Chapter 15

Body Fluid and Circulation

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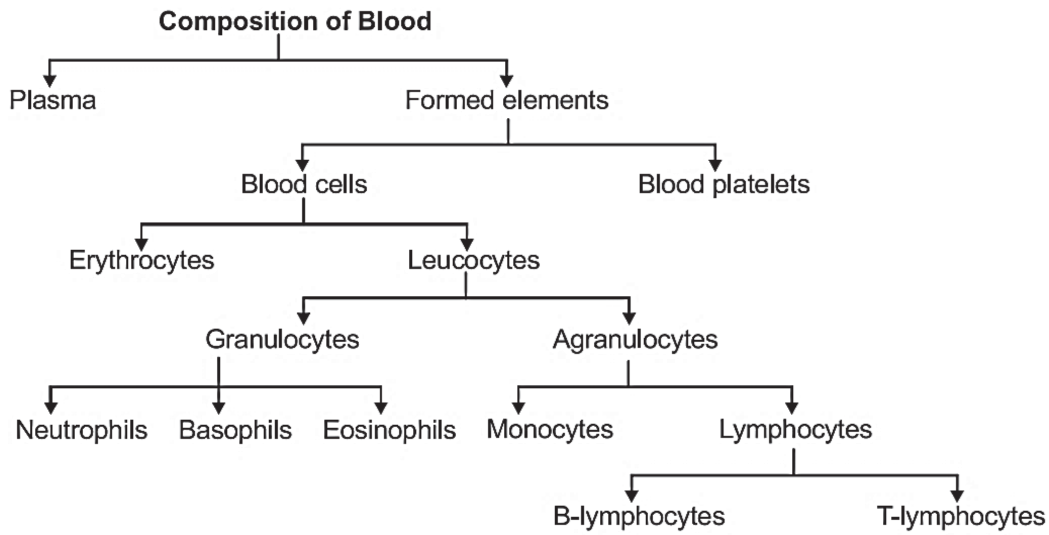
INTRODUCTION

In sustaining life, a continuous supply of nutrients, oxygen (O_2), and other vital substances is indispensable for all living cells. Simultaneously, the removal of waste or harmful substances must occur continuously to ensure the optimal functioning of tissues. Efficient mechanisms for the movement of these substances to and from cells are, therefore, essential.

Simple organisms, such as sponges and coelenterates, achieve this through the circulation of water present in their surroundings through body cavities. This facilitates the exchange of substances at the cellular level. In contrast, more complex organisms have specialized fluids within their bodies for the transportation of materials. In the case of higher organisms, including humans, blood emerges as the predominant body fluid for these purposes. Additionally, lymph, a related body fluid, contributes to the transport of specific substances. This chapter delves into the exploration of the composition, properties, and mechanisms of blood and lymph (tissue fluid), shedding light on the intricate process of blood circulation.

BLOOD

Blood, an intricately specialized connective tissue, comprises two main components: plasma, a fluid matrix, and formed elements, a cellular portion. Plasma constitutes roughly 55% of blood volume, while the formed elements make up the remaining 45%.



Plasma

Plasma, a straw-colored and viscous fluid, serves as the fundamental matrix of blood. In tissues, the matrix is the non-living substance occupying the intercellular space.

Composition of Plasma

- **Water:** Constituting 90-92% of plasma, water serves as the primary solvent for various solutes.
- **Proteins:** Approximately 6-8% of plasma consists of proteins, playing crucial roles in various physiological processes.
  Fibrinogen: Synthesized by the liver, fibrinogen is a key factor in blood clotting, essential for hemostasis.
  Globulins: These proteins contribute significantly to the body's defense mechanisms. Categorized into three subtypes—alpha, beta, and gamma—globulins, particularly gamma globulins, function as antibodies vital for immune response. Alpha and beta globulins facilitate the transport of lipids and fat-soluble vitamins.
  Albumins: Essential for maintaining osmotic balance, albumins help regulate osmotic pressure. This mechanism draws water from surrounding tissue fluid into capillaries, crucial for maintaining blood volume and pressure.
- **Minerals:** Plasma contains trace amounts of minerals such as sodium (Na^+), calcium (Ca^{++}), magnesium (Mg^{++}), bicarbonate ions (HCO_3^-), and chloride ions (Cl^-), contributing to various metabolic processes.
- **Nutrients:** Glucose, amino acids, lipids, and other essential nutrients are transient passengers in the plasma, constantly shuttling from one location to another within the body. These substances undergo continuous exchange with tissues, entering and leaving the plasma at regular intervals.
  Plasma lacking clotting proteins is referred to as serum, representing the fluid component of blood devoid of fibrinogen and other coagulation factors.

