CHAPTER 5 MEMBRANE STRUCTURE AND FUNCTION

Chapter Outline

5.1 Membrane Models

A. Early Observations
   1. At turn of the century, researchers noted lipid-soluble molecules entered cells more rapidly than water-soluble molecules, suggesting lipids are component of plasma membrane.
   2. Later chemical analysis revealed the membrane contained phospholipids.
   3. Gorter and Grendel (1925) found the amount of phospholipid extracted from a red blood cell was just enough to form one bilayer; they also suggested the nonpolar tails were directed inward and polar heads outward.
   4. To account for permeability of membrane to nonlipid substances, Danielli and Davson proposed **sandwich model** (later proved wrong) with phospholipid bilayer between layers of protein.
   5. With an electron microscope available, Robertson proposed that proteins were embedded in an outer membrane and that all membranes in cells had similar compositions—the **unit membrane model.**
   6. However, additional research showed a high diversity in membrane structure and function.

B. **Fluid-Mosaic Model**
   1. In 1972, S. Singer and G. Nicolson introduced the currently accepted **fluid-mosaic model**.
   2. A plasma membrane is phospholipid bilayer in which protein molecules are partially or wholly embedded.
   3. Embedded proteins are scattered throughout membrane in an irregular pattern; this varies among membranes.
   4. Electron micrographs of freeze-fractured membrane support the fluid-mosaic model.

5.2 Plasma Membrane Structure and Function

A. Separating the Internal and External Environment
   1. A membrane's structure has two components: lipids and proteins.
   2. Phospholipids are arranged in a bilayer.
   3. Plasma phospholipids spontaneously arrange themselves into a bilayer.
   4. This bilayer has a fluid consistency similar to light oil.
   5. Nonpolar tails are hydrophobic and directed inward.
   6. Polar heads are hydrophilic (water-loving) and are directed outward to face both extracellular and intracellular fluids.
   7. **Glycolipids** have a structure similar to phospholipids except the hydrophilic head is a variety of sugar; they are protective and assist in various functions.
   8. **Cholesterol** is a lipid found in animal plasma membranes; it stiffens and strengthens the membrane.
   9. **Glycoproteins** have an attached carbohydrate chain of sugar that projects externally.
   10. The plasma membrane is asymmetrical; glycolipids and proteins occur only on outside and cytoskeletal filaments attach to proteins only on the inside surface.

B. Carbohydrate Chains
   1. In animal cells, the glycocalyx is a sugar coat of carbohydrate chains used in cell recognition.
   2. Cells are unique in a "fingerprint" of highly varied carbohydrate chains.
   3. The immune system recognizes foreign tissues that have strange carbohydrate chains.
   4. Carbohydrate chains are the basis for A, B, and O blood groups in humans.

C. Fluidity of the Plasma Membrane
   1. At body temperature, the phospholipid bilayer has consistency of olive oil.
   2. The greater the concentration of unsaturated fatty acid residues, the more fluid the bilayer.
   3. In each monolayer, the hydrocarbon tails wiggle, and entire phospholipid molecules can move sideways at a rate of about 2 μm—the length of a prokaryotic cell—per second.
   4. Phospholipid molecules rarely flip-flop from one layer to the other.
   5. Fluidity of the phospholipid bilayer allows cells to be pliable.
   6. Some proteins are held in place by cytoskeletal filaments; most drift in fluid bilayer.

D. The Functions of the Proteins

1. Plasma membrane and organelle membranes have unique proteins; red blood cells (RBC) plasma membrane contains 50+ types of proteins.
2. Membrane proteins determine most of the membrane's functions.
3. **Channel proteins** allow a particular molecule to cross membrane freely (e.g., Cl^- channels).
4. **Carrier proteins** selectively interact with a specific molecule so it can cross the plasma membrane (e.g., Na^+-K^+ pump).
5. **Cell recognition proteins** are glycoproteins that allow the body's immunie system to distinguish between foreign invaders and body cells.
6. **Receptor proteins** are shaped so a specific molecule (e.g., hormone or other molecule) can bind to it.
7. **Enzymatic proteins** carry out specific metabolic reactions.

