



**ALNOOR UNIVERSITY COLLEGE 2023-2024 2<sup>nd</sup> Year Stage**

**Department of Medic.Lab Techn.**

**Human Physiology**

## **Chapter 1-** General Introduction to Physiology

Cell Physiology: General Functions, Cell Membrane Transport

**Objective :** After studying this chapter, students should be able to:

- Name the prominent cellular organelles and state their functions in cells.
- Define the processes of exocytosis and endocytosis, and describe the contribution of each to normal cell function.
- Define proteins that contribute to membrane permeability and transport.

### Physiology

Is a science, that study the functions of a living creature, it deal with the functions and mechanisms of action of all biological activities at flowing levels :

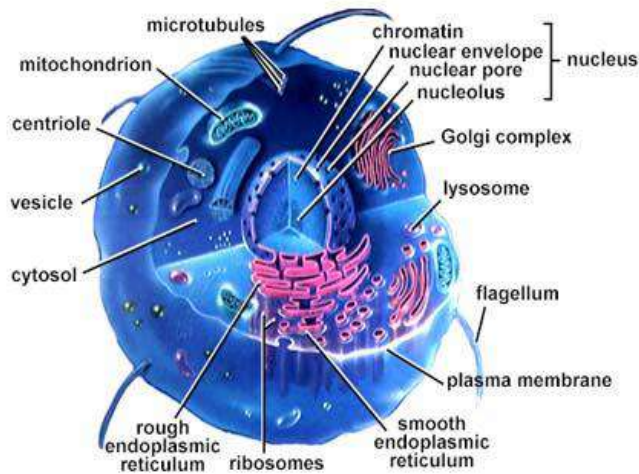
- 1- Chemical or molecular level
- 2- Cellular level
- 3- Tissue level
- 4-Organ level
- 5- Systemic level
- 6- Organismic level

### **The cell**

The **cell** is the fundamental functional unit of all organisms.

A **basic** knowledge of **cell** biology is essential to an understanding of the organ systems and the way they **function** in the body.

## Chapter 1- Cell physiology



### Human cells structure

#### Cell Membranes

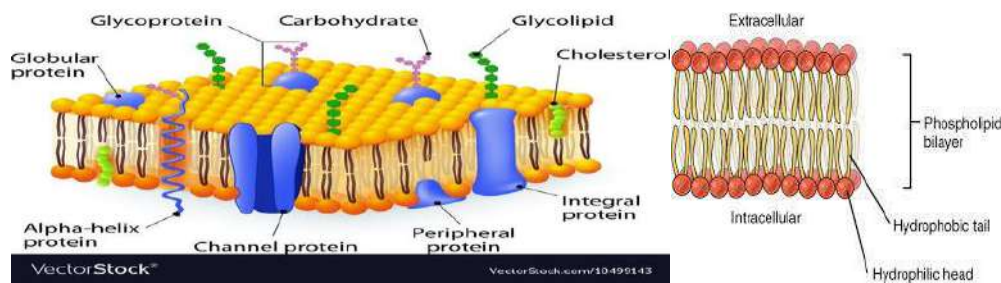
Is the boundary of the cell, sometimes called the plasma membrane, the plasma membrane is selectively permeable to ions and organic molecules. its function are:

- 1-Separates internal metabolic events from the external environment .
- 2-Controls the movement of materials into and out of the cell in selective characteristic.

#### Cell membrane structure

The cell membrane is consist of a double outer and inner phospholipid layer, each molecule has a polar hydrophilic heads toward the outside and nonpolar hydrophobic tails pointing toward the inside of the membrane . Phospholipid layers forming the inner and outer surfaces of the cell membrane. Proteins embedded in the phospholipid membrane.

#### CELL MEMBRANE



### **Types of Protein in the cell membrane on bases of location**

- 1-Peripheral proteins, that attach loosely to the inner or outer surface of the plasma membrane.
- 2-Integral proteins , that lie across the membrane, extending from inside to outside.

### **Types of membrane proteins on the functions bases :**

There are a variety of membrane proteins with in the cell membrane that serve various functions:

**1-Channel proteins:** Proteins that provide passageways through the membranes for certain hydrophilic or water-soluble substances such as polar and charged molecules with no spend energy.

**2-Transport proteins:** Proteins that spend energy (ATP) to transfer materials across the membrane by active transport.

**3-Recognition proteins:** Proteins that distinguish the identity of neighboring cells. These proteins have non protein chains extending out from their cell surface.

**4-Adhesion proteins:** Proteins that attach cells to neighboring cells.

**5-Receptor proteins:** Proteins that initiate specific cell responses for hormones or other molecules bind to them.

**6-Electron transfer proteins:** Proteins that are involved in moving electrons from one molecule to another during chemical reactions.

### **Transport Across the Cell Membrane**

Generally the materials transport across cell membrane by three mods:

#### **-First modes -Passive Transports**

Include following mechanisms

**1-Passive transport** is the movement of substances down a concentration gradient and does not require energy use.

## Chapter 1- Cell physiology

**2-Bulk flow** is the collective movement of some substances in the same direction in response to a force, such as pressure.

**3-Simple diffusion**, is the process by which solutes are moved along a concentration gradient in a solution or across a semipermeable membrane independent from the motion of other molecules.

**4-Facilitated diffusion** is the diffusion of solutes through channel proteins in the plasma membrane.

**5-Osmosis** is the diffusion of water molecules across a selectively permeable membrane.

**6-Dialysis** is the process of move of excess water, solutes, and toxins across a selectively permeable membrane as in artificial kidney .

### **-Second modes -Active Transports**

Active transport is the movement of solutes against a gradient and requires the expenditure of energy, usually in the form of ATP. Active transport is achieved through one of these two mechanisms:

#### **1-Protein Pumps**

Proteins pumps are specific proteins in the plasma membrane that transfer solutes such as small ions ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{H}^+$ ), amino acids, and monosaccharides.

**2-The sodium-potassium pump** (also called the  $\text{Na}^+/\text{K}^+$ -ATPase enzyme) is actively moves sodium to out of the cell and potassium into the cell.

#### **-Third mods of transport-Vesicular Transport**

Is transport of macromolecules or large particles across the plasma membrane, by following mechanisms:

**1- Exocytosis** is release of cellular substances contained in cell vesicles to the out side by fusion with the plasma membrane and release of the vesicles contents to the exterior of the cell.

**2-Endocytosis:** is a cellular process in which substances are brought into the cell by surrounding with an area of cell membrane, which then buds off inside the cell to form a vesicle containing the ingested material.

There are three kinds of endocytosis:

**1 -Phagocytosis** or cellular eating, is engulfs the solid material by the plasma membrane phagocytic vesicle.

**2 -Pinocytosis** is a process by which liquid droplets are ingested by living cells.

## Chapter 1- Cell physiology

**3 - Receptor-mediated endocytosis** : is a process by which cells absorb metabolites, hormones, proteins by bind to specialized receptors in the plasma membrane.

### Cytoplasm

The gel-like material with a fluid matrix, which consists of 80% to 90% water, and contain salts, organic molecules and many enzymes, along with dissolved substances such as proteins and nutrients.

#### Cytoplasm Functions

- 1-The cytoplasm functions to support and suspend organelles and cellular molecules.
- 2-Many cellular processes also occur in the cytoplasm, such as protein synthesis, mitosis, and meiosis.
- 3-The cytoplasm helps to move materials around the cell.

### Cytoskeleton

Thread like proteins, it helps cells maintain their shape and allows cells and their contents to move. Is composed of two elements: microtubules, and microfilaments.

**A-Microfilaments** are fine, thread-like protein fibers, 3-6 nm in diameter. They are composed predominantly of a contractile protein called actin. Microfilaments can carry out cellular movements including gliding, contraction, and cytokinesis.

**B-Microtubules** are cylindrical tubes, 20-25 nm in diameter. They are composed of subunits of the protein tubulin--these subunits are termed alpha and beta. Microtubules determine cell shape, and provide a set of "tracks" for cell organelles and vesicles to move on. Microtubules also form the spindle fibers for separating chromosomes during mitosis.

### Nucleus

The nucleus is the largest of the cells organelles. The nucleus is bounded by the nuclear envelope of a phospholipid bilayer similar to the plasma membrane. Its function is controls the cell; houses the genetic material (DNA).

## Chapter 1- Cell physiology

### **Chromosomes**

Chromosomes are made up of chromatin, which is made up of protein and DNA strands. Humans have 23 pairs of chromosomes.

