Chapter 20

The Cardiovascular System

Blood

Lecture Presentation by
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Introduction

• The cardiovascular system functions as a system to transport numerous substances throughout the body such as:
  • Nutrients
  • Oxygen and carbon dioxide
  • Enzymes and hormones
  • Ions
  • Transports metabolic wastes to the kidneys
  • Transports leukocytes to aid in fighting infectious agents
Introduction

- Other functions of the cardiovascular system are:
  - Stabilization of body temperature
  - Prevention of the loss of body fluids via the clotting process
  - Stabilization of pH and electrolyte balance
Functions and Composition of the Blood

- Blood consists of two components
  - **Plasma**
    - Liquid matrix of blood
  - **Formed elements**
    - Blood cells and cell fragments that are suspended in the plasma, and include:
      - **Erythrocytes (red blood cells)**: transport oxygen and carbon dioxide
      - **Leukocytes (white blood cells)**: function in the immune system
      - **Platelets**: involved in blood clotting
Sample of whole blood consists of:

**Plasma (46–63%)**

### Plasma Composition

- **Plasma proteins**
  - 7%
- **Other solutes**
  - 1%
- **Water**
  - 92%

**Components of plasma**

**Other Solutes**

<table>
<thead>
<tr>
<th>Electrolytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal extracellular fluid ion composition essential for vital cellular activities; ions contribute to osmotic pressure of body fluids; major plasma electrolytes are Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, HPO₄²⁻, SO₄²⁻</td>
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<th>Organic nutrients</th>
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<td>Used for ATP production, growth, and maintenance of cells; include lipids (fatty acids, cholesterol, glycerides), carbohydrates (primarily glucose), and amino acids</td>
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<td>Carried to sites of breakdown or excretion; include urea, uric acid, creatinine, bilirubin, ammonium ions</td>
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### Plasma Proteins

- **Albumins (60%)**
  - Major contributors to osmotic pressure of plasma; transport lipids, steroid hormones

- **Globulins (35%)**
  - Transport ions, hormones, lipids; immune function

- **Fibrinogen (4%)**
  - Essential component of clotting system; can be converted to insoluble fibrin

- **Regulatory proteins (< 1%)**
  - Enzymes, proenzymes, hormones
Functions and Composition of the Blood

• Whole blood consists of:
  • Plasma, erythrocytes, leukocytes, platelets

• Whole blood can be fractionated to form:
  • Plasma
  • Packed cells
  • Platelets

• Packed cells consists of:
  • Mostly erythrocytes
Functions and Composition of the Blood

• Whole Blood
  • Males: 4–6 liters
  • Females: 4–5 liters
  • **Hypovolemic**: low blood volumes
  • **Normovolemic**: normal blood volumes
  • **Hypervolemic**: excessive blood volumes
  • pH: 7.35–7.45
Functions and Composition of the Blood

• Plasma
  • Makes up about 55 percent of the volume of whole blood
  • Consists of:
    • 92 percent water
    • 7 percent proteins
      • Albumin, globulins, fibrinogen, regulatory proteins
    • 1 percent other solutes
      • Electrolytes, organic nutrients, organic waste
Sample of whole blood consists of Plasma (46–63%).

**PLASMA COMPOSITION**
- Plasma proteins: 7%
- Other solutes: 1%
- Water: 92%

**Components of plasma**
- Transports organic and inorganic molecules, formed elements, and heat

**Plasma Proteins**
- Albumins (60%): Major contributors to osmotic pressure of plasma; transport lipids, steroid hormones
- Globulins (35%): Transport ions, hormones, lipids; immune function
- Fibrinogen (4%): Essential component of clotting system; can be converted to insoluble fibrin
- Regulatory proteins (< 1%): Enzymes, proenzymes, hormones

**Other Solute**
- Electrolytes: Normal extracellular fluid ion composition essential for vital cellular activities; ions contribute to osmotic pressure of body fluids; major plasma electrolytes are Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, HPO₄⁻, SO₄²⁻
- Organic nutrients: Used for ATP production, growth, and maintenance of cells; include lipids (fatty acids, cholesterol, glycerides), carbohydrates (primarily glucose), and amino acids
- Organic wastes: Carried to sites of breakdown or excretion; include urea, uric acid, creatinine, bilirubin, ammonium ions
Functions and Composition of the Blood

- Differences between Plasma and Interstitial Fluid
  - **Dissolved oxygen in plasma**
    - Concentration is higher than in interstitial fluid
    - Therefore, oxygen diffuses into the tissues
  - **Carbon dioxide concentration in plasma**
    - Concentration is lower than in interstitial fluid
    - Therefore, carbon dioxide diffuses out of the tissues
  - Plasma consists of **dissolved protein**
    - Interstitial fluid does not have dissolved protein
Functions and Composition of the Blood

