ANATOMY AND PHYSIOLOGY (N3)
1st Semester 2022-2023
STUDY GUIDE

CELLULAR LEVEL OF ORGANIZATION

Introduction

Hello everyone! This is the 2nd part of this week's discussion. As we have learned about how the human body has a wonderful way to organize. Now we will move to the next part where our body has trillions of this. These provide structure for the body, take nutrients from the food, convert those nutrients into energy, and carry out specialized functions. And you know that these contain hereditary material and can make copies of themselves.

The cells are the basic and functional unit of life. There are different cell types in the body and each of them fulfill roles that contribute to homeostasis. In this study guide, we will look closely at the parts of the cells and their functions. We will also look at how substances are transported within the cell and how cells communicate with each other. Communication between cells is important to regulate processes necessary for homeostasis. We will also study the various organelles found in a cell and their functions.

Learning outcomes

After going through this topic, you should be able to:

1. Identify the different cellular functions
2. Discuss the structure and the functions of the plasma membrane and membrane proteins
3. Explain how substances are transported across the plasma membrane
4. Explain the structure and functions of the cytoplasm
5. Discuss the structure and functions of the various cell organelles
6. Discuss the structure and functions of the nucleus
7. Explain the importance and the process of protein synthesis
8. Discuss the process of cell division

Resources that you need to read

Please read the main references below to have a better understanding of the topic.

1. Betts JG, Desaix Peter, Johnson E et al (2017). *Anatomy and Physiology.* OpenStax Rice University.

   Specific chapter you need to read:
   Chapter 4: The Cellular Level of Organization pages 87-134

   Note: You may access this open education resource in this link: https://openstax.org/details/books/anatomy-and-physiology. You have an option to view the book online or download the PDF file.

2. Tortora GJ & Derrickson B. (2014). *Principles of Anatomy and Physiology.* John Wiley & Sons, Inc. 14 edition.

Specific chapter you need to read:

Chapter 3: The Cellular Level of Organization pages 87-134

Note: We are still requesting the College of Nursing Library for the purchase of the e-book of this edition.

3. *Cellular Biology* pre-recorded lecture video by Asst. Prof. Peter James B. Abad uploaded in Canvas

Topic outline

The specific topics that will be covered in this study guide are as follows:

1. Cellular Functions
2. Parts of a cell
3. The plasma membrane
4. Transport across the plasma membrane
5. The cytoplasm and the organelles
6. The nucleus
7. Protein synthesis
8. Cell Division

1. Cellular Functions

As you may recall in the previous topic on Organization of the Human Body, one of the basic life processes is *differentiation*. Differentiation is the process by which unspecialized cells, like those in the stem cells, become specialized through maturation. As the cells mature, they acquired specialized functions. For example, as nerve cells mature from stem cells, they acquire the function of being conductive and so they can respond to a stimulus by producing action potential (or nerve impulse). Each cell type will acquire a specialized function as they mature, and these functions are enumerated below:

A. MOVEMENT- as an example of this function, muscle cells generate force that produce motion. Skeletal muscles produce limb movement while smooth muscles in the blood vessels regulate blood flow by either constricting (narrowing in diameter) or dilation (increasing in diameter).

B. CONDUCTIVITY- This is a chief function of nerve cells and cardiac cells. They respond to stimuli by generating nerve impulses that are conducted to other cells.

C. METABOLIC ABSORPTION- all cells take in and use nutrients and other substances from their surroundings. But there are cells like those in intestines and in the kidneys that specialize to carry out absorption and reabsorption (especially for the kidney cells).

D. SECRETION- for example, the mucus gland cells can synthesize new substances which they secrete as needed.

E. EXCRETION- all cells can get rid of metabolic wastes. These wastes are degraded by organelles called *lysosomes* prior to excretion.

F. RESPIRATION- cells absorb oxygen which is used to generate ATP. The process of cellular respiration occurs in the mitochondria.