### **Centrioles**

Centrioles are rod like structures composed of 9 bundles which contain three microtubules each, are very important in cellular division, where they arrange the mitotic spindles that pull the chromosome apart.

### **Ribosomes**

Ribosomes are minute particles consisting of RNA and associated proteins that function to synthesize proteins. Ribosomes can be found floating within the cytoplasm or attached to the endoplasmic reticulum.

### **Mitochondria**

**Mitochondria** are double membrane-bound cell organelles that generate most of the chemical energy needed to power the cell's biochemical reactions. Chemical energy produced by the **mitochondria** is stored in a small molecule called adenosine triphosphate (ATP).

### **Endoplasmic Reticulum**

A complex three dimensional internal membrane system of flattened sheets, sacs and tubes, serves multiple functions, being important particularly in the synthesis, folding, modification, and transport of proteins .

### **Golgi Apparatus**

The **Golgi apparatus** is a membrane bound organelle found in most cells. The Golgi is made of 5-8 folds called **cisternae**. It is responsible for modifies proteins and lipids that it receives from the endoplasmic reticulum.

### **Lysosomes**

Lysosomes are sac-like compartments that contain a number of powerful degradative enzymes.

### **Peroxisomes**

Organelles in which oxygen is used to oxidize substances, breaking down lipids and detoxifying certain chemicals.

## Chapter 1- Cell physiology

### Cell Junctions

In certain tissues, the membranes of adjacent cells may join and form a junction. Three kinds of cell junctions are recognized:

**1-Desmosomes** are protein attachments between adjacent cells.

**2-Tight junctions** are multiprotein **junctional** complexes whose general function is to preventing the movement of material between the cell. Tight junctions are characteristic of cells lining the digestive tract, where materials are required to pass through cells, rather than intercellular spaces, to penetrate the bloodstream.

**3-Gap junctions** are narrow tunnels that directly connect the cytoplasm of two neighboring cells, consisting of proteins called connexons. These proteins allow only the passage of ions and small molecules.

### Cell Metabolism

**Cell metabolism** is the total energy released and consumed by a cell.

**Catabolism:** The energy releasing process in which a chemical or food is used by degradation or decomposition, into smaller pieces.

**Anabolism:** Is a portion of metabolism, the cell consumes energy to produce larger molecules via smaller ones.

#### **Types of intercellular signaling :**

There are many types of intercellular signaling , depending on the function:

1- Autocrine : **Autocrine** signaling mean a cell targets itself, releasing a signal that can bind to receptors on its own surface.

2-Paracrine: a cell targets a nearby cell.

3- Endocrine : when the cell produce a signal that affect distance cells .

#### **Types of cell membrane receptors :**

I. Cell surface receptors : integral proteins in the cell membrane that bind to the ligand.

II. Intracellular receptors , that are soluble proteins found in the cytoplasm or the nucleus . It binds the lipophilic ligands that can cross the cell membrane.

## Chapter 2 Human body fluids



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**2023-2024 2<sup>nd</sup> Year Stage**

**Department of Medic.Lab Techn.**

**Human Physiology Lecturer : Pro. Dr. Esmail Salih**

## Chapter 2 Human body fluids

**Contents :**General Idea about Body fluids: Types, Composition, and Functions. Unit of Measurement, Conversion and Conversion factor.

### Body fluids

Body fluids are liquids originating from inside the bodies of humans. They include fluids that are excreted or secreted from the body. Total amount of fluids in the human body is approximately 70% of body weight .

### Types of body fluids

The bodily fluid in humans can be divided into two categories based on its location:

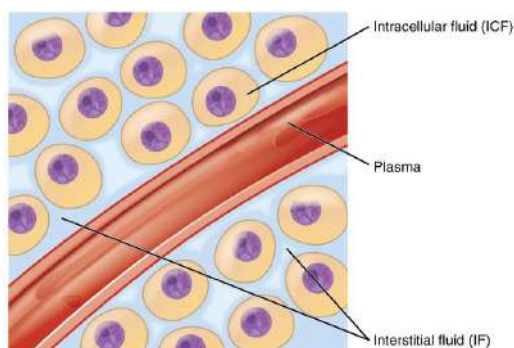
#### **A. Intracellular fluid**

- a-The intracellular fluid is a bodily fluid that exists within a cell(s).
- b. In humans, intracellular fluid accounts for 67 per cent of total body water. It is made up of water and dissolved ions.

#### **B. Extracellular fluid**

- a. Extracellular fluid is a type of bodily fluid that exists outside of the cell(s).
- b. In humans, it makes up roughly 26% of total body water composition.
- c. Extracellular fluid is made up of intravascular fluid (blood plasma), interstitial fluid, lymph, and transcellular fluid.

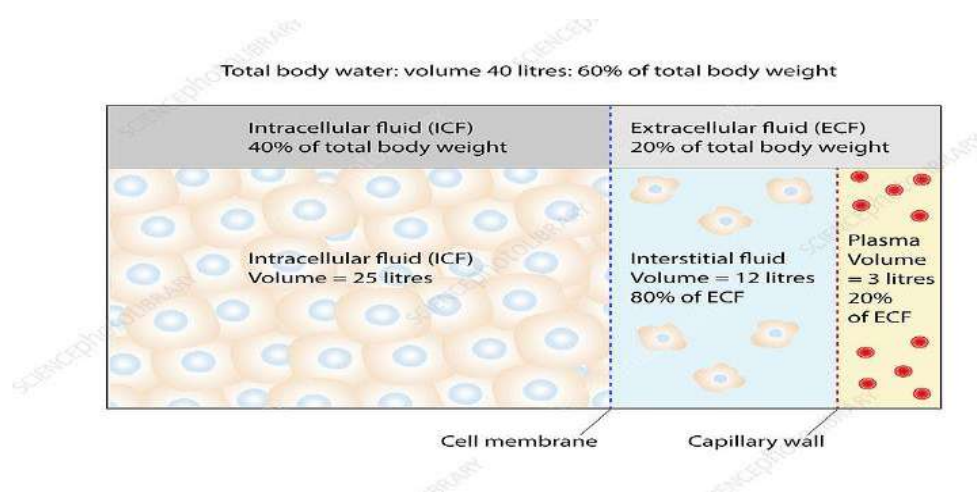
## Chapter 2 Human body fluids



### Composition of body fluids

Body fluids contain ,organic substances , glucose , amino acids ,fatty acids ,hormones and enzymes . The composition of the body fluids is explained below:

Fluids	position
Intra cellular Body Fluids	70% water, ions, and molecules
Extra cellular Body Fluids	Cations and Anions
Transcellular Fluid	Electrolytes such as sodium, bicarbonate and chloride ions.

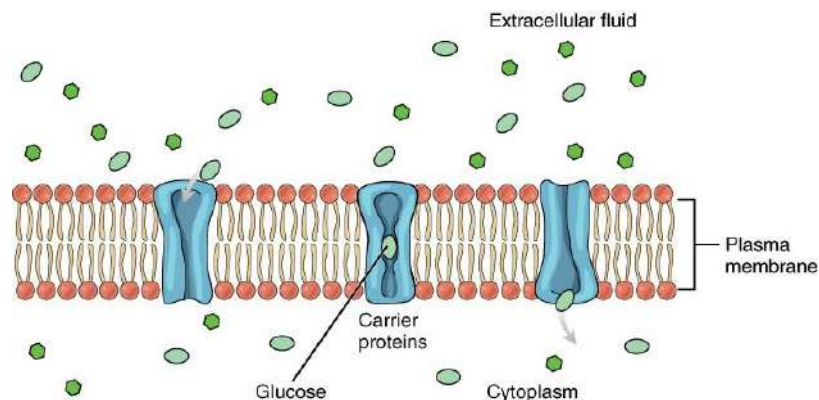


## Chapter 2 Human body fluids

### Functions of Body Fluids

The important functions of body fluids include:

1. The body fluids facilitate the transportation of oxygen and nutrients throughout the body and remove waste from the body.
2. They help in regulating body temperature.
3. They maintain an efficient metabolism of the body



### Unit of Measurement

To measure the volume of any fluid compartment within the body, must inject or infuse a marker substance that will diffuse freely to a uniform concentration throughout this compartment, this substance must also not be metabolised, Tritiated ( $^3\text{H}$ ) water is a good marker for the whole body fluid compartment because it diffuses throughout the body, it is chemically identical to normal water and it is easy to measure the equilibrium concentration because  $^3\text{H}$  water is radioactive.

