Unit III – Body Fluids, Blood, and Lymphatic System

Understanding Body Fluids and Blood: A Comprehensive Guide

Part 1: The Blood - Life's Essential River

Chapter 1: Introduction to Blood

- **What is Blood?** Blood is a unique **fluid connective tissue**, which originates from the mesoderm. It is a vital body fluid in humans and other animals, performing crucial roles. The scientific field dedicated to studying blood, blood-forming tissues, and related disorders is known as **haematology**. Blood's primary function is to **deliver necessary substances** such as nutrients and oxygen to the body's cells, and simultaneously to **transport metabolic waste products** away from these cells.

- **Key Properties of Blood**

    - **Colour**: Blood is naturally red. When oxygen-rich, as in arterial blood, it appears **scarlet red**. In contrast, venous blood, which contains more carbon dioxide, has a **purple red** hue.
    - **Reaction & pH**: Blood maintains a **slightly alkaline** state. Under normal conditions, its pH is **7.4**.
    - **Volume**: The average human adult has approximately **5 litres** of blood. In a newborn baby, the volume is around **450 ml**. Adult females generally have a slightly lower volume, roughly **4.5 litres**.

Chapter 2: The Components of Blood

Blood is composed of two main parts: plasma and formed elements.

- **Plasma** Plasma constitutes about 55% of blood volume. It is predominantly **water (90%)** and contains various essential components, including proteins (albumin, globulin, and fibrinogen), sodium chloride, iron, urea, uric acid, and cholesterol. **Serum** is a derivative of plasma, obtained by removing fibrinogen.

    - **Plasma Proteins**: These proteins make up 7-8% of the blood and play diverse roles:

        - **Albumin**: Present in very high concentrations, albumin is responsible for maintaining the **osmotic pressure of blood**. It is synthesized in the liver.
        - **Globulin**: There are three types: Alpha, Beta, and Gamma. Globulins are produced in **lymphoid tissues** and are responsible for producing **antibodies** and other immune substances.
        - **Fibrinogen**: This protein is crucial for the **coagulation of blood** and is also synthesized in the liver.
- **Formed Elements (Overview)** The formed elements make up about 45% of the blood and include red blood cells, white blood cells, and platelets.

Chapter 3: Red Blood Cells (Erythrocytes)

Red blood cells (RBCs) are the most abundant type of blood cell and are vital for oxygen transport.

- **Characteristics and Functions**
    - RBCs are **non-nucleated** formed elements, also known as **erythrocytes**.
    - Their characteristic red colour comes from the pigment **haemoglobin**.
    - The RBC count typically ranges between **4 and 5.5 million per cubic millimeter of blood**. Specifically, adult males usually have 5 million/cu mm, while adult females have 4.5 million/cu mm.
    - The average lifespan of an RBC is about **120 days**. After this period, old or senile RBCs are destroyed in the **reticuloendothelial system**, with the **spleen** often referred to as the "Graveyard of RBCs".
    - **Major Function**: The primary role of RBCs is the **transport of respiratory gases**:
        - **Transport of Oxygen**: Haemoglobin in RBCs combines with oxygen to form **oxyhaemoglobin**. Approximately **97% of oxygen** is transported in the blood in this form from the lungs to the tissues.
        - **Transport of Carbon Dioxide**: Haemoglobin also combines with carbon dioxide to form **carboxyhaemoglobin**. About **30% of carbon dioxide** is transported in this manner from the tissues to the lungs.
- **Important Terminology Related to Red Blood Cells**

- **Hypoxia**: A condition where the body or a region of the body is **deprived of adequate oxygen supply** at the tissue level, often due to partial or incomplete blood flow.
- **Rouleaux formation**: The tendency of RBCs to **stick to one another** in stacks, resembling a pile of coins, due to their discoid shape.
- **Polycythemia**: A condition characterised by an **increase in the number of RBCs**.
- **Anaemia**: A condition defined by a **decrease in the number of RBCs or haemoglobin**.

- **Erythrocyte Sedimentation Rate (ESR)** The ESR is a common **haematology test** that measures the rate at which red blood cells descend in anticoagulated whole blood within a standardized tube over one hour. It essentially measures how quickly RBCs sink to the bottom when an anticoagulant is added.