• The Plasma Proteins
  • Produced mainly by the liver
  • Makes up about 7 percent of the plasma
  • Consists of three major classes of protein
    • Albumins (60 percent)
    • Globulins (35 percent)
    • Fibrinogens (4 percent)
Functions and Composition of the Blood

• The Plasma Proteins
  • Albumins (smallest of the plasma proteins)
    • Contribute to the osmotic pressure of plasma
    • Transport fatty acids and steroid hormones
  • Globulins
    • Two major types
      • Immunoglobulins: attack pathogens
      • Transport globulins: transport ions and hormones
  • Fibrinogens (largest of the plasma proteins)
    • Involved in blood clotting processes
Sample of whole blood consists of:

**Plasma (46–63%)**

- **Plasma composition**
  - Plasma proteins: 7% (Major contributors to osmotic pressure of plasma; transport lipids, steroid hormones)
  - Other solutes: 1% (Transport ions, hormones, lipids; immune function)
  - Water: 92% (Essential component of clotting system; can be converted to insoluble fibrin)
  - Components of plasma:
    - Albumins (60%): Transport ions, hormones, lipids; immune function
    - Globulins (35%): Essential component of clotting system; can be converted to insoluble fibrin
    - Fibrinogen (4%): Enzymes, proenzymes, hormones
    - Regulatory proteins (< 1%): Normal extracellular fluid ion composition essential for vital cellular activities; ions contribute to osmotic pressure of body fluids; major plasma electrolytes are Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻, HPO₄⁻, SO₄²⁻
    - Electrolytes: Organic nutrients (Used for ATP production, growth, and maintenance of cells; include lipids (fatty acids, cholesterol, glycerides), carbohydrates (primarily glucose), and amino acids)
    - Organic nutrients: Carried to sites of breakdown or excretion; include urea, uric acid, creatinine, bilirubin, ammonium ions

- **Other solutes**
  - Water transports organic and inorganic molecules, formed elements, and heat
Formed Elements

- Formed Elements
  - Makes up about 45 percent of whole blood
  - Platelets (<0.1 percent of whole blood)
  - Leukocytes (<0.1 percent of whole blood)
    - Neutrophils (50–70 percent of the WBCs)
    - Eosinophils (2–4 percent of the WBCs)
    - Basophils (<1 percent of the WBCs)
    - Lymphocytes (20–30 percent of the WBCs)
    - Monocytes (2–8 percent of the WBCs)
  - Erythrocytes (99.9 percent of whole blood)
Sample of whole blood consists of formed elements (37–54%).

**FORMED ELEMENTS**
- Platelets: < 0.1%
- White blood cells: < 0.1%
- Red blood cells: 99.9%

**White Blood Cells**
- Neutrophils (50–70%)
- Eosinophils (2–4%)
- Monocytes (2–8%)
- Basophils (< 1%)
- Lymphocytes (20–30%)

**Red Blood Cells**
Formed Elements

- Red Blood Cells (RBCs) or Erythrocytes
  - **Hematocrit** readings
    - Also called *packed cell volume* (PCV)
    - Also called *volume of packed red cells* (VPRC)
    - Defined as the percentage of whole blood occupied by the formed elements
      - Males: 45 percent (5.4 million RBCs per microliter)
      - Females: 42 percent (4.8 million RBCs per microliter)
Formed Elements

- Red Blood Cells (RBCs) or Erythrocytes
  - One microliter (or cubic millimeter) of blood consists of millions of RBCs
    - Male: 5.4 million per cubic millimeter
    - Female: 4.8 million per cubic millimeter
Formed Elements

• Structure of RBCs
  • Biconcave disc
  • Thin central region
  • Measure about 7.7 microns in diameter
  • Lack cell organelles
  • Lack a nucleus (anucleated)
  • Contain hemoglobin
A scanning electron micrograph of red blood cells reveals their three-dimensional structure quite clearly.

