SECTION 5

BLOOD

BLOOD

Blood is the only liquid tissue of the human body which comes into contact with all other tissues in order to perform its functions. Thus, it is the mode of transport which flows inside the vascular circulatory system with the help of cardiac function, ensuring the chemical communication between the various tissues of the body. The total blood volume in an adult is 6-8% of his body weight which amounts to about 5.0-5.5 liters.

Blood is composed of the formed elements and plasma. The constituents of the formed elements of the blood are the erythrocytes or red blood cells, the leukocytes or white blood cells, and the thrombocytes or platelets (Figure 20.1; Table 20.1). The blood cells are constantly renewed by the hemopoietic stem cells of the red bone marrow.

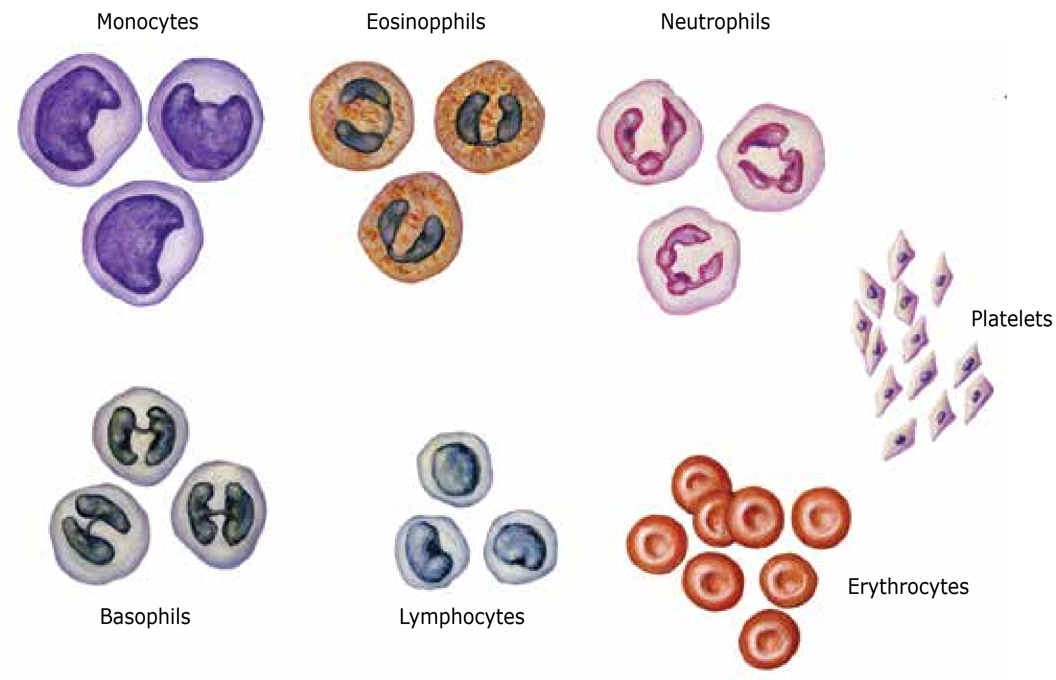

FIGURE 20.1: *The formed elements of the blood.*

TABLE 20.1: Description and Function of the Blood Components in the Human Body

BLOOD COMPONENT	DESCRIPTION	FUNCTION
Erythrocyte	Anucleus; biconcave disc shape; contains hemoglobin; lifespan 120 days	Transfers oxygen from the lungs to the various body tissues and carbon dioxide from the body tissues to the lungs
Platelet	Cell fragment; lifespan 5-7 days	Contribution to blood clotting by releasing serotonin, which causes vasoconstriction
Neutrophil	Nucleus has 2 to 5 lobes; pink-staining granules in the cytoplasm; short lifespan 12 hours to 3 days	Phagocytosis of bacteria
Eosinophil	Nucleus has 2 lobes; red-staining granules in the cytoplasm; short lifespan 12 hours to 3 days	Phagocytosis of antigen-antibody complexes in allergic reactions. Fights against infections caused by parasites, where they adhere to parasites and release substances that kill them
Basophil	Nucleus is lobed; blue-staining granules in the cytoplasm; short lifespan 12 hours to 3 days	They accelerate the removal of fat droplets from the blood after a fatty meal. In allergic reactions, they bind to antibodies where the basophil is ruptured and releases large amounts of histamine, bradykinin, serotonin, heparin and lysosomal enzymes that cause allergic reactions.
Monocyte	Nucleus is kidney- or horseshoe-shaped; 3 times larger than erythrocytes; they are transformed into macrophages when entering tissues; lifespan 100-300 days	Phagocytosis of bacteria and larger particles such as whole erythrocytes
Lymphocyte	Only slightly larger than erythrocytes; very large round nucleus with very little cytoplasm; lifespan 100-300 days	The cellular immune response is dependent on T-lymphocytes, while the chemical immune response is dependent on B-lymphocytes. B-lymphocytes produce antibodies.
Plasma	Translucent yellowish liquid part of blood; consists of water, proteins, inorganic electrolytes, nutrients, vitamins, trace elements, waste products and hormones, antibodies and clotting factors	Transfers useful substances such as nutrients, minerals and vitamins to various body tissues. Transfers waste products of metabolism (urea, uric acid) from the tissues to the excretory organs. Transfer of hormones from the endocrine glands to all body tissues. Contribution to acid-base balance, thermoregulation, body's defence mechanisms, and water exchange between vessels and tissue fluid.