  - **Normal values of ESR**:
    - Newborn child: **0.5 mm/hour**
    - Adult male: **3 to 57 mm/hour**
    - Adult female: **4 to 7 mm/hour**
    - Pregnant women: **35-45 mm/hour**

Chapter 4: White Blood Cells (Leukocytes)

White blood cells (WBCs), also known as **leukocytes**, are crucial components of the immune system.

- **Characteristics and Functions**

1. WBCs are **colourless** and generally **much larger than red blood cells**.
2. One cubic millimeter of blood typically contains **7000 to 8000 WBCs**.
3. They are formed in the bone marrow.
4. Their lifespan can vary significantly, from months to even years, depending on the body's needs.
5. **Functions**: WBCs are the body's defence mechanism, involved in **protecting the body against infectious diseases and foreign invaders**. Their functions include:
   - **Scavenging**
   - **Pus formation**
   - **Phagocytosis** (engulfing foreign particles)

        - **Inflammation**
        - **Antibodies formation**
- **Types of White Blood Cells** WBCs are broadly divided into two categories based on the presence or absence of granules in their cytoplasm:

    1. **Granulocytes**: These cells have cytoplasm containing organelles that appear as coloured granules under a light microscope. They include:
        - **Neutrophils**: Possess very fine cytoplasmic granules and are also called polymorphonuclear (MN) due to their varied nuclear shapes. They play a key role in the **destruction or inhibition of bacterial growth** by releasing chemicals.
        - **Eosinophils**: Characterised by large granules and a prominent bilobed nucleus. They function in the **destruction of allergens and inflammatory chemicals**, and release enzymes that **disable parasites**.
        - **Basophils**: Have a pale nucleus often hidden by granules. They secrete **histamine**, which causes **dilation of blood vessels**, and **heparin**, an anticoagulant that promotes the mobility of other WBCs by preventing clotting.
    2. **Agranulocytes**: These cells do not contain granules. They consist of:
        - **Lymphocytes**: Possess a pale nucleus, often obscured by granules. They are classified as small, medium, or large. Medium and large lymphocytes are mainly found in fibrous connective tissue and only occasionally in the bloodstream. Lymphocytes are crucial for immunity, **destroying cancer cells, virus-infected cells, and foreign invading cells**.
        - **Monocytes**: These are the **largest of the formed elements** with abundant and clear cytoplasm. They function by **activating other immune cells** and differentiate into **macrophages**. Macrophages are **large phagocytic cells** that digest pathogens, dead neutrophils, and cellular debris. Like lymphocytes, monocytes also present antigens.

Chapter 5: Platelets (Thrombocytes)

- **Their Role in Blood Clotting** Platelets, also known as **thrombocytes**, are formed in the bone marrow, a sponge-like tissue found in your bones. They play a **major role in blood clotting**.

Part 2: The Formation and Regulation of Blood

Chapter 6: Haematopoiesis - The Birth of Blood Cells

- **Process and Locations** The process of forming blood cellular components—RBCs, WBCs, and platelets—is called **haematopoiesis**. All cellular blood components are derived from **haematopoietic stem cells**. In a healthy adult, approximately 10^11 to 10^12 new blood cells are produced daily to maintain stable levels in peripheral circulation. The sites where blood formation occurs are known as **haematopoietic tissues or organs**, including the **bone marrow, liver, and spleen**.

    - **Location in Developing Embryos**: Blood formation occurs in aggregates of blood cells in the yolk sac, known as **blood islands**.
    - **Location in Children**: Haematopoiesis takes place in the marrow of **long bones**, such as the femur and tibia.
    - **Location in Adults**: It occurs mainly in the **pelvis, cranium, vertebrae, and sternum**.
- **Erythropoiesis - Red Blood Cell Formation Erythropoiesis** is the specific process by which red blood cells are formed. It is stimulated by a **decreased oxygen level in the blood**, which triggers the secretion of **erythropoietin**. Erythropoietin is a hormone central to the formation of red blood cells.

