Chapter 11

The Cardiovascular System: Blood

PowerPoint® Lecture Slides
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Lone Star College - North Harris
Introduction to the Cardiovascular System

• A circulating transport system
  – A pump (the heart)
  – A conducting system (blood vessels)
  – A fluid medium (blood):
    • Is specialized fluid of connective tissue
    • Contains cells suspended in a fluid matrix
Introduction to the Cardiovascular System

• To transport materials to and from cells
  – Oxygen and carbon dioxide
  – Nutrients
  – Hormones
  – Immune system components
  – Waste products
11-1 Blood has several important functions and unique physical characteristics
Functions of Blood

- Transport of dissolved substances
- Regulation of pH and ions
- Restriction of fluid losses at injury sites
- Defense against toxins and pathogens
- Stabilization of body temperature
Composition of Blood

• Whole Blood

  – Plasma:
    • Fluid consisting of:
      – water
      – dissolved plasma proteins
      – other solutes

  – Formed elements:
    • All cells and solids
The Composition of Whole Blood

Figure 11-1

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The Composition of Whole Blood

Sample of whole blood

- Formed elements (37–54%)

**(c) Formed elements of blood**

- Platelets
- White blood cells 0.1%
- Red blood cells 99.9%

PLATELETS

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

WHITE BLOOD CELLS

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

RED BLOOD CELLS

Figure 11-1

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The Composition of Whole Blood

• Three Types of Formed Elements
  – Red blood cells (RBCs) or erythrocytes:
    • Transport oxygen
  – White blood cells (WBCs) or leukocytes:
    • Part of the immune system
  – Platelets:
    • Cell fragments involved in clotting
The Composition of Whole Blood

- Hemopoiesis
  - Process of producing formed elements
  - By myeloid and lymphoid stem cells

- Fractionation
  - Process of separating whole blood for clinical analysis:
    - Into plasma and formed elements
The Composition of Whole Blood

- Blood volume (liters) = 7% of body weight (kilograms)
  - Adult male: 5 to 6 liters
  - Adult female: 4 to 5 liters
Blood Collection and Analysis

• Three General Characteristics of Blood
  – 38°C (100.4°F) is normal temperature
  – High viscosity
  – Slightly alkaline pH (7.35–7.45)
11-2 Plasma, the fluid portion of blood, contains significant quantities of plasma proteins.
The Composition of Plasma

• Makes up 46% to 63% of blood volume
• More than 90% of plasma is water
• Extracellular fluids
  – Interstitial fluid (IF) and plasma
  – Materials plasma and IF exchange across capillary walls:
    • Water
    • Ions
    • Small solutes
The Composition of Plasma

• Differences between Plasma and IF
  – Levels of $O_2$ and $CO_2$
  – Concentrations and types of dissolved proteins:
    • Plasma proteins do not pass through capillary walls
Plasma Proteins

- **Albumins** (60%)
  - Transport substances such as fatty acids, thyroid hormones, and steroid hormones

- **Globulins** (35%)
  - Antibodies, also called immunoglobulins
  - Transport globulins (small molecules): hormone-binding proteins, metalloproteins, apolipoproteins (**lipoproteins**), and steroid-binding proteins

- **Fibrinogen** (4%)
  - Molecules that form clots and produce long, insoluble strands of fibrin
Plasma Proteins

• Serum
  – Liquid part of a blood sample:
    • In which dissolved fibrinogen has converted to solid fibrin

• Other Plasma Proteins
  – 1% of plasma:
    • Changing quantities of specialized plasma proteins
    • Enzymes and hormones
Plasma Proteins

• Origins of Plasma Proteins
  – 90% + made in liver
  – Antibodies made by plasma cells
  – Peptide hormones made by endocrine organs
11-3 Red blood cells, formed by erythropoiesis, contain hemoglobin that can be recycled
Red Blood Cells

- Red blood cells (RBCs) make up 99.9% of blood’s formed elements

- Hemoglobin
  - The red pigment that gives whole blood its color
  - Binds and transports oxygen and carbon dioxide
Abundance of RBCs

