CHAPTER 4 CELL STRUCTURE AND FUNCTION

An overview of the cell theory and the history of microscopy leads into the detailed structure and function of both prokaryotic and eukaryotic cells, with special attention to the endomembrane system.

Chapter Outline

4.1 Cellular Level of Organization

A. **Cell Theory**
   1. In 1830s, Matthias Schleiden studying plants and Theodor Schwann studying animals independently declared these organisms were made of cells.
   2. All organisms, both unicellular or multicellular, are made up of cells.
   3. **Cells** are the smallest units of living matter and are the structural and functional units of all organisms.
   4. Cells are capable of self-reproduction; Rudolf Virchow declared cells come only from preexisting cells.

B. Cell Size
   1. Cells range in size from a frog's egg (one millimeter) down to one micrometer.
   2. Cells need a surface area of plasma membrane large enough to adequately exchange materials.
   3. **Surface-area-to-volume ratio** requires that cells be small.
      a. As cells get larger in volume, surface area relative to volume decreases.
      b. Size limits how large the actively metabolizing cells can become.
      c. Cells that need greater surface area use modifications such as folding, microvilli, etc.

C. Microscopy of Today
   1. **Bright-field microscope** uses light rays focused by glass lenses.
   2. **Transmission electron microscope** (TEM) uses electrons passing through specimen; focused by magnets.
   3. **Scanning electron microscope** (SEM) uses electrons scanned across metal-coated specimen.
   4. **Magnification** is a function of wavelengths; the shorter wavelengths of electrons allow greater magnification.
   5. **Resolution** is the minimum distance between two objects before they are seen as one larger object.
   6. **Immunofluorescence microscopy** uses fluorescent antibodies to reveal proteins in cells.
   7. **Confocal microscopy** uses laser beam to focus on shallow plane; this forms a series of optical sections.
   8. **Video-enhanced contrast microscopy** accentuates the light and dark regions and may use a computer to contrast regions with false colors.
   9. **Bright-field, phase contrast, differential interference** and **darkfield** are different types of light microscopy that improve our ability to see various features.

4.2 Prokaryotic Cells

A. **Types of Prokaryotic Cells**
   1. All prokaryotic cells lack a nucleus and are smaller and simpler than eukaryotic cells.
   2. Prokaryotic cells were the first cells and date back to earliest evolutionary history.
   3. Because they are biochemically different, prokaryotes are divided into two domains: Bacteria and Archaea.

B. **The Structure of Bacteria**
   1. Most bacteria average 1–1.4 μm wide and 2–6 μm long , just visible with light microscopes.
   2. Bacteria occur in three basic shapes: spherical coccus, rod-shaped bacillus, and spiral spirillum.
   3. Cell Envelope
      a. A plasma membrane is the same as eukaryotic cells: a phospholipid bilayer.
      b. The plasma membrane can form internal pouches called mesosomes that increase surface area for enzymes and metabolism.
      c. A cell wall holds the shape of the cell ans is strengthened by **peptidoglycan**.
      d. A glycocalyx is a layer of polysaccharides on the outside of the cell wall; it is called a capsule if organized and not easily washed off.

4. Cytoplasm
    a. The **cytoplasm** contains a semifluid solution with enzymes that carry on the chemical reactions that maintain the bacterium.
    b. The **nucleoid** is a region that contains the genes in a single, circular DNA molecule.
    c. **Plasmids** are small accessory rings of DNA aside from the nucleoid.
    d. **Ribosomes** are particles with two subunits that synthesize proteins.
    e. Inclusion bodies are stored granules of substances in the cytoplasm..
    f. **Cyanobacteria** are bacteria that photosynthesize; they lack chloroplasts but have thylakoid membranes with chlorophyll and other pigments.
5. Appendages
    a. Motile bacteria usually have **flagella;** the filament, hook and basal body work to rotate the flagellum like a propeller to move through fluid medium.
    b. **Fimbriae** are short appendages that help them attach to an appropriate surface.
    c. **Sex pili** are tubes used by bacteria to pass DNA from cell to cell.

