Blood Physiology

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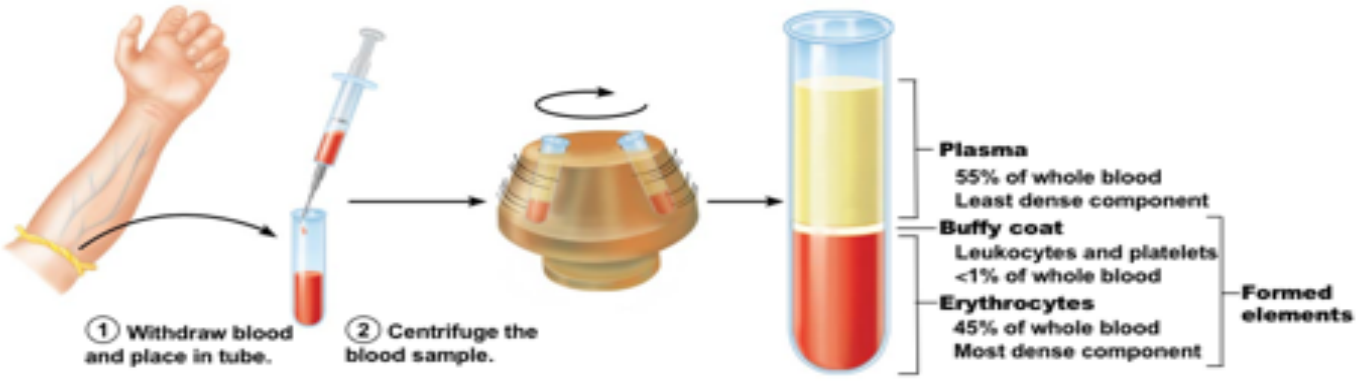
Blood Generalizations

- Connective tissue in fluid form
- Fluid of life – carries oxygen from lungs to all parts of body and carbon-di-oxide from all parts of the body to the lungs
- Fluid of growth – carries nutritive substances from the digestive system and hormones from endocrine gland to all the tissues.
- Fluid of health – protects the body against diseases and get rid of unwanted substances by transporting them into excretory organs like kidney.

