10

Blood

ESSENTIALS OF HUMAN ANATOMY & PHYSIOLOGY
EIGHTH EDITION

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Blood

- The only fluid tissue in the human body
- Classified as a connective tissue
  - Living cells = formed elements
  - Non-living matrix = plasma
Figure 10.1

Blood

Plasma 55%

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Major Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Solvent for carrying other substances; absorbs heat</td>
</tr>
<tr>
<td>Salts (electrolytes)</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td>Osmotic balance, pH buffering, regulation of membrane permeability</td>
</tr>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td></td>
</tr>
<tr>
<td>Bicarbonate</td>
<td></td>
</tr>
<tr>
<td>Plasma proteins</td>
<td></td>
</tr>
<tr>
<td>Albumin</td>
<td>Osmotic balance, pH buffering</td>
</tr>
<tr>
<td>Fibrinogen</td>
<td>Clotting of blood</td>
</tr>
<tr>
<td>Globulins</td>
<td>Defense (antibodies) and lipid transport</td>
</tr>
<tr>
<td>Substances transported by blood</td>
<td></td>
</tr>
<tr>
<td>Nutrients (glucose, fatty acids, amino acids, vitamins)</td>
<td></td>
</tr>
<tr>
<td>Waste products of metabolism (urea, uric acid)</td>
<td></td>
</tr>
<tr>
<td>Respiratory gases (O₂ and CO₂)</td>
<td></td>
</tr>
<tr>
<td>Hormones</td>
<td></td>
</tr>
</tbody>
</table>

Formed elements (cells) 45%

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Number (per mm³ of blood)</th>
<th>Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythrocytes (red blood cells)</td>
<td>4 – 6 million</td>
<td>Transport oxygen and help transport carbon dioxide</td>
</tr>
<tr>
<td>Leukocytes (white blood cells)</td>
<td>4000 – 11,000</td>
<td>Defense and immunity</td>
</tr>
<tr>
<td>Basophil</td>
<td></td>
<td>Lymphocyte</td>
</tr>
<tr>
<td>Eosinophil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutrophil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Platelets</td>
<td>250,000 – 500,000</td>
<td>Blood clotting</td>
</tr>
</tbody>
</table>
Physical Characteristics of Blood

- **Color range**
  - Oxygen-rich blood is scarlet red
  - Oxygen-poor blood is dull red

- pH must remain between 7.35–7.45

- Blood temperature is slightly higher than body temperature
Blood Plasma

- Composed of approximately 90 percent water
- Includes many dissolved substances
  - Nutrients
  - Salts/Electrolytes (metal ions)
  - Respiratory gases
  - Hormones
  - Proteins
  - Waste products
Plasma Proteins

- Albumin – regulates osmotic pressure
- Clotting proteins – help to stem blood loss when a blood vessel is injured
- Antibodies – help protect the body from antigens
Formed Elements

- Erythrocytes = red blood cells
- Leukocytes = white blood cells
- Thrombocytes/Platelets = cell fragments
Photomicrograph of a Blood Smear

Figure 10.2
### Characteristics of Formed Elements of the Blood

<table>
<thead>
<tr>
<th>Cell type</th>
<th>Occurrence in blood (per mm³)</th>
<th>Cell anatomy*</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Erythrocytes</strong></td>
<td>4–6 million</td>
<td>Salmon-colored biconcave disks; anucleate; literally, sacs of hemoglobin; most organelles have been ejected</td>
<td>Transport oxygen bound to hemoglobin molecules; also transport small amount of carbon dioxide</td>
</tr>
<tr>
<td>(red blood cells, or RBCs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Leukocytes</strong></td>
<td>4000–11,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(white blood cells, or WBCs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Granulocytes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Neutrophils</td>
<td>3000–7000 (40–70% of WBCs)</td>
<td>Cytoplasm stains pale pink and contains fine granules, which are difficult to see; deep purple nucleus consists of three to seven lobes connected by thin strands of nucleoplasm</td>
<td>Active phagocytes; number increases rapidly during short-term or acute infections</td>
</tr>
<tr>
<td>• Eosinophils</td>
<td>100–400 (1–4% of WBCs)</td>
<td>Red coarse cytoplasmic granules; figure-8 or bilobed nucleus stains blue-red</td>
<td>Kill parasitic worms; increase during allergy attacks; might phagocytize antigen-antibody complexes and inactivate some inflammatory chemicals</td>
</tr>
</tbody>
</table>
## Characteristics of Formed Elements of the Blood