5.3 Permeability of the Plasma Membrane

A. Types of Membranes and Transport
   1. The plasma membrane is **differentially permeable**; only certain molecules can pass through freely.
   2. A **semipermeable membrane** allows some molecules to pass through.
      a. Small non-charged lipid molecules (alcohol, oxygen) pass through the membrane freely.
      b. Small polar molecules (carbon dioxide, water) easily pass along a **concentration gradient**, from high to low concentration.
      c. Ions and charged molecules have difficulty crossing the hydrophobic phase of the bilayer and usually combine with carrier proteins.
   3. Both passive and active mechanisms move molecules across membrane.
      a. **Passive transport** moves molecules across membrane without expenditure of energy by cell; includes **diffusion** and **facilitated transport.**
      b. **Active transport** requires a carrier protein and uses energy (ATP) to move molecules across a plasma membrane; includes **active transport, exocytosis**, **endocytosis,** and **pinocytosis.**

B. Diffusion and Osmosis
   1. **Diffusion** moves molecules from higher to lower concentration (i.e., down their concentration gradient).
      a. A solution contains a **solute,** usually a solid, and a **solvent,** usually a liquid.
      b. In the case of a dye diffusing in water, dye is a solute and water is the solvent.
      c. Once a solute is evenly distributed, random movement continues but with no net change.
      d. Membrane chemical and physical properties allow only a few types of molecules to cross by diffusion.
      e. Gases readily diffuse through the lipid bilayer; movement of oxygen from air sacs (alveoli) to the blood in lung capillaries depends on the concentration of oxygen in alveoli.
   2. **Osmosis** is the diffusion of water across a differentially permeable membrane.
      a. **Osmotic pressure** is illustrated by the thistle tube example:
         1) A differentially permeable membrane separates two solutions.
         2) The beaker has more water (lower percentage of solute) and the thistle tube has less water.
         3) The membrane does not permit passage of the solute; water enters but the solute does not exit.
         4) The membrane permits passage of water with a net movement of water from the beaker to the inside of the thistle tube.
      b. **Osmotic pressure** is the pressure that develops in such a system due to osmosis.
      c. Osmotic pressure results in water being absorbed by the kidneys and water being taken up from tissue fluid.
   3. **Tonicity** is strength of a solution in relationship to osmosis.
      a. **Isotonic solutions** occur where the relative solute concentrations of two solutions are **equal**; a 0.9% salt solution is used in injections because it is isotonic to red blood cells (RBCs).
      b. A **hypotonic solution** has a solute concentration that is **less** than another solution; when a cell is placed in a hypotonic solution, water enters the cells and they may undergo **lysis** (burst).
      c. Swelling of plant cell in hypotonic solution creates **turgor pressure;** how plants maintain erect position.
      d. A **hypertonic** solution has a higher percentage of solute than a cell; as a result, water may leave the cells.
      e. Solutions that cause cells to shrink are hypertonic solutions; red blood cells placed in salt solutions above 0.9% shrink and wrinkle, a condition called **crenation.**

    f. Plasmolysis is shrinking of the cytoplasm due to osmosis in a hypertonic situation, often in a plant cell.

