Chapter 06
Lecture Outline

See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.
Cardiovascular System: Blood
Points to ponder

• What type of tissue is blood and what are its components?
• What is found in plasma?
• Name the three formed elements in blood and their functions.
• How does the structure of red blood cells relate to their function?
• Describe the structure and function of each white blood cell.
• What are disorders of red blood cells, white blood cells, and platelets?
• What do you need to know before donating blood?
• What are antigens and antibodies?
• How are ABO blood types determined?
• What blood types are compatible for blood transfusions?
• What is the Rh factor and how is this important to pregnancy?
• How does the cardiovascular system interact with other systems to maintain homeostasis?
What are the functions of blood?

- Transportation: oxygen, nutrients, wastes, carbon dioxide, and hormones
- Defense: against invasion by pathogens
- Regulatory functions: body temperature, water-salt balance, and body pH
What is the composition of blood?

- Remember: blood is a fluid connective tissue.

- **Formed elements** are produced in red bone marrow.
  - Red blood cells/erythrocytes (RBCs)
  - White blood cells/leukocytes (WBCs)
  - Platelets/thrombocytes
What is the composition of blood?

- **Plasma**
  - It consists of 91% water and 9% salts (ions) and organic molecules.
  - **Plasma proteins** are the most abundant organic molecules.
Three major types of plasma proteins

- **Albumins** – most abundant and important for plasma’s **osmotic pressure** as well as transport
- **Globulins** – also important in transport
- **Fibrinogen** – important for the formation of blood clots
Where do the formed elements come from and what are they?

- **Stem cells**
- **Erythroblasts**
- **Lymphoblasts**
- **Monoblasts**
- **Myeloblasts**
- **Megakaryoblasts**

**Stem cells for the white blood cells**

- **Erythroblasts**
  - Red Blood Cell (erythrocyte) transports $O_2$ and helps transport $CO_2$
- **Lymphoblasts**
  - Lymphocyte active in specific immunity
- **Monoblasts**
  - Monocyte becomes large phagocyte
- **Myeloblasts**
  - Neutrophil (contains granules) phagocytizes pathogens
  - Eosinophil (contains granules) active in allergies and worm infections
  - Basophil (contains granules) releases histamine
- **Megakaryoblasts**
  - Platelets (thrombocytes) aid blood clotting

**Figure 6.1** How cells in the blood are formed.
The structure of red blood cells is important to their function

- They lack a nucleus and have few organelles.
- Their biconcave shape increases surface area.
- Each RBC contains about 280 million hemoglobin molecules that bind 3 molecules of O\textsubscript{2} each.
The structure of red blood cells is important to their function.

**Figure 6.3** Red blood cells and the structure of hemoglobin.
How is carbon dioxide transported?

- 68% as a bicarbonate ion in the plasma (this conversion takes place in RBCs)
- 25% bound to hemoglobin in red blood cells
- 7% as carbon dioxide in the plasma

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^-
\]
Production of red blood cells

• They are produced in the red bone marrow.

• They have a lifespan of about 120 days.

• Erythropoietin (EPO) is secreted by kidney cells and moves to red marrow when oxygen levels are low.

• Old cells are destroyed by the liver and spleen.
Production of red blood cells

1. Low $O_2$ blood level
2. Kidney increases production of erythropoietin.
3. Stem cells increase red blood cell production.
4. $O_2$ blood level returns to normal.

Normal $O_2$ blood level

Figure 6.4 Response of the kidneys to a decrease in blood oxygen concentration.
What is blood doping?

• It is any method of increasing the number of RBCs to increase athletic performance.

• It allows more efficient delivery of oxygen and reduces fatigue.

• EPO is injected into a person months prior to an athletic event.

• It is thought to be able to cause death due to thickening of blood that leads to a heart attack.
What disorders involve RBCs?

- **Anemia** – a condition resulting from too few RBCs or too little hemoglobin that causes a “run-down” feeling

- **Sickle-cell anemia** – genetic disease that causes RBCs to become sickle-shaped and prone to rupture

- **Hemolytic disease of the newborn** – a condition with incompatible blood types that leads to rupturing of blood cells in a baby before and continuing after birth
White blood cells

- Derived from red bone marrow
- Large blood cells that have a nucleus
- Production regulated by colony-stimulating factor (CSF)
- Can be found in the tissues as well as the blood
- Fight infection and are an important part of the immune system
- Some live for only days while others live months or years
### What do white blood cells look like?