A sectional view of a red blood cell.
Formed Elements

• RBC Life Span and Circulation
  • Circulating RBCs lack:
    • A nucleus
    • All organelles
  • Due to the lack of a nucleus and organelles, the life span is only about:
    • 120 days
Formed Elements

- RBC Life Span and Circulation
  - Significance of a lack of a nucleus:
    - Allows the cell to be flexible as it travels through the circulatory system
    - Allows for more room for hemoglobin
  - Significance of a lack of mitochondria:
    - Mitochondria use oxygen to manufacture ATP
    - Without mitochondria, oxygen can be transported to the tissues instead of being “used” by the mitochondria
Formed Elements

- RBCs and Hemoglobin
  - A developing erythrocyte loses its nucleus and organelles
  - A mature erythrocyte is mainly a cell membrane surrounding water and protein
    - The water accounts for 66 percent of the RBC’s volume
    - The protein accounts for 33 percent of the RBC’s volume of which >95 percent is hemoglobin
  - Hemoglobin is responsible for transporting oxygen and carbon dioxide (the main function of RBCs)
    - 280 million molecules of hemoglobin per RBC
Formed Elements

- RBCs and Hemoglobin
  - Consists of four polypeptide subunits
    - Two alpha chains
    - Two beta chains
  - Each subunit contains a molecule of heme
  - Heme is a porphyrin ring
  - Each heme consists of an iron ion
    - Iron binds to oxygen
    - The polypeptide units bind to carbon dioxide
    - Oxygen and carbon dioxide do not compete with each other for binding sites
Figure 20.3 The Structure of Hemoglobin
Formed Elements

• Blood Types
  • Blood types are determined by the antigens on the surface of the erythrocytes
    • Also known as agglutinogens
    • These agglutinogens are either glycoproteins or glycolipids
  • In the plasma of blood are proteins called antibodies
    • Also known as agglutinins
Formed Elements

• Blood Types
  • There are three major types of agglutinogens
    • Agglutinogen A
    • Agglutinogen B
    • Agglutinogen D
  • There are two major types of agglutinins
    • Agglutinin a
    • Agglutinin b
Formed Elements

• Blood Types (continued)
  • People with type A blood have:
    • A agglutinogen on the RBC
    • b agglutinin in the plasma
  • People with type B blood have:
    • B agglutinogen on the RBC
    • a agglutinin in the plasma
• Blood Types (continued)
  • People with type AB blood have:
    • Agglutinogen A and agglutinogen B on the RBC
    • No agglutinin in the plasma
  • People with type O blood have:
    • Neither agglutinogen A nor B on the RBC
    • Both types of agglutinins in the plasma (a and b)
Your blood type is a classification determined by the presence or absence of specific surface antigens in RBC plasma membranes. There are four blood types based on the A and B surface antigens.

<table>
<thead>
<tr>
<th>Type A</th>
<th>Type B</th>
<th>Type AB</th>
<th>Type O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A blood has RBCs with surface antigen A only.</td>
<td>Type B blood has RBCs with surface antigen B only.</td>
<td>Type AB blood has RBCs with both A and B surface antigens.</td>
<td>Type O blood has RBCs lacking both A and B surface antigens.</td>
</tr>
<tr>
<td><img src="Image" alt="Surface antigen A" /></td>
<td><img src="Image" alt="Surface antigen B" /></td>
<td><img src="Image" alt="Surface antigen A and B" /></td>
<td><img src="Image" alt="Surface antigen A and B" /></td>
</tr>
<tr>
<td>If you have Type A blood, your plasma contains anti-B antibodies, which will attack Type B surface antigens.</td>
<td>If you have Type B blood, your plasma contains anti-A antibodies.</td>
<td>Type AB individuals do not have anti-A or anti-B antibodies.</td>
<td>An individual with Type O blood has plasma containing both anti-A and anti-B antibodies.</td>
</tr>
</tbody>
</table>
Formed Elements

• Blood Donations
  • Type B (packed cells) donor cannot donate to type A patient
    • The B agglutinogen of the donor will activate the b agglutinin in the plasma of the type A patient
    • Agglutination will occur
    • This is not a safe donation
• Blood Donations (continued)
  • Type AB (packed cells) donor cannot donate to type B patient
    • The A agglutinogen of the donor will activate the a agglutinin in the plasma of the type B patient
    • Agglutination will occur
    • This is not a safe donation
• Blood Donations (continued)
  • Type B (packed cells) donor *can* donate to type AB patient
    • The B agglutinogen of the donor will not activate any agglutinins of the patient because the patient does not have any agglutinins in their plasma
    • Agglutination will not occur
    • This is a safe donation
• Blood Donations (continued)
  • Type B (whole blood) donor cannot donate to type A patient
    • The B agglutinogen of the donor will activate the b agglutinin in the plasma of the type A patient
    • The a agglutinin of the donor will be activated by the A agglutinogen of the patient
    • Agglutination will occur
  • This is not a safe donation
• Blood Donations (continued)
  • Type AB (whole blood) donor cannot donate to type B patient
    • The A agglutinogen of the donor will activate the a agglutinin in the plasma of the type B patient
    • Agglutination will occur
    • This is not a safe donation
• Blood Donations (continued)
  • Type B (whole blood) donor cannot donate to type AB patient
    • The B agglutinogen of the donor will not activate any agglutinins of the patient because the patient does not have any agglutinins; however:
    • The A agglutinogen of the patient will activate the a agglutinin from the donor
    • Agglutination will occur
    • This is not a safe donation
• Blood Donations (continued)
  • Type O (packed cells) donor *can* donate to type B patient
    • The type O donor does not have any agglutinogens to activate the a agglutinin in the plasma of the patient
  • **This is a safe donation**
Blood Donations (continued)