    - **Stages of RBC Development**:
        - **Proerythroblast**: The earliest stage in RBC maturation. This unipotential cell has a large, prominent nucleus and **does not have haemoglobin**.
        - **Normoblast**: The second stage, where the cell is smaller, has a degenerated nucleus, and **haemoglobin is fully present**.
        - **Reticulocyte**: In this stage, the red blood cell has **no nucleus but haemoglobin is present**.
        - **Erythrocyte**: The fully developed RBC, which **has no nucleus and no reticulum**.
    - **Note**: **Vitamin B12 and folic acid** are both essential for the development of RBCs.

Chapter 7: Haemoglobin - The Oxygen Carrier

- **Composition and Synthesis** Haemoglobin is a **complex protein** composed of globin and an **iron-containing haem** molecule. It is synthesized inside developing erythrocytes in the red bone marrow. In mature erythrocytes, haemoglobin combines with oxygen to form

oxyhaemoglobin, which gives blood its characteristic **red colour**. Haemoglobin is also involved in the transport of carbon dioxide from body cells to the lungs for excretion. Each haemoglobin molecule contains **four atoms of iron**, and each iron atom can carry one molecule of oxygen, meaning one haemoglobin molecule can carry up to **four molecules of oxygen**.

- **Synthesis Pathway**:
    1. Succinyl-CoA, formed in the Krebs metabolic cycle, binds with glycine to form a pyrrole molecule.
    2. Four pyrroles combine to form protoporphyrin IX.
    3. Protoporphyrin IX then combines with iron to form a heme molecule.
    4. Each heme molecule combines with a long polypeptide chain (globin, synthesized by ribosomes) to form a sub-unit of haemoglobin called a **haemoglobin chain**.
    5. Each chain has a molecular weight of about 16000.
    6. Four of these chains loosely bind together to form the complete haemoglobin molecule.

Part 3: Blood Disorders and Their Mechanisms

Chapter 8: Anaemia - When Oxygen Carrying Capacity is Reduced

- **Understanding Anaemia** Anaemia is a condition where the **oxygen-carrying capacity of the blood is reduced** below the normal quantity of haemoglobin.

    - **Symptoms**: This condition often leads to a pallid complexion, loss of vigour, and lack of energy. Other symptoms include **weakness, tiredness, pale skin, gums and nail beds, fast heartbeat, shortness of breath, fainting, fatigue, and chest pain**.
- **Types of Anaemia** Anaemia can arise from impaired red blood cell production or increased RBC loss.

    - **Impaired RBC Production**:
        - **Iron Deficiency Anaemia**: Caused by inadequate absorption, excessive loss, increased requirement, or insufficient intake of iron. Women are at higher risk due to menstrual blood loss and increased iron demands during pregnancy. It results in the body not making enough red blood cells. Bleeding also causes

faster loss of RBCs than they can be replaced. Infestation by worms (hookworms, whipworms, roundworms) and malaria can also lead to iron-deficiency anaemia. Chronic gastrointestinal bleeding from non-parasitic causes like gastric ulcers, duodenal ulcers, or gastrointestinal cancer is the most common cause.

- **Megaloblastic Anaemia**: Results from insufficient intake of **vitamin B12 or folic acid**, leading to the bone marrow producing large, abnormal red blood cells called megaloblasts. It can also be caused by drugs affecting gastric secretion or used in cancer treatment.
- **Pernicious Anaemia**: Occurs due to insufficient haemopoiesis, resulting from the stomach's inability to produce **intrinsic factor**, which is essential for vitamin B12 absorption in the small intestine (ileum). This can be due to the loss of gastric parietal cells, which secrete intrinsic factor.
- **Aplastic Anaemia**: Caused by the **destruction of red bone marrow**. It can be triggered by toxins, gamma radiation, and certain medications that inhibit enzymes needed for haemopoiesis.

- **Increased RBC Loss**:
  - **Haemorrhagic Anaemia**: Caused by excessive loss of RBCs from large wounds, stomach ulcers, and heavy menstruation.
  - **Haemolytic Anaemia**: A form of anaemia due to **haemolysis**, the abnormal breakdown of red blood cells, either within blood vessels (intravascular haemolysis) or elsewhere in the body (extravascular haemolysis). It can also be caused by parasites, toxins, and antibodies from incompatible blood.
  - **Sickle Cell Anaemia (SCA)**: A serious disorder where the body produces **sickle-shaped red blood cells**. Normal red blood cells are disc-shaped and move easily through blood vessels, containing an iron-rich protein called haemoglobin. Sickle cells contain abnormal haemoglobin (sickle haemoglobin), which causes them to develop a sickle or crescent shape. These sickle cells are stiff and sticky, tending to **block blood flow** in the blood vessels of the limbs and organs, particularly at low oxygen concentrations in capillaries. This distortion leads to the bursting of RBCs in capillaries, resulting in anaemic conditions. This disorder is due to a genetic mutation involving the substitution of a wrong amino acid in a specific portion of the globin protein.