Intracellular fluid volume - Cannot be measured directly but can be calculated by subtracting ECFV by TBW, as the latter two variables are measurable.

Interstitial fluid volume - Cannot be measured directly but can be calculated by subtracting PV by ECFV, as the latter two variables are measurable.

## Chapter 3 Blood physiology



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**2023-2024 2<sup>nd</sup> Year Stage**

**Department of Medic.Lab Techn.**

**Human Physiology**

### **Chapter 3 : Blood Physiology**

#### **Contents**

Blood: Composition, Specific Functions of each Compartment. Plasma and Serum Differences and Separation

Objective :

To describe the following lines:

- 1-The Blood composition and functions.
- 2- Plasma and serum functions, separation & differences .

#### **Blood**

Blood is a body fluid that circulates in the heart and blood vessels carrying nourishment and oxygen to and bringing away waste products from all parts of the body , it is composed of blood cells and blood plasma.

#### **Blood Functions**

Blood has 3 main types of the functions: Distribution & transport, regulation, protection.

##### **1<sup>st</sup> . Distribution & Transport**

- a.Transport O<sub>2</sub> from lungs to cells and Co<sub>2</sub> from cells to lungs.
- b. Transport nutrients from GI tract to body cells.
- c.Transport nitrogenous wastes from body cells to kidneys.
- d.Transport hormones from glands to body cells.

##### **2<sup>nd</sup> . Regulation or maintenance of homeostasis**

Maintenance of normal body pH, temperature and body fluid .

## Chapter 3 Blood physiology

### 3<sup>rd</sup> . Protection

- a. Protection against bleeding by seal vessel damage by clotting .
- b. Protection from foreign material & infections by leukocytes & antibodies.

### Blood Components

Blood have two major components , cells and plasma .

1. Cellular components of blood :

- a. Erythrocytes - red blood cells
- b. Leukocytes - white blood cells
- c. Platelets - cell fragments for clotting

2. Blood plasma - non-cellular fluid contain protein & electrolytes.

### Plasma & serum

Serum and plasma both are the liquid portion of the blood that remains once the cells are removed. The differences are :Serum is the liquid that remains after the blood has clotted. Plasma is the liquid that remains when clotting is prevented with the addition of an anticoagulant.

### Plasma

Plasma is the liquid portion of blood. About 55% of human blood is plasma, and the remaining 45% are blood cell that are suspended in the plasma.

Plasma is about 92% water. It also contains 7% vital proteins such as albumin, gamma globulin and anti-hemophilic factor, and 1% mineral salts, sugars, fats, hormones and vitamins.

### Plasma components

- a. Albumin for osmotic pressure, and immunoglobulins.
- b. Clotting proteins as prothrombin & fibrinogen.
- c. Enzymes, hormones, others.
- d. Nutrients - glucose, fatty acids, amino acids, cholesterol, vitamins
- e. Electrolytes - Na<sup>+</sup>, K<sup>+</sup>, Ca<sup>++</sup>, Mg<sup>++</sup>, Cl<sup>-</sup>, bicarbonate, others.

## Chapter 3 Blood physiology

### Blood Plasma functions

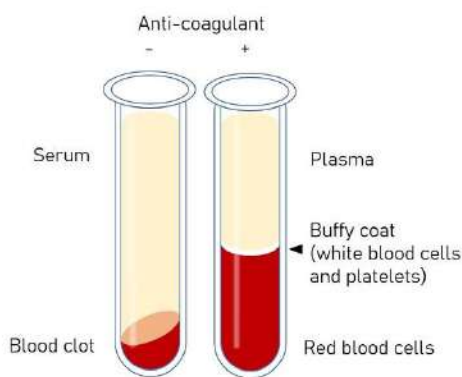
Plasma serves four important functions in our bodies:

1. Helps maintain blood pressure and volume.
2. Supply critical proteins for blood clotting and immunity.
3. Carries electrolytes such as sodium and potassium to our muscles.
4. Helps to maintain a proper pH balance in the body, which supports cell function.

### Plasma separation

Collect whole blood into commercially available anticoagulant-treated tubes e.g., EDTA-treated. Cells are removed from plasma by centrifugation for 10 minutes at 1,000-2,000 x g using a refrigerated centrifuge. Centrifugation for 15 minutes at 2,000 x g depletes platelets in the plasma sample. The resulting supernatant is designated plasma.

Following centrifugation, it is important to immediately transfer the liquid component (plasma) into a clean microcentrifuge tube using a pipette. The samples should be maintained at 2-8°C while handling.



### Blood Serum

## **Chapter 3 Blood physiology**

Serum (/ˈsɪərəm/) is the fluid and solute component of blood which does not play a role in clotting. It may be defined as blood plasma without the clotting factors, or as blood with all cells and clotting factors removed.

### **Serum separation**

Collect whole blood in a microcentrifuge tube. After collection of the whole blood, allow the blood to clot by leaving it undisturbed at room temperature. This usually takes 15-30 minutes. Remove the clot by centrifuging at 1,000-2,000 x g for 10 minutes in a refrigerated centrifuge. The resulting supernatant is designated serum. Following centrifugation, it is important to immediately transfer the liquid component (serum) into a clean microcentrifuge tube using a pipette. The samples should be maintained at 2-8°C while handling.

## Chapter 3- Red Blood Cells



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**2023-2024 2<sup>nd</sup> Year Stage**

**Department of Medic.Lab Techn. Human Physiology Lect. : Pro. Dr. Esmail Salih**

### **Chapter -3 Red Blood Cells**

**Contents :** RBCs: Definition, Structure, and Normal Value; Hb Definition, Structure, and Normal Value; Blood Groups.

### **Red Blood Cells RBC (Erythrocytes)**

#### **Definition of RBC**

Is biconcave disk shape, the shape is maintained by elastic protein called spectrin that allows shape change. Mature cells are anucleate (no nucleus). 33% of RBC mass is hemoglobin .

#### **Life Span of Red Blood Cells is About 120 Days**

The life span of RBC in the circulatory system is average of 120 days before being destroyed, they have cytoplasmic enzymes that are capable of metabolizing glucose and forming small amounts of ATP.

#### **Functions of RBC (Erythrocytes):**

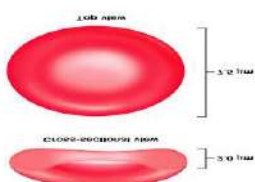
- 1- Transport hemoglobin.
- 2- Responsible for most of the acid-base buffering power of blood .

#### **Shape and Size of RBC**

Normal RBC shapes , are biconcave discs having a mean diameter of about 7.8 micrometers and a thickness of 2.5 micrometers at the thickest point and 1 micrometer in the centre.

The average volume of the RBC is 90 to 95 cubic micrometers.

The shapes of RBC can change when pass through capillaries.



## Chapter 3- Red Blood Cells

### Numbers of Red Blood Cells in the Blood (RBC count )

Red blood cells count per cubic millimeter are :

Its number are :

in Mature male : 5-6 million /mm<sup>3</sup> .

in Mature female : 4-5 million/mm<sup>3</sup>.

in Infants : more than 6 .

Numbers of RBC changed according to these factors: age , sex , exercise , feeding state , lactation , pregnancy, haemodilution , estrous cycle , surrounding temperature altitude , Ecological factors .

Persons living at high altitudes have greater numbers of red blood cells.

### RBC formation (Hematopoiesis )

Hematopoiesis is formation,maturation and development of RBC in the red bone marrow.

#### Erythropoiesis Demands

The formation and maturation of RBC in bone marrow demands the following :

1- vitamin B<sub>12</sub> .

2- Folic acid which help in formation of Nucleic acids and nitrogenous bases (Purine and Pyrimidine ) .

Therefore, lack of either vitamin B<sub>12</sub> or folic acid causes abnormal and diminished DNA and, consequently, failure of nuclear maturation and cell division.

#### Hormonal regulation of hematopoiesis

Erythropoietin hormone released by kidney stimulates RBC production.

Kidneys release erythropoietin in response to low RBCs due to bleeding or excess RBC destruction, and in response to low oxygen levels or increased oxygen demand .

## Chapter 3- Red Blood Cells

### Production of RBC

#### Areas of the Body That Produce RBC

- 1-In the early weeks of embryonic life, RBC are produced in the yolk sac.
- 2-During middle trimester of gestation, RBC produced in liver, spleen and lymph nodes.
- 3-During the last months of gestation and after birth, RBC are produced in bone marrow.

