The Cell Part I, Chapter 2

Outline of class notes

Objectives for Part I and II:

After studying this chapter you should be able to:

1. Discuss the Cell Theory, the two classes of cells, and the cell’s 3 principle components.
2. Explain the functions and components of the plasma membrane.
3. Describe how body fluids are classified.
4. Describe membrane permeability and discuss how materials move across a plasma membrane by passive transport processes. Be sure to include an explanation of diffusion, simple diffusion, facilitated diffusion, osmosis, and filtration.
5. Describe osmosis, tonicity, and their effect on red blood cells.
6. Discuss how materials move across a plasma membrane by active transport processes. Focus on vesicular transport which includes endocytosis (phagocytosis, pinocytosis) and exocytosis.
7. Describe the cytoskeleton and vesicular transport. Describe how reverse axonal transport helps in the movement of certain viruses.
8. Describe the structure and functions of the following: cytoskeleton, nucleus, nucleolus, endoplasmic reticulum, ribosomes, golgi complex, lysosomes, peroxisomes, proteosomes, mitochondria, flagella, cilia, and centrosome/centrioles.
9. Explain how DNA is replicated.
10. Describe the function and types of cell division.
11. Give a definition for mitosis and meioses and describe the general characteristics of chromosomes.
12. Describe the cell cycle. Emphasis should be placed on the events of interphase, mitoses, and cytokinesis.
13. Describe the characteristics of a tumor/cancer including the difference between benign and malignant tumors. Include a discussion on the basis of how cancers are named, the genetic basis of cancers and the role of tumor suppressor genes.
14. Discuss the following disorders: Tay-Sachs disease, ectopic pregnancy, and the Human Papillomavirus (HPV).
15. Discuss the Clinical Applications from the study guide and assigned Applications to Health.
16. Identify the cell structures/organelles from the file found on my web page (student resources).

Chapter Overview, Part I

- Cell Theory
- Plasma Membrane Components
- Classification of Body Fluids
- Movement through a Plasmal Membrane.
  - Passive Transport
  - Active transport
- Important Organelles

Cell Theory

- Cell theory proposes that:
  1. All organisms are composed of one or more
     - Schleiden and Schwann, 1839
  2. The cell is the smallest unit having the structural and functional properties of life.
     - Schleiden and Schwann, 1839
  3. Cells can only arise from preexisting cells.
     - Virchow, 1889
  - Activity of an organism depends on individual and collective activity of cells
Two classes of Cells
- The human body contains two classes of cells
  1. **Somatic cells** include all cells of the body except reproductive (germ) cells.
  2. **Reproductive cells** are of two types:
     - Sperm from a male
     - Ova from a female

Typical Cell has 3 Principle Components:
1. **Plasma (cell) membrane**: Selectively permeable membrane that separates intracellular fluids from extracellular fluids.
2. **Cytoplasm**: Region between the nucleus and plasma membrane and includes all the cell’s contents (except the nucleus).
   - Cytosol: The fluid portion of the cytoplasm
   - Protoplasm: All the cell’s contents – nucleoplasm + cytoplasm
   - Organelles: Structures that perform specific functions
3. **Nucleus**: Contains the cell’s genetic material

Functions of the Plasma Membrane
- **Physical isolation**
  - Is a physical barrier that separates the cell’s internal environment from the external environment.
- **Regulation of exchange with the environment**
  - Controls the entry of ions and nutrients, secretions, and elimination of wastes
  - Has receptors for response to specific molecules in the cell’s environment
- **Structural support**
  - Connections between cell membranes and extracellular materials give tissues stability

Components of the Plasma Membrane
- The plasma membrane is a semi-permeable membrane between the cell’s internal and external environment consisting of mostly lipids and proteins.
- **Fluid Mosaic Model** depicts the plasma membrane as a mosaic of inserted protein molecules drifting in a phospholipid bilayer that is in a fluid-like state
Lipid Component of Plasma Membrane
- Membrane Lipids:
  - **Phospholipid bilayer**: Double layer of phospholipids with imbedded proteins, cholesterol, and glycolipids/glycoproteins
    - A **phospholipid molecule** contains:
      - A **hydrophobic tail** made of two fatty acids which face toward the center of the bilayer.
      - A **hydrophillic head** made of a glycerol and a phosphate group which face the water inside and outside the cell
    - Function: Barrier for maintenance of internal environment and enhance membrane mobility
  - **Cholesterol**:
    - Function: Stabilizes and strengthens (making it less flexible) the membrane.
  - **Glycolipids**: Lipids attached to carbohydrates

![Diagram of phospholipid bilayer and cholesterol](image)