C. **The Structure of Archaea**
1. In addition to spheres, rods, and spirals, Archaea can also be lobed, plate-shaped, and just irregular.
2. The cell was has various polysaccharides rather than peptidoglycan.
3. The DNA and RNA base sequences are closer to eukaryotes than bacteria.
4. Many Archaea are found in extremely salty or hot environments and may have been the first cells.

4.3 Eukaryotic Cells

A. Eukaryotic Cells
1. Eukaryotic cells are members of the domain Eukarya, including kingdoms Fungi, Animalia, Plantae, and Protista.
2. A membrane-bounded **nucleus** houses DNA.
3. The nucleus may have originated as an invagination of the plasma membrane.

B. The **Cytoplasm** and the Organelles
1. Eukaryotic cells have a cytoplasm that includes everything outside the nucleus and inside the plasma membrane.
2. The cytoplasm is compartmentalized with small organelles that perform special functions.
3. The mitochondria and chloroplasts are unique in being self-sufficient and having their own genetic material.
4. Other organelles communicate with each other and exchange products in transport vesicles.

C. The Cytoskeleton
1. The **cytoskeleton** is a lattice of protein fibers that maintains the shape of the cell.
2. Protein fibers serve as tracts of transport for vesicles that travel between organelles.

D. The Outer Boundary
1. The plasma membrane separates cell contents from the environment and regulates passage into and out of the cell.
2. The plasma membrane is a phospholipid bilayer (this will be detailed in Chapter 5).
3. Proteins within the membrane can be receptors that bind to vesicles or molecules.
4. In plant cells, the outer boundary includes a cell wall with cellulose fibers (in contrast to the bacterial cell wall).
5. A cell wall does not interfere with the function of the cell membrane.

E. **The Nucleus**
1. Structures
    a. The nucleus has a diameter of about 5 μm.
    b. **Chromatin** is a threadlike material that coils into chromosomes just before cell division occurs; contains DNA, protein, and some RNA.
    c. **Nucleoplasm** is the semifluid medium of nucleus.
    d. **Chromosomes** are rodlike structures formed during cell division; it is coiled or folded chromatin.
    e. **The nucleolus** is a dark-staining spherical body inside the nucleus; it is the site where rRNA joins proteins to form ribosomes.
    f. The nucleus is the site of DNA and determines characteristics of the cell by coding for proteins.

g. The **nuclear envelope** is a double membrane separating nucleoplasm from cytoplasm.
h. **Nuclear pores** (100 nm) in the nuclear membrane permit passage of proteins into the nucleus and mRNA and ribosomal subunits out of the nucleus.

F. **Ribosomes**
1. Ribosomes of eukaryotic cells are 20 nm by 30 nm; ribosomes in prokaryotic cells are slightly smaller.
2. Ribosomes are composed of a large and a small subunit.
3. Each subunit has its own mix of proteins and rRNA.
4. In eukaryotic cells, **polyribosomes** are several ribosomes synthesizing same protein; they may be attached to ER or may float free.
5. Ribosomes attached to ER depend on an ER signal sequence to bind to a receptor protein.
6. Ribosomes coordinate the assembly of amino acids into polypeptide chains; this protein synthesis results in new proteins within the interior of the ER.