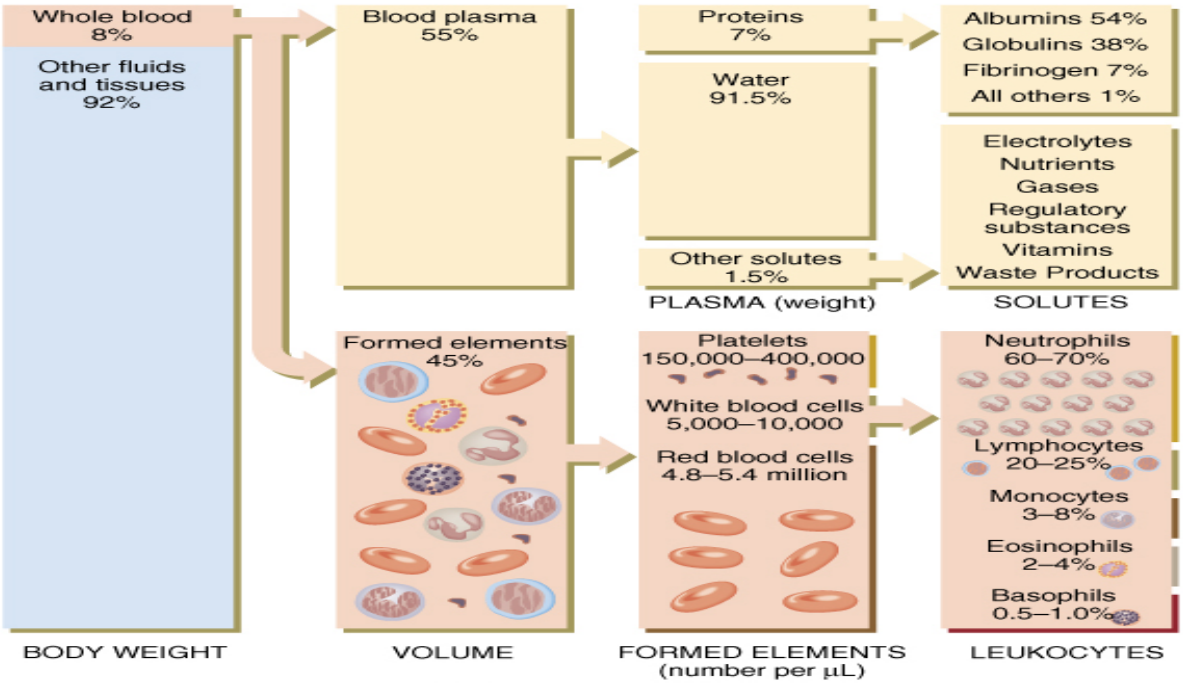
Composition of Blood

- Blood is the body's only fluid tissue
- It is composed of liquid plasma and formed elements
- Formed elements include:
    - Erythrocytes, or red blood cells (RBCs)
    - Leukocytes, or white blood cells (WBCs)
    - Platelets
- Hematocrit – the percentage of RBCs out of the total blood volume
    - Normal 47% male, 42% female



Physical Characteristics and Volume

- Blood is a sticky, opaque fluid with a metallic taste
- Color varies from scarlet (oxygen-rich) to dark red (oxygen-poor)
- The pH of blood is 7.35–7.45
- Temperature is 38°C, slightly higher than "normal" body temperature
- Blood accounts for approximately 8% of body weight
- Average volume of blood is 5–6 L for males, and 4–5 L for females



Functions of Blood

- **Distribution** - Blood transports
  - Oxygen from the lungs and nutrients from the digestive tract
  - Metabolic wastes from cells to the lungs and kidneys for elimination
  - Hormones from endocrine glands to target organs
  - O_2 from lungs to tissues
  - CO_2 from tissues to lungs
  - "Food" from gut to blood
- **Regulation -** Blood maintains
  - Appropriate body temperature by absorbing and distributing heat
  - Normal pH in body tissues using buffer systems
  - Adequate fluid volume in the circulatory system
  - Coolant properties of water
  - Vasodilatation of surface vessels dump heat
  - Water content of cells by interactions with dissolved ions and proteins
    - Water- high heat capacity, thermal conductivity, heat of vaporization
    - Typical heat generation is 3000 kcal/day
- **Protection -** Blood prevents blood loss by
  - Activating plasma proteins and platelets
  - Initiating clot formation when a vessel is broken
- **Protection -** Blood prevents infection by:
  - Synthesizing and utilizing antibodies
  - Activating complement proteins
  - Activating WBCs to defend the body against foreign invaders

Blood Plasma

- Straw-colored, sticky fluid portion of blood
- 55% of whole blood. Approximately 90% water.
- Contains over 100 solutes, including:
    - Plasma Proteins (about 7% of plasma)
        - Plasma proteins are made in the liver and confined to the bloodstream
        - There are three main plasma proteins:
            - **Albumin** - Prevents water from diffusing out of blood vessels. This maintains blood osmotic pressure.
            - **Globulins –** Includes antibodies and blood proteins that transport lipids, iron, and copper. Also called immunoglobulins, which are antibodies that bind to foreign substances.
            - **Fibrinogen** – One of the molecules in chemical reactions for blood clotting
    - Other plasma substances (about 2% to 3%)
        - Nonprotein nitrogenous substances – lactic acid, urea, creatinine
        - Organic nutrients – glucose, carbohydrates, amino acids
        - Electrolytes – sodium, potassium, calcium, chloride, bicarbonate
        - Respiratory gases – oxygen and carbon dioxide

Functions of Blood Plasma

- Coagulation of blood – Fibrinogen to fibrin
- Defense mechanism of blood – Immunoglobulins
- Transport mechanism – α Albumin, β globulin transport hormones, gases, enzymes, etc.
- Maintenance of osmotic pressure in blood
- Acid-base balance
- Provides viscosity to blood
- Provides suspension stability of RBC
- Reserve proteins

Erythrocytes (RBCs)

- Oxygen-transporting cells—7.5 μm in diameter (diameter of capillary 8–10mm)
- Are the ideal measuring tool for estimating sizes of nearby structures
- Biconcave discs, anucleate, essentially no organelles
- Filled with hemoglobin (Hb), a protein that functions in gas transport
- Contain the plasma membrane protein that:
    - Give erythrocytes their flexibility
    - Allow them to change shape as necessary
- Structural characteristics contribute to its gas transport function
    - Biconcave shape that has a huge surface area relative to volume
    - Discounting water content, erythrocytes are more than 97% hemoglobin