#### Stages of Differentiation of RBC

The first cell that produce the RBC series is the **proerythroblast**, Proerythroblast divides multiple times, forming many mature RBC.

The first-generation cells are called basophil erythroblasts because they stain with basic dye. In the succeeding generations, the cells become filled with hemoglobin to a concentration of about 34 percent, the nucleus condenses to a small size, and its final remnant is absorbed or extruded from the cell.

Rate of RBC production increased by any condition that causes the quantity of oxygen transported to the tissues to decrease as following conditions:

- 1-Extremely anemic .
- 2- Destruction of major portions of the bone marrow .
- 3-At very high altitudes.

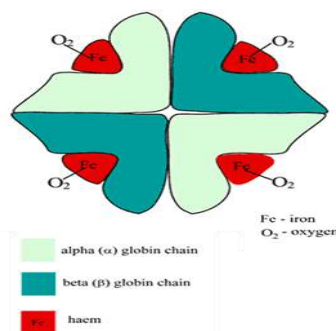
### Hemoglobin Hb

Hemoglobin is a protein in RBC that carries oxygen to body's organs and tissues and transports carbon dioxide from organs and tissues back to lungs. The average normal hemoglobin content of blood is 16 g/dL in men and 14 g/dL in women. .

### Structure of Hb

Hemoglobin is made up of four protein globulin molecules connected together. Each globulin chain contains an iron-containing porphyrin compound named hem. Iron atom is vital in transporting oxygen and carbon dioxide in the blood.

## Chapter 3- Red Blood Cells



### Synthesis of Hemoglobin

Hb is synthesized in a series of steps. The heme part is synthesized in a series of steps in the mitochondria and the cytosol of immature red blood cells, while the globin protein parts are synthesized by ribosomes in the cytosol. In the body of a 70-kg man, there are about 900 g of hemoglobin, and 0.3 g of hemoglobin is destroyed and 0.3 g synthesized every hour.

### Quantity of Hemoglobin Hb in the Cells

RBC have the ability to concentrate Hb up to about 34 grams in each 100 milliliters of cells.

The Hb of normal men contains an average of 15 grams / 100 milliliters of cells.

For women, it contains an average of 14 grams /100 milliliters.

Each gram of pure Hb is capable of combining with 1.34 ml of oxygen.

### Iron Metabolism

Iron is important for the formation of Hb. The total quantity of iron in the body averages 4 to 5 grams, about 65 percent of which is in the form of hemoglobin. About 4 percent is in the form of myoglobin.

### Destruction of Hemoglobin

When old red blood cells are destroyed in the tissue macrophage system, the globin portion of the hemoglobin molecule is split off, and the heme is converted to biliverdin,

### Chapter 3- Red Blood Cells

most of the biliverdin is converted to bilirubin and excreted in the bile . The iron from the heme is reused for hemoglobin synthesis.

#### Human Blood Groups

There are 4 main blood groups – A, B, AB and O. ABO grouping is based on the presence of antigens on RBCs .

ABO Blood Groups - determined by:

- 1- presence or absence of type A and type B antigens on RBC membrane.
- 2- presence or absence of antibodies alpha or beta in the plasma .

#### Types of blood groups

- i. Group A contain antigen A and anti-beta , can receives blood from A,O (not B)
- ii.Group B contain antigen B and anti-alpha , receives B,O (not A)
- iii.Group AB contain antigens AB and with none antibodies, receives from A, B, AB, O and therefore called universal recipient.
- iv.Group O without antigens, and with both anti-alpha and beta , receives blood only from O , and called universal donor

#### Distribution of antigens & antibodies in blood groups:

<u>Blood group</u>	<u>antigen</u>	<u>antibodies</u>
A	A	$\beta$
B	B	$\alpha$
AB	A,B	-----
O	-----	$\alpha,\beta$

#### Agglutination

Agglutination is the process of clumping of RBC that occurs if an antigen is mixed with its corresponding antibody called isoagglutinin. *Agglutination* can be used as an indicator of the presence of *antibodies* .

## Chapter 3- Red Blood Cells

### The Rh factor

Rhesus (Rh) factor is an inherited protein D found on the surface of red blood cells. If blood has the protein, Rh is positive. If blood lacks the protein, Rh negative. The Rh typing used in routine blood typing , 85% percent are D-positive and 15% are D-negative.

### Blood Transfusion

Blood transfusion must be from same group , group O may be used for other groups that is called *universal donor* , group AB can take from all other group that is called *universal recipient* .

### Clotting of blood (Coagulation)

It is body defense mechanism by which the bleeding of the blood stopped .

### Factors of clotting

Factors associated with blood clotting are :

<b>Fibrinogen</b>	<b>factor I</b>
<b>Prothrombin</b>	<b>factor II</b>
<b>Thromboplastin</b>	<b>factor III</b>
<b>Calcium ions</b>	<b>factor IV</b>
<b>Proaccelerin</b>	<b>factor V</b>
<b>Proconvirtin</b>	<b>factor VII</b>
<b>Antihæmophilic</b>	<b>factor VIII</b>
<b>Christmas</b>	<b>factor IX</b>
<b>Stuart factor</b>	<b>factor X</b>
<b>Hageman factor (HF)</b>	<b>factor XII</b>
<b>Fibrin stabilizing factor</b>	<b>factor XIII</b>

Stage 1: Formation of thromboplastin (*Thrombokinase* ).

Stage2: Conversion of prothrombin into *thrombin* by thrombokinase in

### Chapter 3- Red Blood Cells

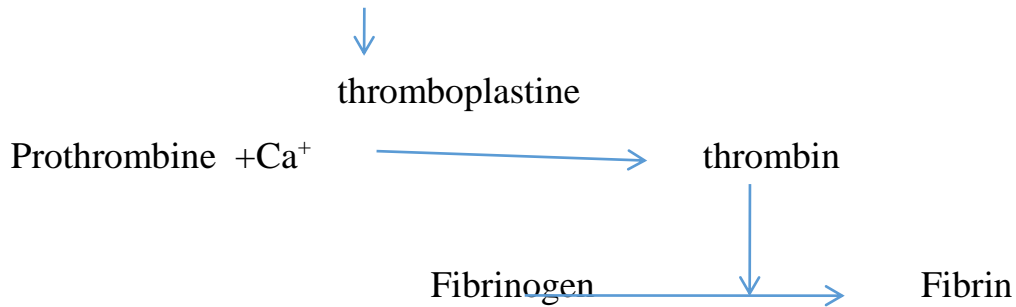
presence of  $\text{Ca}^{+}$  ions .

Stage 3: Conversion of soluble plasma Protein (*fibrinogen* ) into insoluble Protein (*fibrin* )by thrombin .

Stage 4: fibrin forms a network of strands which entrap blood cells by adhering to surrounding tissues and form jelly-like clot .

Stage 5: clott retracts and exudes fluid (serum) and become hard.

#### Platelet break down (tissue damage)



(Diagram of blood clotting )

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**2023-2024 2<sup>nd</sup> Year Stage**

**Department of Medic.Lab Techn. Human Physiology Lect. : Pro. Dr. Esmail Salih**

## **Chapter 5 White Blood Cells**

**Contents :White Blood Cells, Classification, Specific Function,Normal Value**

### **White Blood Cell Count (WBC)**

White blood cells, or leukocytes, are nucleated blood cells, the lifespan of WBC ranges from 13 to 20 days, after which time they are destroyed in the lymphatic system.

### **General Functions of WBC**

1. Protection body against from microbes, parasites, toxins, cancer.
2. Produce, transport, and distribute antibodies as part of the body's immune response.

### **Types of WBC**

On the bases of presence of granules in the cytoplasm WBC are classified into two main groups: agranulocytes and granulocytes.

**A-Agranulocytes** - WBCs without granules in cytoplasm. Are 2 types:

1-Monocytes. Monocytes, the largest type of WBCs with single lobe nucleus , have a longer lifespan than other WBC and help to break down bacteria, viruses.

2-Lymphocytes. Are small leucocyte with a single round nucleus, occurring especially in the lymphatic system. They create antibodies to fight against bacteria, viruses, and other invaders. Are of two types:

- a. T lymphocytes - (thymus) respond against virus infected cells and tumour cells.

b. B lymphocytes - produce antibodies against different antigens.