<table>
<thead>
<tr>
<th>White Blood Cells</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Granular leukocytes</strong></td>
<td></td>
</tr>
<tr>
<td>• Neutrophils</td>
<td>Phagocytize pathogens and cellular debris.</td>
</tr>
<tr>
<td>• Eosinophils</td>
<td>Use granule contents to digest large pathogens, such as worms, and reduce inflammation.</td>
</tr>
<tr>
<td>• Basophils</td>
<td>Promote blood flow to injured tissues and the inflammatory response.</td>
</tr>
<tr>
<td><strong>Agranular leukocytes</strong></td>
<td></td>
</tr>
<tr>
<td>• Lymphocytes</td>
<td>Responsible for specific immunity; B cells produce antibodies; T cells destroy cancer and virus-infected cells.</td>
</tr>
<tr>
<td>• Monocytes</td>
<td>Become macrophages that phagocytize pathogens and cellular debris.</td>
</tr>
</tbody>
</table>

**Figure 6.5** Some example of white blood cells.
How are white blood cells categorized?

- **Granular leukocytes** – contain noticeable granules, lobed nuclei
  - Neutrophil
  - Eosinophil
  - Basophil

- **Agranular leukocytes** – no granules, nonlobed nuclei
  - Lymphocyte
  - Monocyte
**Neutrophils**

- About 50-70% of all WBCs

- Have a multilobed nucleus

- Upon infection, move out of circulation into tissues to engulf pathogens by phagocytosis
Eosinophils

- Small percentage of WBCs
- Have a bilobed nucleus
- Many large granules function in parasitic infections and play a role in allergies
Basophil

- Small percentage of WBCs
- Have a U-shaped or lobed nucleus
- Release histamine related to allergic reactions
Lymphocyte

- About 25-35% of all WBCs
- Large nucleus that takes up most of the cytoplasm
- Develop into B and T cells that are important in the immune system
Monocyte

- Relatively uncommon WBCs

- Largest WBC, with horseshoe-shaped nucleus

- Take residence in tissues and develop into macrophages

- Macrophages use phagocytosis to engulf pathogens
How do blood cells leave circulation?

Figure 6.6 Movement of white blood cells into the tissue.
What disorders involve WBCs?

- **Severe combined immunodeficiency disease (SCID)** – an inherited disease in which stem cells of WBCs lack an enzyme that allows them to fight infection.

- **Leukemia** – a group of cancers that affect white blood cells in which these cells proliferate without control.

- **Infectious mononucleosis** – also known as the “kissing disease” and occurs when the Epstein-Barr virus (EBV) infects lymphocytes resulting in fatigue, sore throat, and swollen lymph nodes.
Platelets

• They result from fragmentation of large cells, called megakaryocytes, in the red bone marrow.

• About 200 billion platelets are made per day.

• They function in blood clotting.

• Blood proteins named thrombin and fibrinogen create clots by forming fibrin threads that catch RBCs.
How do platelets clot blood?

1. Blood vessel is punctured.

2. Platelets congregate and form a plug.

3. Platelets and damaged tissue cells release prothrombin activator, which initiates a cascade of enzymatic reactions.

4. Fibrin threads form and trap red blood cells.

Figure 6.7 The steps in the formation of a blood clot.

- Blood-clotting process
- Blood clot

4,400x

Figure 6.7b: © Eye of Science/Science Source
What disorders involve platelets?

- **Thrombocytopenia** – a disorder in which the number of platelets is too low due to not enough being made in the bone marrow or the increased breakdown outside the marrow.

- **Thromboembolism** – when a clot forms and breaks off from its site of origin and plugs another vessel.

- **Hemophilia** – a genetic disorder that results in a deficiency of a clotting factor so that when a person damages a blood vessel they are unable to properly clot their blood both internally and externally.
What do you need to know about donating blood?

• Donating blood is a safe and sterile procedure.

• You will donate about a pint of blood.

• You will replace the plasma in a few hours and the cells in a few weeks.

• A few people may feel dizzy afterwards so sit down, eat a snack, and drink some water.
What do you need to know about donating blood?

• Your blood will at least be tested for syphilis, HIV antibodies, and hepatitis; if any of them come back positive you will be notified.

• Your blood can help save many lives.

• You should not give blood if you
  – have ever had hepatitis or malaria, or been treated for syphilis or gonorrhea within the past 12 months.
  – are at risk for having HIV or have AIDS.
What terminology can help you understand ABO blood typing?

- **Antigen** – a foreign substance, often a polysaccharide or a protein, that stimulates an immune response

- **Antibody** – a protein made in response to an antigen in the body which binds specifically to that antigen

- **Blood transfusion** – the transfer of blood from one individual into another individual
What determines the A, B, AB, or O blood type?

• Presence and/or absence of 2 blood antigens, A and B

• Type of antibodies present

• Antibodies are only present for those antigens lacking on the cells because these proteins recognize and bind the protein they are named after.
What determines the A, B, AB, or O blood type?

Type A blood. Red blood cells have type A surface antigens. Plasma has anti-B antibodies.

Figure 6.8 The ABO blood type system (Type A blood).
How can you remember what each blood type means?