C. Transport by Carrier Proteins

1. The plasma membrane impedes passage of most substances but many molecules enter or leave at rapid rates.
2. **Carrier proteins** are membrane proteins that combine with and transport only one type of molecule or ion; they are believed to undergo a change in shape to move the molecule across by active and facilitated transport.
3. **Facilitated transport** is passive transport of specific solutes down their concentration gradient, facilitated by a carrier protein; glucose and amino acids move although not lipid-soluble.
4. **Active transport** is transport of specific solutes across plasma membranes against the concentration gradient through use of cellular energy (ATP).
    a. Iodine is concentrated in cells of thyroid gland, glucose is completely absorbed into lining of digestive tract, and sodium is mostly reabsorbed by kidney tubule lining.
    b. Active transport requires both carrier proteins and ATP; therefore cells must have high number of mitochondria near membranes.
    c. Proteins involved in active transport are often called "pumps"; the sodium-potassium pump is an important carrier system in nerve and muscle cells.
    d. Salt (NaCl) crosses a plasma membrane because sodium ions are pumped across and the chloride ion is attracted to the sodium ion and simply diffuses across channels.
5. **Membrane-Assisted Transport**
    a. In **exocytosis,** a vesicle often formed by Golgi apparatus fuses with the plasma membrane as secretion occurs; insulin leaves insulin-secreting cells by this method.
    b. During **endocytosis**, cells take in substances by vesicle formation as plasma membrane pinches off by either phagocytosis, pinocytosis, or receptor-mediated endocytosis.
    c. In **phagocytosis,** cells engulf large particles forming an endocytic vesicle.
        1) Phagocytosis is commonly performed by ameboid-type cells (e.g., amoebas and macrophages).
        2) When the endocytic vesicle fuses with a lysosome, digestion occurs.
    d. **Pinocytosis** occurs when vesicles form around a liquid or very small particles; this is only visible with electron microscopy.
    e. **Receptor-mediated endocytosis** occurs when specific macromolecules bind to plasma membrane receptors.
        1) The receptor proteins are shaped to fit with specific vitamin, hormone, or lipoprotein molecules and are found at one location in the plasma membrane.
        2) This location is a coated pit with a layer of fibrous protein on cytoplasmic side; when the vesicle is uncoated, it may fuse with a lysosome.
        3) Pits are associated with exchange of substances between cells (e.g., maternal and fetal blood).
        4) This system is selective and more efficient; it is important in moving substances from maternal to fetal blood.
        5) When cholesterol enters a cell from the bloodstream via coated pits; in familial hypocholesterolemia, the LDL receptor cannot bind to the coated pit and the excess cholesterol accumulates in the circulatory system.

5.3 Modification of Cell Surfaces

A. Plasma Membrane

1. Many cells have an extracellular component formed outside of membrane.
2. Plant, fungi, algae, and prokaryotes form a rigid cell wall.
3. Animal cells have a varied extracellular anatomy depending on tissue type.

B. Cell Surfaces in Animals

1. **Cell junctions** are points of contact that physically link neighboring cells or provide functional links; animal cells have three types: adhesion junctions, tight junctions, and gap junctions.
2. In **adhesion junctions (desmosomes)**, internal cytoplasmic plaques firmly attached to cytoskeleton within each cell are joined by intercellular filaments; they hold cells together where tissues stretch (e.g., in heart, stomach, bladder).
3. In **tight junctions**, plasma membrane proteins attach in zipper-like fastenings; they hold cells together so tightly that the tissues (e.g., epithelial lining of stomach, kidney tubules) are barriers.

4. A **gap junction** allows cells to communicate.
    a. They are formed by the joining of two identical plasma membrane channels; the channel of each cell is lined by six plasma proteins.
    b. They provide strength to the cells involved and allow the movement of small molecules and ions from the cytoplasm of one cell to the cytoplasm of the other cell.
    c. Gap junctions permit flow of ions for heart muscle and smooth muscle cells to contract.
5. The **extracellular matrix** is a meshwork of polysaccharides and proteins produced by animal cells.
6. **Collagen** gives the matrix strength and **elastin** gives it resilience.
7. **Fibronectins** and **laminins** bind to membrane receptors and permit communication between matrix and cytoplasm.
8. **Fibronectins** and **laminins** also form "highways" that direct the migration of cells during development.
9. **Proteoglycans** are glycoproteins that provide a packing gel that joins the various proteins in matrix and most likely regulate signaling proteins that bind to receptors in the plasma protein.

C. Plant Cell Walls
1. Plant cells are surrounded by a porous cell wall; it varies in thickness, depending on function of cell.
2. Plant cells have a primary cell wall composed of cellulose polymers united into threadlike microfibrils that form fibrils.
3. Cellulose fibrils form a framework whose spaces are filled by non-cellulose molecules:
    a. **Pectins** allow cell wall to stretch and are abundant in the middle lamella that holds cells together.
    b. **Non-cellulose** polysaccharides harden the wall of mature cells.
4. **Lignin** adds strength and is a common ingredient of secondary cell walls in woody plants.
5. **Plasmodesmata** are narrow membrane-lined channels that pass through cell walls of neighboring cells and connect their cytoplasms, allowing direct exchange of molecules and ions between neighboring plant cells.