Chapter 1 Blood

♦ Definition
- Blood is a type of connective tissue that consists of cells surrounded by a fluid extracellular matrix.
- Blood, blood vessels, and the heart collectively form the cardiovascular system.

♦ Physical Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>volume</td>
<td>5 L</td>
</tr>
<tr>
<td>pH</td>
<td>7.4</td>
</tr>
<tr>
<td>temperature</td>
<td>38°C (100.4°F)</td>
</tr>
<tr>
<td>% Body Weight</td>
<td>8</td>
</tr>
<tr>
<td>viscosity</td>
<td>thicker than water</td>
</tr>
</tbody>
</table>

The temperature of blood is slightly higher than the normal body temperature of 37°C (98.6°F).

♦ Functions
- Blood has 4 major functions:

1. It transports dissolved gases, nutrients, nitrogenous wastes, and hormones.

2. It provides the body with immunity (defense) against foreign microbes (pathogens) and their toxins.

3. It regulates the electrolyte (ion) composition and volume of body fluids.

4. It protects the body from excessive fluid loss by clotting.
Components

-Blood consists of 2 major components: **plasma**, which is the fluid matrix, and the **formed elements**, which are the cells (Figure 19.1, Tortora).

1. **plasma**
   -the fluid matrix of blood
   -constitutes 55% of blood
   -straw-colored (i.e. light yellow)
   -Composition
     a. water
        -the main component (92%) of plasma and, consequently, is also the main component of blood
     b. solutes
        -constitute 1% of plasma
        -include
          1. nutrients
          2. electrolytes
             -include Na$^+$ ions, Ca$^{+2}$ ions, K$^+$ ions, etc.
             -The **amount** of Na$^+$ ions in the blood regulates the blood volume.
             -This is due to the fact that Na$^+$ ions attract water via osmosis.
          3. dissolved gases
          4. nitrogenous wastes
          5. hormones
     c. proteins
        -constitute 7% of plasma
        -3 types:
          1. **albumins**
             -the most abundant plasma proteins
             -produced by the liver
             -Functions:
               a. They provide the blood with viscosity.
               b. They serve as transporters for hydrophobic hormones in the blood.
          2. **antibodies**
             -also called **immunoglobulins**
             -function in immunity (i.e. antibodies specifically destroy foreign microbes)
             -Antibodies are produced by plasma cells, which are derived from B cells (a type of white blood cell).
          3. **fibrinogen**
             -produced by the liver
             -functions as a participant in the blood clotting process
2. **formed elements**
- the cells found in blood
- constitute 45% of blood
- 3 types of formed elements: erythrocytes, leukocytes, and platelets.
  a. **erythrocytes**
    - also called *red blood cells* (RBCs)
    - constitute 99% of the formed elements and, consequently, are the main cell type in blood
  - **Structure**
    - RBCs resemble *biconcave discs* (they are circular in shape with very thin central regions) (Figure 19.4, Tortora).
    - The diameter of a red blood cell is typically about 8 µm.
    - However, a capillary (a type of blood vessel that undergoes gas exchange with tissue cells of the body) has a diameter of 5 to 8 µm.
      - Hence, RBCs must bend as they travel through capillaries; in addition, RBCs often stack on top of one another forming a *rouleaux*.
    - A mature RBC lacks organelles (not even a nucleus); consequently, a mature RBC cannot reproduce nor repair itself and, therefore, only lasts for about 120 days.
    - A mature RBC, however, does contain hemoglobin (Figure 19.4, Tortora).
  - **hemoglobin**
    - a red protein that is responsible for the red color of the RBC and, in fact, for the red color of blood
    - Each RBC has millions of hemoglobin molecules located in the cytosol.
      - Hemoglobin is produced when the RBC is immature and still has a nucleus.
    - Hemoglobin consists of 4 protein subunits referred to as *globins* (α₁, α₂, β₁, and β₂); each globin contains a red *heme* group, which consists of a *porphyrin ring* that surrounds an *iron ion* (Fe⁺² ) in the center.
    - Hemoglobin binds to O₂ and to CO₂ and transports these gases through the blood.
      - **Transport of O₂ by hemoglobin from lungs to body cells**
        - The iron ion (Fe⁺² ) in each heme group of a hemoglobin molecule can bind to one molecule of O₂; since there are four heme groups, one hemoglobin molecule can bind to a maximum of four O₂ molecules.
        - Oxygen and hemoglobin bind in a reversible reaction; by convention, this reaction is written for a single heme-polypeptide unit of a hemoglobin molecule:
-Hence, a single heme-polypeptide unit can exist in two forms: **deoxyhemoglobin**, in which no O$_2$ is bound and **oxyhemoglobin**, in which O$_2$ is bound.

