Chapter 10
Blood

Slides 10.1 – 10.31

Lecture Slides in PowerPoint by Jerry L. Cook

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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
## Blood

**Figure 10.1**

### 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</td>
</tr>
<tr>
<td>Salts (electrolytes)</td>
<td></td>
</tr>
<tr>
<td>Sodium</td>
<td></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></td>
</tr>
<tr>
<td>Fibrinogen</td>
<td></td>
</tr>
<tr>
<td>Globulins</td>
<td></td>
</tr>
<tr>
<td>Substances transported by blood</td>
<td>Nutrients (e.g., glucose, fatty acids, vitamins, amino acids)</td>
</tr>
<tr>
<td></td>
<td>Waste products of metabolism</td>
</tr>
<tr>
<td></td>
<td>(urea, uric acid)</td>
</tr>
<tr>
<td></td>
<td>Respiratory gases ($O_2$ and $CO_2$)</td>
</tr>
<tr>
<td></td>
<td>Hormones</td>
</tr>
</tbody>
</table>

### Formed Elements (cells) 45%

| Cell type                  | Number (per mm$^2$ of blood) | Functions                                                            |
|----------------------------|------------------------------|                                                                     |
| Erythrocytes (red blood cells) | 4–6 million                  | Transport oxygen and help transport carbon dioxide                   |
| Leukocytes (white blood cells) | 4000–11,000                  | Defense and immunity                                                  |
|                            |                              | Lymphocyte                                                           |
| Basophil                   |                              |                                                                      |
| Eosinophil                 |                              |                                                                      |
| Neutrophil                 |                              |                                                                      |
| Monocyte                   |                              |                                                                      |
| Platelets                  | 250,000–500,000              | Blood clotting                                                      |
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 (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
- Platelets = cell fragments
<table>
<thead>
<tr>
<th>Cell type</th>
<th>Occurrence in blood (per mm$^3$)</th>
<th>Cell anatomy*</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythrocytes (red blood cells, or RBCs)</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>Leukocytes (white blood cells, or WBCs)</td>
<td>4000–11,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granulocytes</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>

*Appearance when stained with Wright*
<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>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>Agranulocytes</td>
<td></td>
<td></td>
<td></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 “clean-up team”; 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*
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
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 millimeter

- Abnormal leukocyte levels
  - Leukocytosis
    - Above 11,000 leukocytes/ml
    - 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 types](Figure 10.4)
Types of Leukocytes

- Agranulocytes
  - Lack visible cytoplasmic granules
  - Include lymphocytes and monocytes
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
- Monocytes
  - Largest of the white blood cells
  - Function as macrophages
  - Important in fighting chronic infection
Platelets

- Derived from ruptured multinucleate cells (megakaryocytes)
- Needed for the clotting process
- Normal platelet count = 300,000/mm$^3$
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
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 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

Stimulus: Decreased RBC count, decreased availability of $O_2$ to blood, or increased tissue demands for $O_2$.

Reduced $O_2$ levels in blood

Kidney releases erythropoietin

Erythropoietin stimulates

Red bone marrow

Enhanced erythropoiesis

More RBCs

Increased $O_2$-carrying ability of blood

Normal blood oxygen levels

Imbalance

Imbalance

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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
- PF$_3$ (a phospholipid) interacts with thromboplastin, blood protein clotting factors, and calcium ions to trigger 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)
Blood Clotting

• Blood usually clots within 3 to 6 minutes
• The clot remains as endothelium regenerates
• The clot is broken down after tissue repair
Undesirable Clotting

- Thrombus
  - A clot in an unbroken blood vessel
  - Can be deadly in areas like the heart

- Embolus
  - A thrombus that breaks away and floats freely in the bloodstream
  - Can later clog vessels in critical areas such as the brain
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
Human Blood Groups

- Blood contains genetically determined proteins
- A foreign protein (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
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)
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
- Cross matching – testing for agglutination of donor RBCs by the recipient’s serum, and vice versa
Developmental Aspects of Blood

- Sites of blood cell formation
  - The fetal liver and spleen are early sites of blood cell formation
  - Bone marrow takes over hematopoiesis by the seventh month
- Fetal hemoglobin differs from hemoglobin produced after birth