G. REPRODUCTION- tissue growth occurs as cells enlarge and reproduce themselves. New cells are produced to replace cells lost through *apoptosis*. Apoptosis is also known as programmed cell death and this usually happens if the cell detects molecular or metabolic errors within itself. Apoptosis is important to prevent propagation of cells with molecular or metabolic errors preventing disease conditions like cancer.

H. COMMUNICATION- cells communicate with each other and this is critical for all other cellular functions to work. Cellular communication also allows for the maintenance of a dynamic steady state.

2. Parts of a Cell

A generalized view of a cell like those found in many textbooks is a composite of many different cells in the body. No single cell includes all of the features seen in the generalized cell. Examples would be:

a. Not all cells have a nucleus. The red blood cell does not have a nucleus and so it has a definite lifespan of 120 days.
b. Not all cells have flagella. The sperm cell is a notable cell that has a flagellum.
c. The number of specific organelles found in each cell also varies depending on cell type.

To illustrate, skeletal muscle cells would have more mitochondria because they would need to produce more ATPs. Liver cells would have more peroxisomes because of their function to neutralize metabolic wastes. In general, a cell can be divided into three principal parts:

1. Plasma (cell) membrane
2. Cytoplasm- consisting of the cytosol and the organelles
3. Nucleus

We will go through each of the three principal parts in this study guide.

3. The Plasma Membrane

The plasma membrane is a flexible barrier that surrounds the cytoplasm of the cell. The structure of the plasma membrane is explained by the *fluid mosaic model* such that it is described as a "sea of lipids in which proteins float like icebergs". The lipid layer is a barrier to entry or exit of polar substances. There are also proteins that are embedded in the membrane (called *membrane proteins)* and these serve as "gatekeepers" that regulate the entry or exit of substances.

<u>The Lipid Bilayer</u>
The *lipid bilayer* is the basic framework of the plasma membrane and is made up of three types of lipid molecules: (a) phospholipids, (b) cholesterol, and (c) glycolipids.

A. Phospholipids

- These comprise 75% of the lipids found in the plasma membrane
- Each molecule is *amphipathic* which means that it has both a polar and nonpolar region. The polar parts (heads) are *hydrophilic* and face on both surfaces a watery environment. The nonpolar parts (tails) are *hydrophobic* and line up next to each other in the interior.

B. Cholesterol
- These comprise 20% of the cell membrane lipids
- They are weakly amphipathic and interspersed among the other lipids in both layers
- There are still steroid rings and hydrocarbon tail that are nonpolar and hide in the middle of the cell membrane

C. Glycolipids
- Comprise 5% of the lipids of the cell membrane
- They have a carbohydrate group that forms a polar head only on the side of the membrane facing the extracellular fluid.

<u>The Membrane Proteins</u>

The membrane proteins are divided into *integral* and *peripheral* proteins. Integral proteins extend into or across the entire lipid bilayer among the fatty acid tails of the phospholipid molecules. Peripheral proteins, on the other hand, are found at the inner or outer surface of the membrane and can be stripped away from the membrane without disturbing membrane integrity.

The membrane proteins function as *channels* (or *pores*), *transporters, receptors, enzymes, cell-identify markers,* and *linkers*. The different proteins help to determine many of the functions of the plasma membrane.

Let us take a look at the specific functions of the membrane proteins:

A. Formation of channel- membrane proteins become passageway to allow specific substances to pass through

B. Transporter proteins- there are membrane proteins that bind to specific substances, change their shape, and move the substance across the plasma membrane (in a process called *transporter-mediated diffusion)*.

C. Receptor proteins- there are membrane proteins that act as receptor proteins or cellular recognition sites which bind to specific substance (usually to a hormone, neurotransmitter, cytokine, growth factors etc.)

D. Cell identify marker- membrane proteins also allow cells to recognize other similar cells (for example the *Major Histocompatibility Complex*). This membrane proteins allows for the recognition of 'self' from 'non-self' to enable the immune system to attach foreign antigens and not the self-antigens.

E. Linkers- there are membrane proteins that anchor proteins in the cell membrane to other cells. They also allow cell movement and maintain shape and structure of the cells. F. Enzymes- membrane proteins also act as enzymes that speed up cellular reactions.