PLASMA

Plasma is the liquid portion of the blood through which the cellular components and many other substances are transported. It comprises of about 55 percent of the total blood volume and has a translucent yellowish color due to the presence of bilirubin which is a product of hemoglobin degradation.

The composition of plasma is: 91.5% water, 7% proteins such as albumin, globulins (alpha globulins, beta globulins, and gamma globulins), lipoproteins and fibrinogen, about 1% inorganic electrolytes such as Na, K, Cl, Mg, H, Ca, HCO_3, HPO_4, and SO_4, and 0.5% nutrients such as glucose, amino acids, lipids, cholesterol, vitamins and trace elements, gases such as O_2, CO_2 and N_2, by-products of metabolism such as urea, creatinine, uric acid and bilirubin, and finally hormones, antibodies and clotting factors.

WHITE BLOOD CELLS

White blood cells are the mobile units of the body's protection system. Their percentage amounts to below 0.5% of the total blood volume and the normal number contained in a cubic millimeter of blood (1mm^3 or 1μl) ranges from 5,000-10,000 leukocytes (Table 20.2). Values of less than 5,000 white blood cells per mm^3 of blood are characterized as leucopenia, while values above 10,000 per mm^3 are characterized as leukocytosis. In the case of infection and inflammation, their number increases up to 50,000 per mm^3 and even more in the case of leukemia.

The white blood cells are classified into the following categories (Figure 20.1):

1) Polymorphonuclear granulocytes, which are subdivided into eosinophils (Figure 20.2A), basophils (Figure 20.2B) and neutrophils (Figure 20.2C).
2) Large monocytes.
3) Lympocytes (Figure 20.2D), which are separated into 3 subsets: T-lymphocytes, B-lymphocytes and natural killer cells. B-Lymphocytes can be differentiated into beta-lymphoblasts, plasma cells and memory beta-cells, while T-lymphocytes are transformed into T-lymphoblasts which are divided into helper T-cells, suppressor T-cells or regulatory T-cells, cytotoxic T-cells and memory T-cells.

TABLE 20.2: Relative Percentage of Leukocytes in Adults.

Type of Cell	Relative Percentage (%)	Function
Neutrophils	62-70	Phagocytosis
Basophils	1	Allergic reactions
Eosinophils	2	Allergic reactions Defense against parasites
Lymphocytes	23-28	Immunity
Monocytes	4-7	Phagocytosis

They are produced in part by the bone marrow (polymorphonuclear granulocytes, monocytes and a few large lymphocytes) and in part by the lymphatic tissue (lymphocytes and plasma cells).

The primary function of white blood cells is to fight infection by attaching and destroying harmful foreign substances and microorganisms (Table 20.1). Therefore, they work in two different ways in order to fight against the disease: 1) via the actual destruction of the intruder by the process of phagocytosis and 2) via the production of antibodies and sensitized lymphocytes, which may destroy or inactivate the intruder.

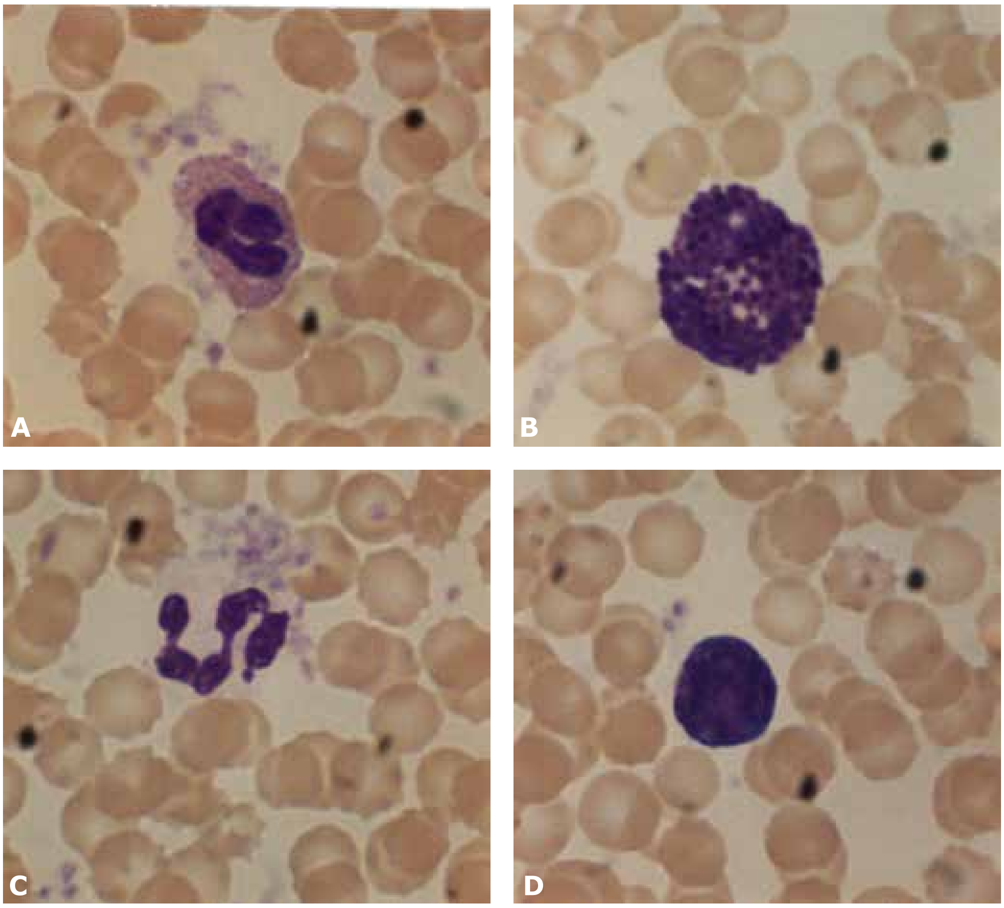

FIGURE 20.2: *Leukocytes as seen through the microscope (A= eosinoplil; B= basophil; C= neutrophil; D= lymphocyte)*