Formed Elements

The formed elements constitute the cellular portion of blood and encompass erythrocytes (red blood cells), leucocytes (white blood cells), and thrombocytes (platelets).

- **Erythrocytes (Red Blood Corpuscles or RBCs):** Red blood cells, also known as erythrocytes, represent the most prevalent cell type within the bloodstream.
  Number: Erythrocytes stand as the most plentiful cell type in blood, with a healthy adult man typically possessing 5 million to 5.5 million RBCs per cubic millimeter of blood.
  Shape and Structure: In most mammals, RBCs adopt a biconcave shape and lack a nucleus. Exceptions include camels and llamas, where RBCs are oval despite lacking a nucleus. The distinctive biconcave shape is intricately tied to their primary function of oxygen transport. The absence of a nucleus and other organelles maximizes space for the oxygen-binding pigment, hemoglobin. Due to the lack of mitochondria, RBCs undergo anaerobic respiration and do not consume the oxygen they carry. These cells also harbor the enzyme carbonic anhydrase, pivotal in the transport of carbon dioxide.
  Quantity of Hemoglobin in RBCs: A healthy individual possesses 12-16 grams of hemoglobin per 100 milliliters of blood. Iron is an integral component of hemoglobin.
  Formation: The generation of RBCs, termed erythropoiesis, primarily occurs in the red bone marrow in adults, while embryonically, it initiates in the yolk sac. The life span of RBCs spans around four months.

Functions

- **Respiratory Gas Transport:** Hemoglobin within erythrocytes plays a pivotal role in transporting respiratory gases. Hemoglobin readily associates with oxygen, forming oxyhemoglobin. In tissues, oxyhemoglobin efficiently releases oxygen for the breakdown or oxidation of food.
- **Carbon Dioxide Transport:** RBCs also facilitate the transportation of carbon dioxide from tissues to the lungs. Carbon dioxide is carried by hemoglobin as Carbamino-hemoglobin.
  Haemopoiesis: This term refers to the overall process of blood formation, marking a dynamic and essential aspect of the blood's composition and functionality.

- **Leukocytes (White blood cells or WBCs):** Leukocytes, also known as white blood cells or white blood corpuscles, lack the pigment hemoglobin, rendering them colorless.
  Number: White blood cells are significantly fewer in number compared to erythrocytes, with an average count ranging from 6000 to 8000 cells per cubic millimeter of blood.
  Shape and structure: Unlike erythrocytes, leukocytes possess nuclei and other cellular organelles. They exhibit amoeboid movement, enabling them to traverse capillary walls and migrate to sites of infection, a process known as diapedesis.

Types:

- **Granulocytes:** Leukocytes are classified based on their staining properties. Those containing granules in their cytoplasm are termed granular leukocytes or granulocytes.
- **Agranulocytes:** These lack cytoplasmic granules and include lymphocytes and monocytes.
  Lymphocytes: Comprising 20-25 percent of the total WBC count, lymphocytes are small cells with round nuclei and minimal cytoplasm. They play crucial roles in immune responses, existing in B and T-lymphocyte forms.
  Monocytes: Monocytes, the largest leukocytes, possess kidney or horse-shoe shaped nuclei. They transform into macrophages upon entering tissues, acting as phagocytic cells that engulf bacteria and cellular debris.
- **Granulocytes:** Granulocytes consist of three types:
  Eosinophils: Eosinophils, comprising 2-3 percent of WBCs, feature bilobed nuclei and coarse granules containing hydrolytic enzymes and peroxidases. They participate in allergic reactions, resist infections, and have antihistaminic properties.

Basophils: Basophils, the least abundant WBCs (0.5-1 percent), possess generally three-lobed nuclei. They secrete serotonin, heparin, and histamine, contributing to inflammation.
Neutrophils or polymorph nuclear leukocytes (PMNL): Neutrophils, the most abundant WBCs (60-65 percent), are phagocytic cells that migrate to infected areas and ingest bacteria.

Formation: Leukocyte production, termed leucopoiesis, occurs in the bone marrow. B-lymphocytes mature in the bone marrow, while T-lymphocytes mature in the thymus.
Life span: Granulocytes have a short lifespan of 4 to 8 hours in circulation and 4 to 5 days in tissues. Monocytes survive for 10-20 hours, while lymphocytes persist for days, months, or even years.
Leukocytosis: An elevation in WBC count, known as leukocytosis, typically occurs at sites of infection.