<u>Membrane Permeability</u>

The plasma membrane is *selectively permeable*. This means that some substances can pass through it while others cannot. The lipid bilayer portion of the membrane is permeable to small, non-polar, uncharged molecules but it is impermeable to ions and charged or polar molecules. The membrane is also permeable to water. *Transmembrane proteins* act as channels or transporters to increase the permeability

of the membrane to molecules that cannot cross the lipid bilayer. There are very large molecules, however, that cannot pass through even with membrane proteins but only through *vesicular transport.*

What then drives the transport of substances across the plasma membrane?

Substances cross the plasma membrane depending on the relative *concentration gradient*. A concentration gradient is the difference in the concentration of a chemical between one side of the plasma membrane and the other. For example, oxygen and sodium ions are more concentrated outside the cell membrane with carbon dioxide and potassium ions more concentrated inside the cell membrane.
We have two gradients across the membrane – (1) concentration gradient and the (2) electrical gradient. We have tackled a little bit about concentration gradient in the previous paragraph but let us take a look at the electrical gradient. The inner surface of the membrane is more negatively charged, and the outer surface is more positively charged. This difference sets up an electrical gradient, also called the *membrane potential*. This electrical gradient is important as it provides power to operate cell membrane functions and use to transmit signal between cells (for example in the heart and the neurons).

Additional Resource
You may want to watch the Khan Academic video on *Cell Membrane Overview and Fluid Mosaic Model* for more information. You can view it at this link: https://www.youtube.com/watch?v=LXaPt9i9hqk

Activity 1. Plasma Membrane Answer these questions in the VLE. 1. What substances can and cannot pass through the lipid bilayer? 2. What factors contribute to a concentration and electrical gradient?

4. Transport across the plasma membrane

Some substances cross the lipid bilayer easily while others cross through ion channels. The transport processes that move substances across the cell membrane are either *active* or *passive.* Materials can also enter or leave the cell through *vesicle transport*.

Passive Transport
Passive transport mechanisms are those that does not require energy and usually moves across a concentration gradient. There are three types of passive process:

A. Diffusion through the lipid bilayer
B. Diffusion through ion channels
C. Facilitated diffusion

Before we talk about these three passive transport mechanisms, let's review diffusion first. When we talk about diffusion, we refer to the movement of substances across its concentration gradient—this means that the substance moves from an area of higher concentration to an area of lower concentration. Say for example, we have a cylinder of water and a crystal dye is placed at the bottom. The net diffusion movement is from the area of higher dye concentration to the region of lower dye concentration. In this case, diffusion is the random mixing of particles that occurs in a solution because of the kinetic energy of

the particles.

Diffusion rate across the plasma membrane is influenced by several factors:

1. Steepness of the concentration gradient- the higher the concentration of a substance in one side of the plasma membrane, the faster is the diffusion.
2. Temperature- in general, higher temperature facilitates faster diffusion as the there is higher kinetic energy in the substance
3. Size or mass of the diffusing substance- in general, size of the diffusing substance has an inverse relationship with the rate of diffusion
4. Surface area- the size of the surface area is directly proportional to the rate of diffusion
5. Diffusion distance- the longer the diffusion distance, the slower the rate of diffusion.

Now that you know the principle of diffusion, let us take a look at the *diffusion through the lipid bilayer.* Non-polar, hydrophobic molecules such as respiratory gasses (O2 and CO2), some lipids, small alcohols, and ammonia can diffuse readily across the lipid bilayer. This transport mechanism is, therefore, important for gas exchange, absorption of some nutrients, and excretion of some wastes.

However, not all substances can readily diffuse through the lipid bilayer. Some of them are transported through *diffusion through membrane channels*. Still remember the membrane proteins earlier? Most of these membrane channels are *ion channels*, allowing the passage of small, inorganic ions which are hydrophilic. Ion channels, however, are *selective* and *specific* and maybe *gated* or open all the time.