- Type O (whole blood) donor *cannot* donate to type B patient
  - The type O donor is also donating the a and b agglutinins
  - The B agglutinogen of the patient will activate the b agglutinins from the plasma of the type O donor
- **This is not a safe donation**
The plasma contains antibodies that will react with foreign surface antigens in a process called agglutination. The cells may also break apart, an event known as hemolysis.
Formed Elements

• Leukocytes
  • There are two major classes of leukocytes consisting of a total of five major types of leukocytes
    • Granulocytes:
      • Neutrophils, eosinophils, basophils
    • Agranulocytes:
      • Monocytes, lymphocytes
Figure 20.5 Histology of White Blood Cells

- Neutrophil
- Eosinophil
- Basophil
- Monocyte
- Lymphocyte

LM x 1500
Leukocytes (continued)

- There are 6000 to 9000 per microliter of blood
  - A total WBC count is performed on an instrument called a hemocytometer
    - A low count is called leukopenia
    - An elevated count is called leukocytosis
- A differential count is performed to determine which of the leukocytes is in excess or deficient
• Leukocytes (continued)
  • Have a short life span (usually a few days)
  • When the body is compromised, the white blood cells multiply to combat the invading agent or allergen, etc.
  • Leukocytes can undergo diapedesis
  • Chemotaxis draws the leukocytes toward the invading agent
Formed Elements

- Granulocytes
  - **Neutrophils** (normal range is 50–70 percent)
    - Granules contain chemicals to kill bacteria
    - Typically the first WBC at the bacterial site
    - Very active phagocytic cells
    - Nucleus is multilobed
Figure 20.5 Histology of White Blood Cells
Formed Elements

• Granulocytes
  • **Eosinophils** (normal range is 2–4 percent)
    • Granules release chemicals that reduce inflammation
    • Attack a foreign substance that has reacted with circulating antibodies (such as an allergic reaction or parasites)
    • Typically have a bilobed nucleus
Figure 20.5 Histology of White Blood Cells

- Neutrophil
- Eosinophil
- Basophil
- Monocyte
- Lymphocyte

LM x 1500
Formed Elements

• Granulocytes
  • **Basophils** (normal range less than 1 percent)
    • Granules release **histamine** and **heparin**
      • Histamine dilates blood vessels
      • Heparin prevents abnormal blood clotting
    • Nucleus is usually hidden due to all the granules
Figure 20.5 Histology of White Blood Cells

- Neutrophil
- Eosinophil
- Basophil
- Monocyte
- Lymphocyte

LM x 1500
Formed Elements

• Agranulocytes
  • **Monocytes** (normal range is 2–8 percent)
    • Large phagocytic cells
    • Nucleus is kidney-shaped or large oval-shaped
    • Release chemicals to attract other phagocytic cells
    • Release chemicals to attract fibroblasts
      • **Fibroblasts** produce collagen fibers to surround an infected site
      • These collagen fibers can produce scar tissue
      • Scar tissue forms a wall around the pathogen to prevent it from spreading
Figure 20.5 Histology of White Blood Cells

- Neutrophil
- Eosinophil
- Basophil
- Monocyte
- Lymphocyte

LM x 1500
Formed Elements

• Agranulocytes
  • **Lymphocytes** (normal range is 20–30 percent)
    • Responsible for specific immunity
    • Can differentiate to form:
      • T cells
      • B cells
      • NK cells
    • Nucleus is typically large and round leaving a small halo around the entire nucleus or part of it
Figure 20.5 Histology of White Blood Cells

- Neutrophil
- Eosinophil
- Basophil
- Monocyte
- Lymphocyte

LM x 1500
Formed Elements

• Agranulocytes
  • T cells
    • Attack foreign cells directly
  • B cells
    • Secrete antibodies to attack foreign cells
• NK cells
  • Responsible for immune surveillance
Formed Elements