-The net direction of the reaction between oxygen and hemoglobin depends on the oxygen level.

-In the alveoli of the lungs, there is plenty of O$_2$ available because O$_2$ has been inhaled; as a result, O$_2$ binds to hemoglobin to form oxyhemoglobin, which is bright red.

-In all other tissues of the body, the O$_2$ level is low because the cells are using up O$_2$ in metabolic reactions. As blood flows through tissue capillaries, the reaction between hemoglobin and oxygen reverses: hemoglobin releases O$_2$ to tissue cells, forming deoxyhemoglobin, which is dark red.

-Arterial blood is bright red because nearly all of its hemoglobin molecules exist in the oxyhemoglobin form; venous blood is dark red because it contains a significant number of deoxyhemoglobin molecules.

-Transport of CO$_2$ by hemoglobin from body cells to lungs

-Certain amino acids in each globin subunit of a hemoglobin molecule bind to CO$_2$, forming a complex called **carbaminohemoglobin**:

\[
\text{Hb} + \text{CO}_2 \rightleftharpoons \text{Hb-CO}_2
\]

-The net direction of the reaction between carbon dioxide and hemoglobin depends on the carbon dioxide level.

-In body tissues other than the alveoli, the CO$_2$ level is high because cells produce CO$_2$ as a waste product via metabolic reactions. As a result, blood flowing through tissue capillaries picks up CO$_2$, some of which combines with hemoglobin to form carbaminohemoglobin.

- In the alveoli of the lungs, the level of CO$_2$ is low because CO$_2$ has been exhaled. As blood flows through the capillaries around the alveoli, the reaction between carbon dioxide and hemoglobin reverses: CO$_2$ is released from hemoglobin and then exhaled from the body.

-Function

-RBCs transport O$_2$ from the lungs to body cells and CO$_2$ from body cells to the lungs.

-This transport function of blood occurs via hemoglobin.
b. leukocytes
- constitute less than 1% of the formed elements
- also called white blood cells because they lack hemoglobin and are clear (i.e. not red)
  - Since they are clear, they must be stained with dyes in order to be observed under the light microscope (Figure 19.7 and Table 19.3, Tortora).
- nucleated (i.e. each leukocyte contains a nucleus)
- 2 major types of leukocytes: granular leukocytes and agranular leukocytes.
  1. granular leukocytes
    - also called granulocytes
    - leukocytes that have visible cytoplasmic granules (secretory vesicles such as lysosomes) under the light microscope and that have lobed nuclei
    - 3 types based on (i) the color of the cytoplasmic granules and (ii) the number of lobes of the nucleus.
    a. neutrophils
      - the most numerous type of leukocyte
      - Structure
        - A neutrophil contains cytoplasmic granules that stain light pink.
        - The nucleus of a neutrophil has 3 to 4 lobes connected by thin strands; hence, a neutrophil is also called a polymorphonuclear leukocyte.
      - Function
        - Neutrophils participate in nonspecific immunity by phagocytizing foreign microbes that invade the body.
    b. eosinophils
      - Structure
        - An eosinophil contains cytoplasmic granules that stain orange to red.
        - The nucleus is bilobed (has 2 lobes).
      - Function
        - Eosinophils participate in nonspecific immunity by phagocytizing foreign microbes (especially parasitic worms) that invade the body.
    c. basophils
      - Structure
        - A basophil contains cytoplasmic granules that stain dark purple.
        - The nucleus is lobed, often shaped like the letter S or U.
      - Function
        - Basophils participate in nonspecific immunity
by promoting **inflammation** in response to tissue damage caused by injury or foreign microbes that invade the body. Inflammation is characterized by redness, pain, heat, and swelling; it serves as a “call to arms” that attracts other leukocytes to the area to fight the invading pathogens. Basophils promote inflammation by releasing a substance called **histamine**.

2. **agranular leukocytes**
   - also called **agranulocytes**
   - leukocytes that lack visible cytoplasmic granules under the light microscope
     - Note that these cells actually do have cytoplasmic granules but they are too small to be seen under a light microscope.
   - Agranulocytes also lack lobed nuclei.
   - There are 2 major types of agranular leukocytes: lymphocytes and monocytes.
     a. **lymphocytes**
        - Structure
          - A lymphocyte has a round nucleus that takes up most of the space in the cell, leaving only a thin peripheral ring of cytoplasm.
          - Found in blood and in lymphatic tissue (for example: lymph nodes)
        - 2 types
          1. **B lymphocytes**
             - also called **B cells**
          2. **T lymphocytes**
             - also called **T cells**
        - Function
          Lymphocytes participate in specific immunity.
     b. **monocytes**
        - Structure
          - A monocyte contains a nucleus that is shaped like a kidney or a horseshoe.
          - Typically, there is more cytoplasm in a monocyte than in a lymphocyte.
        - Function
          - Monocytes participate in nonspecific immunity by phagocytizing foreign microbes that invade the body.
          - During the process, monocytes develop into huge cells called **macrophages**.
          - Macrophages are the most phagocytic leukocytes.
c. **platelets**
   - constitute less than 1% of the formed elements
   - also called **thrombocytes**
   - **Structure**
     - Platelets are actually fragments of cells.
   - **Function**
     - Platelets cause blood to clot, a process called **hemostasis**.
     - Both fibrinogen and factor VIII are proteins that are involved in hemostasis.