Typical Counts

- 4,600,000 – 6,200,000 males
- 4,200,000 – 5,400,000 females
- 4,500,000 – 5,100,000 children

General Erythrocyte Function

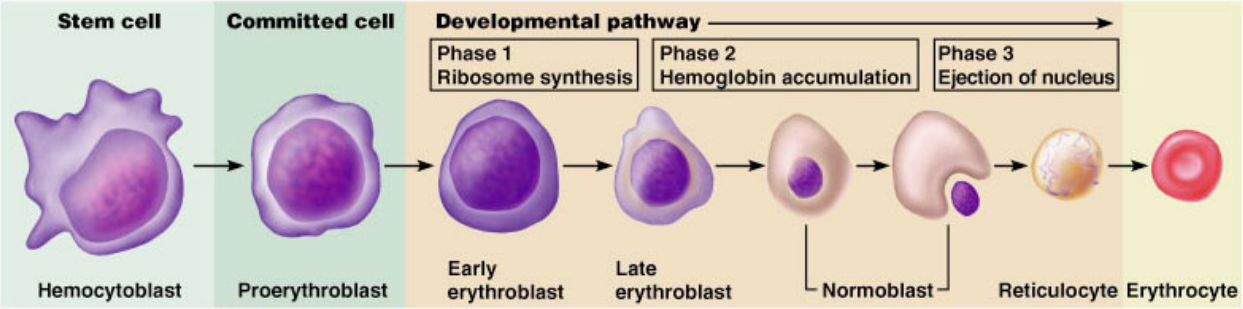
- Erythrocytes are dedicated to respiratory gas transport
- Each RBC contains approximately 300 million hemoglobin molecules
- In the systemic capillaries, hemoglobin gives up much of it's oxygen
- In the pulmonary capillaries, RBCs pick up oxygen
- Transport oxygen from lungs to the tissues (oxyhemoglobin).
- Transport carbon-di-oxide from tissues to lungs (carboxyhemoglobin)
- Hemoglobin acts as a buffer and regulates the hydrogen ion concentration (acid base balance)
- Carry the blood group antigens and Rh factor

Specific Erythrocyte Functions

- **Gas Transport**
    - Continuous interchange of CO_2 and O_2 between lungs and tissues.
    - Oxygen
        - indispensable for ATP production.
    - CO_2
        - major by product of energy metabolism
- **pH Maintenance**
    - Oxygen release maintains pH in tissues
    - Lungs:
        - $HHb + O_2 = HbO_2 + H^+$
    - Tissues:
        - CO_2 forms proton and bicarbonate
        - Proton is bound to Hb, when O_2 is released
        - Bicarbonate leaves RBC
        - Cl^- / HCO^{3-} interchange
- **Hb**
    - Higher ability of Hb to release O_2 but lower ability to bind O_2 - Right shift
    - Useful at site of O_2 release (tissues)
- **CO2 Transport**
    - Bicarbonate formation within RBC and Cl interchange
    - CO_2 dissolved in blood plasma
    - Carbaminohemoglobin formation