E. The Endomembrane System
1. Endomembrane system is a series of intracellular membranes that compartmentalize the cell.
2. This system compartmentalizes a cell into particular regions; vesicles transport molecules in the cell.
3. **Endoplasmic Reticulum**
   a. Endoplasmic reticulum (**ER**) is system of membrane channels continuous with outer membrane of the nuclear envelope.
   b. **Rough ER** is studded with ribosomes on the cytoplasm side; it is the site where proteins are synthesized and enter the ER interior for processing and modification.
   c. **Smooth ER** is continuous with rough ER but lacks ribosomes; it is a site of various synthetic processes, detoxification, and storage; smooth ER forms **transport vesicles.**
4. **The Golgi Apparatus**
   a. The Golgi apparatus is named for Camillo Golgi, who discovered it in 1898.
   b. The Golgi apparatus consists of a stack of 3–20 slightly curved saccules.
   c. The Golgi apparatus receives protein-filled vesicles that bud from the ER.
   d. Vesicle fuses with the membrane of a Golgi apparatus or moves to the outer face after proteins are repackaged.
   e. Vesicles formed from the membrane of outer face of the Golgi apparatus then move to different locations in a cell; at the plasma membrane they discharge their contents as **secretions**, a process called exocytosis because substances exit the cytoplasm.
5. **Lysosomes**
   a. Lysosomes are membrane-bounded vesicles produced by the Golgi apparatus and contain digestive enzymes.
   b. Lysosomes contain powerful digestive enzymes that are highly acidic.
   c. Macromolecules enter a cell by vesicle formation; lysosomes fuse with vesicles and digest the contents of the vesicle.
   d. White blood cells that engulf bacteria use lysosomes to digest bacteria.
   e. Autodigestion occurs when lysosomes digest parts of cells.
   f. **Apoptosis** is programmed cell death, a normal part of development (e.g., tadpole tail absorption, degeneration of webbing between human fingers).
6. Endomembrane System Summary
   a. Proteins produced in rough ER and lipids from smooth ER are carried in vesicles to the Golgi apparatus.
   b. The Golgi apparatus modifies these products and then sorts and packages them into vesicles that go to various cell destinations.
   c. Secretory vesicles carry products to the membrane where exocytosis produces secretions.
   d. Lysosomes fuse with incoming vesicles and digest macromolecules.

F. **Peroxisomes**
   a. **Peroxisomes** are membrane-bounded vesicles that contain specific enzymes.
   b. Peroxisome action always results in production of hydrogen peroxide.
   c. Hydrogen peroxide (H_2O_2) is broken down to water and oxygen by **catalase.**
   d. Peroxisomes in the liver produce bile salts from cholesterol and also break down fats.

e. Missing or inactive lysosomal enzymes cause serious childhood diseases; the boy in the movie *Lorenzo's Oil* is an example.
f. Peroxisomes also occur in germinating seeds where they convert oils into sugars used as nutrients by growing plant and in leaves where they give off CO_2 that can be used in photosynthesis.

G. **Vacuoles**
a. Vacuoles in some protists are specialized and include water-regulating contractile vacuoles.
b. In plants, a large prominent vacuole is water-filled and gives support to cell.
c. The central plant stores water, sugars, salts, pigments, and toxic substances to protect plant from herbivores.
d. A central vacuole eventually stores plant wastes since no system for excreting wastes occurs in plants.

H. **Energy-Related Organelles**
1. **Chloroplasts** and mitochondria are membranous organelles that serve as sites of photosynthesis and cellular respiration, respectively.
a. Photosynthesis is represented by the equation:
solar energy + carbon dioxide + water $\rightarrow$ carbohydrate + oxygen
b. Cellular respiration is represented by the equation:
carbohydrate + oxygen $\rightarrow$ energy + carbon dioxide + water + energy (in ATP)
c. In eukaryotes, photosynthesis occurs in chloroplasts and cellular respiration occurs in mitochondria.
d. Only plants, algae, and certain bacteria are capable of carrying on photosynthesis.
2. **Chloroplasts**
a. Chloroplasts are a type of **plastid**; plastids in a plant species all contain copies of the same DNA.
b. Chloroplasts are twice as wide and five times as long as mitochondria.
c. Chloroplast is bounded by a double membrane organized into flattened disc-like sacs called thylakoids formed from a third membrane.
d. Chlorophyll and other pigments that capture energy are located within the thylakoid membrane.
e. Chloroplasts have both their own DNA and ribosomes, supporting the endosymbiotic hypothesis.
3. **Mitochondria**
a. Mitochondria vary and may be longer and thinner or short and broad.
b. Mitochondria also can be fixed in one location or form long, moving chains.
c. Mitochondria have a double membrane; the inner membrane has folds (cristae) that project into the matrix.
d. Mitochondria contain ribosomes and their own DNA, again supporting the endosymbiotic hypothesis.
e. The matrix of the mitochondria is concentrated with enzymes that break down carbohydrates.
f. ATP production occurs on the inner membrane (cristae).