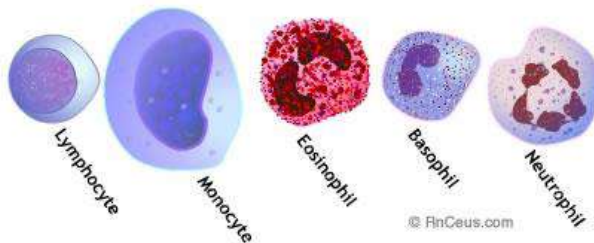
### **B-Granulocyte**

Are WBC that contain granules in their cell cytoplasm and with multilobed nucleus, they are called polymorphonuclear leukocytes, include neutrophils, eosinophils, and basophils.

1-Neutrophils. They are the most numerous type of WBC and first line of defense against bacteria & fungi, causes lysis of infecting bacteria and fungi.

2-Basophils. Are WBC with U or S shaped nucleus, releases Histamine which causes inflammation, vasodilation, attraction of WBCs.

3-Eosinophils. Are two-lobed nucleus WBC, its function is attack against parasitic worms, also inactivate chemicals released during allergies.



### **WBC formation (Leukopoiesis)**

Leukopoiesis is the process by which leukocytes are formed from haematopoietic stem cells in the bone marrow.

#### **Total WBC count**

The normal number of **WBCs** in the blood is 4,500 to 11,000 **WBCs** per microliter ( $4.5$  to  $11.0 \times 10^9/L$ ).

#### **Differential WBC count**

Mean numbers of different types of WBC.

1. Neutrophils : 50 - 70% relative value (2500-7000 absolute value)
2. Eosinophils: 1 - 3% relative value (100-300 absolute value)
3. Basophils: 0.4% - 1% relative value (40-100 absolute value)

4. Lymphocytes: 25 - 35% relative value (1700-3500 absolute value)
5. Monocytes: 4 - 6% relative value (200-600 absolute value)

The numbers of leukocytes changes with age and during pregnancy.

## Chapter 6 White Blood Cells

**Contents :**Platelet: Definition, Function, Normal Value, Thrombopoiesis and Hemostasis

### Platelets

Platelets, or thrombocytes, are small, colorless cell fragments in the blood that form clots and stop or prevent bleeding. Platelets are made in bone marrow from stem cells, Their cytoplasm contains actin, myosin, glycogen, lysosomes.

### Normal value

The normal count about 250,000 platelet/ mm<sup>3</sup> . Its deficiency in the blood is called *thrombocytopenia*. and they normally have a half-life of about 4 days.

### Function:

Platelets play a role in blood clotting by aggregates and break down at injury site and when contact with rough surface , serotonin released from it causing vasoconstriction .

The aggregation of platelets form plug which arrest bleeding.

## **Thrombopoiesis**

Is the process through which thrombocytes are generated. Platelets are made from the large megakaryocyte cells in bone marrow , with out nucleus and are about ( 2---3 M ) in diameter .

## **Hemostasis**

**Is** the stoppage of bleeding or hemorrhage. Also, the stoppage of blood flow through a blood vessel or organ of the body. It is body defense mechanism by which the bleeding of the blood stopped .

## **Clotting stages**

Hemostasis involves three basic mechanisms :1- vascular spasm, 2-the formation of a platelet plug, 3- and coagulation, in which clotting factors promote the formation of a fibrin clot.

Stage 1: Formation of thromboplastin (*Thrombokinese* ).

Stage2: Conversion of prothrombin into *thrombin* by thrombokinese in presence of  $\text{Ca}^+$  ions .

Stage 3: Conversion of soluble plasma Protein (*fibrinogen* ) into insoluble Protein (*fibrin* )by thrombin .

Stage 4: fibrin forms a network of strands which entrap blood cells by adhering to surrounding tissues and form jelly-like clot .

Stage 5: clott retracts and exudes fluid (serum) and become hard.

### **Thrombus formation**

When clot occur in circulation which fixed in occur position called *thrombus*. It occur due to degeneration or injury or roughening of the inner lining of blood vessel wall . The thrombus which become detached from occur position called *embolus* .

### **Anticoagulants**

There are many mechanisms used to prevent blood clotting before blood transfusion or testing .

1-adding Acid sodium citrate (disodium hydrogen citrate ) .

2-Storing blood at 4 c° .

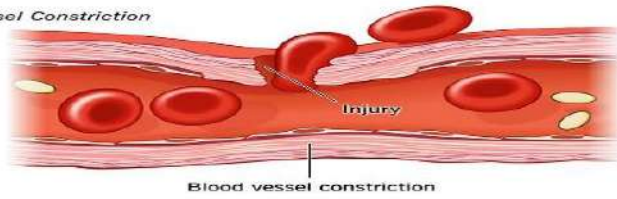
3-Adding fluoride or oxalate.

4-Adding EDTA ( Ethylenediamine tetra acetic Acid ) .

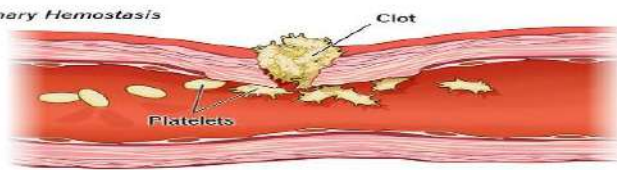
5-Adding Heparin .

## Hemostasis

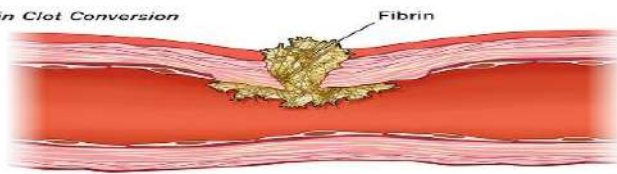
### A) Vessel Constriction



### B) Primary Hemostasis



### C) Fibrin Clot Conversion



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**Depart. of Medic.Lab Techn. Human Physiology Lect. : Pro. Dr. Esmail Salih**

## **Chapter 7 – The Heart , blood vessels and lymph**

Contents: heart physiology: conductive system, cardiac output (mechanics and control), and factor affecting. vascular (blood vessels) physiology: mechanics and control; blood pressure; and factor affecting. lymphatic physiology: organs: composition, function of each part. lymph: structure, hemodynamic and factor affecting their movement.

### **The Heart**

Heart is a muscular pump that contracts to pump blood to the body through blood vessels. The heart is located between the lungs, in the middle compartment of the chest. The heart beats at a resting rate close to 72 beats per minute. Exercise temporarily increases the rate

#### **Heart chambers**

The heart comprise 4 chambers, 2 upper auricles (atrium) and 2 lower ventricles. The atrium receives the blood from body parts. Then through a valve, blood enters the ventricle. Contraction of the ventricles forces blood from the heart through an arteries to lungs and all body parts, heart covered by membrane called pericardium filed with liquid

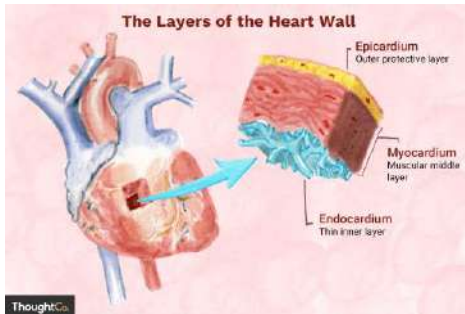
#### **Heart wall**

The wall of the heart is made up of three layers:

- 1-The epicardium, is outer layer of the heart wall is comprised of mesothelial cells and fat and connective tissues.
- 2- Myocardium is the middle layer is the, muscle layer , comprised of cardiomyocytes

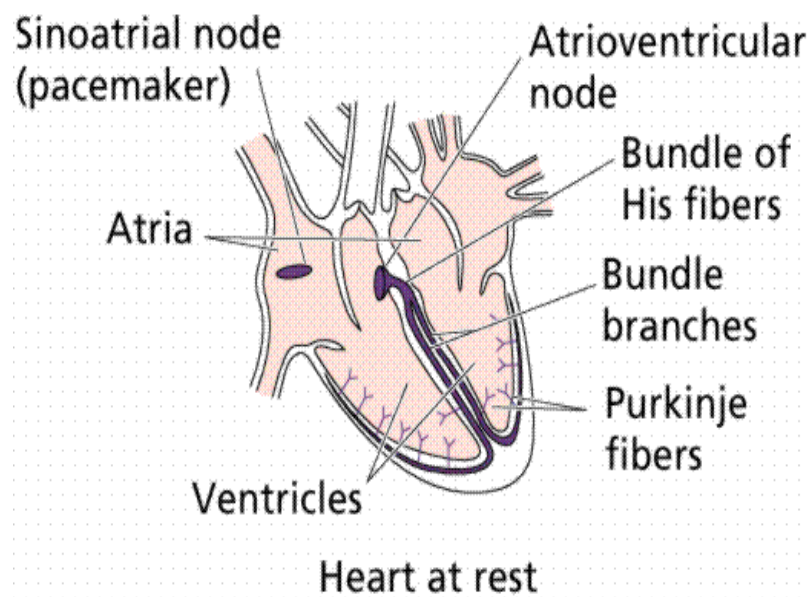
## Chapter 7 – The Heart , blood vessels and lymph

3-The endocardium, is the inner layer is Comprised of a layer of endothelial cells, and a layer of sub endocardial connective tissue.



