.

VI. NUCLEUS

The *nucleus* is usually the most prominent feature of a cell (Figure 3.24).

1. Most body cells have a single nucleus; some (red blood cells) have none, whereas others (skeletal muscle fibers) have several.
2. The parts of the nucleus include the nuclear envelope which is perforated by channels called nuclear pores, nucleoli, and genetic material (DNA)
    a. nucleoli: function in producing ribosomes. Each nucleolus is simply a cluster of protein, DNA, and RNA; it is not enclosed by a membrane
3. Within the nucleus are the cell's hereditary units, called *genes*, which are arranged in single file along chromosomes.
    a. Each chromosome is a long molecule of DNA that is coiled together with several proteins (Figure 3.25).
    b. Human somatic cells have 46 chromosomes arranged in 23 pairs.
4. The various levels of DNA packing are represented by nucleosomes, chromatin fibers, loops, chromatids, and chromosomes.
5. The main parts of a cell and their functions are summarized in Table 3.2.
6. Clinical Connection: Genomics, the study of the genome and its relationship to body function, has the potential for increasing our understanding of normal and abnormal conditions.

VII. PROTEIN SYNTHESIS

A. Much of the cellular machinery is devoted to synthesizing large numbers of diverse proteins.
    1. The proteins determine the physical and chemical characteristics of cells.
    2. The instructions for protein synthesis is found in the DNA in the nucleus.
    3. Protein synthesis involves transcription and translation (Figure 3.26).
B. Transcription

1. *Transcription* is the process by which genetic information encoded in DNA is copied onto a strand of RNA called messenger RNA (mRNA), which directs protein synthesis (Figure 3.27).
    a. Besides serving as the template for the synthesis of mRNA,DNA also synthesizes two other kinds of RNA, ribosomal RNA (rRNA), and transfer RNA (tRNA).
    b. tRNA brings in additional amino acids utilizing binding affinity with its anitcodon region which interacts with a corresponding region or codon of the strand.
    c. Transcription of DNA is catalyzed by RNA polymerase.
        1) RNA polymerase uses a region of the mRNA called the promoter to start synthesis of a new strand
        2) Transcription of the DNA strand ends at another special nucleotide sequence called a terminator
    d. Not all parts of a gene actually code for parts of a protein. Regions within a gene called introns do not code for parts of proteins. They are located between regions called exons that do code for segments of a protein

C. Translation
    1. *Translation* is the process of reading the mRNA nucleotide sequence to determine the amino acid sequence of the protein (Figure 3.28).
    2. The sequence of translation is as follows (Figure 3.29).
        a. Messenger RNA associated with ribosomes, which consist of tRNA and proteins.
        b. Specific amino acids attach to molecules of tRNA. Another portion of the tRNA has a triplet of nitrogenous bases called an anticodon, a codon is a segment of three bases of mRNA.
        c. Transfer RNA delivers a specific amino acid to the codon; the ribosome moves along an mRNA strand as amino acids are joined to form a growing polypeptide.

D. Clinical Connection: As a result of recombinant DNA techniques, genetic engineering has arisen; strains of recombinant bacteria produce important therapeutic substances such as human growth hormone, insulin, and vaccines against several viruses.

VIII. CELL DIVISION

A. Cell division is the process by which cells reproduce themselves. It consists of nuclear division (mitosis and meiosis) and cytoplasmic division (*cytokinesis*).
    1. *Cell division* that results in an increase in body cells is called *somatic cell division* and involves a nuclear division called *mitosis*, plus cytokinesis.
    2. Cell division that results in the production of sperm and eggs is called reproductive cell division and consists of a nuclear division called *meiosis* plus cytokinesis.

B. The Cell Cycle in Somatic Cells
    1. The *cell cycle* is an orderly sequence of events by which a cell duplicates its contents and divides in two. It consists of interphase and the mitotic phase (Figure 3.30).
    2. Interphase
        a. During *interphase* the cell carries on every life process except division. Interphase consists of three phases: G_1, S and G_2 (Figure 3.30).
            1) In the G_1 phase, the cell is metabolically active, duplicating its organelles and cytosolic components except for DNA.
                a) Cells that remain in G1 for a very long time, perhaps destined never to divide again, are said to be in the G0 phase
            2) In the S phase, chromosomes are replicated (Figure 3.31).
            3) In the G_2 phase, cell growth continues and the cell completes its preparation for cell division.
        b. A cell in interphase shows a distinct nucleus and the absence of chromosomes (Figure 3.32a).
    3. Mitotic Phase
        a. The mitotic phase consists of mitosis (or nuclear division) and cytokinesis (or cytoplasmic division).
        b. Nuclear division: mitosis
            1) *Mitosis* is the distribution of two sets of chromosomes, one set into each of two separate nuclei.
            2) Stages of mitosis are prophase, metaphase, anaphase, and telophase.
                a) During *prophase*, the chromatin condenses and shortens into chromosomes (Figure 3.32b).
                b) During *metaphase*, the centromeres line up at the exact center of the mitotic spindle, a region called the metaphase plate or equatorial plane region (Figure 3.32c).

c) *Anaphase* is characterized by the splitting and separation of centromeres and the movement of the two sister chromatids of each pair toward opposite poles of the cell (Figure 3.32d).

d) Telophase begins as soon as chromatid movement stops; the identical sets of chromosomes at opposite poles of the cell uncoil and revert to their threadlike chromatin form, microtubules disappear or change form, a new nuclear envelope forms, new nucleoli appear, and the new mitotic spindle eventually breaks up. (Figure 3.32 e)

c. Cytoplasmic Division: Cytokinesis

1) *Cytokinesis* is the division of a parent cell's cytoplasm and organelles. The process begins in late anaphase or early telophase with the formation of a cleavage furrow (Figure 3.32 d and e).