<table>
<thead>
<tr>
<th>Cell type</th>
<th>Occurrence in blood (per mm³)</th>
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<th>Function</th>
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<tbody>
<tr>
<td>Agranulocytes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basophils</td>
<td>20–50 (0–1% of WBCs)</td>
<td>Cytoplasm has a few large blue-purple granules; U- or S-shaped nucleus with constrictions, stains dark blue</td>
<td>Granules contain histamine (vasodilator chemical), which is discharged at sites of inflammation</td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>1500–3000 (20–45% of WBCs)</td>
<td>Cytoplasm pale blue and appears as thin rim around nucleus; spherical (or slightly indented) dark purple-blue nucleus</td>
<td>Part of immune system; one group (B lymphocytes) produces antibodies; other group (T lymphocytes) involved in graft rejection, fighting tumors and viruses, and activating B lymphocytes</td>
</tr>
<tr>
<td>Monocytes</td>
<td>100–700 (4–8% of WBCs)</td>
<td>Abundant gray-blue cytoplasm; dark blue-purple nucleus often kidney-shaped</td>
<td>Active phagocytes that become macrophages in the tissues; long-term &quot;clean-up team&quot;; increase in number during chronic infections such as tuberculosis</td>
</tr>
<tr>
<td>Platelets</td>
<td>250,000–500,000</td>
<td>Essentially irregularly shaped cell fragments; stain deep purple</td>
<td>Needed for normal blood clotting; initiate clotting cascade by clinging to broken area; help to control blood loss from broken blood vessels</td>
</tr>
</tbody>
</table>

*Appearance when stained with Wright's stain.
Erythrocytes (Red Blood Cells)

- The main function is to carry oxygen
- Anatomy of circulating erythrocytes
  - Biconcave disks
  - Essentially bags of hemoglobin
  - Anucleate (no nucleus)
  - Contain very few organelles
- Outnumber white blood cells 1000:1
Erythrocyte Levels in the Blood

- **Anemia**
  - A decrease in the oxygen carrying-capacity of the blood due to low number of erythrocytes or deficient hemoglobin percentage in erythrocytes

- **Polycythemia**
  - Abnormally high number of erythrocytes
Hemoglobin

- Iron-containing protein
- Binds strongly, but reversibly, to oxygen
- Each hemoglobin molecule has four oxygen binding sites
- Each erythrocyte has 250 million hemoglobin molecules
Leukocytes (White Blood Cells)

- Crucial in the body’s defense against disease
- These are complete cells, with a nucleus and organelles
- Able to move into and out of blood vessels (diapedesis)
- Can move by ameboid motion
- Can respond to chemicals released by damaged tissues
Leukocyte Levels in the Blood

- Normal levels are between 4,000 and 11,000 cells per cubic millimeter

- Abnormal leukocyte levels
  - Leukocytosis
    - Above 11,000 leukocytes/mm$^3$
    - Generally indicates an infection
  - Leukopenia
    - Abnormally low leukocyte level
    - Commonly caused by certain drugs
Types of Leukocytes

- **Granulocytes**
  - Granules in their cytoplasm can be stained
  - Include neutrophils, eosinophils, and basophils

![Diagram of blood cell development](image)
Types of Leukocytes

- **Agranulocytes**
  - Lack visible cytoplasmic granules
  - Include lymphocytes and monocytes

Figure 10.4
Granulocytes

- Neutrophils
  - Multilobed nucleus with fine granules
  - Act as phagocytes at active sites of infection

- Eosinophils
  - Large brick-red cytoplasmic granules
  - Found in response to allergies and parasitic worms
Granulocytes

- Basophils
  - Have histamine-containing granules
  - Initiate inflammation
Agranulocytes

- Lymphocytes
  - Nucleus fills most of the cell
  - Play an important role in the immune response (includes B & T cells)
- Monocytes
  - Largest of the white blood cells
  - Function as macrophages
  - Important in fighting chronic infection
Platelets

- Cell fragments derived from ruptured multinucleate cells (megakaryocytes)
- Needed for the clotting process
- Normal platelet count = 300,000/mm³
Hematopoiesis

- Blood cell formation
- Occurs in red bone marrow
- All blood cells are derived from a common stem cell (hemocytoblast)
- Hemocytoblast differentiation
  - Lymphoid stem cell produces lymphocytes
  - Myeloid stem cell produces other formed elements (blood cells)
Fate of Erythrocytes

- Unable to divide, grow, or synthesize proteins
- Wear out in 100 to 120 days
- When worn out, are eliminated by phagocytes in the spleen or liver
- Lost cells are replaced with new cells by division of hemocytoblasts
Control of Erythrocyte Production

- Rate is controlled by a hormone (erythropoietin)
- Kidneys produce most erythropoietin as a response to reduced oxygen levels in the blood
- Homeostasis is maintained by negative feedback from blood oxygen levels
Control of Erythrocyte Production

Figure 10.5

- Increased O₂-carrying ability of blood
- More RBCs
- Enhanced erythropoiesis
- Erythropoietin stimulates
- Red bone marrow
- Kidney releases erythropoietin

Stimulus: Decreased RBC count, decreased availability of O₂ to blood, or increased tissue demands for O₂

Reduced O₂ levels in blood
Hemostasis

- Stoppage of blood flow
- Result of a break in a blood vessel
- Hemostasis involves three phases
  - Platelet plug formation
  - Vascular spasms
  - Coagulation
Platelet Plug Formation

- Collagen fibers are exposed by a break in a blood vessel
- Platelets become “sticky” and cling to fibers
- Anchored platelets release chemicals to attract more platelets
- Platelets pile up to form a platelet plug
Vascular Spasms

- Anchored platelets release serotonin
- Serotonin causes blood vessel muscles to spasm
- Spasms narrow the blood vessel, decreasing blood loss
Coagulation

- Injured tissues release thromboplastin

- PF₃ (a phospholipid) interacts with thromboplastin, blood protein clotting factors, and calcium ions to form an activator that triggers a clotting cascade

- Prothrombin activator converts prothrombin to thrombin (an enzyme)
Coagulation

- Thrombin joins fibrinogen proteins into hair-like fibrin
- Fibrin forms a meshwork (the basis for a clot)
1. Injury to lining of vessel exposes collagen fibers; platelets adhere

2. Platelets release serotonin, which causes vessels to constrict; vascular spasms occur. Platelets also release chemicals that attract more platelets to the site.