### Heart conductive system

Is the network of nodes or groups of cells that can be either nerve or muscle tissue that initiate and conduct heart beating, HCS consist of sinoatrial , SA node generates an electrical signal that causes the upper heart chambers (atria) to contract. The signal then passes by jumping to the AV (atrioventricular) node, causing ventricles to contract , AV node is attached to bundle of fibers called **bundle of His**, and this bundle branches into branches that spread to ventricles wall called **fibers of Purkinje** .



## **Chapter 7 – The Heart , blood vessels and lymph**

### **Cardiac output (CO)**

Is a measurement of the amount of blood pumped by each ventricle in one minute. This is calculated by multiplying the stroke volume (SV) by the beats per minute of the heart rate (HR).

So that:  $CO = SV \times HR$

The average cardiac output, using an average stroke volume of about 70mL, is 5.25 L/min (with a normal range of 4.0–8.0 L/min.).

Cardiac output is dependent on the heart as well as the circulatory system- veins and arteries.

### **Regulation of Heart Pumping**

There are two primary modes by which heart pumping functions are regulated:

1-Intrinsic cardiac regulation of pumping in response to changes in volume of blood flowing into the heart.

#### **2-Extrinsic Control of Heartbeat**

Extrinsic control systems include autonomic nervous and endocrine systems that control heart functions from outside of the heart .

#### **Neural control of the cardiovascular system**

The brain controls the heart directly through the sympathetic and parasympathetic branches of the autonomic nervous system.

### **Heart beats rate**

Is a frequency or number of heart beats in one minute, and expressed as "beats per minute" (bpm). When resting, the adult human heart beats at about 70 bpm (males) and 75 bpm (females), the reference range is between 60 bpm (if less termed bradycardia) and 100 bpm (if greater, termed tachycardia).

## Chapter 7 – The Heart , blood vessels and lymph

The heart rate is affected by the following factors : exercise; age; body temperature; basal metabolic rate; emotional state; high levels of the hormones epinephrine, norepinephrine, and thyroid hormones can increase the heart rate; low blood oxygen; low blood pressure; dehydration may increase it.

### Blood pressure

Blood pressure is the pressure of circulating blood against the walls of blood vessels. Most of this pressure results from the heart pumping blood through the circulatory system. The cardiac cycle consists of two phases , systole and diastole.

Systole occurs when the heart contracts to pump blood out, while diastole occurs when the heart relaxes after contraction.

### Cardiovascular center **المركز القلبي الوعائي**

Is a part of the human brain in the medulla oblongata, responsible for the regulation of the heart beats rate through the nervous and endocrine systems.

The center comprises two control sub centers:

- 1-The cardioacceleratory center (CAC): is responsible for increasing cardiac output.
- 2-The cardioinhibitory center (CIC) is responsible for reducing cardiac output.

### Vasomotor center (VMC) **المركز الوعائي الحركي**

Is a portion of the medulla oblongata that, together with the cardiovascular center and respiratory center, regulates blood pressure and other homeostatic processes **العمليات الاتزانیه البدنيه**.

### Heart valves

Include the following 4 valves:

#### 1-Tricuspid Valve

- 1-Has three leaflets or cusps.
- 2-Locate between the right atrium and the right ventricle.

## **Chapter 7 – The Heart , blood vessels and lymph**

3-Opens to allow blood to flow from the right atrium to the right ventricle and closed to prevents the back flow of blood from the right ventricle to the right atrium.

### **2-Mitral Valve**

1-Has two leaflets.

2- Locate between left atrium and the left ventricle.

3-Opens to allow blood to flow from the left atrium to the left ventricle and closed to prevents the back flow of blood from the left ventricle to the left atrium.

### **3-Pulmonary Valve ( Pulmonic Valve)**

1-Has three leaflets.

2-Locate between the right ventricle and pulmonary artery.

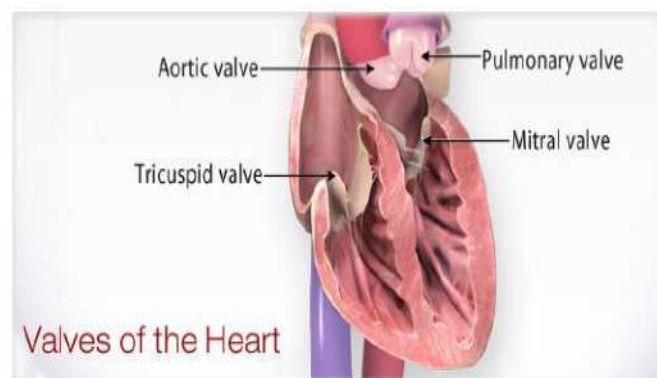
3-Opens to allow blood to be pumped from the right ventricle to pulmonary artery and closed to prevents back flow of blood.

### **4- Aortic Valve**

1-Has three leaflets.

2-Locate between the left ventricle from the aorta.

3-Opens to allow blood to leave the heart from the left ventricle through the aorta and the body and closed to prevents the backflow of blood from the aorta to the left ventricle.



### **Blood vessels**

#### **1-The arteries:**

Are blood vessels that distribute oxygen-rich blood from heart to entire body. The aorta is the largest artery in the body, taking blood from the heart, branching into other arteries that send oxygenated blood to the rest of the body. The arteries have strong walls, and blood flows at a high velocity in the arteries.

The function of the arteries is to transport blood under blood pressure to the tissues.

**2-The arterioles:** Are the small branches of the arterial system. Arterioles feed oxygenated blood to the capillaries. The arteriole has a strong muscular wall that can close the arteriole by contraction , or dilate arteriole by relaxing.

**3-The capillaries:** They are extremely thin walls , with only one cell thick wall , capillaries connect the arterioles with the venules . Their functions are distribute the nutrients and oxygen to the body's tissues and remove deoxygenated blood and waste.

**4-The venules:** Are small branches of veins collect blood from the capillaries, and conduct to larger veins.

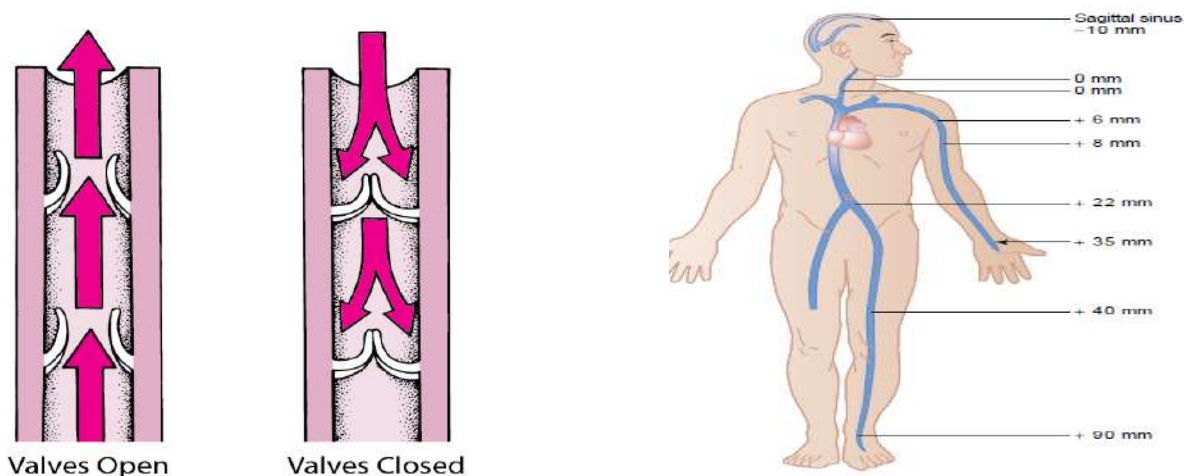
**5-The veins:** Veins are blood vessels located throughout body that collect oxygen-poor blood and return it to heart The vein walls are similar to arteries but thinner and less elastic.