PLATELETS

Platelets are colorless cell fragments containing numerous granules (Figure 20.1). They are produced in the bone marrow by megakaryocytes which lose parts of their cytoplasm. Each part is enclosed by a cell membrane fragment creating platelets after they enter the bloodstream where they live for 5-7 days. They constitute less than 0.5% of the total blood volume. Normal values range between 150,000 and 400,000 platelets per mm^3. Values below the normal range are considered as thrombocytopenia that may lead to bruising and spontaneous bleeding.

Platelets form clots to prevent blood leakage from wounds and therefore they play a crucial role in blood coagulation and hemostasis, that is to inhibit bleeding within minutes. Thus when a vessel is sheared or ruptured, hemostasis is achieved by various mechanisms, which include:

1. Spasms of the vessel.
2. Formation of platelet thrombus.
3. Blood clot formation by coagulation.
4. Fibrous tissue growth into the blood clot for permanent occlusion of the shear made in the blood vessel.

RED BLOOD CELLS

Red blood cells consist of 38-48% of the total blood volume. They are the most abundant cell type in the circulatory system and they give blood its characteristic red color. They are produced in the

BLOOD TYPES

Blood types were discovered in 1901 by the German scientist, Karl Landsteiner. So far over thirty ordinary antigens have been discovered along with hundreds of other rare antigens which are attached to the surface of red blood cells in humans, each of which can cause an antigen-antibody reaction. Most of them are weak and play a role in the inheritance of genes particularly in establishing paternity. However, two groups of antigens, called agglutinogens, are important because they can cause reactions during blood transfusion. These two groups of antigens are the ABO system and the Rhesus system.

1. THE ABO SYSTEM

Agglutinogens A and B

The agglutinogens A and B, which can be inherited, are located on the red blood cell membrane in large populations. Both of them, one of them or none of the agglutinogens can be found on the surface of the human red blood cells. If there is only agglutinogen A, the blood group of the individual is A. When only agglutinogen B is on the surface of the red blood cells then the blood type is B. When both agglutinogens A and B are on the red blood cells, the blood type is AB, whereas when neither of these two are on the surface of the red blood cells the blood type is O (Table 21.1).

The four blood types of the ABO system is the result of the inheritance of various combinations of three different allele genes called I: I^A for the agglutinogen A, I^B for the agglutinogen B or i for neither agglutinogen A and B. Each person inherits two alleles, one from his father and one from his mother, from which his blood type is derived (Table 21.2). Thus, six possible combinations of genes create the following four blood groups:

1) I^AI^A or I^Ai creates the blood group A
2) I^BI^B or I^Bi creates the blood group B
3) I^AI^B creates the blood group AB
4) ii creates the blood group O.

TABLE 21.1: Frequency of blood types in Greek individuals

Blood Type	Percentage (%)
A	38
B	13
AB	5
O	44

Agglutinins

The absence of agglutinogens A from red blood cells of an individual generates the development of anti-A antibodies which are called anti-A agglutinins. Similarly, the absence of agglutinogens

B on the erythrocytes generates anti-B agglutinins, while the absence of both agglutinogens generates both agglutinins A and B. Therefore, blood type A contains agglutinogens A and anti-B agglutinins. Blood group B contains agglutinogens B and anti-A agglutinins and blood type AB contains both agglutinogens A and B and no agglutinins. Finally, blood group O contains none of the two agglutinogens but both anti-A and anti-B agglutinins.

Immediately after the birth of an individual, the levels of agglutinins in the plasma are nearly zero. However, four to eight months after birth, the baby begins to produce anti-A and/or anti-B agglutinins depending on the blood type of the individual.

Maximum quantities of anti-A and anti-B agglutinins are observed at the age of 8 to 10 years with a progressive decrease thereof during the life of the individual. However, despite the gradual reduction of anti-A and anti-B agglutinins over the years, they are still at high levels during the first 5-6 decades.

The agglutinins are gamma globulins produced by the same cells, ie plasma cells, which produce antibodies against any other antigens. Sensitization of the body to produce anti-A and anti-B agglutinins is due to the entry of small quantities of agglutinogens A and B in the body via food, microorganisms and other means of entry, where they cause the development of anti-A and anti-B agglutinins respectively.