• **Red blood cell count**: the number of RBCs in 1 microliter of whole blood
  – Male: 4.5–6.3 million
  – Female: 4.2–5.5 million

• **Hematocrit** (packed cell volume, PCV): percentage of RBCs in centrifuged whole blood
  – Male: 40–54
  – Female: 37–47
Structure of RBCs

• Small and highly specialized discs
• Thin in middle and thicker at edge
  – Importance of RBC shape and size:
    • High surface-to-volume ratio:
      – Quickly absorbs and releases oxygen
    • Discs bend and flex entering small capillaries
Figure 11-2

(a) Blood smear

(b) SEM of RBCs

(c) Sectional view of RBC

0.45–1.16 μm    2.31–2.85 μm
7.2–8.4 μm
Hemoglobin Structure and Function

- Hemoglobin (Hb)
  - Protein molecule that transports respiratory gases
  - Normal hemoglobin (adult male):
    - 14–18 g/dL whole blood
  - Normal hemoglobin (adult female):
    - 12–16 g/dL whole blood
Hemoglobin Structure and Function

• Hemoglobin Structure
  – Complex quaternary structure
  – Four globular protein subunits:
    • Each with one molecule of heme
    • Each heme contains one iron ion
  – Iron ions:
    • Associate easily with oxygen (oxyhemoglobin)
      » OR
    • Dissociate easily from oxygen (deoxyhemoglobin)
Hemoglobin Structure and Function

• Lack nuclei, mitochondria, and ribosomes
  – Means no repair and *anaerobic* metabolism
  – Live about 120 days
Hemoglobin Structure and Function

• Hemoglobin Function
  – Carries oxygen
  – With low oxygen (peripheral capillaries):
    • Hemoglobin releases oxygen
    • Binds carbon dioxide and carries it to the lungs
Abnormal Hemoglobin

Figure 11-3

(a) Normal RBC

(b) Sickled RBC
RBC Life Span and Circulation

- RBC Formation and Turnover
  - 1% of circulating RBCs wear out per day:
    - About 3 million RBCs per second
  - Macrophages of liver, spleen, and bone marrow:
    - Monitor RBCs
    - Engulf RBCs before membranes rupture (hemolyze)
• Hemoglobin Recycling
  – Phagocytes break hemoglobin into components:
    • Globular proteins to amino acids
    • Heme to *biliverdin*
    • Iron
  – Hemoglobinuria:
    • Hemoglobin breakdown products in urine due to excess hemolysis in bloodstream
  – Hematuria:
    • Whole red blood cells in urine due to kidney or tissue damage
Iron Recycling

- Iron removed from heme leaving biliverdin
- To transport proteins (transferrin)
- To storage proteins (ferritin and hemosiderin)
Figure 11-4

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RBC Formation

• RBC Production
  – Erythropoiesis:
    • Occurs only in **myeloid tissue** (red bone marrow) in adults
    • Stem cells mature to become RBCs

• Hemocytoblasts
  – Stem cells in myeloid tissue divide to produce:
    • **Myeloid stem cells**: become RBCs, some WBCs
    • **Lymphoid stem cells**: become lymphocytes
Figure 11-5
Red Blood Cells

• Regulation of Erythropoiesis
  – Building red blood cells requires:
    • Amino acids
    • Iron
    • Vitamins B\textsubscript{12}, B\textsubscript{6}, and folic acid:
      – pernicious anemia:
        » low RBC production
        » due to unavailability of vitamin B\textsubscript{12}
Red Blood Cells

• Stimulating Hormones
  – Erythropoietin (EPO):
    • Also called erythropoiesis-stimulating hormone
    • Secreted when oxygen in peripheral tissues is low (hypoxia)
    • Due to disease or high altitude
Figure 11-6