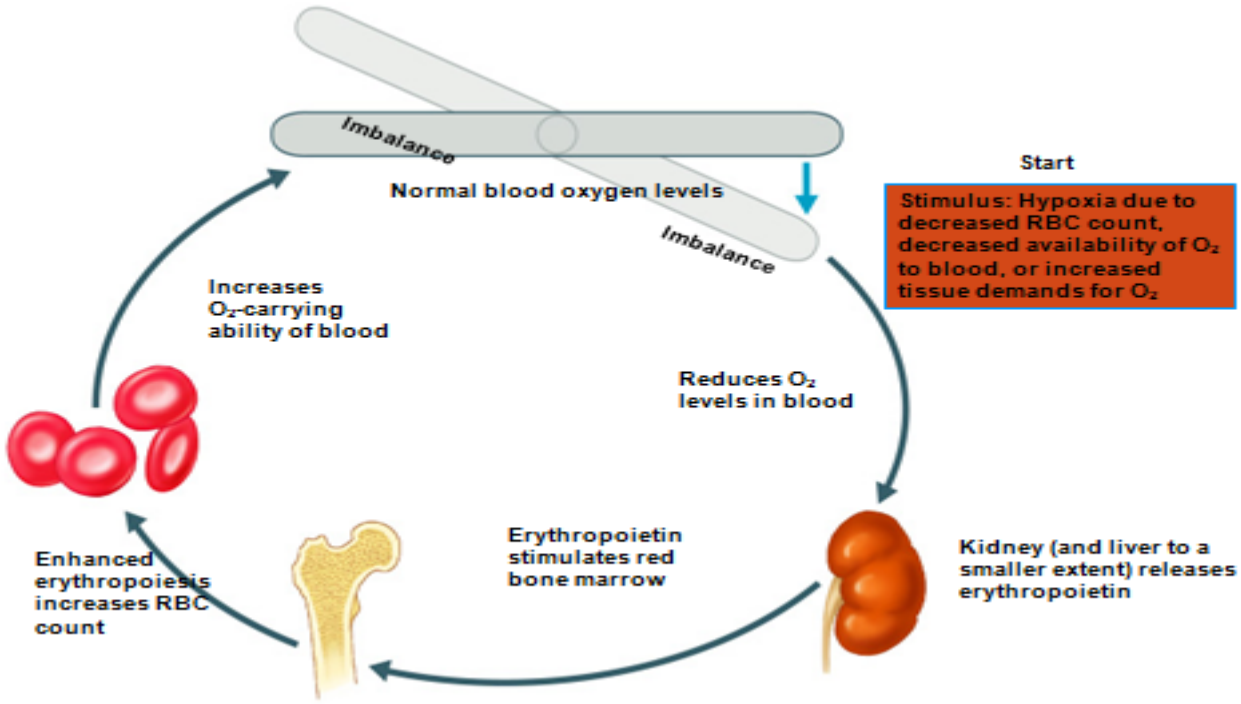
Production of Erythrocytes

- Hematopoiesis – blood cell formation
- 100 billion new blood cells formed each day
- Hematopoiesis occurs in the red bone marrow of the:
    - Axial skeleton and girdles and Epiphyses of the humerus and femur



Regulation of Erythropoiesis

- Circulating erythrocytes – the number remains constant and reflects a balance between RBC production and destruction
    - Too few red blood cells leads to tissue hypoxia
    - Too many red blood cells causes undesirable blood viscosity
- Erythropoiesis is hormonally controlled and depends on adequate supplies of iron, amino acids, and B vitamins
- Erythropoietin (EPO) release by the kidneys is triggered by:
    - Hypoxia due to decreased RBCs
    - Decreased oxygen availability
    - Increased tissue demand for oxygen



Dietary Requirements of Erythropoiesis

- Erythropoiesis requires:
    - Proteins, lipids, and carbohydrates
    - Iron, vitamin B_{12}, and folic acid
- The body stores iron in Hb (65%), the liver, spleen, and bone marrow

Lifespan of Erythrocytes

- The life span of an erythrocyte is 100–120 days
- Old erythrocytes become rigid and fragile, and their hemoglobin begins to degenerate
- Dying erythrocytes are engulfed by macrophages
- Heme and globin are separated and the iron is salvaged for reuse

Cell Lines in Blood Cell Formation

- All blood cells originate in bone marrow
- All originate from one cell type - Hemopoietic blood stem cell
- Lymphoid stem cells - Give rise to lymphocytes
- Myeloid stem cells - Give rise to all other blood cells

The Blood Throughout Life

- First blood cells develop with the earliest blood vessels
- Mesenchyme cells cluster into blood islands
- Late in month 2 - Liver and spleen take over blood formation
- Bone marrow becomes major hematopoietic organ at month 7

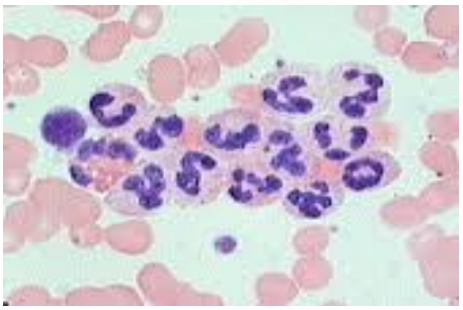
Leukocytes (WBCs)