- Blood types are named after the protein antigens that are present on the surface of the RBCs, except type O whose RBCs entirely lack A and B antigens.
- Blood types only have antibodies to antigens they do not have on the surface of their RBCs.
- For example, someone with type A blood has
  - A proteins on the surfaces of her RBCs.
  - B antibodies in her blood.
- What can you say about someone with type AB blood?
Looking at each blood type in the ABO blood system

Type A blood. Red blood cells have type A surface antigens. Plasma has anti-B antibodies.

Type B blood. Red blood cells have type B surface antigens. Plasma has anti-A antibodies.

Type A B blood. Red blood cells have type A and type B surface antigens. Plasma has neither anti-A nor anti-B antibodies.

Type O blood. Red blood cells have neither type A nor type B surface antigens. Plasma has both anti-A and anti-B antibodies.

Figure 6.8 The ABO blood type system.
How can you determine if blood types are compatible for a blood transfusion?

• First, consider the antigens found on the blood transfusion donor’s RBCs.

• Second, consider the antibodies found in the recipient’s blood.

• If the antibodies in the recipient’s blood can recognize the antigens on the donor’s RBCs, then the blood will agglutinate (clump) and cause rejection.
How can you determine if blood types are compatible for a blood transfusion?

**Figure 6.9** Blood compatibility and agglutination.

- **a. No agglutination**
  - Type A blood of donor + anti-B antibody of type A recipient → no binding

- **b. Agglutination**
  - Type A blood of donor + anti-A antibody of type B recipient → binding
Testing your understanding

• Can a person with blood type O accept blood type A without agglutination occurring? Why or why not?

• Why can people with AB blood type accept more blood types than people with type O, A, or B?

• Which blood type is able to be used most often as a donor blood type? Why?
What about Rh blood groups?

• The Rh factor is often included when expressing a blood type by naming it positive or negative.

• People with the Rh factor are positive and those without it are negative.

• Rh antibodies only develop in a person when they are exposed to the Rh factor from another’s blood (usually a fetus).
When is the Rh factor important?

- During pregnancy under these conditions:
  - Mom: Rh⁻
  - Dad: Rh⁺
  - Fetus: Rh⁺ (possible with the parents above)

- In the case above, some Rh⁺ blood can leak from the fetus to the mother during birth causing the mother to make Rh antibodies.

- This can be a problem if the mother later has a second fetus that is Rh⁺ because she now has antibodies that can leak across the placenta and attack the fetus.

- This condition, known as hemolytic disease of the newborn, can lead to retardation and even death.
How can we visualize hemolytic disease of the newborn?

a. Fetal Rh-positive red blood cells leak across placenta into mother's blood stream.

b. Mother forms anti-Rh antibodies that cross the placenta and attack fetal Rh-positive red blood cells.

Figure 6.10  Rh factor disease (hemolytic disease of the newborn).
How can hemolytic disease of the newborn be prevented?

- Rh\(^-\) women are given an injection of anti-Rh antibodies no later than 72 hours after giving birth to an Rh\(^+\) baby.

- These antibodies attack fetal red blood cells in the mother before the mother’s immune system can make antibodies.

- This will have to be repeated if an Rh\(^-\) mother has another Rh\(^+\) baby in case she has later pregnancies.
6.6 Homeostasis

How do the heart, blood vessels, and blood work with other systems to maintain homeostasis?

**Cardiovascular System**
- Heart pumps the blood. Blood vessels transport oxygen and nutrients to the cells of all the organs and transport wastes away from them. The blood clots to prevent blood loss. The cardiovascular system also specifically helps the other systems as mentioned below.

**Muscular System**
- Muscle contraction keeps blood moving through the heart and in the blood vessels, particularly the veins.

**Digestive System**
- Blood vessels deliver nutrients from the digestive tract to the cells. The digestive tract provides the molecules needed for plasma protein formation and blood cell formation. The digestive system absorbs the water needed to maintain blood pressure and the Ca^{2+} needed for blood clotting.

**Urinary System**
- Blood vessels transport wastes to be excreted. Kidneys excrete wastes and help regulate the water-salt balance necessary to maintain blood volume and pressure and help regulate the acid-base balance of the blood.

**Nervous System**
- Nerves help regulate the contraction of the heart and the constriction/dilation of blood vessels.

**Endocrine System**
- Blood vessels transport hormones from glands to their target organs. The hormone epinephrine increases blood pressure; other hormones help regulate blood volume and blood cell formation.

**Respiratory System**
- Blood vessels transport gases to and from lungs. Gas exchange in lungs supplies oxygen and rids the body of carbon dioxide, helping to regulate the acid-base balance of blood. Breathing aids venous return.

**Lymphatic System**
- Capillaries are the source of tissue fluid, which becomes lymph. The lymphatic system helps maintain blood volume by collecting excess tissue fluid (i.e., lymph), and returning it via lymphatic vessels to the cardiovascular veins.

**Skeletal System**
- The rib cage protects the heart, red bone marrow produces blood cells, and bones store Ca^{2+} for blood clotting.

**Figure 6.11** How body systems cooperate to ensure homeostasis.