TABLE 21.2: Blood Types with their Allele Genes, Agglutinogens and Agglutinins

ALLELE GENES	AGGLUTINOGENS	AGGLUTININS	BLOOD TYPE
I^AI^A or I^Ai	A	Anti-B	A
I^BI^B or I^Bi	B	Anti-A	B
I^AI^B	A and B	none	AB
ii	none	Anti-A and Anti-B	O

2. RHESUS SYSTEM

Another group of agglutinogens found on the surface of erythrocytes in most individuals is the Rhesus system. The most important difference between the Rh and ABO system is that in the ABO system the anti-A and anti-B agglutinins of the plasma are automatically produced during the first months of an individual's life, while in the Rh system, the agglutinins are not automatically generated. So the person must be exposed to a large extent to Rh agglutinogens in order to be sensitized and start producing anti-Rh agglutinins.

There are six types of Rh agglutinogens, C, D, E, c, d and e. However, the agglutinogen D displays a wide prevalence in the population and has the strongest antigenicity compared to the other agglutinogens of the Rh system. Therefore, people who carry agglutinogen D on their erythrocytes are called Rh positive, while those who do not have agglutinogen D are called Rh negative. However, some people who are Rh negative can cause mild agglutinogen-agglutinin reactions. The incidence of individuals who are Rh positive in Greece is 85%, while those that are Rh negative is 15%.

3. CLINICAL ASPECT: ERYTHROBLASTOSIS FETALIS OR HEMOLYTIC DISEASE OF THE NEWBORN

The Rhesus system is of a particular significance when Rh-negative mothers give birth to Rh-positive children. When a Rh-negative mother is pregnant with her first Rh-positive child, who has inherited the Rh agglutinogen from the father, the mother is not usually exposed to the Rh agglutinogen of the fetus during pregnancy since the fetal and maternal blood are kept separate due to the impermeable placenta. However, at the time of birth, an amount of fetal blood enters the mother's blood circulation and her immune system may be sensitized and produce large amounts of anti-Rh agglutinins. Thus in subsequent pregnancies, the anti-Rh agglutinins which are created by the mother diffuse slowly from the placenta into the fetal blood, causing slow agglutination of the erythrocytes in the fetus. This causes gradual hemolysis of erythrocytes and fetal hemoglobin is released into the blood plasma. Subsequently, macrophages degrade hemoglobin to bilirubin creating fetal jaundice.

The neonate becomes anemic and the anti-Rh agglutinins continue to circulate in the blood where they destroy more and more erythrocytes. Moreover, hemopoietic tissues of the infant, ie the liver and spleen, strive to replace the damaged erythrocytes and both the liver and spleen of the fetus form a large bulge. This rapid production of erythrocytes results in the release of precursor forms of erythrocytes into circulation, which are not functional eg large in size nucleated cells of a different shape from that of the biconcave disc and with fragile membranes which might encounter difficulties when entering the capillaries. This condition is called erythroblastosis fetalis, or hemolytic disease of the newborn.

The usual treatment for the hemolytic disease of the newborn is the replacement of the blood in the newborn with Rh-negative blood. An amount of 400 ml of Rh-negative blood is administered while simultaneously an equal amount of blood is removed from the newborn in order to minimize the presence of anti-Rh agglutinins which have entered the blood circulation of the newborn from the mother. This process can be repeated several times during the first weeks of the newborn's life to keep the bilirubin levels low.

Erythroblastosis fetalis can be prevented by injecting the mother with an antibody preparation against Rh agglutinogens within 48 hours after the birth of each Rh-positive child to block the sensitization of the mother against Rh agglutinogens. This limits the risk of developing large amounts of anti-Rh agglutinins in her next pregnancy.

EXERCISES

Exercise 1: Match the following terms in Column A with the contextual meanings in Column B:

Column A	Column B
Agglutinogen	Degradation of hemoglobin into bilirubin during severe hemolysis of erythrocytes.
Rhesus system	Protein produced in response to antigen
Hemopoietic tissue	Hemolytic disease of the newborn
Agglutinin	The second most important blood group system after ABO.
Alleles	The product formed by the degradation of hemoglobin
Jaundice	Taking blood from one person and giving it to another
Antibody	Antigen located in the blood
Erythroblastosis fetalis	One is inherited from the father and the other from the mother
Bilirubin	The specific place where the blood cells are developed.
Transfusion	Antibody found in the blood

Exercise 2: Use the terms given below to fill in the blanks found in the paragraph. Note that some of the terms can be used more than once.

agglutinogens A
agglutinogen D
Rhesus system
agglutinogens
blood type
Rh positive
Rh negative
ABO system
anti-A antibodies
surface
anti-A agglutinins
antigen-antibody
antigens

Red blood cells have over thirty ordinary .... that are attached to the .... of red blood cells in humans, each of which can cause an .... reaction. Three antigens, called ...., two of the .... and one of the .... are used to determine a person's .... The absence of .... from an individual's red blood cells generates the development of .... which are called ....

The term .... indicates that the .... is present on the surface of a red blood cell of a person, while those who do not have .... are called ....

Exercise 3: Fill in the blanks.

1) There are .... types of Rhesus agglutinogens.
2) Most common agglutinogen in Rhesus system is the ....
3) The usual treatment for the hemolytic disease of the newborn is .... with ....
4) Erythroblastosis fetalis can be prevented by injecting the mother with .... in order to block the .... of the mother to ....
5) The least common blood type in Greece is ....
6) The anti-A and/or anti-B agglutinins are produced for the first time ....