2) When cytokinesis is complete, interphase begins (Figure 3.32 f).

d. Clinical Connection: Inhibiting the formation of the mitotic spindle has a role in the treatment of cancer.

C. Control of Cell Destiny

1. The three possible destinies of a cell are to remain alive and functioning without dividing, to grow and divide, or to die.
2. Enzymes called cyclin-dependent protein kinase can regulate DNA replication. Turning these on and off is a function of proteins called cyclins.
3. Cell death, a process called *apoptosis*, is triggered either from outside the cell or from inside the cell due to a "cell-suicide" gene.
4. *Necrosis* is a pathological cell death due to injury.

D. Clinical Connection: Tumor-suppressor genes can produce proteins that normally inhibit cell division resulting in the uncontrollable cell growth known as cancer.

E. Reproductive cell division

1. The replication of DNA in Meiosis is similar to Mitosis
2. Meiosis involves two stages (Figure 3.33a-b)

a. Meiosis I

1) The two pairs of sister chromatids pair off to form a tetrad

2) During the formed tetrad parts of the sister chromatids of the homologous chromoses is traded, a process called crossing over.

3) As a result of crossing over, the resulting sister chromatids are not genetically identical, allowing genetic recombination
4) The net result is a haploid cell with only one of the pair of homologous chromosomes, but with paired sister chromatids.

b. Meiosis II

1) The paired sister chromatids making up each homologous chromosome are separated
2) The net result of Meiosis II is a haploid cell with one chromatid
3) Net result of meiosis is the production of four haploid cells that are genetically different
4) Compare mitosis and meiosis with Figure 3.34

IX CELLULAR DIVERSITY

A. Not all cells look alike, nor do they perform identical functional roles in the body.
B. The shapes of cells vary considerably (Figure 3.35).

X CELLS AND AGING

A. *Aging* is a normal process accompanied by a progressive alteration of the body's homeostatic adaptive responses; the specialized branch of medicine that deals with the medical problems and care of elderly persons is called geriatrics.
    1. The physiological signs of aging are gradual deterioration in function and capacity to respond to environmental stresses.
    2. These signs are related to a net decrease in the number of cells in the body and to the dysfunctioning of the cells that remain.
    3. The extracellular components of tissues (e.g., collagen fibers and elastin) also change with age.
B. Clinical Connection: Free Radicals. Many theories of aging have been proposed, including genetically programmed cessation of cell division, glucose addition to proteins, free radical reactions, and excessive immune responses, but non successfully answers all experimental objections.
C. Clinical Connection: Progeria and Werner Syndrome are disorders of aging.

XI. DISORDERS: HOMEOSTATIC IMBALANCES

A. *Cancer* is a group of diseases characterized by uncontrolled cell proliferation.

1. Cells that divide without control develop into a tumor or neoplasm.
2. A cancerous neoplasm is called a malignant tumor or *malignancy*. It has the ability to undergo metastasis, the spread of cancerous cells to other parts of the body. A benign tumor is a noncancerous growth.

B. Types of Cancer
   1. *Carcinomas* arise from epithelial cells.
   2. *Melanomas* are cancerous growths of melanocytes.
   3. *Sarcomas* arise from muscle cells or connective tissues.
   4. *Leukemia* is a cancer of blood-forming organs.
   5. *Lymphoma* is a cancer of lymphatic tissue.

C. Growth and Spread of Cancer
   1. Cancer cells divide rapidly and continuously.
   2. They trigger *angiogenesis*, the growths of new networks of blood vessels.
   3. Cancer cells can leave their site of origin and travel to other tissues or organs, a process called *metastasis*.

D. Causes of Cancer
   1. Environmental agents can cause cancer growth. A chemical agent. or radiation that produces cancer is termed a *carcinogen* and induces mutations in DNA.
   2. Viruses can cause cancer.
   3. Cancer-causing genes, or *oncogenes*, can cause cancer.
      a. The normal counterparts of oncogenes are called *proto-oncogenes*; these are found in every cell and carry out normal cellular functions until a malignant change occurs via a mutation.
      b. Some cancers may also be caused by genes called anti-*oncogenes* or tumor-suppressing genes. These genes may produce proteins that normally oppose the action of an oncogene or inhibit cell division.

E. Carcinogenesis is a multistep process involving mutation of oncogenes and anti-oncogenes; as many as 10 distinct mutations may have to accumulate in a cell before it becomes cancerous.

F. Treatment of Cancer
   1. Treatment of cancer is difficult because it is not a single disease and because all the cells in a tumor do not behave in the same way.
   2. Many cancers are removed surgically.

3. Cancer that is widely distributed throughout the body or exists in organs with essential functions, such as the brain, which might be greatly harmed by surgery, may be treated with chemotherapy and radiation therapy instead.
4. Another potential treatment for cancer that is currently under development is virotherapy, the use of viruses to kill cancer cells.
5. Researchers are also investigating the role of metastasis regulatory genes that control the ability of cancer cells to undergo metastasis. Scientists hope to develop therapeutic drugs that can manipulate these genes and, therefore, block metastasis of cancer cells.