#### **Venous Valves and the “Venous Pump”:**

Venous pump is muscles of venous wall, by contraction and relaxation pressing and pumping the blood towards the heart.

The valves in the veins, are flap like structures that control blood flow in the deep veins. arranged so that the direction of venous blood flow can be only toward the heart.

## Chapter 7 – The Heart , blood vessels and lymph



### Lymphatic system

Is a subsystem of the circulatory system that consists of a complex network of vessels, tissues, and organs.

### Functions of lymph system

- 1) it is responsible for the removal of interstitial fluid from tissues.
- 2) it absorbs and transports fatty acids and fats from the digestive system.
- 3) it transports white blood cells to and from the lymph nodes into the bones.

### Lymphoid organs

The lymphatic system is composed of:

- **Primary lymphoid organs:** These organs include the bone marrow and the thymus. They create special immune system cells called lymphocytes.
- **Secondary lymphoid organs:** These organs include the lymph nodes, the spleen, the tonsils and certain tissue in various mucous membrane layers in the body

### Thymus

The thymus is located behind the breastbone above the heart. Special types of immune system cells called thymus cell lymphocytes (T cells) mature in the thymus.

## **Chapter 7 – The Heart , blood vessels and lymph**

T cells move through the body and constantly monitor the surfaces of all cells for changes. In humans the thymus appears early in fetal development and continues to grow until puberty, after which it begins to shrink.

### **Bone marrow**

Bone marrow is a sponge-like tissue found inside the bones. Is site for most immune system cells production

### **Secondary lymphoid organs**

#### **Lymph nodes**

Lymph nodes are small bean-shaped tissues found along the lymphatic vessels. The lymph nodes act as filters. Various immune system cells trap germs in the lymph nodes and activate the creation of special antibodies in the blood.

#### **Spleen**

The spleen is located in the left upper abdomen, beneath the diaphragm, and is responsible for the functions::

- It stores various immune system cells. When needed, they move through the blood to other organs.
- It breaks down red blood cells (erythrocytes).
- It stores and breaks down platelets (thrombocytes), which are responsible for the clotting of blood, among other things.

## **Chapter 7 – The Heart , blood vessels and lymph**

### **Tonsils**

The tonsils are also part of the immune system. The tonsils contain a lot of white blood cells, which are responsible for killing germs.

### **Mucous membranes**

Mucosa lines the insides of organs and cavities. The mucous membrane lubricates and protects these organs and cavities from abrasive particles and bodily fluids, as well as invasive pathogens. Mucous membranes support the immune system in other parts of the body, too, such as the respiratory and urinary tracts. The immune system cells are directly beneath the mucous membranes, where they prevent bacteria and viruses from attaching.

### **Lymph movement**

There is no pump in the lymphatic system like the heart in the cardiovascular system. The pressure gradients to move lymph through the vessels come from the skeletal muscle action, respiratory movement, and contraction of smooth muscle in vessel walls.

### **Factors of lymph movement**

The Lymph is moved through the lymphatic vessels by contractions of the lymphatic vessels and the movement of the surrounding digestive system and skeletal muscles. Also the one-way action of valves within the lymphatic capillaries, help in its motion or circulation.



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## Chapter 8 Physiology of Respiration

### Contents:

Respiratory Physiology: Parts and Specific Functions; Ventilation: Mechanics and Control. External Respiration, Gas Blood Transport, Internal Respiration: Mechanics, Control and Factor affecting. Lung Volumes: Normal Values and Factor Affecting; Conscious and Un-Conscious Control of Respiration. Role of Pons and Medulla in Respiratory Transient. Acid-Base Balance: Definition, Buffer Systems, and Role of Body Systems In the Regulation.

**Objective:** To learn students following information's :

- 1- Respiratory zones , O<sub>2</sub> & CO<sub>2</sub> exchanges .
- 2-Role of respiration in vital homeostasis .
- 3- Mechanism and regulation of respiration.
- 4-Respiratory diseases .

### Respiration definition

Respiration is the process by which human take O<sub>2</sub> for cellular metabolism and release the CO<sub>2</sub> that produced from cellular metabolism.

### Respiratory system zones

The respiratory system in human divided into two zones: a conducting zone and a respiratory zone.

#### 1-Conducting Zone

The **conducting zone** include the organs that provide a route for incoming and outgoing of air to and from lungs. The functions of this zone are:

- 1-It remove debris جسيمات and pathogens from the incoming air.

## Chapter -8 - Physiology of Respiration

2-Warm and humidify ترطيب the incoming air.

3-Sensing odors by the epithelium of the nasal passages.

4-Metabolize some airborne carcinogens by the bronchial epithelium.

### Parts of the conducting zone

#### 1-The Nose

The nose is major entrance مدخل and exit مخرج for the respiratory system.

#### 2-Pharynx البلعوم

The pharynx is a tube formed by skeletal muscles and lined by mucous membrane.

The pharynx is divided into three major regions: the nasopharynx, the oropharynx, and the laryngopharynx (البلعوم الأنفي والبلعوم الفموي والبلعوم الحنجري).

#### 3-Larynx الحنجرة

The larynx is a cartilaginous structure connects the pharynx to the trachea and helps in regulate the volume of air that enters and leaves the lungs.

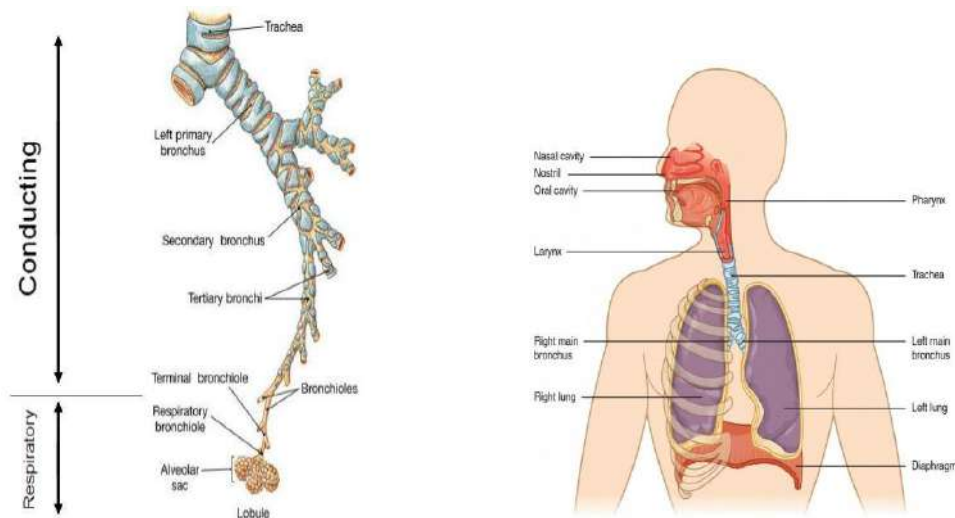
#### 4-Trachea

The trachea extends from the larynx to the lungs. The trachea is formed by 16 to 20 C-shaped pieces of hyaline cartilage غضروف زجاجي that are connected by dense connective tissue.

#### 5-Bronchial Tree القصبات الهوائية

A bronchial tree is the multiple-branched bronchi of the trachea. Trachea branches into the right and left primary bronchi, each one, branches to secondary bronchi, then to the tertiary bronchi, then to bronchioles قصيبات , further branching until they forming the tiny terminal bronchioles, which lead to the alveoli sacs أكياس الحويصلات الهوائية. There are more than 1000 terminal bronchioles in each lung.

## Chapter -8 - Physiology of Respiration



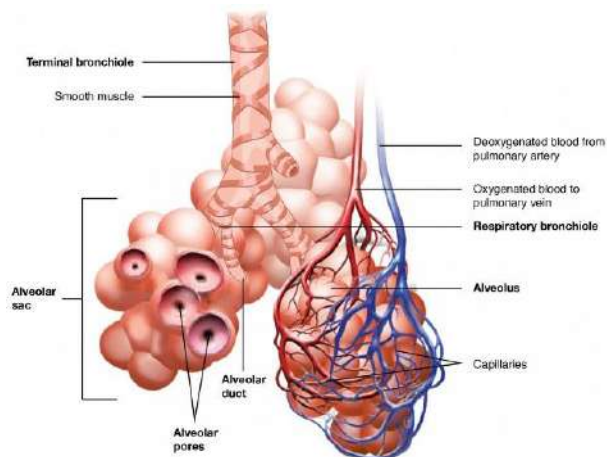
**Figure of Respiratory zones**

### 2-Respiratory Zone

The respiratory zone begins where the terminal bronchioles join to an alveolar duct, that opening into a cluster of alveoli.