Chapter 9: Blood Groups and Transfusion

- **Discovery and Importance** Blood groups were discovered by the Austrian scientist **Karl Landsteiner in 1901**, a discovery for which he was awarded the Nobel Prize in 1930. Blood group is **determined by the genes** inherited from your parents. There are two most important blood group systems for blood transfusions. Each group can be **Rh positive or Rh negative**, leading to eight main blood groups in total.

- **Antibodies and Antigens** Blood is comprised of red blood cells, white blood cells, and platelets suspended in plasma. Blood groups are identified by **antibodies and antigens** in the blood.

    - **Antibodies**: Proteins found in plasma, part of the body's **natural defences**. They recognise foreign substances like germs and alert the immune system to destroy them.
    - **Antigens**: Protein molecules found on the **surface of red blood cells**.
- **Importance of Blood Grouping** Blood grouping is vital for:

    - **Blood transfusion**.
    - Preventing **haemolytic disease** (Rh incompatibility between mother and foetus).
    - **Paternity disputes** (to determine fatherhood).
    - **Medicolegal cases**.
    - Knowing **susceptibility to disease** (e.g., Group O: Duodenal cancer; Group A: Carcinoma of stomach, pancreas & salivary glands).
- **ABO Blood Group System** Based on the presence or absence of antigen A and antigen B, blood is divided into four groups:

    - **Blood group A**: Has A antigens on red blood cells and anti-B antibodies in the plasma. Can donate to A, AB and receive from A, O.
    - **Blood group B**: Has B antigens on red blood cells and anti-A antibodies in the plasma. Can donate to B, AB and receive from B, O.
    - **Blood group O**: Has **no antigens** on red blood cells, but both **anti-A and anti-B antibodies** in the plasma. Can donate to A, B, AB, O and receive from O.
    - **Blood group AB**: Has both **A and B antigens** on red blood cells, but **no antibodies** in the plasma. Can donate to AB and receive from A, B, AB, O.

- **Rh Factor** The Rh factor is an **antigen present in red blood cells**. It was discovered by Landsteiner and Wiener in the Rhesus monkey, hence the name 'Rh factor'.

    - Individuals with the D antigen are called **'Rh positive'**, while those without it are **'Rh negative'**.
    - In patient blood typing, the Rh group is indicated by adding "positive" or "negative" to the ABO type.
    - **Rh-positive blood is compatible with both positive and negative Rh factors**.

Chapter 10: Blood Coagulation - Stopping the Bleed

- **The Process of Clotting (Hemostasis)** Blood clotting, or **coagulation**, is the process by which blood transforms from a liquid to a gel, forming a blood clot. This process potentially results in **hemostasis**, the cessation of blood loss from a damaged vessel, followed by repair. Substances necessary for clotting are normally present in blood in an **inactive form** called **procoagulants**, which are activated during injury, leading to clot formation.

- **Mechanism of Blood Clotting** The mechanism of blood clotting involves three main steps:

    1. **Vasoconstriction (Activation)**: The smooth muscles in blood vessel walls immediately contract when the vessel is broken. This response temporarily reduces blood loss while other haemostatic mechanisms become active.
    2. **Platelet Plug Formation (Aggregation & Adhesion)**: When blood platelets encounter a damaged blood vessel, they form a "platelet plug" to help close the gap. Key stages include platelet adhesion, platelet release reaction, and platelet aggregation.
    3. **Coagulation of Blood**: This is the process where blood loses its fluidity and becomes a jelly-like mass, forming a clot.
- **Stages of Blood Clotting**