- Leukocytes, the only blood components that are complete cells:
    - Are less numerous than RBCs
    - Make up 1% of the total blood volume
    - Can leave capillaries via diapedesis
    - Move through tissue spaces
- 4800–11,000/cubic millimeter
- Protect the body from infectious microorganisms
- Function outside the bloodstream in loose connective tissue
- **Diapedesis**—circulating leukocytes leave the capillaries
- Originate in bone marrow
- Leukocytosis – WBC count over 11,000 per cubic millimeter
    - Normal response to bacterial or viral invasion

Number of Leuckocytes "Never Let Monkeys Eat Bananas"

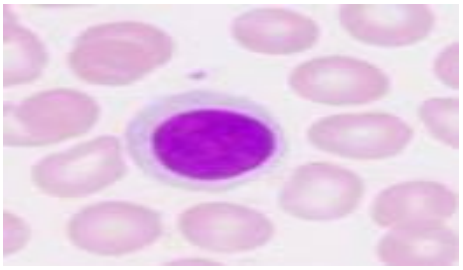
- From the most to the least prevelent
    - Neutrophils, Lymphocytes, Monocytes, Eosinophils, Basophils

Neutrophils



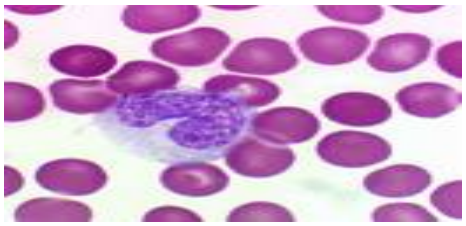
- Neutrophils are the most numerous WBC
- 50-70% of WBC population
- Attracted to sites of inflammation
- Neutrophils are our body's bacteria slayers
- Are phagocytic
- First line of defense against invading micro-organisms.
- Powerful and effective killer machine – contains enzymes like protease, elastase, metalloproteinase, NADPH oxidase; antibody like substances called defensins.
- Defensins – antimicrobial peptides active against bacteria and fungi.
- Secrete Platelet Aggregation Factor (PAF) – accelerates the aggregation of platelet during injury to the blood vessels

Lymphocytes



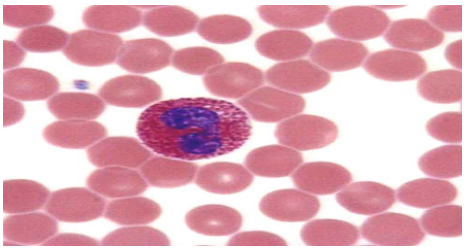
- Account for 25% or more of WBCs
- Only a small number is found in the blood
- Most are found in lymph tissue
- Critical role in Immunity
- Secrete antibodies
- Two main classes of **lymphocyte**
    - **T cells**—attack foreign cells directly
    - **B cells**—multiply to become plasma cells

Monocytes



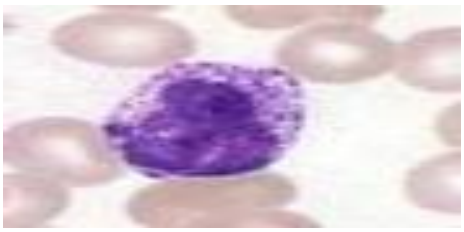
- Monocytes account for 4–8% of leukocytes
- They are the largest leukocytes
- They leave the circulation, enter tissue, and differentiate into macrophages
- They have massive appetites
- Defends against chronic infections, viruses and parasites

Eosinophils



- Eosinophils account for 1–4% of WBCs
- Lead the body's counterattack against parasitic worms
- Lessen the severity of allergies by phagocytizing immune complexes
- Secrete lethal substances at the time of exposure to foreign proteins/parasites
- Eosinophil peroxidase – destroy worms, bacteria and tumor cells.
    - Major basic protein – damage parasites
    - Eosinophil cationic protein (ECP)- destroys helminthes.