Another concept that we need to review when we talk about passive transport is *osmosis*. Osmosis is the movement of water from an area of lower solute concentration to an area of higher solute concentration. Water molecules penetrate the membrane by diffusion through the lipid bilayer or through *aquaporins*, a transmembrane protein that function as water channels. *Aquaporins*, for example, are important when water is reabsorbed by the nephrons in the kidneys. Osmosis occurs only when the membrane is permeable to water but not to certain solutes.

A related concept to osmosis is *tonicity.* Tonicity is a measure of a solution's ability to change the volume of cells by altering their water concentration. There are three types of solutions based on tonicity as follows:

1. Isotonic solution- in an isotonic solution, there is equal solute concentration on both sides of the plasma membrane, hence the net movement of water is zero. To illustrate, a red blood cell that is subjected to an isotonic solution maintains its normal shape.

2. Hypotonic solution- in a hypotonic solution, the amount of solute concentration outside the cell is less compared to the intracellular environment. Hence, the net movement of water is into the cell. To illustrate, a red blood cell subjected to a hypotonic solution will swell and will undergo *hemolysis.*

3. Hypertonic solution- in a hypertonic solution, the amount of solute concentration outside the cell is more compared to the intracellular environment. Hence, the net movement of water is outside the cell. To illustrate, a red blood cell subjected to a hypertonic solution will undergo crenation.

The third type of passive transport is *facilitated diffusion.* In facilitated diffusion, a solute binds to a

specific transporter (a membrane protein) on one side of the membrane and is released on the other side after the transporter undergoes a *conformational change.* The rate of movement through facilitated diffusion depends on (1) steepness of concentration gradient, and (2) the number of transporter proteins (also called *transport maximum).* Transport maximum is the upper limit on the rate at which facilitated diffusion can occur. What does this imply? If all the transporters are occupied, then the rate of facilitated diffusion does not increase.

To illustrate the clinical significance of transport maximum, let's take the example of glucose. Glucose cross the plasma membrane through facilitated diffusion and hence there are specific glucose transporters in the plasma membrane. There are only a limited number of glucose transporters in the plasma membrane. If, for example, there is too much glucose to be transported across the plasma membrane, all the transporters can easily be occupied and therefore the rest of the glucose cannot be transported across. Hence, in individuals with *diabetes mellitus*, they usually exhibit *glucosuria* (or they excrete glucose in their urine) because the amount of glucose that needs to be transported (or reabsorbed in the kidneys) are more than the number of glucose transporters. In this case, the transport maximum is reached.

Active Transport

If passive transport does not require energy to occur, active transport is an *energy-requiring* process that moves solutes such as ions, amino acids, and monosaccharides *against a concentration gradient*. 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.

The most prevalent primary active transport mechanism is the *sodium ion/potassium ion pump.* This required 40% of cellular ATP and all cells have this pump. The main function of this pump is to maintain low concentration of Na+ and a high concentration of K+ in the cytosol.

Transport in Vesicles

The third mechanism by which substances are transported across the plasma membrane is through *vesicle transport*. A vesicle is a small membranous sac formed by budding off from the existing membrane. There are two types of vesicle transport—(1) endocytosis and (2) exocytosis.

Endocytosis means "bringing something into the cell". There are two types of endocytosis—(1) phagocytosis and (2) pinocytosis. In phagocytosis, the cell "eats" solid substances, and this is usually carried out by macrophages and white blood cells. The particle (usually a foreign body or a foreign antigen binds to a receptor protein and this is engulfed and later digested through the lysosomal juices inside the phagocyte. In pinocytosis, on the other hand, the cell "drinks" liquid substances and there are no receptor proteins involved.

Exocytosis, on the other hand, means releasing something from the cell. A substance formed inside the cell is enveloped in a vesicle which then fuses with the cell membranes, until it is released outside the cell. Exocytosis is the process by which substances such as digestive enzymes, hormones, neurotransmitters, or waste products are released by the cells.