3. Coagulation events
   - (a) Tissue factor released by damaged cells
   - (b) PF₃ on platelets + Tissue factor, calcium, vitamin K and other clotting factors in blood plasma

   - (c) Prothrombin activator
   - (d) Prothrombin → Thrombin
     - Fibrinogen (soluble) → Fibrin (insoluble)
Blood Clotting

- Blood usually clots within 3 to 6 minutes
- The clot remains as endothelium regenerates
- The clot is broken down after tissue repair
Fibrin Clot

Figure 10.7
Undesirable Clotting

- **Thrombus (stationary)**
  - A clot in an unbroken blood vessel
  - Can be deadly in areas like the heart → heart attack

- **Embolus (moving)**
  - A thrombus that breaks away and floats freely in the bloodstream
  - Can later clog vessels in critical areas such as the brain → stroke
Bleeding Disorders

- Thrombocytopenia
  - Platelet deficiency
  - Even normal movements can cause bleeding from small blood vessels that require platelets for clotting

- Hemophilia
  - Hereditary bleeding disorder
  - Normal clotting factors are missing
Blood Groups and Transfusions

- Large losses of blood have serious consequences
  - Loss of 15 to 30 percent causes weakness
  - Loss of over 30 percent causes shock, which can be fatal
- Transfusions are the only way to replace blood quickly
- Transfused blood must be of the same blood group/type
Human Blood Groups

- Blood contains genetically determined proteins (self antigen)
- A foreign protein (foreign antigen) may be attacked by the immune system
- Blood is “typed” by using antibodies that will cause blood with certain proteins to clump (agglutination)
Human Blood Groups

- There are over 30 common red blood cell antigens
- The most vigorous transfusion reactions are caused by ABO and Rh blood group antigens
ABO Blood Groups

- Based on the presence or absence of two antigens
  - Type A
  - Type B
- The lack of these antigens is called type O
ABO Blood Groups

- The presence of both A and B is called type AB
- The presence of either A or B is called types A and B, respectively
Blood being tested

Type AB (contains antigens A and B); agglutinates with both sera

Type B (contains antigen B); agglutinates with anti-B serum

Type A (contains antigen A); agglutinates with anti-A serum

Type O (contains no antigens); no agglutination occurs
### Table 10.3  ABO Blood Groups

<table>
<thead>
<tr>
<th>Blood group</th>
<th>Frequency (% U.S. population)</th>
<th>RBC antigens (agglutinogens)</th>
<th>Illustration</th>
<th>Plasma antibodies (agglutinins)</th>
<th>Blood that can be received</th>
</tr>
</thead>
<tbody>
<tr>
<td>AB</td>
<td>4 4 5</td>
<td>A B</td>
<td><img src="image" alt="A and B illustration" /></td>
<td>None</td>
<td>A, B, AB, O Universal recipient</td>
</tr>
<tr>
<td>B</td>
<td>11 20 27</td>
<td>B</td>
<td><img src="image" alt="B illustration" /></td>
<td>Anti-A</td>
<td>B, O</td>
</tr>
<tr>
<td>A</td>
<td>40 27 28</td>
<td>A</td>
<td><img src="image" alt="A illustration" /></td>
<td>Anti-B</td>
<td>A, O</td>
</tr>
<tr>
<td>O</td>
<td>45 49 40</td>
<td>None</td>
<td><img src="image" alt="O illustration" /></td>
<td>Anti-A Anti-B</td>
<td>O Universal donor</td>
</tr>
</tbody>
</table>
Blood Typing

- Blood samples are mixed with anti-A and anti-B serum
- Coagulation or no coagulation leads to determining blood type
- Typing for ABO and Rh factors is done in the same manner
Rh Blood Groups

- Named because of the presence or absence of one of eight Rh antigens (agglutinogen D)
- Most Americans are Rh$^+$
- Problems can occur in mixing Rh$^+$ blood into a body with Rh$^-$ blood
Rh Dangers During Pregnancy

- Danger is only when the mother is Rh\(^-\) and the father is Rh\(^+\), and the child inherits the Rh\(^+\) factor
Rh Dangers During Pregnancy

- The mismatch of an Rh\(^-\) mother carrying an Rh\(^+\) baby can cause problems for the unborn child
  - The first pregnancy usually proceeds without problems
  - The immune system is sensitized after the first pregnancy
  - In a second pregnancy, the mother’s immune system produces antibodies to attack the Rh\(^+\) blood (hemolytic disease of the newborn)