Protein Component of Plasma Membrane
- Two categories based on position in membrane
  1. **Integral proteins**: Extend through the bilayer and are firmly imbedded (transmembrane proteins)
  2. **Peripheral proteins**: Remain on the inner or outer surfaces of the cell membrane.
    - Protein molecules can move among the phospholipid bilayer
    - Glycoproteins: Carbohydrates attached to proteins

**Plasma Membrane: Glycocalyx**
- **Glycocalyx** is the extensive network formed from the carbohydrate portions of **glycolipids** and **glycoproteins**.
- **Functions**:
  - Cell recognition markers, protection from enzymes in extracellular fluid, adhesion to other cells.
Functions of Membrane Proteins

- **Cell Junctions**
  - Cell junctions connect cells together and stabilize their position

- **Cell-identity markers**
  - Immune system cells recognize normal and abnormal cells based on outer membrane proteins
  - ABO blood type markers.

- **Enzymes**
  - Catalyze reactions at the inside or outside surface of the cell

- **Receptors**
  - Bind to specific extracellular material called **ligands** which triggers changes in the cell’s activity

- **Channels**
  - Forms a passageway that permits the movement of ions (K, Na, Ca), water, and other small molecules across the membrane

**Plasma Membrane: Microvilli**

- **Microvilli** are fingerlike projections that occur on the outer (apical) membrane surface
  - Function to increase surface area of the cell membrane
  - Ex: The epithelial cells of the intestine and kidney tubules

**Classification of Body Fluids**

- **Intracellular fluid (ICF) or cytosol**: Fluid within the cells.
- **Extracellular fluid (ECF)**: Fluid outside the cells.
  - **Interstitial (Intercellular) fluid**: The ECF filling the microscopic spaces between the cells of tissues
  - **Plasma**: The ECF in blood vessels
  - **Lymph**: The ECF in lymphatic vessels

**Membrane Permeability: Movement Through the Cell Membrane**

- Movement of substances across the plasma membrane is essential to the life of the cell and organism.
- The plasma membrane is **selectively permeable**, meaning that some substances, but not others, can pass into or out of the cell.
  - Allows for the intracellular environment to be different than the extracellular environment
  - Passage may be based on size, electrical charge, molecular shape, or lipid solubility
Passive and Active Transport Processes

- Transport across the cell membrane can occur by **passive** or **active** transport processes
  - **Passive transport** processes do not require energy from ATP; substances move down their concentration gradient. Processes include: simple diffusion; facilitated diffusion, osmosis, filtration
  - **Active transport** processes require energy from ATP and include 2 main categories
    1. **Primary and secondary active transport** involved in movement of ions across the plasma membrane.
    2. **Vesicular transport** consists of endocytosis (phagocytosis, pinocytosis) and exocytosis

Review of Key Science Terms

- Before discussing membrane transport you should be familiar with the following terms: solute, solvent, diffusion and concentration gradients.
  - **Solute** are substances that are dissolved in a predominant liquid or gas, which is called the **solvent**
  - **Diffusion**: The movement of solutes (ions and molecules) from an area of higher concentration to an area of lower concentration.
    - Driven by the molecular or kinetic (thermal) energy of the ions or molecules, size of the molecules, and their concentration gradient.
  - **Concentration gradient** is the difference between high and low concentrations of a substance.
    - The rate at which molecules diffuse depends on the size of the concentration gradient
      - Larger (steeper) the gradient, the faster the diffusion

Simple Diffusion

- **Simple diffusion** is the movement of ions or molecules across the membrane from an area of higher concentration to an area of lower concentration **without** the use of energy.
- **Lipid soluble** (nonpolar) molecules diffuse directly through the cell membrane because they can pass through the hydrophobic interior of the plasma membrane with ease.
  - Include: alcohol, fat soluble vitamins, fatty acids, steroids, O2, and CO2

Simple Diffusion

Dialysis is an example of simple diffusion

- In renal failure (kidney failure), nitrogenous wastes can accumulate in the blood, blood pH dangerously drops, and the ionic composition of the blood goes awry.
- **Hemodialysis**: Patient’s blood is passed through a membrane tubing that is permeable only to selected substances, and the tubing is set in a bath that is similar to normal plasma.
  - As blood circulates through the tubing, substances such as nitrogenous wastes in the blood (but not in the bath) diffuse out of the blood and into the bath.
  - At the same time buffering chemicals (which restore pH) and glucose (for malnourished patients) will diffuse from the bath into the blood.
Facilitated Diffusion
• This is simple diffusion but the ions or molecules are not lipid soluble and thus must diffuse through membrane channels (carrier proteins) – integral membrane proteins
  – **Carrier proteins** bind solutes and transport them across the cell membrane.
    • They move substances into or out of a cell from a higher to a lower concentration of that substance
    • Ex: Electrically charged ions (Na+, K+, Cl-), glucose, and amino acids

Osmosis
• **Osmosis is the diffusion of water across a selectively permeable membrane.** Water moves from an area of higher water concentration to one of lower water concentration.
  – Water will flow toward the solution that has the higher concentration of solutes, because that is where the concentration of water is lowest.
  – It’s important that you understand the following:
    • An area that has a high water concentration has a low dissolved particles concentration.
    • An area that has a low water concentration has a high dissolved particles concentration.