♦ Separation of Blood
   - The components of blood can be separated in the following ways:

   (i) blood centrifugation (Figure 19.1, Tortora)

   Spin blood in a **centrifuge** tube.

   The plasma and formed elements separate from each other based on density. The RBCs are heaviest (most dense) and, thus, settle at the bottom of the centrifuge tube. The plasma is least dense and is found at the top of the centrifuge tube. Between the RBCs and the plasma is a thin layer of white blood cells and platelets.

   - This procedure is used to calculate the **hematocrit**:

     hematocrit (hct)
     - the % of blood that is RBCs
     - can be calculated by dividing the length of the tube that consists of RBCs by the total length of all of the components in the tube and then multiplying by 100
     - For men, the typical hct is 45.
     - For women, the typical hct is 40.

(ii) blood standing

   Take a drop of blood and let it stand for a period of time.

   Gradually, the blood will separate into a central **clot** and a peripheral region of **serum**. The clot consists of the formed elements and the clotting proteins (such fibrinogen) that are usually present in plasma. The serum is a straw-colored fluid that consists of the remaining components of plasma (H₂O, antibodies, albumins, wastes, etc.). **Hence, serum is plasma without its clotting proteins.**
Origin of the Formed Elements: Hematopoiesis

-Overview

-Blood cells are not immortal; they suffer physical wear and tear as they pass through blood vessels and perform their various functions in the body.
-Eventually, aged blood cells are removed from the circulation and destroyed, usually by macrophages of the spleen.
-As the chart illustrates below, blood cells differ in their life spans:

<table>
<thead>
<tr>
<th>Blood Cell</th>
<th>Life Span</th>
</tr>
</thead>
<tbody>
<tr>
<td>erythrocyte</td>
<td>120 days</td>
</tr>
<tr>
<td>neutrophil, eosinophil, basophil</td>
<td>hrs to days</td>
</tr>
<tr>
<td>monocyte/macrophage</td>
<td>days to months</td>
</tr>
<tr>
<td>B and T lymphocytes</td>
<td>decades</td>
</tr>
<tr>
<td>platelets</td>
<td>10 days</td>
</tr>
</tbody>
</table>

-New blood cells must be formed as aged blood cells are destroyed; this process of blood cell formation is called hematopoiesis.

-Hematopoiesis

-also called hemopoiesis
- the formation of blood cells
-occurs in red bone marrow, which is found in spongy bone (such as in the epiphyses of the humerus and femur)
-accomplished via stem cells called hemocytoblasts (pluripotent stem cells) (Figure 19.3, Tortora)

-Hemocytoblasts can develop into the following immature cell types:

1. proerythroblasts
   -develop into mature erythrocytes

erythropoiesis

- the formation of RBCs
-involves special nutritional requirements:
  a. iron
    -required for the heme group
  b. folic acid
  c. vitamin B12
-occurs when the kidney releases the hormone erythropoietin in response to low oxygen in tissues and cells (hypoxia), which can occur due to
hemorrhage, high altitudes, or exercise (Figure 19.6, Tortora)

The erythropoietin then travels through the blood to the red bone marrow of a bone to stimulate the hemocytoblasts to develop into proerythroblasts, which then differentiate into mature RBCs.

2. myeloblasts
   - develop into granular leukocytes

3. lymphoblasts
   - develop into lymphocytes (both B and T cells)

4. monoblasts
   - develop into monocytes

- Myeloblasts, lymphoblasts, and monoblasts are all part of the collective process called leukopoiesis.
  
  **leukopoiesis**
  - the formation of WBCs
  - stimulated by **cytokines** (interleukins and colony stimulating factors), which are released by existing leukocytes.

5. megakaryoblasts
   - develop into platelets

**thrombopoiesis**
- the formation of platelets.
- stimulated by **thrombopoietin (TPO)**, which is produced by the liver.
Blood Groups

-The cell membranes of RBCs contain self antigens, while the plasma contains antibodies that destroy foreign antigens (like pathogens or the blood cells from another blood type of another person).