    1. **Stage 1: Formation of Prothrombin Activator** Blood clotting begins with the formation of a substance called **prothrombin activator**, which converts prothrombin into thrombin. Its formation is initiated by substances produced either within or outside the blood, occurring via two pathways:

- **Intrinsic pathway**: Initiated by liquid blood making contact with a foreign surface, or something not part of the body.
- **Extrinsic pathway**: Initiated by liquid blood making contact with damaged tissue. Both intrinsic and extrinsic systems involve interactions between various **coagulation factors**.
- **Coagulation Factors (Examples)**:
    - Factor I: Fibrinogen (converted to fibrin)
    - Factor II: Prothrombin (converted to thrombin)
    - Factor III: Tissue thromboplastin (essential for *in vivo* coagulation)
    - Factor IV: Ca++ ions (required for factors to bind phospholipid)
    - Factor V: Labile factor (co-factor involved in converting prothrombin to thrombin)
    - Factor VIII: Anti-hemophilic factor (co-factor in activating Factor X)
    - Factor IX: Plasma thromboplastin component (PTC) (involved in activating Factor X)
    - Factor X: Stuart power factor (involved in converting prothrombin to thrombin)
    - Factor XI: Plasma thromboplastin antecedent (PTA) (*in vivo* activated by thrombin and factor XII)
    - Factor XII: Hageman factors (activates XI and VII)
    - Factor XIII: Fibrin stabilizing factor (converts fibrin polymer to stable insoluble fibrin)

2. **Stage 2: Conversion of Prothrombin into Thrombin** Once thrombin is formed, it definitively leads to clot formation. **Prothrombinase** (formed in Stage 1) converts prothrombin, which is a plasma protein formed in the liver, into the enzyme **thrombin**.

    - **Positive Feedback Effect of Thrombin**: The prothrombin activator (formed in the intrinsic and extrinsic pathways) converts prothrombin into thrombin in the presence of calcium (Factor IV). Once formed, thrombin initiates the formation of more thrombin molecules. The initially formed thrombin activates Factor V, which in turn accelerates the formation of both intrinsic and extrinsic prothrombin activator, further converting prothrombin into thrombin. This accelerating effect of thrombin is known as a **positive feedback effect**.

3. **Stage 3: Conversion of Fibrinogen (Soluble) into Fibrin (Insoluble)** The final stage of blood clotting involves the conversion of **fibrinogen into fibrin by thrombin**. Thrombin converts inactive fibrinogen into activated fibrinogen, also called **fibrin monomer**. Fibrin is insoluble and forms the threads that bind the clot. Fibrin monomer polymerizes to form loosely arranged strands of fibrin. These loose strands are then modified into dense and **tight fibrin threads by fibrin-stabilizing factor (Factor XIII)**, in the presence of calcium ions. All these tight fibrin threads aggregate to form a **meshwork of stable clot**.

Chapter 11: Other Blood Disorders

- **Haemophilia** Haemophilia is the **oldest known hereditary bleeding disorder**. It is an **inherited deficiency of clotting factors** that impairs the body's ability to stop bleeding. In severe cases, patients often experience **internal bleeding**. The two most common types are **haemophilia A** and **haemophilia B**, caused by deficiencies of different blood clotting factors. Treatment involves injections of genetically engineered clotting factors to prevent prolonged bleeding.

- **Leukaemia** Leukaemia is a form of **cancer that affects the blood-forming tissue**, such as the bone marrow and lymphatic organs. It causes a **large number of abnormal blood cells to be produced**, which multiply uncontrollably. The accumulation of cancerous white blood cells (WBCs) in the red bone marrow interferes with the normal production of red blood cells, white blood cells, and platelets. Treatment often includes **surgery, chemotherapy, radiation therapy, immunotherapy, and vaccine therapy**.