Test Your Knowledge!
Which way do you think the water molecules will move?
Water molecules are the solvent.
Tonicity: Effects of Osmosis
- Tonicity is used to describe the effects of various osmotic solutions on living cells
  - **Isotonic solution**: Has the same concentration as the cell.
    - Water moves into and out of the cell at the same rate - there is no net movement of water (state of equilibrium).
    - Most intravenous solutions are isotonic (e.g., 0.9% saline or 5% glucose). Why is this necessary?
  - **Hypotonic solution**: Has a lower solute concentration (thus, higher water concentration) than inside the cell.
    - Water moves into the cell by osmosis causing it to swell and possibly burst (process called lysis).
  - **Hypertonic solution**: Has a higher solute concentration (thus, lower water concentration) than inside the cell
    - Water moves out of the cell causing it to shrink (process called crenation).

Remember!
- **Tonicity** always refers to the concentration of the solution outside the cell relative to the solution inside the cell.
  - **Isotonic**: Solutions with the same solute concentration as that of the cell. “equal solute and water”
  - **Hypertonic**: Solutions having greater solute concentration than that of the cell. “more solute, less water”
  - **Hypotonic**: Solutions having less solute concentration than that of the cell. ”less solute, more water”
- Do you think pure water is hypertonic or hypotonic to the cell?
  - Hypotonic

DEATH Due to Drinking too much Water! WHY?
Filtration
- **Filtration** is movement of fluid through a partition containing small holes.
- The rate that solute molecules are filtered depends on:
  - Their size
  - The force of hydrostatic pressure or gravity
  - The rate at which water passes thru the membrane.
  - Ex: Kidney – glomerular filtrate; capillaries; Coffee filter

Review: Movement Thru the Cell Membrane
- Transport across the cell membrane can occur by passive or active transport processes
  - **We covered**: Passive transport processes do not require energy and include (1) simple diffusion; (2) facilitated diffusion, (3) osmosis, and (4) filtration
  - **Next**: Active transport processes require energy and include (1) primary active transport; (2) secondary active transport; (3) Vesicular transport which includes endocytosis (phagocytosis, pinocytosis) and exocytosis
Active Transport
- Involves the expenditure of energy (ATP) to move solutes across the cell membrane against their concentration gradient (from an area of lesser to one of greater concentration).
  - Details of primary and secondary active transport will be covered in Physiology

Exocytosis
- Exocytosis literally means “out of the cell”
- It accounts for hormone secretion, neurotransmitter release, mucus secretion, release of digestive enzymes and, in some cases, ejection of wastes.
  - Inside the cell, the substance to be exported is enclosed in a membranous sac called a vesicle.
  - The vesicle will migrate to the plasma membrane fuse with it, and then rupture, releasing the contents into the extracellular space.

Endocytosis
- Reverse of exocytosis. Allows macromolecules to enter cells.
  - The substance is progressively enclosed by an enfolding portion of the plasma membrane.
  - This forms a vesicle which will pinch off the plasma membrane and enter the cytosol where it is typically digested.
- Types of endocytosis are:
  - Phagocytosis
  - Pinocytosis (bulk-phase endocytosis)
  - Receptor-mediated endocytosis

Phagocytosis
- Phagocytosis means “cell-eating.”
- Cytoplasmic extensions called pseudopods “reach out and grab” large, solid material such as a bacteria, viruses, and worn out cells and then engulf it. This is a selective process.
  - Two main types of phagocytes are macrophages and neutrophils
- Usually, the vesicle fuses with a lysosome, an organelle that contains digestive enzymes, which breaks down the material.