Basophils



- Account for 0.5% of WBCs
- Rarest of all WBC
- Releases histamine in inflammations
- Histamine – inflammatory chemical that acts as a vasodilator and attracts other WBCs (antihistamines counter this effect)

  Basophill granules release some important substances like –
  1. Histamine – Acute hypersensitivity reaction- vascular changes, increase capillary permeability
  2. Heparin – prevents intravascular blood clotting
  3. Hyaluronic acid – necessary for deposition of ground substances in basement membrane
  4. Proteases – exaggerate inflammation
  - Basophill have IgE receptor – hypersensitivity reaction

Production of Leukocytes

- Overproduction of WBC occurs in leukemia and infectious mononucleosis
- On the opposite end of the spectrum is Leukopenia, which is an abnormally low WBC count.
  - Common with cancer medications and glucocorticoids
- Many hematopoietic hormones are used clinically to stimulate bone marrow

Leukocytes Disorders: Leukemias

- "White blood"
- Leukemia refers to cancerous conditions involving white blood cells
- In all leukemias, the bone marrow becomes almost totally occupied by cancerous WBC and immature WBC before flowing into the boodstream.
- Because other cells can be crowded out, severe anemia and bleeding problems occur.
- Chronic leukemia is more prevalent in older people.

Platelets

- Platelets are also known as thrombocytes
- They lack a nucleus and are roughly half the size of a RBC
- There are approximately 130,000 – 360,000 per cubic millimeter of blood
- They help repair damaged blood vessels by sticking to broken surfaces

1. **Blood clotting**
2. **Clot retraction**
3. **Defence mechanism**
4. **Homeostasis**
5. **Repair and rupture of blood vessel**

The Big Picture: Blood and the Whole Body

- Blood plasma transports substances, including heat, around the body, linking all body tissues together
    - Substances can be transported between almost any two points in the body
- Blood tissue contains formed elements—blood cells and platelets
    - RBCs assist in the transport of oxygen and carbon dioxide
    - WBCs assist in the defense mechanisms of the whole body
    - Platelets prevent loss of the fluid that constitutes the internal environment
- No organ or system of the body can maintain proper levels of nutrients, gases, or water without direct or indirect help from blood
    - Other systems assist the blood
- Blood is useless unless it continues to transport, defend, and maintain balance

Summary of Formed Elements of the Blood

Cell Type	Illustration	Description*	Cells/mm³ (μl) of Blood	Duration of Development (D) and Life Span (LS)	Function
Erythrocytes (red blood cells, RBCs)		Biconcave, anucleate disc; salmon-colored; diameter 7–8 μm	4–6 million	D: 5–7 days LS: 100–120 days	Transport oxygen and carbon dioxide
Leukocytes (white blood cells, WBCs)		Spherical, nucleated cells	4800–10,800		
Granulocytes					
▪ Neutrophil		Nucleus multilobed; inconspicuous cytoplasmic granules; diameter 10–12 μm	3000–7000	D: 6–9 days LS: 6 hours to a few days	Phagocytize bacteria
▪ Eosinophil		Nucleus bilobed; red cytoplasmic granules; diameter 10–14 μm	100–400	D: 6–9 days LS: 8–12 days	Kill parasitic worms; destroy antigen-antibody complexes; inactivate some inflammatory chemicals of allergy

Cell Type	Illustration	Description*	Cells/mm³ (μl) of Blood	Duration of Development (D) and Life Span (LS)	Function
▪ Basophil		Nucleus lobed; large blue-purple cytoplasmic granules; diameter 8–10 μm	20–50	D: 3–7 days LS: ? (a few hours to a few days)	Release histamine and other mediators of inflammation; contain heparin, an anticoagulant
Agranulocytes					
▪ Lymphocyte		Nucleus spherical or indented; pale blue cytoplasm; diameter 5–17 μm	1500–3000	D: days to weeks LS: hours to years	Mount immune response by direct cell attack or via antibodies
▪ Monocyte		Nucleus U or kidney shaped; gray-blue cytoplasm; diameter 14–24 μm	100–700	D: 2–3 days LS: months	Phagocytosis; develop into macrophages in tissues
Platelets		Discoid cytoplasmic fragments containing granules; stain deep purple; diameter 2–4 μm	150,000–400,000	D: 4–5 days LS: 5–10 days	Seal small tears in blood vessels; instrumental in blood clotting