SECTION 8

RESPIRATORY SYSTEM

RESPIRATORY STRUCTURES AND THE BREATHING PROCESS

1. OVERVIEW OF RESPIRATORY SYSTEM

The main function of the respiratory system is to deliver oxygen to the blood and to eliminate carbon dioxide from blood. This exchange of oxygen and carbon dioxide between the atmosphere and the blood is performed in the lungs, which are located in the thoracic cavity. The exterior surface of the lungs and the internal surface of the chest wall are covered by a membrane called pleura. Between the two pleurae, an intrapleural space is formed which is filled with a small volume of intrapleural fluid (about 10-15ml).

During breathing, the lungs communicate with the atmosphere via air passageways. These passageways are divided into two zones. In the conducting zone there is no gas exchange. It includes the nasal and oral cavity, the pharynx (throat), the larynx, the trachea, the bronchi, the bronchioles and the terminal bronchioles. However, in the respiratory zone the exchange of oxygen and carbon dioxide is performed. The respiratory zone includes the respiratory bronchioles, the alveolar ducts, the alveolar sacs and the alveoli.

2. THE UPPER RESPIRATORY TRACT

The upper respiratory tract consists of the nose, nasal cavity, paranasal sinuses and pharynx (Figure 27.1). The nose is the predominant passageway for the air entering the respiratory tract. Air enters through the external nares or nostrils which reach up to the nasal cavity. The air that enters through the nose is warmed, filtered and moistened as it passes over the epithelial cells of the nasal cavity. Coarse hairs project across the epithelium of the external nares and nasal cavity where large airborn particles, such as sand, dust, swept dirt, or even insects, are trapped between the hairs and therefore are prevented from entering the nasal cavity.

The nasal septum separates the nasal cavity into two parts, the left part and the right part of the nasal cavity.

Near the nose, there are air-filled cavities lined with mucous membranes that drain into the nasal cavity. These air-filled cavities are called paranasal sinuses. The mucus secretions produced in the sinuses serve to keep the surfaces of the nasal cavity moist and clean.

The pharynx is the passageway leading from the oral and nasal cavities to the esophagus and larynx. The pharynx is a chamber that serves both the digestive and the respiratory systems. The human pharynx is divided into the nasopharynx, the oropharynx and the laryngopharynx.

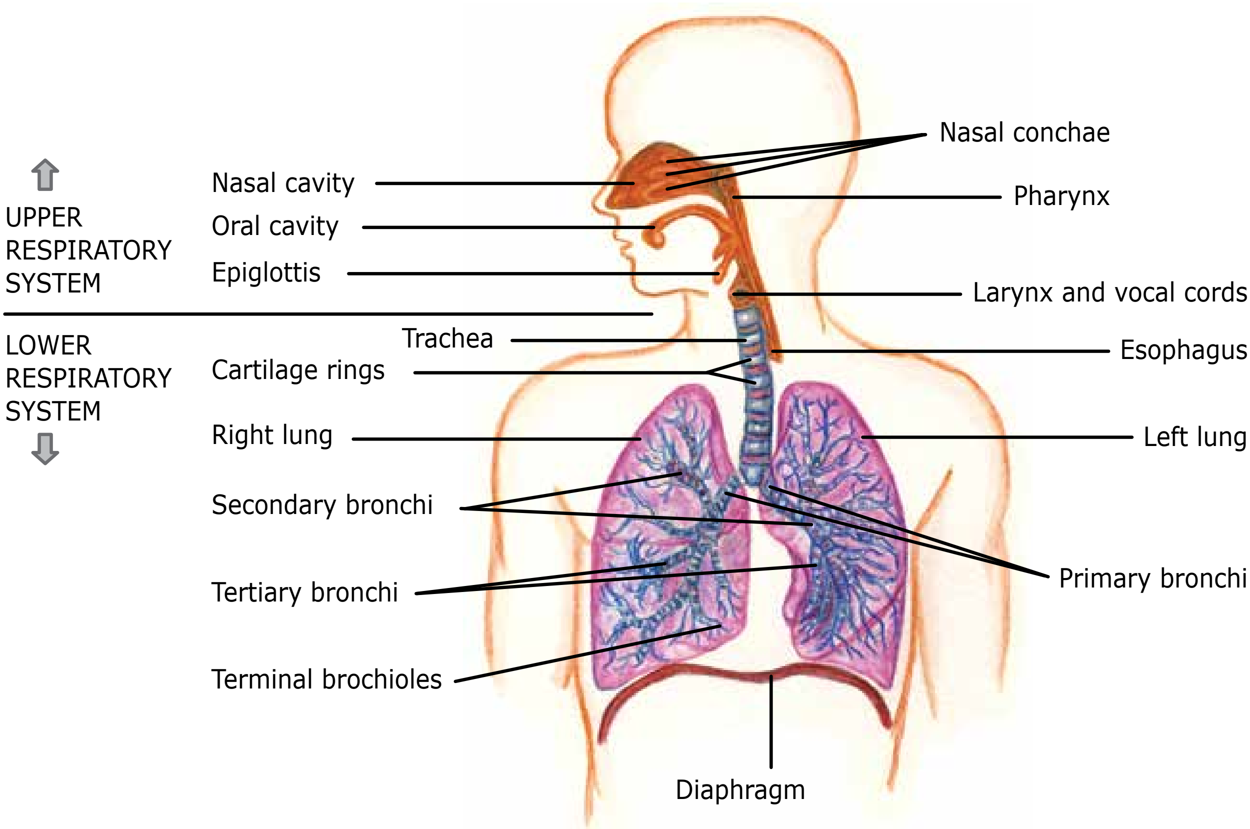

FIGURE 27.1: *Main anatomical structures of the respiratory system.*

3. THE LOWER RESPIRATORY TRACT

The lower respiratory tract is comprised of the larynx, trachea, right and left primary bronchi and the anatomical structures of the two lungs (Figure 27.1).