Pinocytosis (Bulk-phase Endocytosis)
- Pinocytosis means “cell-drinking.”
- Engulfment of small quantities of extracellular fluid by the infolding of the plasma membrane. This creates a tiny membranous vesicle that can fuse with a lysosome.
- Most cells routinely perform this. Not specific
Receptor-Mediated Endocytosis (RME)
- Main mechanism for the **specific uptake** of macromolecules by most cells
- Molecules taken up by cells via RME include:
  - Enzymes
  - Hormones
  - Low-density lipoproteins (LDL), i.e., the “bad cholesterol”
  - Flu viruses and the diphtheria toxin also use RME to enter cells
- Receptors for the molecule to be ingested by a cell are on the cell membrane.
  - Different cells have different receptors and thus take up different molecules.
- A macromolecule will bind with its particular receptor and then these receptor-macromolecule complexes cluster together in regions called **clathrin-coated pits**, invaginate, and are internalized.

Cell Organelles
- **Organelles** are specialized cellular components and consist of:
  - **Membrane bound organelles**: Nucleus; rough and smooth endoplasmic reticulum; golgi apparatus; secretory vesicles; lysosomes and peroxisomes; mitochondria; and some cells have cilia, flagella, and/or microvilli
  - **Nonmembrane bound organelles**: nucleoli; cytoskeleton; ribosomes; centrosomes/centrioles
Cytoskeleton
- **Cytoskeleton** is a network of protein fibers that support the cell, hold or transport organelles, and enable the cell to change shape/move. **Consists of:**
  - **Microtubules:** Hollow tubes that determine cell shape, distribution of organelles and aid in their movement.
    - Components of centrioles, cilia, and flagella.
    - Made of protein tubulin
    - Centrosome is initiation site of microtubules
  - **Intermediate Filaments:** Provide support of the cell.
    - Anchor organelles and hold cells together via their cell membrane and attach to extracellular structures
    - Made of several different proteins
  - **Microfilaments:** Concentrated at periphery of a cell and made of actin protein.
    - Movement – muscle contraction, cell locomotion

Vesicular Transport and the Cytoskeleton
- Transport of vesicles throughout the cell relies on the cytoskeleton and molecular motors called kinesins and dyneins.
  - Molecular motors are proteins that attach to the vesicle or particle to be transported and use the energy of ATP to “walk” along the microtubule.
  - **Kinesin’s** consist of 2 “feet”, a stalk, and a fanlike tail which binds to the vesicle and carry cargo away from centrosome.
    - In nerves they carry secretory vesicles from the cell body along the axon to be released at the nerve terminal.
  - **Dynein’s** are molecular motors that transport vesicles toward the centrosome.
    - In nerves they carry vesicles containing debris from the axon terminal to the cell body for degradation by lysosomes.
• Reverse axonal transport can serve as a pathway for the movement of infectious agents such as herpes viruses, poliomyelitis virus, and the rabies virus.
  − These viruses travel backward along nerves from their surface site of contamination such as a break in the skin or an animal bit to the central nervous system.

Nucleus
• Contains the genetic material that determines the structural and functional characteristics of the cell by controlling what proteins are synthesized and in what amounts
  − Nuclear envelope (double membrane) surrounds the nucleus.
    • Outer membrane is continuous with the rough ER.
  − Nuclear pores are openings in the nuclear membrane through which materials can pass into or out of the nucleus.
• Chromosomes: Threadlike structures composed of nucleotides or genetic material (deoxyribonucleic acid or DNA) and proteins (histones)
  − Chromatin is the unraveled form of a chromosome found in non-dividing cells.
  − Chromosomes are the condensed form at the time cell division
  − Gene: A sequence of nucleotides in DNA that is a set of instructions for making a specific protein
  − The DNA strands coil around histone proteins which help to organize the coiling and folding of DNA into a small space
    • Nucleosome: DNA wrapped twice around a core of eight histone proteins
    • If the DNA base pairs on one human cell were strung end-to-end, it would be about 2 m long.

Check Your Understanding!
• What is the major difference between chromatin and a chromosome?
  Chromatin is not condensed (coiled), a chromosome is condensed.

Nucleolus and Ribosomes
• Nucleolus (little nucleus): Produce ribosomes.
• Ribosomes function in protein synthesis. They help in translating the genetic message, carried by messenger RNA (mRNA), into a protein.
  − Each ribosome consists of 2 subunits
• Ribosomes function in two cytoplasmic locations
  − Free Ribosomes: Suspended in the cytoplasm
  − Bound Ribosomes: Are attached to the outside of the endoplasmic reticulum
Ribosomes and Medicine

- **Ribosomes** of bacteria are smaller and differ in molecular composition. This difference is medically significant.
  - **Tetracycline** and **streptomycin** are antibiotics that interfere with the function of ribosomes in bacteria thus stopping protein production.
  - Without important enzymes (made from proteins) the bacteria die.