**ABO Blood Group**

-The ABO blood group is based on two glycolipid antigens (agglutinogens) called A and B (Figure 19.12, Tortora):

- Type A blood contains only the A antigen in the cell membranes of red blood cells.
- Type B blood contains only the B antigen in the membranes of red blood cells.
- Type AB blood contains both A and B antigens in red blood cell membranes.
- Type O blood contains neither A nor B antigens in red blood cell membranes.

-Plasma usually contains antibodies (agglutinins) that react with A or B antigens; you do not have antibodies that react with the antigens of your own red blood cells, but you do have antibodies for any antigens that your red blood cells lack (Figure 19.12, Tortora):

- Type A blood contains only anti-B antibodies in the plasma.
- Type B blood contains only anti-A antibodies in the plasma.
- Type AB blood contains neither anti-A antibodies nor anti-B antibodies in the plasma.
- Type O blood contains both anti-A antibodies and anti-B antibodies in the plasma.

-In practice, a person should receive their same blood type during a blood transfusion.

-This means that ideally, a person with type A blood should receive type A blood; a person with type B blood should receive type B; a person with type AB blood should receive type AB; and a person with type O blood should receive type O.

-When a person receives the wrong blood type, the antigens and antibodies interact, causing **agglutination** (clumping) of blood.

-This can be fatal because the red blood cells in agglutinated blood are at a standstill and no oxygen will be delivered to the cells of the body; in addition, agglutination leads to **hemolysis** (rupturing) of the red blood cells.

- Agglutination occurs, for example, if a person with type A blood receives a transfusion of type B blood (Figure 1.1, Derrickson).

- The recipient’s blood (type A) contains A antigens on the red blood cells and anti-B antibodies in the plasma; the donor’s blood (type B) contains B antigens and anti-A antibodies.

- In this situation, two things can happen:

- First, the anti-B antibodies in the recipient’s plasma can bind to the B antigens on the donor’s red blood cells, causing agglutination and hemolysis of the red blood cells.

- Second, the anti-A antibodies in the donor’s plasma can bind to the A antigens on the recipient’s red blood cells, a less serious reaction because the donor’s anti-A antibodies become so diluted in the recipient’s plasma that they do not cause significant agglutination and hemolysis of the recipient’s red blood cells.
-Universal Recipient vs. Universal Donor

-Type AB blood is called the **universal recipient** because it lacks anti-A antibodies and anti-B antibodies.

-However, the antibodies of donor blood can cause agglutination, but the agglutination is usually not significant due to the low concentration of donor antibodies relative to the volume of the recipient blood.

-Type O blood is called the **universal donor** because no A antigens or B antigens are introduced into the recipient.

-However, there are antibodies in O blood, but usually these antibodies cause only minor agglutination due to the low concentration of these antibodies relative to the volume of the recipient blood.

Table 19.6 (Tortora) summarizes the ABO blood group interactions.

**-Rh Blood Group**

-Rh antigen

-Another self antigen that may be present in the cell membranes of RBCs

-Named as such because it was first described in the Rhesus monkey

-If the Rh antigen is present, then the person is Rh⁺ (positive).

-If the Rh antigen is absent, then the person is Rh⁻ (negative).

-Figure 1.2 (Derrickson) illustrates the Rh blood group.

-The ABO blood group system and the Rh blood group system are typically used together.

-For example, if a person has blood cells with the B antigen but lacks the Rh antigen, the person is B⁻.

♦ Clinical Applications and Disorders

-Look up the following clinical applications and disorders in Tortora:

1. withdrawing blood
   p. 669

2. bone marrow examination
   p. 674

3. blood doping
   p. 677-678

4. complete blood count
   p. 681

5. aspirin and thrombolytic agents
   p. 687
6. hemolytic disease of the newborn  
   p. 689
7. anticoagulants  
   p. 690
8. anemia  
   p. 690-691
9. sickle-cell disease  
   p. 691
10. hemophilia  
    p. 691-692
11. leukemia  
    p. 692
12. cyanosis  
    p. 692
13. hemorrhage  
    p. 692
14. jaundice  
    p. 692
15. phlebotomist  
    p. 692
16. septicemia  
    p. 692
17. venesection  
    p. 692
18. whole blood  
    p. 692
Figure 1.1
Agglutination and Hemolysis

The amount of agglutination and hemolysis that occurs in this reaction is significant because the recipient has a large volume of plasma that contains many anti-B antibodies.

The amount of agglutination and hemolysis that occurs in this reaction is insignificant because the donor’s anti-A antibodies are diluted in the large volume of the recipient’s plasma.
Figure 1.2
Rh Blood Group

(a) Type A⁺ blood, an example of Rh⁺ blood

(b) Type A⁻ blood, an example of Rh⁻ blood