The larynx is made up of nine cartilages that enclose and protect the glottis. It participates in breathing, voice production and the protection of trachea from choking due to liquid and food swallowed.

The epiglottis is composed of elastic cartilage, attached to the entrance of the larynx. During breathing, the epiglottis is open and so it allows air to enter the larynx. However, during swallowing, the epiglottis closes to prevent choking from food and liquid swallowed by forcing them to go down the esophagus.

The trachea, or windpipe, is a tough, rigid tube made up of 15 to 20 tracheal cartilages, each being a C-shaped ring, which serve to stiffen the tracheal walls and prevent the air passageways from collapsing. It has a diameter of about 2.5cm and a length of about 11cm. The trachea extends from the larynx and branches into the left and right primary bronchi, or left and right main stem bronchi, before their entry into the lungs. The trachea is lined with ciliated columnar epithelium for dust entrapment. The dust is then eliminated by swallowing or expectoration.

The lungs have distinguishable lobes that are separated by fissures. The right lung has three lobes, whereas the left lung has only two lobes.

The primary bronchi also have cartilaginous C-shaped rings to provide support for the bronchi. The right primary bronchus supplies air to the right lung and the left supplies air to the left lung. The right bronchus is shorter in length but larger in diameter than the left bronchus. The right bronchus is divided into three secondary bronchi or lobar bronchi, which enter its three lobes, whereas the left bronchus is divided into two secondary bronchi that enter its two lobes. The secondary bronchi are then divided to form tertiary bronchi or segmental bronchi. Each tertiary bronchus is divided several times to generate multiple branches of bronchioles.

As the air passageways progress from the primary bronchi to the bronchioles, the amount of cartilage in the walls progressively decreases and simultaneously the relative amount of smooth muscle increases.

The smallest passageways that belong to the conducting zone are the terminal bronchioles, each of which is divided up to form several respiratory bronchioles. The respiratory bronchioles are connected to the alveolar ducts which end at alveolar sacs that are connected to multiple individual alveoli (Figure 27.2). It is estimated that each lung contains about 300 million alveoli.

The exchange of gases, such as oxygen and carbon dioxide, first occurs in the respiratory bronchioles and the exchange gradually increases as it progresses down the bronchial tree to the alveoli.

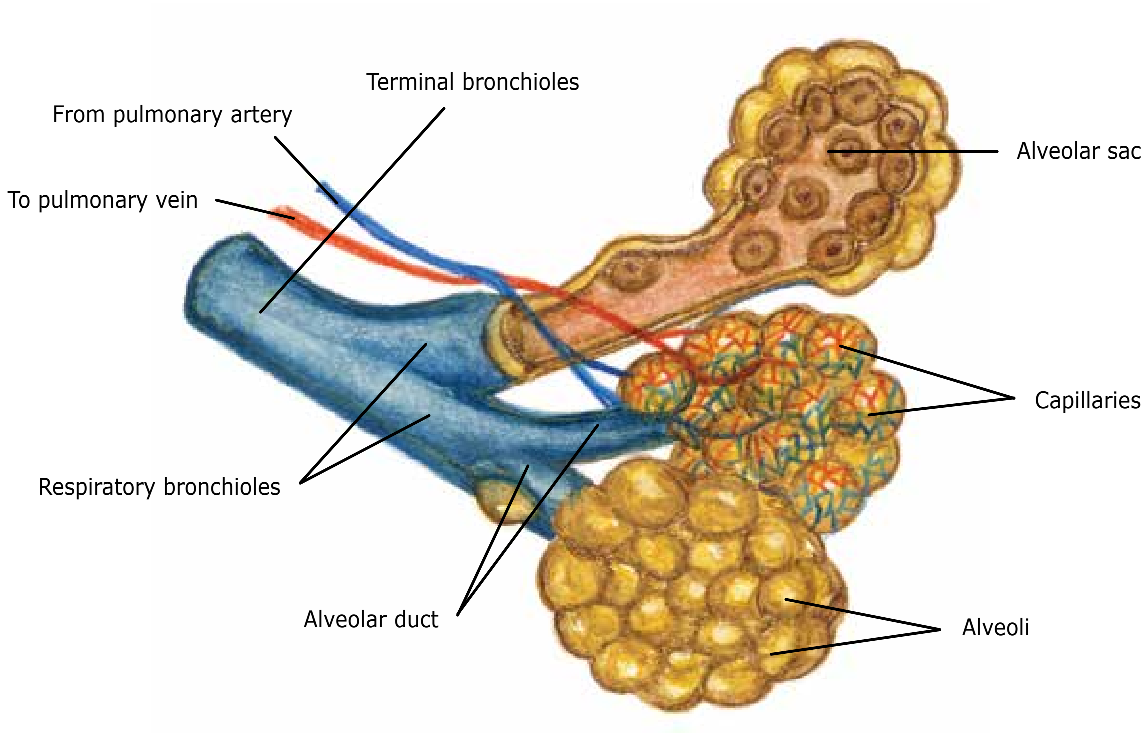

FIGURE 27.2: *The respiratory zone.*

4. ALVEOLI

Alveoli are small hollow sacs. There are over 300 million alveoli in the respiratory system. Two adjacent cells are separated by a cell wall of a single cell thickness, which is a continuous layer of squamous epithelial cells, called type I cells. Among them, there are some larger dispersed cells, called type II cells or septal cells, which produce a substance with detergent properties called surfactant. Inside the alveoli there are numerous alveolar macrophages destroying any dust or microbes via phagocytosis that escaped other respiratory defenses and reached the alveolar surfaces. Additionally, among the alveoli there is elastic connective tissue with a dense network of capillaries and lymphatic vessels.