    - **Types of Leukaemia**:
        1. Acute lymphocytic leukaemia (ALL) – most common in young children.
        2. Acute myelogenous leukaemia (AML) – a common type.
        3. Chronic lymphocytic leukaemia (CLL).
        4. Chronic myelogenous leukaemia (CML).
- **Haemolytic Disease of the Newborn (HDN)** Also known as **erythroblastosis fetalis**, HDN occurs when pregnant mothers produce **red cell antibodies** that can cross the placenta and destroy the baby's red blood cells. This happens if a small amount of Rh-positive foetal blood leaks into the bloodstream of an **Rh-negative mother**, causing her to make anti-Rh antibodies. The greatest possibility of foetal blood leakage into the

maternal circulation occurs at delivery, so the firstborn baby is usually not affected. If the mother becomes pregnant again with an Rh-positive foetus, her anti-Rh antibodies can cross the placenta and enter the foetus's bloodstream. If the foetus is Rh-negative, no reaction will occur. However, if the foetus is **Rh-positive**, **agglutination and haemolysis** brought on by foetal-maternal incompatibility may occur in the foetal blood. An injection of **anti-Rh antibodies called anti-Rh gamma globulin** can be given to prevent HDN.

- **Polycythemia Vera** Polycythemia vera is a type of **blood cancer** where the bone marrow makes too many red blood cells. These excess cells **thicken the blood**, slowing its flow and potentially causing serious problems like **blood clots**. Polycythemia vera is rare.

- **Thalassemia** Thalassemia is an **inherited blood disorder** in which the body makes an **abnormal form of haemoglobin**. Haemoglobin is the protein molecule in red blood cells that carries oxygen. The disorder results in **excessive destruction of red blood cells**, leading to anaemia. There are two main, more serious forms of thalassemia:

    - **Alpha thalassemia**: At least one of the alpha globin genes has a mutation or abnormality.
    - **Beta thalassemia**: The beta globin genes are affected.
- **Von Willebrand Disease** This is a bleeding disorder caused by **low levels of clotting protein** in the blood.

Part 4: The Body's Defence and Drainage Systems

Chapter 12: The Reticuloendothelial System (RES)

The Reticuloendothelial System (RES) is a system of cells with high **phagocytic properties**.

- **Components** The RES consists of:

    - **Monocytes**: These are the largest leukocytes. Immature cells present in the blood with limited ability to fight infectious agents. After about 72 hours, they enter tissues to become "tissue macrophages". In the tissue, they swell and increase in size, with their cytoplasm filling with lysosomes.
    - **Mobile (Wandering) Tissue Macrophages**: Monocytes leaving the blood become activated and differentiate into macrophages. Those that have recently left the blood

are sometimes referred to as wandering macrophages. During maturation, monocytes show an increase in cell size, number and complexity of intracellular organelles (like Golgi, mitochondria, lysosomes), and an increase in intracellular digestive enzymes.

- **Fixed Tissue Macrophages**: These are macrophages located in specific tissues and known by different names in various sites:
  - **Alveolar macrophages**: Pulmonary alveolus of lungs
  - **Adipose tissue macrophages**: Adipose tissue
  - **Kupffer cells**: Liver
  - **Microglia**: Neural tissue
  - **Osteoclasts**: Bone
  - **Sinusoidal lining cells**: Spleen
  - **Histiocytes**: Connective tissue
  - **Giant cells**: Connective tissue
  - **Peritoneal macrophages**: Peritoneal cavity
  - **Macrophage**: Serosa and lymphoid organs
  - **Hofbauer cells**: Placenta

- **Functions of Monocytes and Macrophages**

  - Enter tissue and form tissue macrophages, acting as **scavengers**.
  - **Phagocytose** several bacteria (up to 100).
  - **Engulf large particulate matter**, dead tissue cells, and senile cells.
  - Along with other macrophages, they are involved in **phagocytosis and destruction of necrotic material**.
  - **Engulf inorganic particulate matter** (e.g., carbon & dust particles).
  - When confronted with large insoluble particles, many macrophages can fuse together to become a **'Multinucleated Giant Cell'**.
  - Destroy organic foreign matter such as thorns, fish bones, and catgut by enzyme action and lysis.
  - **Engulf microorganisms, senile WBC, RBC, tissue debris, and some parasites**.
  - Help T and B lymphocytes in acquired immunity by **presenting antigens**.

- **Overall Functions of the Reticuloendothelial System**

  - **Phagocytic Function**: Bacteria, other foreign bodies, and tissue debris are engulfed and digested by the lysosomes of macrophages.

- **Destruction of senile red cells**.
- **Storage and metabolism of iron**.
- **Formation of bile pigments**.