Erythropoiesis
<table>
<thead>
<tr>
<th>TEST</th>
<th>DETERMINES</th>
<th>TERMS ASSOCIATED WITH ABNORMAL VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HEMATOCRIT (HCT)</strong></td>
<td>Percentage of formed elements in whole blood</td>
<td>ELEVATED</td>
</tr>
<tr>
<td></td>
<td>Normal = 37–54%</td>
<td>Polycythemia (may result from erythrocytosis or leukocytosis)</td>
</tr>
<tr>
<td><strong>COMPLETE BLOOD COUNT (CBC)</strong></td>
<td>Number of RBCs per mL of whole blood</td>
<td>Erythrocytosis/polycythemia</td>
</tr>
<tr>
<td>RBC count</td>
<td>Normal = 4.2–6.3 million/μL</td>
<td>Anemia</td>
</tr>
<tr>
<td><strong>Hemoglobin concentration (Hb)</strong></td>
<td>Concentration of hemoglobin in blood</td>
<td>Anemia</td>
</tr>
<tr>
<td></td>
<td>Normal = 12–18 g/dL</td>
<td>Reticulocytosis</td>
</tr>
<tr>
<td><strong>Reticulocyte count (Retic.)</strong></td>
<td>Circulating percentage of reticulocytes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal = 0.8%</td>
<td></td>
</tr>
<tr>
<td><strong>Mean corpuscular volume (MCV)</strong></td>
<td>Average volume of a single RBC</td>
<td>Macrocytic</td>
</tr>
<tr>
<td></td>
<td>Normal = 82–101μm³ (normocytic)</td>
<td>Hyperchromic</td>
</tr>
<tr>
<td><strong>Mean corpuscular hemoglobin concentration (MCHC)</strong></td>
<td>Average amount of Hb in one RBC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal = 27–34 pg/μL (normochromic)</td>
<td></td>
</tr>
</tbody>
</table>
11-4 The ABO blood types and Rh system are based on antigen–antibody responses
Blood Typing

• Are cell surface proteins that identify cells to immune system

• Normal cells are ignored and foreign cells attacked

• Blood types
  – Are genetically determined
  – By presence or absence of RBC surface antigens A, B, Rh (or D)
Blood Types and Cross-Reactions

**Figure 11-7a**
Figure 11-7b

Surface antigens + Opposing antibodies → Agglutination (clumping) and hemolysis
• The Rh Factor
  – Also called D antigen
  – Either Rh positive (Rh\(^+\)) or Rh negative (Rh\(^-\)):
    • Only **sensitized** Rh\(^-\) blood has anti-Rh antibodies
<table>
<thead>
<tr>
<th>POPULATION</th>
<th>PERCENTAGE WITH EACH BLOOD TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>O</td>
</tr>
<tr>
<td>U.S. (AVERAGE)</td>
<td>46</td>
</tr>
<tr>
<td>African American</td>
<td>49</td>
</tr>
<tr>
<td>Caucasian</td>
<td>45</td>
</tr>
<tr>
<td>Chinese American</td>
<td>42</td>
</tr>
<tr>
<td>Filipino American</td>
<td>44</td>
</tr>
<tr>
<td>Hawaiian</td>
<td>46</td>
</tr>
<tr>
<td>Japanese American</td>
<td>31</td>
</tr>
<tr>
<td>Korean American</td>
<td>32</td>
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<tr>
<td>NATIVE NORTH AMERICAN</td>
<td>79</td>
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<tr>
<td>NATIVE SOUTH AMERICAN</td>
<td>100</td>
</tr>
<tr>
<td>AUSTRALIAN ABORIGINAL</td>
<td>44</td>
</tr>
</tbody>
</table>
11-5 The various types of white blood cells contribute to the body’s defenses
White Blood Cells

- Also called leukocytes
- Do not have hemoglobin
- Have nuclei and other organelles
- WBC functions
  - Defend against pathogens
  - Remove toxins and wastes
  - Attack abnormal cells
• Most WBCs in
  – Connective tissue proper
  – Lymphoid system organs

• Small numbers in blood
  – 5000 to 10,000 per microliter
• Characteristics of circulating WBCs
  – Can migrate out of bloodstream
  – Have amoeboid movement
  – Attracted to chemical stimuli (positive chemotaxis)
  – Some are phagocytic:
    • Neutrophils, eosinophils, and monocytes
White Blood Cells