#### Alveolar ducts and Alveoli الحويصلات الهوائية

An alveolar duct is a tube that joins to terminal bronchioles, which opens into a cluster of alveoli. An alveolar sac is a cluster of many alveoli that are responsible for gas exchange. An alveolus is about 200  $\mu$ m in diameter with elastic walls that allow the alveolus to stretch during air intake. Alveoli are connected to their neighbors by alveolar pores, which help maintain equal air pressure throughout the alveoli and lung.



## Chapter -8 - Physiology of Respiration

### **Ventilation, or breathing**

Ventilation, or breathing, is the movement of air through the conducting passages between the atmosphere and the lungs. The air moves through the passages because of pressure gradients that are produced by contraction of the diaphragm and thoracic muscles.

### **Steps of respiration**

Respiration in humans from taking air up to utilization of O<sub>2</sub> in cells, involve five steps:

- 1-Breathing or ventilation
- 2-External respiration
- 3-Gas transport
- 4-Internal respiration
- 5-Cellular respiration

**1-Breathing** or ventilation, is the movement of air through the conducting passages between the atmosphere and the lungs. The air moves through the passages because of pressure gradients that are produced by contraction of the diaphragm and thoracic muscles.

**Breathing** comprise two phases , inspiration and expiration. Inspiration is the process of taking in of the air and expiration is the flush out of the air. Breathing is usually automatic, controlled subconsciously by the respiratory center at the base of the brain. Breathing continues during sleep and usually even when a person is unconscious. People can also control their breathing when they wish, for example during speech, singing, or voluntary breath holding.

### **2 -External Respiration**

Is gas exchange between the lung alveoli air and the blood of the pulmonary circulation. This process depends on gases partial pressure differences, O<sub>2</sub> and CO<sub>2</sub> diffuse in the direction of concentration gradient from high to low pressure, and as a

## Chapter -8 - Physiology of Respiration

result blood loaded with O<sub>2</sub> and CO<sub>2</sub> enter alveoli air, then O<sub>2</sub> transported through pulmonary circulation to heart and then to all body tissues through systemic circulation.

### **3-Gas Transport by blood**

Comprise O<sub>2</sub> and CO<sub>2</sub> transport by blood.

#### **A- O<sub>2</sub> Transport**

After entrance of O<sub>2</sub> into blood capillaries of the lung, is transported in blood of pulmonary circulation to heart then to all bodies tissues in following forms:

1-In binding to hemoglobin forming oxyhemoglobin, about 98.5% of all O<sub>2</sub> bind to Hb.

2 - Dissolved in the plasma in about 1.5%.

#### **B-CO<sub>2</sub> Transport**

CO<sub>2</sub> transported by blood in following forms:

1-In bicarbonate (HCO<sub>3</sub>) form, by reaction of CO<sub>2</sub> with water by carbonic anhydrase enzyme. About 60% CO<sub>2</sub> transported in this form.

2- Combines with hemoglobin, about - 30% of CO<sub>2</sub> transported by this form.

3 - In dissolved form in the plasma about - 10% of CO<sub>2</sub> transported by this form.

### **4-Internal Respiration**

Internal respiration is the process of exchange of O<sub>2</sub> and CO<sub>2</sub> between the blood capillaries and the interstitial fluid of all bodies tissues, O<sub>2</sub> enter interstitial fluid and CO<sub>2</sub> enter the blood of capillaries. The exchanges are on bases of concentration gradient from high to low concentration.

### **Control and regulation of respiration**

The respiration controlled by neural and chemical modes

### 1-Neural regulation

The respiration is controlled by nerve center called respiratory center found in the medulla oblongata in the brain . The respiratory center(RC) divided into an inspiratory center (I neurons) and an expiratory center (E neurons).

This respiratory center contain chemoreceptors is very sensitive to the  $p\text{CO}_2$  and to the pH level of the blood.

The sense of RC for  $\text{CO}_2$  and Ph , form a message, then sent neural impulses down through the spinal chord and into the diaphragm and chest muscles to adjust the ventilation rate by increasing or decreasing the removal of  $\text{CO}_2$ .

### 2-Chemical regulation

The chemical regulation of respiration is by the hydrogen ion content of the respiratory neurons center , which in turn is dependent upon the carbon dioxide tension of the blood and the rate of flow of blood through the medulla.

### Lung Volumes and Capacities الحجوم والسعات الرئوية

Lung volumes and lung capacities refer to the volume of air in the lungs at different phases of the respiratory steps . Lung volumes measured by spirometer .

The following lung volumes can be measured directly or indirectly with a spirometer:

**1-Tidal Volume (VT)** حجم المد والجزر : volume of air inspired or expired during a normal spontaneous breath.

**2-Residual Volume (RV)** الحجم المتبقي : is the amount of air that remains in a lungs after fully exhaling.

**3-Vital Capacity (VC)** السعة الحيوية : is the maximum amount of air a person can expel from the lungs after a maximum inhalation.

**4-Total Lung Capacity (TLC)** إجمالي سعة الرئة : is the total volume of air in the lung at the maximal end inspiration.

### **Muscles of respiration**

Skeletal muscles that play a role in the respiration include:

- 1- External intercostal muscles (muscles located between the ribs).
- 2- Diaphragm ( muscle between thoracic abdominal cavities).
- 3- Abdominal wall muscles .

### **Mechanism of Pulmonary (Alveolar) ventilation**

Ventilation, or breathing (inspiration and expiration), is the movement of air through the conducting passages between the atmosphere and the lungs.

#### **Inspiration**

Inspiration is the active phase of ventilation because it resulted by muscles contraction. During inspiration, the diaphragm and intercostal muscles contract pulling thoracic cavity downward and forward increases in thoracic cavity volume, causing decreases the intra alveolar pressure so that air flows into the lungs.

#### **Expiration**

Expiration (exhalation) is the process of letting air out of the lungs. During expiration, the relaxation of the diaphragm and intercostal muscles decreases the thoracic volume and increases the intra alveolar pressure pushes air out of the lungs.

### **Sites or levels of Gas exchanges**

#### **1-Exchange at Lung**

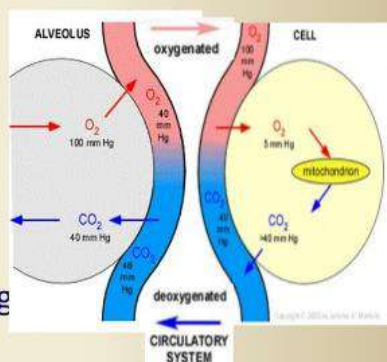
During pulmonary gas exchange O<sub>2</sub> from inhaled air is diffused into the alveoli in the lungs and the CO<sub>2</sub> from the blood diffuses out through the alveoli to be exhaled back into the air.

#### **2-Exchanges at tissues**

About 98.5% of the oxygen in arterial blood that enter into body tissues diffuse to the interstitial fluid then it can enter the cells by diffusion or active transport. Co<sub>2</sub>, can diffuse out of cells and into the interstitial fluid then to the blood capillaries.

## Gas Exchange

- Sites of Gas exchange:
  - **At tissues**  
(between blood & tissues).
  - **At the lungs**  
(between blood & air).
- Mechanism of Gas exchange
  - **Simple diffusion.**  
i.e. down partial pressure gradient.  
from high to low partial pressure.



### Acid–base balance

Refers to the balance between input (intake and production) and output (elimination) of hydrogen ion. The body is an open system in equilibrium with the alveolar air where the partial pressure of carbon dioxide  $pCO_2$  is identical to the carbon dioxide tension in the blood.

### Role of body systems in acid-base balance

Defense against acid–base imbalance is accomplished through three interacting systems: the chemical buffers of the blood, the respiratory system, and the renal system. The chemical buffers resist changes in plasma pH by binding  $H^+$  ions when they are in excess and dissociating to form  $H^+$  ions when the  $[H^+]$  falls.

The respiratory tract can adjust the blood pH upward in minutes by exhaling  $CO_2$  from the body. The renal system can also adjust blood pH through the excretion of hydrogen ions ( $H^+$ ) and the conservation of bicarbonate, but this process takes hours to days to have an effect.