Chapter 13: The Lymphatic System - Immune Defence and Fluid Balance

- **Introduction and Components** The lymphatic system is a major part of the body's **immune system**. It is a complex system responsible for **fluid drainage, transport, immune response, and disease resistance**. It comprises lymph vessels, lymph capillaries, and lymph nodes.

  - **Parts of the Lymphatic System**:
    - **Lymph**: The tissue fluid.
    - **Lymphatic vessels**: Including lymph trunks and ducts (thoracic/left lymphatic duct, right lymphatic duct).
    - **Lymphatic tissue**: Including lymph nodes, tonsils, spleen, and thymus gland.
- **Lymph and Its Flow Lymph** is a clear-to-white fluid made of white blood cells, especially lymphocytes (cells that attack bacteria in the blood). It is a collection of extra fluid that drains from cells and tissues. Lymph is derived from blood plasma as fluids pass through capillary walls at the arterial end. In the small intestine, fats absorbed by lymphatic capillaries (called **lacteals**) give the lymph a milky appearance.

  - **Chemical Composition of Lymph**: Contains proteins (2.6 g/100 ml), chloride (116 m. eq/lit), calcium (4.6 m. eq/lit), and urea (23.5 mg/100 ml).
  - **Flow of Lymph**: The flow of lymph is regulated by **movements of skeletal muscles** and **breathing movements**. This movement compresses the lymphatic vessels and forces the fluid towards the **subclavian veins**.
  - **Pathway of Lymph Flow**: Blood capillaries (blood) -> Interstitial spaces (interstitial fluid) -> Lymphatic capillaries (lymph) -> Lymphatic Vessels (lymph) -> Lymphatic ducts (lymph) -> Junction of the internal jugular and subclavian veins (blood).
- **Lymphatic Vessels, Trunks, and Ducts** Lymphatic vessels transport lymph fluid around the body. There are two main systems: **superficial** (in subcutaneous tissue, accompanying venous flow) and **deep vessels** (drain deeper structures, accompanying deep arteries). These vessels are tiny, thin-walled, and closed at one end. Their main purpose is to **drain excess interstitial fluid** from around the cells to the venous circulation. The wall of lymphatic capillaries is made of endothelium, and they are larger in diameter than blood

capillaries. Anchoring filaments hold endothelial cells to nearby tissues.

- **Lymph trunks and ducts**: A lymph trunk is a collection of lymph vessels that carries lymph, formed by the confluence of many efferent lymph vessels.
  - **Jugular trunks**: Drain the neck.
  - **Subclavian trunks**: Drain the upper limbs.
  - **Bronchomediastinal trunks**: Drain the chest.
  - **Intercostal trunks**: Drain the chest wall.
- Lymphatic capillaries extend into tissues to absorb fluids and return them to circulation, preventing the accumulation of excess fluid. Lymphatic vessels resemble small veins.

Chapter 14: Lymphoid Organs

- **Lymph Nodes** Lymph nodes are oval or bean-shaped organs located along the lymphatic vessels. Inside, they contain a combination of different types of immune system cells. These specialized cells **filter lymphatic fluid** as it travels through the body, **protecting by destroying invaders**. They range from 1 to 25 mm in length and are greyish-pink in colour. Lymph nodes are present in various sites including the **Spleen, Thymus, Tonsils, Appendix, and Peyer's patches in the intestine**.

  - **Cellular Composition**: Lymph nodes contain **lymphocytes**, a type of white blood cell, primarily made up of B and T cells. B cells are mainly found in the **outer cortex**, clustered as follicular B cells in lymphoid follicles. T cells and dendritic cells are mainly found in the **paracortex**, with the deeper part of the cortex containing T cells. These T cells circulate freely between the blood, lymph nodes, and lymph, performing surveillance.
  - **Structure**: The medulla contains **medullary cords**, which are thin inward extensions from the cortical lymphoid tissue. The internal part of the capsule is a supporting network of **reticular fibres and fibroblasts**. These, along with the capsule and trabeculae, constitute the stroma of the lymph node. Each node has a concave surface called a **hilum**. Four or five afferent lymph vessels may enter a lymph node, while only one efferent vessel carries lymph away. Lymphocytes and macrophages destroy foreign substances by **phagocytosis**.
  - **Functions of Lymph Nodes**:
    1. **Filter out solid particles**, including bacteria.