G. The Cytoskeleton
1. **Cytoskeleton** is a network of connected filaments and tubules; it extends from the nucleus to the plasma membrane in eukaryotes.
a. Electron microscopy reveals an organized cytosol.
b. Immunofluorescence microscopy identifies protein fibers.
c. Elements of the cytoskeleton include: actin filaments, intermediate filaments, and microtubules.
2. **Actin Filaments**
a. Actin filaments are long, thin fibers (about 7 nm in diameter) that occur in bundles or meshlike networks.
b. The actin filament consists of two chains of globular actin monomers twisted to form a helix.
c. Actin filaments play a structural role, forming a dense complex web just under the plasma membrane; this accounts for the formation of pseudopods in amoeboid movement.
d. Actin filaments in microvilli of intestinal cells likely shorten or extend cell into intestine.
e. In plant cells, they form tracks along which chloroplasts circulate.
f. Actin filaments move by interacting with **myosin**: myosin combines with and splits ATP, binding to actin and changing configuration to pull actin filament forward.
h. Similar action accounts for pinching off cells during cell division.

3. **Intermediate Filaments**
   a. Intermediate filaments are 8–11 nm in diameter, between actin filaments and microtubules in size.
   b. They are rope-like assemblies of fibrous polypeptides.
   c. Some support the nuclear envelope; others support plasma membrane and form cell-to-cell junctions.
4. **Microtubules**
   a. Microtubules are small hollow cylinders (25 nm in diameter and from 0.2–25 μm in length).
   b. Microtubules are composed of a globular protein **tubulin** that occurs as α tubulin and β tubulin.
   c. Assembly brings these two together as dimers and the dimers arrange themselves in rows.
   d. Regulation of microtubule assembly is under control of a microtubule organizing center (MTOC): a **centrosome**.
   e. Microtubules radiate from the MTOC, helping maintain shape of cells and acting as tracks along which organelles move.
   f. Similar to actin-myosin, the motor molecules kinesin and dynein are associated with microtubules.
   g. Different kinds of kinesin proteins specialize to move one kind of vesicle or cell organelle.
   h. Cytoplasmic dynein is similar to the molecule dynein found in flagella.
5. Cytoskeleton Overview
   a. The cytoskeleton is the cellular analogy to the bones and muscles of an animal.
   b. The cytoskeletal elements can rapidly assemble and disassemble, as during cell division.
   c. Temporary formation of a spindle distributes chromosomes in an orderly manner.
6. **Centrioles**
   a. **Centrioles** are short cylinders with a ring pattern (9 + 0) of microtubule triplets.
   b. In animal cells and most protists, centrosome contains two centrioles lying at right angles to each other.
   c. Plant and fungal cells have equivalent of a centrosome but it does not contain centrioles.
   d. Centrioles serve as **basal bodies** for cilia and flagella.
7. **Cilia and Flagella**
   a. **Cilia** are short, usually numerous hairlike projections that can move in an undulating fashion (e.g., *Paramecium*; lining of human upper respiratory tract).
   b. **Flagella** are longer, usually fewer, whip-like projections that move in whip-like fashion (e.g., sperm cells).
   c. Both have similar construction, but differ from prokaryotic flagella.
      1) Membrane-bounded cylinders enclose a matrix containing a cylinder of nine pairs of microtubules encircling two single microtubules (9 + 2 pattern of microtubules).
      2) Cilia and flagella move when the microtubules slide past one another.
      3) Cilia and flagella have a basal body at base with same arrangement of microtubule triples as centrioles.
      4) Cilia and flagella grow by the addition of tubulin dimers to their tips.