- Types of WBCs
  - Neutrophils
  - Eosinophils
  - Basophils
  - Monocytes
  - Lymphocytes
Types of WBCs

Figure 11-8
Types of WBCs

Figure 11-8
Types of WBCs

- Neutrophils
  - Also called **polymorphonuclear leukocytes**
  - 50% to 70% of circulating WBCs
  - Pale cytoplasm granules with:
    - Lysosomal enzymes
    - Bactericides (hydrogen peroxide and superoxide)
Types of WBCs

• Eosinophils
  – Also called acidophils
  – 2% to 4% of circulating WBCs
  – Attack large parasites
  – Excrete toxic compounds:
    • Nitric oxide
    • Cytotoxic enzymes
  – Are sensitive to allergens
  – Control inflammation with enzymes that counteract inflammatory effects of neutrophils and mast cells
Types of WBCs

• Basophils
  – Are less than 1% of circulating WBCs
  – Are small
  – Accumulate in damaged tissue
  – Release histamine:
    • Dilates blood vessels
  – Release heparin:
    • Prevents blood clotting
Types of WBCs

- Monocytes
  - 2% to 8% of circulating WBCs
  - Are large and spherical
  - Enter peripheral tissues and become macrophages
  - Engulf large particles and pathogens
  - Secrete substances that attract immune system cells and fibrocytes to injured area
Types of WBCs

- Lymphocytes
  - 20% to 30% of circulating WBCs
  - Are larger than RBCs
  - Migrate in and out of blood
  - Mostly in connective tissues and lymphoid organs
  - Are part of the body’s specific defense system
Differential Counts

- Detects changes in WBC populations
- Infections, inflammation, and allergic reactions
WBC Formation

• All blood cells originate from hemocytoblasts
  – Which produce myeloid stem cells and lymphoid stem cells

• Myeloid Stem Cells
  – Differentiate into progenitor cells, which produce all WBCs except lymphocytes

• Lymphoid Stem Cells
  – Lymphopoiesis: the production of lymphocytes
Figure 11-5
## Table 11-3: A Review of the Formed Elements of the Blood

<table>
<thead>
<tr>
<th>CELL</th>
<th>ABUNDANCE (AVERAGE PER μL)</th>
<th>FUNCTIONS</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>RED BLOOD CELLS</td>
<td>5.2 million (range: 4.4–6.0 million)</td>
<td>Transport oxygen from lungs to tissues, and carbon dioxide from tissues to lungs</td>
<td>Remain in bloodstream; 120-day life expectancy; amino acids and iron recycled; produced in bone marrow</td>
</tr>
<tr>
<td>CELL</td>
<td>ABUNDANCE (AVERAGE PER μL)</td>
<td>FUNCTIONS</td>
<td>REMARKS</td>
</tr>
<tr>
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<td>---------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>WHITE BLOOD CELLS</td>
<td>7000 (range: 6000–9000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutrophils</td>
<td>4150 (range: 1800–7300)</td>
<td>Phagocytic: Engulf pathogens or debris in tissues, release cytotoxic enzymes and chemicals</td>
<td>Move into tissues after several hours; survive minutes to days, depending on tissue activity; produced in bone marrow</td>
</tr>
<tr>
<td>Eosinophils</td>
<td>165 (range: 0–700)</td>
<td>Attack antibody-labeled materials through release of cytotoxic enzymes and/or phagocytosis</td>
<td>Move into tissues after several hours; survive minutes to days, depending on tissue activity; produced in bone marrow</td>
</tr>
<tr>
<td>Basophils</td>
<td>44 (range: 0–150)</td>
<td>Enter damaged tissues and release histamine and other chemicals that promote inflammation</td>
<td>Survival time unknown; assist mast cells of tissues in producing inflammation; produced in bone marrow</td>
</tr>
<tr>
<td>CELL</td>
<td>ABUNDANCE (AVERAGE PER μL)</td>
<td>FUNCTIONS</td>
<td>REMARKS</td>
</tr>
<tr>
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<td>-------------------------------------------------</td>
</tr>
<tr>
<td>Monocytes</td>
<td>456 (range: 200–950)</td>
<td>Enter tissues to become macrophages; engulf pathogens or debris</td>
<td>Move into tissues after 1–2 days; survive months or longer; primarily produced in bone marrow</td>
</tr>
<tr>
<td></td>
<td>Differential count: 2–8%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>2185 (range: 1500–4000)</td>
<td>Cells of lymphoid system; provide defense against specific pathogens or toxins</td>
<td>Survive months to decades; circulate from blood to tissues and back; produced in bone marrow and lymphoid tissues</td>
</tr>
<tr>
<td></td>
<td>Differential count: 20–30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CELL</td>
<td>ABUNDANCE (AVERAGE PER µL)</td>
<td>FUNCTIONS</td>
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</tr>
<tr>
<td>-----------</td>
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<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>PLATELETS</td>
<td>350,000 (range: 150,000–500,000)</td>
<td>Hemostasis: Clump together and stick to vessel wall (platelet phase); initiate coagulation phase</td>
<td>Remain in circulation or in vascular organs; survive 7–12 days; produced by megakaryocytes in bone marrow</td>
</tr>
</tbody>
</table>
11-6 Platelets, disc-shaped structures formed from megakaryocytes, function in the clotting process
Platelets