2. **Production of lymphocytes**.
3. **Production of plasma proteins** like globulin.
4. **Prevent foreign particles** from entering the bloodstream.
5. **Filter the blood** before it is returned to the blood circulation.

- **Spleen** The spleen is the **largest lymphoid organ** in the body and is highly vascular. It is the **largest organ in the body's lymphatic system**, a dark purple-coloured lymphoid structure. The parenchyma of the spleen is divided into **red and white pulp**. It is highly vascular, bean-shaped, and measures 12 cm. It is situated in the left hypochondrial region. The spleen's external surface is divided into a diaphragmatic surface and a visceral surface.

    - **Composition**: The spleen consists of two different kinds of tissue:
        1. **White pulp**: Consists of masses of lymphocytes and macrophages.
        2. **Red pulp**: Consists of blood sinuses.
    - **Anatomy**: The spleen has a concave surface called a hilum where the splenic artery, splenic vein, lymph vessels, and nerves enter and leave. It is supplied by the splenic artery and drained by the splenic vein. The diaphragmatic surface faces the diaphragm, while the visceral surface faces downwards towards the organs of the "viscera" or "gut". The red pulp acts as a **storage point for important blood components**. The spaces between trabeculae contain the splenic tissue called **malphigian corpuscles**.
    - **Functions of Spleen**:
        1. **Making antibodies**.
        2. **Storing emergency reserves of red blood cells** that can be released in case of blood loss.
        3. **Storing emergency reserves of white blood cells** that can be released to fight infection and promote healing.
        4. Responsible for **promoting immune functions**.
        5. **Filtering the blood** and **managing blood volume**.
        6. **Breaking down waste products** from dead cells.
        7. **Removes old RBCs** and holds a reserve of blood valuable in case of haemorrhagic shock.
        8. **Recycling useful components**, such as iron, for use in future red blood cell production.

- **Tonsils** Tonsils are located at the posterior root of the tongue near the pharynx. They contain many **T and B cells** to protect the body from infections. They serve as the **first line of defence** against ingested and inhaled substances. Tonsils commonly become inflamed in response to infection.

- **Peyer's Patches** These are small, round or ovoid masses of lymphatic tissue found in the **ileum of the small intestine**. Peyer's patches are clusters of subepithelial, lymphoid follicles. They contain T and B cells that monitor the contents of the intestinal lumen for pathogens.

- **Thymus** The thymus is a small, triangular gland found just posterior to the sternum and anterior to the heart. It is made of glandular epithelium and hematopoietic connective tissues. The vast majority of **T cells mature, develop, and reproduce in the thymus**. Upon maturation, the T cells spread throughout the body to other lymphatic tissues to fight infections.

Chapter 15: Functions of the Lymphatic System

The lymphatic system plays a multifaceted role in the body:

1. It flows in lymphatic vessels, carrying **lipid and lipid-soluble vitamins** absorbed by the gastrointestinal tract to the blood.
2. It is a reticular connective tissue system consisting of tissues and organs that produce, mature, and store **lymphocytes and macrophages** for the body's defence.
3. It acts as a **transport channel** that carries white blood cells to and from lymph nodes, into the bones, and transports antigen-presenting cells to the lymph nodes.
4. The lymphatics carry **waste products from tissues to blood**.
5. Lymph nodes are the sites where **lymphocytes are produced**.
6. The lymphatics **drain excess fluid** from tissues back to circulation.
7. Lymph nodes protect the body against infection by **filtering and destroying bacteria**.
8. It protects the body from illness-causing invaders, maintains body fluid levels, **absorbs digestive tract fats**, and removes cellular waste.
9. It is involved in the **absorption of fatty acids** and subsequent transport of fat (chyle) to the circulatory system.

10. It is crucial for the **production, storage, maintenance, and distribution of lymphocytes**.
11. Aids in **fat absorption in the GI tract**.
12. Contributes to the **maintenance of normal blood volume**.
13. Helps to **filter out and phagocytize foreign agents**.
14. Produces and "activates" **lymphocytes (B cells and T cells)**.
15. **Absorbs fat from the intestine** and transports it to the liver.