Endoplasmic Reticulum (ER)

- **ER** is a membranous network of flattened channels that are involved in the synthesis, storage, and transport of important molecules.
  - Can be classified as either rough or smooth
- **Rough ER**: Have ribosomes attached to its membrane surface.
  - Makes two main products:
    1. Membrane and Membrane proteins
    2. Secretory proteins to be secreted from the cell.
      - Ex: Antibodies from white blood cells (WBCs)
- **Smooth ER**: Have no ribosomes lining its membrane surface.
  - Produce enzymes that function in:
    - Metabolism
    - Synthesis of lipids (**steroids, fats, phospholipids**)
    - Detoxification of drugs and poisons.
  - In cells such as liver cells, barbiturates, alcohol, and other drugs induce the proliferation of smooth ER and its associated detoxification enzymes.
  - This increases tolerance to the drugs, meaning that higher doses are required to achieve a particular effect.

Golgi Apparatus (Body)

- **Golgi** are stacks of membranes (cisternae) that receive, modify, and package the proteins and lipids made by the endoplasmic reticulum.
  - Basically a refinery, warehouse, and shipping center
  - The products are packaged into vesicles for distribution to within the cell or for secretion.
Lysosomes and Peroxisomes
- **Lysosomes**: Vesicles containing hydrolytic enzymes made from the golgi complex. Used to digest food, old organelles (autophagy), and destruction of foreign particles (bacteria, viruses, and toxins).
- **Peroxisomes**: Vesicles that contain enzymes (oxidases) that use molecular oxygen to oxidize organic materials.
  - **Oxidation**: Loss of electrons from a substance
  - Can convert hydrogen peroxide to water and oxygen
  - Abundant in liver and kidney cells; detoxify toxic substances such as alcohol and hydrogen peroxide.

Tay-Sachs Disease
- **Tay-Sachs** is a progressive neurodegenerative disease.
- **Cause**: Inherited disorder. Lysosomes lack a single lipid-digesting enzyme.
  - Results in excess accumulation of lipids within nerve cells causing them to function poorly and die.
- **Outcome**:
  - Symptoms include seizures, muscle rigidity, blindness, and dementia
  - Children usually die before age 5.
  - More gradual and less severe forms can also affect people into their 20s and 30s.
  - One of the most common initial symptoms is a red spot in the eyes described as a 'cherry-red spot' due to change in the retina at the back of the eye.
- Currently there is no cure or effective way to delay the progression of the disease.

Proteasomes
- **Proteasomes** contain proteases that degrade cellular proteins that are unneeded, damaged or faulty.
  - Breaks apart the proteins into amino acids that can be reused by the cell.
  - Proteasomes are found within the cytosol and nucleus and are seen only with an electron microscope.

Mitochondria
- **Powerhouse of the cell**: Provide most of the cell's energy (ATP) by aerobic cellular respiration.
  - Takes in O2 and organic molecules and release end products – CO2, H2O, and ATP.
- Composed of a smooth outer membrane and an inner folded membrane (cristae).
- Contain their own (mitochondrial) DNA and are self replicating.
  - Mitochondria are passed from mother to child and do not come from sperm.
Cilia and Flagella
- **Cilia** are cylindrical cell extensions that move in a wave like fashion to move substances in one direction or provide locomotion for cells.
  - Ex: Cells that line the respiratory tract – move the mucus imbedded dust particles away from the lungs
- **Flagella** are single whip-like structures that propel a cell forward.
  - Ex: In humans, flagella are only found on the sperm cells
- **Note:** Both Cilia and Flagella contain microtubules in a 9+2 array covered by plasma membrane.
  - 9 clusters of doublet microtubules that surround 2 single microtubules at the center
  - Anchored to a basal body that contains 9 clusters of 3 triplet microtubules (9+0 array)

Ectopic Pregnancy
- In an **ectopic pregnancy**, a fertilized egg has implanted outside the uterus.
  - The egg is fertilized in the fallopian tubes more than 95% of the time. Common site of fertilization is the ampulla of the uterine tube.
  - **Cause:** An infection or inflammation of the tube may have partially or entirely blocked it or decreased the cilia's function preventing the fertilized egg from making it to the uterus.

Centrosome/Centrioles
- **Centrosome/Centriole** is the material that produces and helps organize microtubules
  - Contains a pair of centrioles
  - Each centriole is a cylindrical structure that consists of a bundle of parallel microtubules, which consist of 9 clusters of 3 microtubules – arrangement called a 9+0 array.
- **Functions:**
  - During cell division, microtubules will extend out from the centrioles, attach to chromosomes and facilitate the movement of those chromosomes
  - Help organize microtubule portion of cytoskeleton