Additional Resources

You may want to watch the following videos for more information:

1. How do things move across a cell membrane (a Khan Academy video)- https://www.youtube.com/watch?v=knv4fNNoEG8

2. You may want to review the concepts of diffusion and osmosis in this Khan Academy video: https://www.youtube.com/watch?v=aubZU0iWtgI
3. Passive transport through facilitate diffusion (a Khan Academy video)- https://www.youtube.com/watch?v=ZAbrCJxk8fs

5. The Cytoplasm and the organelles

The cytoplasm has two main components—(1) cytosol and (2) the organelles.

The Cytosol

The cytosol is the intracellular fluid. It is a semifluid portion of the cytoplasm that contains inclusions and dissolved solutes. It is composed mostly of water, plus proteins, carbohydrates, lipids, and inorganic substances. Functionally, the cytosol is the medium in which many metabolic reactions occur.

The Organelles

The organelles are specialized structures that have characteristic shapes and perform specific functions in cellular growth, maintenance, and reproduction. The following are the organelles that are found in human cells:

A. CYTOSKELETON

The cytoskeleton is a network of protein filaments throughout the cytosol. It has functions in cell support and shape maintenance, organization of chemical reactions, and cell and organelle movement.

B. CENTROSOMES

These are dense areas of cytoplasm containing *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.

C. CILIA AND FLAGELLA

Cilia are numerous, short, hair-like projections extending from the surface of a cell and functioning to move materials across the surface of the cell. For example, cilia are found in the airways and the uterine tube. *Flagella*, on the other hand, are similar to cilia but are much longer, usually functioning to move an entire cell. The only example of a flagellum in the human body is the sperm cell tail.

D. RIBOSOMES

These are tiny spheres consisting of ribosomal RNA and several ribosomal proteins. They occur free (singly or in clusters) or together with endoplasmic reticulum. Functionally, the ribosomes are the sites of *protein synthesis*. We will discuss protein synthesis in a while. The *free ribosomes* are loose in the cytosol and they synthesize proteins found inside the cell. The *membrane-bound ribosomes* are attached to the endoplasmic reticulum or nuclear membrane. They synthesize proteins needed for plasma membranes or for export to other parts of the body. Inside the mitochondria, ribosomes synthesize mitochondrial proteins.

E. ENDOPLASMIC RETICULUM

This is a network of membranes that form flattened sacs or tubules called *cisterns.* There are two types of endoplasmic reticulum—the rough and the smooth endoplasmic reticulum (ER).

The *rough ER* is continuous with the nuclear membrane and has its outer surface studded with ribosomes. It functions to synthesize glycoproteins and phospholipids. The *smooth ER,* on the other hand, extends from the rough ER to form a network of membrane tubules but does not contain ribosomes on its membrane surface. It functions to synthesize fatty acids and steroids, detoxifies drugs, and stores calcium.

The ER transports substances, stores newly synthesized molecules, synthesizes and packages molecules, detoxifies chemicals, and releases calcium ions involved in muscle contraction.

F. GOLGI COMPLEX

The Golgi complex consists of three to twenty stacked, flattened membranous sacs (or *cisterns).* The principal function of the Golgi complex is to process, sort, and deliver proteins, and lipids to the plasma membrane, lysosomes, and secretory vesicles.

G. LYSOSOMES

These are membrane-enclosed vesicles that contain powerful digestive enzymes. It functions to digest foreign substances, perform *autophagy,* and *autoloysis.*

H. PEROXISOMES

These are similar in structure to lysosomes but they are smaller. They contain enzymes (e.g., *catalases*) that use molecular oxygen to oxidize various organic substances.

I. MITOCHONDRIA

The mitochondrion is bound by a double membrane. The outer membrane is smooth with the inner membrane arranged in folds called *cristae.* The cristae provides the surface area for chemical reactions of *cellular respiration*. As such, the mitochondria are the site of ATP production in the cell by the catabolism of nutrient molecules. The process of cellular respiration produces 38 ATP for every glucose molecule.

Activity 2. Parts of the Cell

Answer the questions below in VLE.

You do not consume alcoholic beverages, but your friend does, and he consumes these drinks regularly and in large amounts. If we could examine your liver cells and compare with your friend, would we see a difference in smooth ER and peroxisomes?

6. The Nucleus

The *nucleus* is usually the most prominent feature of a cell. Most body cells have a single nucleus; some (e.g., red blood cells) have none, whereas others (e.g., skeletal muscle fibers) have several. The parts of the nucleus include the *nuclear envelope* which is perforated by channels called nuclear pores, *nucleoli*, and the genetic material (i.e., the deoxyribonucleic acid). Within the nucleus are the cell's hereditary units, called *genes*, which are arranged in single file along chromosomes.

Inside the nucleus are the 46 chromosomes and in those chromosomes are the genes that provide direction for the synthesis or specific proteins which are necessary cellular processes and metabolism. In each of the chromosomes is a long molecule of DNA that is coiled together with several proteins. Human somatic cells (i.e., all cells except the gametes) have 46 chromosomes arranged in 23 pairs. The various levels of DNA packing are represented by nucleosomes, chromatin fibers, loops, chromatids, and chromosomes.

7. Protein Synthesis

Much of the cellular machinery is devoted to synthesizing large numbers of proteins. The proteins determine the physical and chemical characteristics of cells. The instructions for protein synthesis are found in the DNA in the nucleus. Protein synthesis involves two processes – (1) *transcription* and (2) *translation.*

The instructions for making specific proteins is found in the DNA (specifically in the genes). Inside the nucleus, the information from the DNA is transcribed into a messenger RNA molecule – this is the *transcription process*. The message in the messenger RNA is then translated into a sequence of amino acids to build a protein molecule. This process is called *translation,* and this happens outside the nucleus in the ribosomes.

Additional Resource
You may watch the video in the following link (video by The Organic Chemistry Tutor) to learn more about protein synthesis: https://www.youtube.com/watch?v=8wAwLwJAGHs

Activity 3. Genes

Answer the question below in the VLE.

When we say a gene is expressing itself, what does "gene expression" mean in relation to protein synthesis?

8. Cell Division

Cell division is the process by which cells reproduce themselves. It consists of nuclear division (*mitosis* and *meiosis*) and cytoplasmic division (*cytokinesis).* Cell division that results in an increase in body cells is called *somatic cell division* and this involves a nuclear division called *mitosis* plus cytokinesis. 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.

The Cell Cycle in Somatic Cells
The cell cycle is an orderly sequence of events by which a cell duplicates its contents and divides in two. It consists of the interphase and the *mitotic phase*.

During the interphase stage of the cell cycle, the cell carries on every life process except division. This is

also the time when the chromosomes are replicated in preparation for cell division. During mitosis, the two sets of chromosomes are distributed with one set each into two separate nuclei. The stages of mitosis are: (1) Prophase, (2) Metaphase, (3) Anaphase, and (4) Telophase.

After mitosis, cytokinesis happens. This 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. When cytokinesis is complete, interphase begins.

The Cell Cycle in Reproductive Cells

Meiosis results in the production of haploid cells that contain only 23 chromosomes. Meiosis occurs in two successive stages: *meiosis I* and *meiosis II.*

Additional Resource

Watch this video on the cell cycle (video by Khan Academy) for more information:
https://www.youtube.com/watch?v=U5vAO_f2LDQ

To know more about the specific phases in the cell cycle, you may want to check these videos out (videos by Khan Academy):

1. Interphase- https://www.youtube.com/watch?v=VXLSTd_dlKg
2. Mitosis- https://www.youtube.com/watch?v=TKGcfbyFXsw
3. Meiosis- https://www.youtube.com/watch?v=ijLc52LmFQg

Activity 4. Cell Division

Answer the following questions in the VLE.

1. Distinguish between somatic and reproductive cell division and explain the importance of each.
2. What is the significance of interphase?

References:

1. Betts JG, Desaix Peter, Johnson E et al (2017). Chapter 1 An Introduction to the Human Body. *Anatomy and Physiology.* OpenStax Rice University. Pp 7-40.

2. Tortora GJ & Derrickson B. (2014). Chapter 1 An Introduction to the Human Body. *Principles of Anatomy and Physiology.* John Wiley & Sons, Inc. 14 edition. Pp 1-26.