- Cell fragments involved in human clotting system
  - Nonmammalian vertebrates have thrombocytes (nucleated cells)
- Circulate for 9 to 12 days
- Are removed by spleen
- Two-thirds are reserved for emergencies
Platelets

- **Platelet Counts**
  - 150,000 to 500,000 per microliter
  - **Thrombocytopenia:**
    - Abnormally low platelet count
  - **Thrombocytosis:**
    - Abnormally high platelet count
11-7 Hemostasis involves vascular spasm, platelet plug formation, and blood coagulation.
Phases of Hemostasis

• Hemostasis is the cessation of bleeding

• Consists of three phases
  – Vascular phase
  – Platelet phase
  – Coagulation phase
Phases of Hemostasis

• The Vascular Phase
  – A cut triggers vascular spasm that lasts 30 minutes
  – Three steps of the vascular phase:
    • Endothelial cells contract:
      – expose basal lamina to bloodstream
    • Endothelial cells release:
      – chemical factors: ADP, tissue factor, and prostacyclin
      – local hormones: endothelins
      – stimulate smooth muscle contraction and cell division
    • Endothelial plasma membranes become “sticky”:
      – seal off blood flow
Phases of Hemostasis

• The Platelet Phase
  – Begins within 15 seconds after injury
  – Platelet adhesion (attachment):
    • To sticky endothelial surfaces
    • To basal laminae
    • To exposed collagen fibers
  – Platelet aggregation (stick together):
    • Forms platelet plug
    • Closes small breaks
Phases of Hemostasis

• The Coagulation Phase
  
  – Begins 30 seconds or more after the injury
  
  – Blood clotting (coagulation):
    
    • Cascade reactions:
      
      – chain reactions of enzymes and proenzymes
      
      – form three pathways
      
      – convert circulating fibrinogen into insoluble fibrin
The Coagulation Phase of Hemostasis

Figure 11-10
The Coagulation Phase of Hemostasis

Figure 11-9

- Trapped RBC
- Fibrin network
- Platelets
Hemostasis

• Three Coagulation Pathways
  – **Extrinsic pathway:**
    • Begins in the vessel wall
    • Outside bloodstream
  – **Intrinsic pathway:**
    • Begins with circulating proenzymes
    • Within bloodstream
  – **Common pathway:**
    • Where intrinsic and extrinsic pathways converge
• **Clot Retraction**

  – After clot has formed:
    
    • Platelets contract and pull torn area together

  – Takes 30 to 60 minutes
Clot Retraction and Removal

• Fibrinolysis
  – Slow process of dissolving clot:
    • Thrombin and tissue plasminogen activator (t-PA):
      – activate plasminogen
  – Plasminogen produces plasmin:
    • Digests fibrin strands