5. BREATHING PROCESSES

Air can be moved in and out of the lungs by a process called ventilation. This consists of a respiratory cycle with repeated inhalations (inspirations) and exhalations (expirations), separated by a rest period.

RESPIRATORY RATES AND VOLUMES, INTERNAL AND EXTERNAL RESPIRATION

1. RESPIRATORY VOLUMES AND CAPACITIES

Tidal volume (V_T) is the amount of air that enters the lungs during inhalation or exits the lungs during exhalation during a single respiratory cycle, at rest. The tidal volume is about 500ml in both male and female adults (Figure 28.1).

Inspiratory reserve volume (IRV) is the extra amount of air that can be taken into the lungs over and above the tidal volume after the deepest possible inhalation. Since the lungs of the male adults are larger than those of female adults, the inspiratory reserve volume of males is about 3,300ml whereas those of females is about 1,900ml (Figure 28.1).

Expiratory reserve volume (ERV) is the extra amount of air that can be expelled from the lungs after a normal respiratory cycle with maximum expiratory movement. The expiratory reserve volume is approximately 1,000ml (Figure 28.1).

Residual volume (RV) is the amount of air that remains in the lungs after maximum exhalation. The residual volume is about 1,200ml in males and 1,100ml in females (Figure 28.1).

Inspiratory capacity (IC) is the total amount of air that can enter the lungs after the completion of a normal inhalation followed by the deepest possible inhalation. It is the sum of the tidal volume and the inspiratory reserve volume (Figure 28.1).

Functional residual capacity (FRC) is the total amount of air that remains in the lungs after the completion of a normal respiratory cycle. It is the sum of the expiratory reserve volume and the residual volume (Figure 28.1).

Vital capacity (VC) is the maximum amount of air that can enter the lungs or be expelled from the lungs in a single respiratory cycle. The vital capacity is the sum of the inspiratory reserve volume, the tidal volume, and the expiratory reserve volume. The vital capacity is around 4,800ml in males and 3,400ml in females (Figure 28.1).

Total lung capacity (TLC) is the total amount of air in the lungs and equals the sum of vital capacity and the residual volume. The total lung capacity is approximately 6,000ml in males and 4,500ml in females (Figure 28.1).

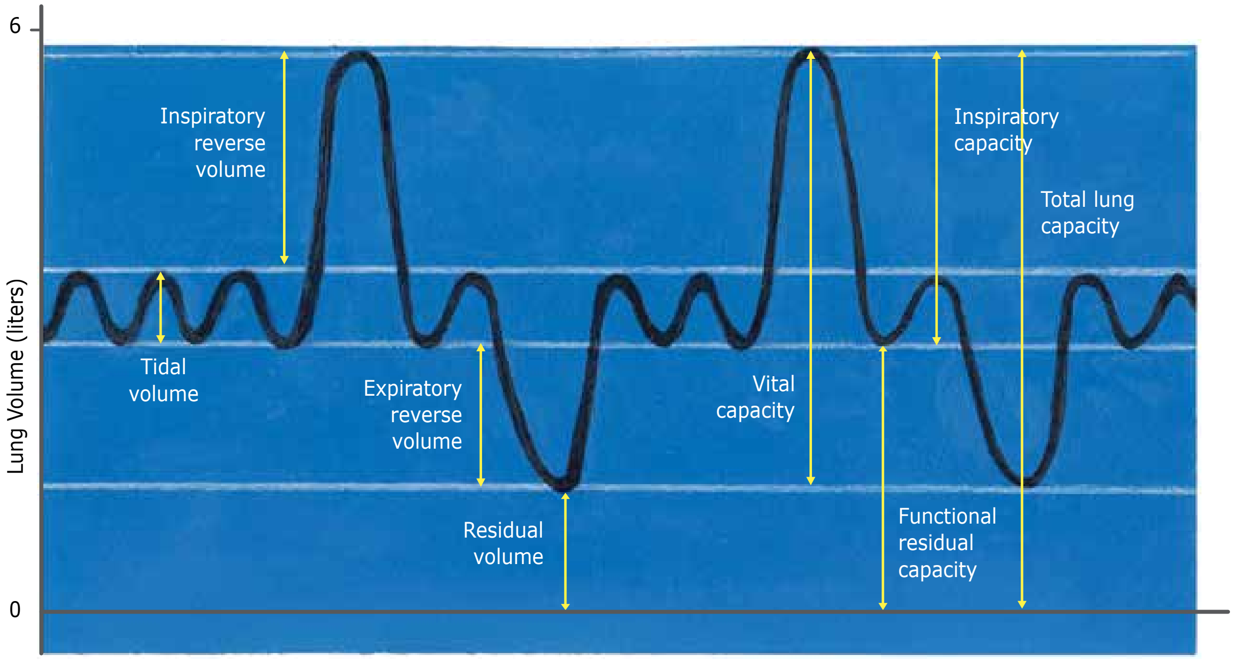

FIGURE 28.1: *Lung volumes and capacities.*

2. ANATOMIC DEAD SPACE

Anatomic dead space is the volume of air that remains in the conducting zone during each respiratory cycle. It amounts to about 150ml.