• Platelets

  • Derived from **megakaryocytes**
    • Megakaryocytes will fragment forming bits and pieces of membrane-enclosed packets of chemicals
      • The main chemical is platelet thromboplastin factor
  • About 350,000 per microliter of blood
  • Formerly called **thrombocytes**
Figure 20.6 Histology of Megakaryocytes and Platelet Formation

Nutrient artery

Venous sinuses

Red bone marrow

Developing erythrocytes and granulocytes

Adipocyte

Bone marrow section

LM × 673

Megakaryocyte

Platelets

Red blood cell
Formed Elements

• Platelets
  • Thrombocytopenia
    • Lower than normal number of platelets
  • Thrombocytosis
    • Higher than normal number of platelets
Formed Elements

• Platelet Function
  • Involved in blood clotting (hemostasis)
  • Release chemicals to initiate the clotting process (platelet thromboplastin factor)
  • Clump together to form a platelet plug
  • Contain actin and myosin that function to contract the clot
Hemopoiesis

• Hemopoiesis (blood formation)
  • Begins with pluripotential stem cells
  • Differentiate to form two cells:
    • Myeloid stem cells
    • Lymphatic stem cells
Hemopoiesis

• Hemopoiesis
  • Myeloid stem cells differentiate to eventually form:
    • Erythrocytes
    • Platelets
    • Basophils
    • Eosinophils
    • Neutrophils
    • Monocytes
Hemopoiesis

• Hemopoiesis (continued)
  • Lymphatic stem cells differentiate to eventually form:
    • Lymphocytes
Hemopoiesis

• Details of Hemopoiesis (blood formation)
  • Begin with **pluripotential stem cells**
  • Differentiate to form **myeloid stem cells**
  • Differentiate to form **progenitor cells**
  • Differentiate to form **proerythroblast cells**
  • Differentiate to form **erythroblast cells**
  • Differentiate to form **reticulocytes**
  • Differentiate to form **erythrocytes**
Hemopoiesis

• Details of Hemopoiesis (continued)
  • Begin with **pluripotential stem cells**
  • Differentiate to form **myeloid stem cells**
  • Differentiate to form **progenitor cells**
  • Differentiate to form **megakaryoblasts**
  • Differentiate to form **platelets**
Details of Hemopoiesis (continued)

- Begin with pluripotential stem cells
- Differentiate to form myeloid stem cells
- Differentiate to form progenitor cells
- Differentiate to form myeloblasts and monoblasts
  - Myeloblasts differentiate to form myelocytes
  - Monoblasts differentiate to form promonocytes
Figure 20.8 The Origins and Differentiation of Formed Elements

- Pluripotential Stem Cells
  - Myeloid Stem Cells
    - Progenitor Cells
      - Blasts
        - Myelocytes
        - Band Cells
        - Reticulocyte
      - Erythroblast stages
        - Proerythroblast
        - Ejection of nucleus
        - Reticulocyte
  - Lymphatic Stem Cells
    - Proerythroblast
    - Megakaryocyte
    - Platelets
    - Erythrocytes
    - Basophils
    - Eosinophils
    - Neutrophils
    - Monocytes
    - Lymphocytes
    - Granulocytes
    - Agranulocytes
Hemopoiesis

• Details of Hemopoiesis (continued)
  • Myelocytes differentiate to form **band cells** (nucleus forms a band)
  • Band cells form segmented cells (nucleus becomes segmented)
    • Basophils
    • Eosinophils
    • Neutrophils
  • Promonocytes differentiate to form **monocytes**
Hemopoiesis

• Details of Hemopoiesis (continued)
  • Begin with pluripotential stem cells
  • Differentiate to form lymphatic stem cells
  • Differentiate to form lymphoblasts
  • Differentiate to form prolymphocytes
  • Differentiate to form lymphocytes
  • Differentiate to form:
    • B cells
    • T cells
    • NK cells
Figure 20.8 The Origins and Differentiation of Formed Elements

- Red bone marrow
- Pluripotential Stem Cells
  - Myeloid Stem Cells
  - Lymphatic Stem Cells
- Progenitor Cells
- Blast Cells
- Myelocytes
- Band Cells
- Erythroblast stages
- Ejection of nucleus
- Megakaryocyte
- Platelets
- Erythrocyte

- Red Blood Cells (RBCs)
- White Blood Cells
  - Basophil
  - Eosinophil
  - Neutrophil
  - Monocyte
  - Lymphocyte
  - Granulocytes
  - Agranulocytes

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