- **Thrombocytes (Blood platelets):** Thrombocytes, commonly known as blood platelets, are the smallest components among the formed elements.
  Number: Blood typically contains between 150,000 to 350,000 platelets per cubic millimeter.
  Shape and structure: Thrombocytes appear as rounded or oval disc-like structures and are considered cell fragments rather than complete cells. They lack nuclei but contain a few organelles and secretory granules.
  Formation: Derived from specialized cells in the bone marrow known as megakaryocytes, thrombocytes are produced through a process called thrombopoiesis.
  Life span: Blood platelets have a normal life span of approximately one week before they are removed from circulation, primarily in the spleen and liver.
  Function: Thrombocytes play a crucial role in blood clotting (coagulation). They release various substances involved in coagulation, contributing to the formation of blood clots. Platelets are integral to clot formation, as they aggregate at the site of injury and release factors that activate plasma clotting proteins, leading to the formation of fibrin threads that stabilize the clot.
  A decrease in platelet count, known as thrombocytopenia, can result in excessive bleeding due to impaired clot formation. Purpura, a group of bleeding disorders, can arise from thrombocytopenia.

Blood Groups

In the human body, certain molecules on cell surfaces can be recognized as foreign by another individual's immune system, inducing an immune response. These molecules, known as antigens, lead to the production of antibodies that specifically bind to them. Red blood cells (RBCs) also possess various antigens on their membranes, and blood grouping is determined by the nature of these antigens. Two widely used blood groupings are ABO and Rh.

- **ABO Grouping:** Karl Landsteiner and his colleagues recognized the ABO blood grouping in 1901, based on the presence or absence of two surface antigens on RBCs – A and B. The plasma of different individuals also contains natural antibodies, anti-A and anti-B.
- According to Landsteiner's law, if an antigen is present on RBCs, the corresponding antibody must be absent from the plasma and vice versa. Persons with different blood groups produce antibodies against the absent antigens. For instance, those with 'A' group produce anti-B antibodies, and 'B' group individuals produce anti-A antibodies.
- **Transfusion Reactions:** Blood transfusions require compatibility to prevent clumping or destruction of RBCs. A major cross-match is performed by mixing recipient serum with donor blood cells. If blood groups do not match, clumping (agglutination) occurs, leading to potential complications. The compatibility chart shows that 'O' group individuals can donate to any blood group, making them universal donors, while 'AB' group individuals can receive blood from any group, making them universal recipients.

Blood group	Antigens on RBCs	Antibodies in plasma	Donor's group
A	A	Anti-B	A, O
B	B	Anti-A	B, O
AB	A, B	nil	AB, A, B, O
O	nil	AB	O

- **Rh Grouping:** Another set of antigens, the Rh factor, is found on most people RBCs. Rh+ve individuals have these antigens, while Rh-ve individuals lack them. Rh-ve individuals exposed to Rh+ve blood develop specific antibodies against Rh antigens. This matching is crucial to avoid complications during transfusions.
- **Rh Incompatibility:** Rh-ve pregnant mothers can develop antibodies against Rh antigens if exposed to Rh+ve blood during childbirth. This can lead to hemolysis of Rh+ve RBCs in subsequent pregnancies, causing complications like hemolytic disease of the newborn (HDN) or erythroblastosis fetalis. To prevent this, Rh-ve mothers are injected with anti-Rh antibodies after the birth of each Rh+ve baby.
  Understanding and matching blood groups is vital to ensure the safety and effectiveness of blood transfusions, preventing potentially harmful reactions.

Coagulation of Blood

When you sustain a cut or injury, the body's response to prevent excessive blood loss is through coagulation or clotting. This mechanism quickly stops bleeding by forming a clot at the wound site. You might notice a dark reddish-brown scab forming over time, which is primarily a network of fibrin threads trapping dead and damaged blood elements.

Mechanism of Blood Coagulation

- **Platelet Activation:** An injury triggers platelets to release thromboplastins, substances that promote coagulation. Additionally, tissues at the injury site release tissue thromboplastins.
- **Thromboplastin Activity:** Thromboplastins facilitate the formation of thrombokinase, an enzyme complex. This process involves a cascade of enzymatic reactions, activating various plasma clotting factors.
- **Prothrombin Activation:** Thrombokinase converts an inactive plasma protein, prothrombin, into thrombin, an enzyme critical for clot formation.

$$\text{Prothrombin} \xrightarrow[Ca^{2+}]{\text{Thrombokinase}} \text{Thrombin}$$

- **Fibrin Formation:** Thrombin acts on soluble fibrinogen in plasma, converting it into insoluble fibrin. Calcium ions are necessary for both thrombin activation and function.

$$\text{Fibrinogen} \xrightarrow[Ca^{2+}]{\text{Thrombin}} \text{Fibrin}$$

- **Clot Formation:** Fibrin molecules form a mesh-like network of threads, entrapping blood elements and sealing the wound, preventing further bleeding.
  Blood coagulation is a crucial mechanism that ensures rapid wound closure and prevents excessive blood loss, promoting the body's healing process.