The functions of the anatomical dead space are a) to preheat the inhaled air so that it does not reach the alveoli at low temperature, b) to impart moisture into the inhaled air in order to avoid water evaporation from the surface of the alveoli and thus can be saturated with water vapor, c) to relieve the inhaled air from dust, germs etc because they adhere to the mucus layer, and due to the cilliary movement of the epithelium are moved upwards to be expelled by expectoration or are passed down to the gastrointestinal tract by swallowing, and d) to serve as a speaker in the production and modulation of voice during speaking and singing.

3. RESPIRATORY RATE

Respiratory rate is the number of breaths that an individual can take each minute. In normal male adults, at rest, the respiratory rate ranges from 14 to 18 breaths each minute, whilst in females the respiratory rate is a little higher. In the case of elevated respiratory needs, it can reach up to 60 breaths per minute.

4. RESPIRATORY MINUTE VOLUME

Respiratory minute volume is the amount of inhaled or exhaled air in one minute. It is calculated by multiplying the tidal volume by the respiratory rate. The respiratory minute volume is calculated by using the following formula:

$$V_E = f \times V_T$$

Where V_E is the respiratory rate, f is breaths per minute, and V_T is the tidal volume. At rest, the respiratory minute volume is approximately 6 liters per minute.

5. ALVEOLAR VENTILATION (V_A)

Alveolar ventilation is the amount of air that reaches the alveoli each minute. The amount of air reaching the alveoli is lower than the respiratory minute volume, because some of the air never reaches the alveoli, but remains in the conducting zone as the anatomic dead volume of the lungs. The anatomic dead space volume of the conducting zone is about 150ml. Therefore, the alveolar ventilation is calculated by using the following formula:

$$V_A = f \times (V_T - V_D)$$

Where V_A is the alveolar ventilation, f is breaths per minute, V_T is the tidal volume, and V_D is the anatomic dead space. At rest, the alveolar ventilation is approximately 4.2 liters per minute.

6. EXTERNAL AND INTERNAL RESPIRATION

External respiration is the exchange of gases between the respiratory bronchioles, alveolar ducts, alveolar sacs and alveoli and the pulmonary circulation. Here, the gas exchange is the diffusion of oxygen from the alveoli into the pulmonary capillaries and the diffusion of carbon dioxide in the opposite direction.

This diffusion of oxygen and carbon dioxide between the alveoli and blood occurs across the respiratory membrane. This membrane is composed of a single layer of type I alveolar cells that make up the walls of the alveoli, the alveolar and capillary basement membranes and a single layer of endothelial cells that constitute the capillary wall.

Internal respiration or cellular respiration is the exchange of gases between the blood circulation and the tissue cells. During internal respiration, oxygen is released by the blood to the cell tissues and carbon dioxide is absorbed by the blood. Once inside the cells, the oxygen is used for producing energy in the form of ATP.

7. SURFACTANT

The internal surface of the alveoli is coated by a substance called surfactant, an oily secretion containing a mixture of proteins and phospholipids whose presence reduces surface tension and thus the alveoli are kept open. If the liquid layer consisted of only water and electrolytes it would show such a great surface tension that it would make the alveoli collapse. The surfactant is secreted by large septal cells or type II cells.

EXERCISES

Exercise 1: Match the following terms in Column A with the contextual meanings in Column B:

Column A	Column B
Tidal volume	Total amount of air that enters and exits the lungs in one minute
Total lung capacity	The part of the lungs where gas exchange cannot take place
Residual volume	It is composed of an inspiration and an expiration
Respiratory rate	Amount of air that can be inspired additional to normal inspiration
Expiratory reserve volume	Amount of inspired air in a single normal breath
Anatomical dead space	Breaths per minute
Functional residual capacity	Amount of air that ventilates the alveoli in one minute
Alveolar minute volume	Vital capacity plus residual volume
Inspiratory reverse volume	Amount of expelled air after the end of normal expiration
Respiratory cycle	Amount of air that remains in the lung after normal expiration
Respiratory minute volume	Amount of air in the lungs after maximal expiration

Exercise 2: Fill in the following gaps so that the sentences are complete.

1) The amount of air moved in or out of the lungs in a normal breath is the ....
2) The diffusion of oxygen from the alveoli into the pulmonary capillaries is known as ....
3) The amount of air that reaches the alveoli in one minute is called ....
4) The amount of air that remains in the lungs after maximal exhalation is the ....
5) The diffusion of oxygen and carbon dioxide between the alveoli and blood occurs across the ....
6) The amount of air that remains in the conducting zone during each respiratory cycle is the ....
7) The exchange of gases between the blood and the tissues is called ....
8) The amount of inhaled or exhaled air in one minute is called ....
9) The number of respiratory cycles that an individual can complete at rest is called ....
10) The presence of a substance called .... keeps the alveoli open by reducing the .... of the alveolar fluid.

Exercise 3: Identify the lung volumes and capacities represented in the following figure: