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Introduction to Physiology: Cell Chemistry; The Living Cell; Tissues; and Organ Systems

Reading Assignment

Chapter 1 "The Human Body: An Orientation" (pp. 2-12)
Chapter 2 "Chemistry Comes Alive" (pp. 43-57)
Chapter 3 "Cells: The Living Units" (pp. 64-97)
Chapter 4 "Tissue: The Living Fabric" (pp. 117-119, 126-127, 139-141)

Learning Objectives

The readings and activities in this lesson will help you to

- understand the levels of organization in the body and be able to give examples of each level.
- have a basic knowledge of positive and negative feedback systems and their components used in maintaining homeostasis.
- visualize all the structures within the cell and discuss them with regard to their structure and function.
- understand the structure and function of the cell membrane, as well as the several means of transport across the membrane.
- have a basic understanding of tissues.

Key Terms

homeostasis
negative feedback
positive feedback
carbohydrates
lipids
proteins
nucleic acids
plasma membrane
unit membrane
fluid mosaic model
integral proteins
peripheral proteins
interstitial fluid
osmosis
solute
hypertonic
hypotonic
isotonic
oxidative phosphorylation
liposomes
autolysis
secretory granules
microtubules
epithelial tissue
connective tissue
nervous tissue
muscle tissue
nucleus
nuclear envelope
nucleoplasm
smooth endoplasmic reticulum
rough endoplasmic reticulum
ribosomes
Golgi apparatus
ameboid movement
pseudopodium
ciliary movement
chromosomes
nucleolus
cytoplasm
organelles
mitochondrion
exocytosis
endocytosis
centrioles

Commentary

Levels of Organization

The body is organized structurally into a hierarchy. The smallest **living** unit in the body is the **cell**. Many cells of the same type are grouped into a **tissue**. Several tissue types, in turn, comprise an **organ**. Finally, there may be several organs in an **organ system.**

Organizational Unit	Example
Cell ↓	Muscle fiber (one muscle cell)
Tissue ↓	Muscle (a group of fibers)
Organ ↓	Heart (consisting of muscle tissue, blood vessels, etc.)
Organ System	Circulatory system (consisting of the heart and the entire network of blood vessels in the body)

We will study each organ system after we learn about the individual cells.

Homeostasis

Perhaps the most important principle in physiology is that, within narrow limits, the body's internal environment remains constant. The body's temperature, the acidity of its fluids, the pressure exerted by those fluids, the concentration of dissolved substances, and many other parameters remain constant. Much of what we study in physiology is the way in which the body maintains this constant environment. **Homeostasis** is the term applied to the steady state, or constant environment, occurring in living organisms.

Communication within the body is the key to maintaining homeostasis. This is achieved primarily by the actions of the nervous and endocrine systems. The basic components of communication are illustrated in **Figure 1.4** (p. 9). There are three components (at least) that interact in a control system to achieve homeostasis: a receptor (sensor) responsible for input data, a control center that integrates the input data, and an effector responsible for output or the response of the control system.

Feedback mechanisms are very significant in communication. The two types of feedback are negative and positive. **Negative feedback** is used extensively in the body and serves to "normalize" a particular parameter. Negative feedback reverses or turns an activity in the opposite direction in an attempt to bring it back within normal range. For example, the furnace thermostat in your home uses negative feedback. In your text, this is illustrated in **Figure 1.5** (p. 11).

In the body, one example of negative feedback is the maintenance of a relatively constant glucose metabolism. Your body cells must have constant access to a relatively stable amount of glucose in order to carry out energy conversion functions. Let's suppose you just ate a giant chocolate bar to fortify yourself before you began this lesson. The sugars from the candy bar flood your blood stream, raising your blood glucose (a simple sugar) level and disrupting the homeostasis of your blood glucose. The rising glucose levels stimulate your pancreas to release the hormone insulin into your bloodstream. Insulin, in turn, causes most of the cells of the body to increase their uptake of glucose from the blood, so that the blood sugar levels drop back to normal. Without the stimulus (excess blood glucose) to secrete more insulin, insulin secretion now decreases, and cells slow down their glucose uptake.

Positive feedback mechanisms are much less common in the body because they carry the activity *away* from the normal settings. Examples of positive feedback mechanisms include labor contractions during childbirth (**Figure 28.16**, p. 1135) and blood clotting (**Figure 1.6**, p. 12).

Since feedback mechanisms are so important in the body, it is imperative that you understand the basic mechanisms well.

Many disease conditions are a result of homeostatic imbalances. In fact, the disorder diabetes mellitus manifests itself when there is a disruption of the insulin levels in the body, leading to an increased blood sugar level. (Note that your textbook identifies homeostatic imbalances using an icon of an unbalanced scale.)

We continue with consideration of the cell, the unit that makes up the structure of all living things. This is discussed in **Chapter 3 "Cells: The Living Units."**

Cell Structure and Function

There are many types of cells (neurons, epithelial cells, blood cells, muscle cells, etc.), and each cell type has its own unique features. However, all animal (eukaryotic) cells share some common features. Note the drawing of a "typical" animal cell in your textbook (**Figure 3.2,** p. 66). The cell should be visualized as three-dimensional. Be aware that the drawing is somewhat stylized and that the overall shape and size vary tremendously among cell types. The average diameter of an animal cell is about 10 μm, which is 1×10^{-5} meters.

Plasma Membrane

The **plasma membrane** is composed of two layers of lipid with protein molecules interspersed within the lipid layers. Each lipid molecule has two distinct ends: a hydrophobic (water-hating) end and a hydrophilic (water-loving) end. The hydrophobic ends face each other, internal within the membrane, while the hydrophilic ends face the aqueous environment inside the cell and the aqueous environment surrounding the outside of the cell. Large, globular proteins are distributed throughout the lipid layers. (See **Figure 3.3** and **Figure 3.4** in your text, pp. 67-68.) This structural arrangement is referred to as the **fluid mosaic model**. This configuration is extremely important for the functioning of the cell. The plasma membrane functions to contain the cytoplasm, to allow cell-to-cell recognition, and to allow the cell to be selectively permeable. Selective permeability means that the plasma membrane will allow only certain types of molecules to travel into or out of the cell. The structure of the plasma membrane is typical of all the membranes in the cell. This basic structure, consisting of the lipid bilayer with proteins, is called a **unit membrane**.

The membrane proteins are divided into two groups: the **peripheral proteins** and the **integral proteins**. These provide for many of the specialized functions of the membrane including transport, cell-to-cell identification, enzyme reactions, cellular shape, receptor sites, and intercellular attachment.

We will now leave (temporarily) our discussion of cellular structures to discuss the transport function of the cell membrane in greater detail. Our cells are always bathed in the fluid of their environment, extracellular fluid called **interstitial fluid**. This fluid contains many ingredients such as hormones, nutrients, salts, and wastes. The cell must be able to retrieve substances it needs and to eliminate those it does not need. This is the concept of selective permeability. Some substances require energy for transport across the membrane; others do not.

Types of Transport

1. **Passive**—no energy required

   a. **Simple diffusion**.

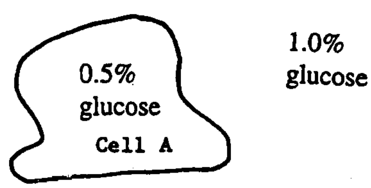
      Simple diffusion refers to the movement of molecules from an area of higher concentration *of that molecule* to an area of lower concentration *of that molecule*. As an example, if a young man were to enter a classroom reeking of cologne that he had just spilled all over himself, the highest concentration would be where? (On him.) As time went on, the cologne molecules would **diffuse** from the area of higher concentration (him) to the areas of lower concentration (the rest of the classroom). Was energy required for this to happen? No. Now, suppose that you were disgusted with smelling his cheap cologne, and you wished to return it to him. How could you do this? Well, you could, perhaps, blow it back in his direction with fans. Would this require energy? (Yes, from the fans.) Moving *up* the concentration gradient (sending the perfume back to him) is *not* diffusion because it requires energy.

      The rate of diffusion is governed by several factors, including size of the concentration gradient, size of the molecules, and the temperature. Note that if several types of molecules are diffused, each will diffuse independently of the others.

Molecules that diffuse across the membrane include gases such as oxygen and carbon dioxide, alcohol, urea, some ions, and small hydrophobic molecules.

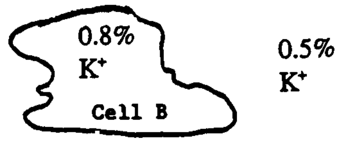
Osmosis is a special type of simple diffusion. It refers to the net movement of water from a region of higher concentration of water to a region of lower concentration of water across a selectively permeable membrane. (Note that this is the same as a movement of water from a region of **lower solute** [dissolved substance such as salt or sugar] concentration to an area of **higher solute** concentration.) The term **hypertonic** refers to the area of greater concentration of solute; **hypotonic** refers to an area of lesser concentration of solute; **isotonic** means an equal concentration of solute. Here are some examples.

Cell A is in a hypertonic glucose solution. This means that there is a higher concentration of glucose outside the cell than inside. When discussing osmosis, we are not concerned with the behavior of the solute, glucose. We are only interested in the water.



Although water will certainly flow in both directions, the net flow will be from inside the cell toward the outside (from the lower solute concentration area to the higher solute concentration area). This will cause the cell to shrink.

Now let's take an example of Cell B in a hypotonic solution of K^+:



In which direction will the net amount of water flow?

The bulk will be from the area of lower solute concentration (outside the cell) to the area of higher solute concentration (inside the cell). Thus, the cell will expand and could rupture.

Note that, in such examples, the terms hypotonic and hypertonic must be given in relation to something else. For example, the medium is hypotonic *relative* to the cell.

b. **Facilitated diffusion**

This type of diffusion requires no energy, but does need a carrier protein located within the membrane to transport the molecule across the membrane. Net movement is from the higher concentration to the lower concentration. Large, hydrophilic molecules such as glucose are transported in this manner.

c. **Filtration**

This is a mechanism that forces water and solutes dissolved in the water through a blood vessel wall by hydrostatic (or fluid) pressure. This is not truly a type of transport, but it is included here for completeness. We will see the importance of this mechanism when we study blood pressure and the functioning of the kidneys.

2. **Active Transport**—requires energy

Active transport involves the movement of substances ***up*** the concentration gradient or against the concentration gradient. This requires energy, most often in the form of ATP (adenosine triphosphate, an energy-carrying molecule involved in chemical metabolism). A carrier protein within the membrane is also required. Your textbook discusses the difference between primary active transport and secondary active transport. Secondary active transport systems involve movement of more than one substance at one time. These coupled systems can push two substances in the same direction as a symport system or push two substances in opposite directions as an antiport system.

Substances that may require active transport include amino acids and charged molecules such as Na^+, K^+, and Ca^{++}. Small ions can diffuse across the plasma membrane as previously mentioned, but may also be actively transported in other situations.

The extensively studied Na^+– K^+ pump is responsible for the transport of Na^+ into the cell and K^+ out of the cell. As you read about it in your text, you will notice that it couples the movement of Na^+ ions to the outside of the cell with the movement of K^+ ions to the inside of the cell, using ATP as the source of energy (**Figure 3.10**). This is an extremely important mechanism that is used in every cell of the body in many different situations.

3. **Vesicular Transport**

   Exocytosis and **endocytosis** are two types of vesicular transport that allow the transfer of larger particles and macromolecules across the plasma membrane. You should refer to your textbook for the discussion of exocytosis and endocytosis. Exocytosis is significant in various functions including hormone secretion and neurotransmitter release. Endocytosis is involved in phagocytosis and significant to nonspecific resistance and immunity.

Membrane Potential

Since cell membranes are selectively permeable and have different concentrations of charged molecules on different sides, they exhibit a voltage. This voltage, also called a membrane potential, is extremely useful in driving certain physiological phenomena, such as the traveling of a nervous impulse along the membrane of neurons (nerve cells). This is explained in the section **Generating and Maintaining a Resting Membrane Potential** (pp. 81-83). You should read this section. This will also be discussed in Lesson 5 "Nerve Impulse Physiology."

Membrane Junctions

One more topic concerning membranes is that, although some cells such as blood cells travel through the body freely, most cells are attached to adjacent cells in some fashion. Be sure to read about these junctions, which include tight junctions, desmosomes, and gap junctions. These are described in the section on **Membrane Junctions** (p. 69) in your text and can be seen in **Figure 3.5** (p. 70).
Now that you have thoroughly covered the information on cell membranes, we can move on to other parts of the cell.

Nucleus

The **nucleus** is surrounded by the **nuclear envelope**, which is a double layer of unit membrane. Discontinuities, or pores, are present in the membrane. This allows the passage of nucleic acids and various nutrients between the nucleus and the cytoplasm. The fluid within the nucleus is called **nucleoplasm**.

Within the nucleus are the **chromosomes**. They represent the genetic material passed from one cellular generation to the next. They are composed of DNA and histones (proteins attached to the DNA). In all human cells except the egg and sperm, there are

46 chromosomes (23 pairs). Also found in the nucleus is the **nucleolus**, the site of ribosome synthesis. There may be several nucleoli, depending on cell type. Numerous nucleoli may be indicative of cancerous cells.

Cytoplasm

The **cytoplasm** is the fluid matrix surrounding the nucleus. It contains various membrane-bound structures called **organelles**. One of the most prominent of these is the **mitochondrion** (varying in number depending on cell type). Mitochondria are constructed of two unit membranes; one forms the outer boundary and the other is folded internally to form layers called cristae. The mitochondria contain the enzymes necessary to capture the energy in nutrients such as glucose and transfer it to the cell's main energy-storage molecule, ATP. This process, called **oxidative phosphorylation**, is very important, as it provides the cell with a storehouse of energy (ATP) to be used for cellular movement, transport of certain substances across the cell membrane, and a host of chemical reactions necessary for cell maintenance and growth. Of special note is the fact that mitochondria have their own DNA and may divide independently of the cell. They also have ribosomes that resemble those of bacteria; it is thought that they were once bacteria that became symbiotically involved with the cell and degenerated into the present mitochondria.

Lysosomes, another type of organelle in the cytoplasm, are sacs bounded by a single unit membrane. They contain digestive enzymes capable of hydrolyzing (breaking down) proteins, carbohydrates, and other potential nutrients into usable units. In addition, lysosomal enzymes are responsible for the destruction of damaged cells. If a cell is irreparably traumatized, its lysosomes will burst, releasing enzymes to digest the cell. This process is called **autolysis**.

Within the cytoplasm is found a very extensive membranous network of tubules called the **endoplasmic reticulum**. The membranes of the endoplasmic reticulum are connected to the nuclear membrane pores to allow transport between the nucleus and the endoplasmic reticulum. There are two types of endoplasmic reticulum—smooth and rough. **Smooth endoplasmic reticulum** has several very important functions, including synthesis of many types of lipids and detoxification of certain drugs. **Rough endoplasmic reticulum** has ribosomes on its surface. Certain proteins, such as those that will be secreted from the cell, are made on those ribosomes, then enter into the reticulum to be transported to the **Golgi apparatus**. The Golgi apparatus consists of a group of layered vesicles designed to package, store, and secrete certain cellular products.

The cytoplasm and nucleoplasm (collectively called protoplasm) of cells contain many substances. The major components are ribosomes, as well as proteins, carbohydrates, lipids, water, and numerous dissolved electrolytes such as potassium, sodium, phosphate, magnesium, and hydrogen ions. Gases (nitrogen, oxygen, and carbon dioxide) are also dissolved in the protoplasm. Many cells are capable of movement. All cellular movement requires the use of the high-energy storage molecule, adenosine triphosphate or ATP. Muscle cells move by the contraction of their myofilaments. We will study this topic later. Other types of motion include **ameboid movement**, in which the cytoplasm streams in a particular direction forming a **pseudopodium** ("false foot"), and **ciliary movement**, involving the rhythmic beating of many cilia propelling the cell forward. Additionally, most cells have a cytoskeleton comprised of microtubules and microfilaments. These help maintain cell shape, assist with movement, and are necessary for cell division.

It is important to note that all cells in the world are divided into two very distinct groups. **Prokaryotic cells** (bacteria and blue-green algae) have no membrane-bound organelles within them. Their DNA is naked (no histones) and is not contained within a nucleus. **Eukaryotic cells** (all cells except bacteria and blue-green algae) do have a nucleus and other internal membranous structures, and these cells (since all animal cells are eukaryotic) are what we have been discussing.

Tissues

Similar cells are grouped together into tissues. The number of tissue types varies depending on the particular histology text. However, we will divide them into the four classes used by many histologists.

Epithelial tissues assume the functions of protection, absorption, secretion, and excretion. They are often anchored to a basement membrane composed of a carbohydrate matrix into which fibers extend from an adjacent connective tissue layer. Their shape may be squamous (flat cells covering surfaces), cuboidal (small cubes used for lining of areas), or columnar (tall, rectangular cells used to line ducts, glands, and various tubes, as well as to form the intestinal villi). Each of these types may be arranged in any of four ways: simple (one-layer thick), stratified (several layers), pseudostratified (only one-layer thick, but has the appearance of several layers), and transitional (layers that extend or compress depending on the pressure placed on them). These are illustrated in the chapter **"Tissue: The Living Fabric"** and in the **Figures 4.1** and **4.2** (pp. 120-124). Epithelial cells, then, may best be thought of as the lining of the outside of the body as well as lining the inside of most internal structures.

Connective tissues are a diverse group whose general functions include support and the allowance of movement. Loose connective tissue includes the main supporting tissues around organs, vessels, muscles, etc., as well as the basic structure of such organs as the liver. Fat, or adipose, tissue is one type of loose connective tissue. Dense connective tissue consists of the collagen and elastic fibers that make up the ligaments and tendons. Specialized connective tissue is a diverse group consisting of vascular tissues (blood, bone marrow, etc., but not the blood vessels), cartilage, bone, and lymphoid tissue. These are illustrated in the **Figure 4.9** (pp. 131-138).

Muscle tissue is comprised of muscle fibers, or cells, of three types: skeletal, smooth, and cardiac. These will be discussed further in the lesson on muscle physiology.

Nervous tissue is composed of neurons and their supporting tissues. The lesson on nerve impulse physiology will cover these in detail.