Chapter 23  Circulation

Introduction

- In many animals, the pull of gravity influences the flow of blood through the body.
- To regulate the pressure of blood in the head, the circulatory system of a giraffe uses
  - special valves,
  - saclike sinuses, and
  - other mechanisms.
- In humans, special one-way valves in veins prevent blood from flowing back down the legs.

23.1 Circulatory systems facilitate exchange with all body tissues

- All cells must
  - receive nutrients,
  - exchange gases, and
  - remove wastes.
- Diffusion alone is inadequate for large and complex bodies.
- In most animals, circulatory systems facilitate these exchanges.
23.1 Circulatory systems facilitate exchange with all body tissues

- An internal transport system assists diffusion by moving materials between
  - surfaces of the body and
  - internal tissues.

- A gastrovascular cavity in cnidarians and flatworms
  - promotes digestion and
  - distributes substances.

- Most animals use a true circulatory system that consists of a
  - circulatory fluid (blood),
  - muscular pump (heart), and
  - set of tubes (blood vessels) to carry the fluid.

- Open circulatory systems are found in arthropods and many molluscs and consist of
  - a heart,
  - open-ended vessels, and
  - blood that directly bathes the cells and functions as the interstitial fluid.

- Closed circulatory systems are found in vertebrates, earthworms, squids, and octopuses and consist of
  - a heart and
  - vessels that confine blood, keeping it distinct from interstitial fluid.

- The vertebrate circulatory system is often called a cardiovascular system, including three types of vessels.
  1. Arteries carry blood away from the heart.
  2. Veins return blood to the heart.
  3. Capillaries convey blood between arteries and veins.
23.1 Circulatory systems facilitate exchange with all body tissues

- The cardiovascular system of a fish includes a heart with two main chambers:
  1. The **atrium** receives blood from veins.
  2. The **ventricle** pumps blood to gills via large arteries.

- These large arteries branch into:
  - **arterioles** that give rise to
  - **capillaries**, the smallest blood vessels, which branch into networks called **capillary beds**.
  - Capillaries converge into **venules**, which in turn converge into larger veins.

23.2 EVOLUTION CONNECTION: Vertebrate cardiovascular systems reflect evolution

- A two-chambered heart
  - is characteristic of fish and
  - pumps blood in a **single circulation** in which blood moves
    - from gill capillaries,
    - to systemic capillaries, and
    - back to the heart.

- Land vertebrates have a **double circulation** consisting of a separate
  - pulmonary circuit and
  - systemic circuit.

- Three-chambered hearts
  - are found in amphibians, turtles, snakes, and lizards and
  - consist of
    - two atria and
    - one undivided ventricle.
  - This arrangement generally separates oxygen-poor and oxygen-rich blood.
23.2 EVOLUTION CONNECTION: Vertebrate cardiovascular systems reflect evolution

- Four-chambered hearts
  - are found in crocodilians, birds, and mammals and
  - consist of
    - two atria and
    - two ventricles.
  - These two circuits do not mix
    - oxygen-rich and
    - oxygen-poor blood.

23.3 The human cardiovascular system illustrates the double circulation of mammals

- Blood flow through the double circulatory system of humans
  - drains from the superior vena cava (from the head and arms) or inferior vena cava (from the lower trunk and legs) into the right atrium,
  - moves out to the lungs via the pulmonary artery,
  - returns to the left atrium through the pulmonary vein,
  - and
  - leaves the heart through the aorta.
23.4 The heart contracts and relaxes rhythmically

- The repeated contraction and relaxation of pumping blood is called the **cardiac cycle**. The cycle consists of two main phases.

  1. During **diastole**, blood flows
     - from veins
     - into heart chambers.
  2. During **systole**, blood flows
     - from atria
     - into ventricles.

23.5 The SA node sets the tempo of the heartbeat

- **The SA (sinoatrial) node**
  - generates electrical signals in atria and
  - sets the rate of heart contractions.

- **The AV (atrioventricular) node**
  - relays these signals to the ventricles and
  - causes ventricular contraction.
23.5 The SA node sets the tempo of the heartbeat

- An electrocardiogram (ECG) records electrical changes in the heart.
- Heart rates normally adjust to body needs.
- Abnormal rhythms may occur in a heart attack.
- Automatic external defibrillators (AEDs)
  - shock the heart,
  - reset the SA node, and
  - save thousands of lives.

23.6 CONNECTION: What is a heart attack?

- A heart attack
  - is damage or death of cardiac muscle and
  - usually results from a blocked coronary artery.
- Cardiovascular diseases are disorders of the heart and blood vessels. These include
  1. a stroke, death of brain tissue from blocked or ruptured arteries in the head, and
  2. atherosclerosis, in which fatty deposits in the walls of arteries narrow the blood vessels and restrict blood flow.
23.7 The structure of blood vessels fits their functions

- **Capillaries**
  - have thin walls consisting of a single layer of epithelial cells,
  - are narrow, about as wide as one red blood cell, and
  - increase surface area for gas and fluid exchange with the interstitial fluid.

- **Arteries and veins**
  - are lined by a single layer of epithelial cells and
  - have elastic fibers in an outer connective tissue layer that allows these vessels to recoil after stretching.
  - Arteries contain a thick layer of smooth muscle in their walls that can constrict and reduce blood flow.
  - Veins have one-way valves that restrict backward flow of blood.

23.8 Blood pressure and velocity reflect the structure and arrangement of blood vessels

- **Blood pressure**
  - is the force blood exerts on vessel walls,
  - depends on cardiac output and resistance of vessels to expansion, and
  - decreases as blood moves away from the heart.
23.8 Blood pressure and velocity reflect the structure and arrangement of blood vessels

- Blood pressure is
  - highest in arteries and
  - lowest in veins.
- Blood pressure is measured as
  - systolic pressure—caused by ventricular contraction, and
  - diastolic pressure—low pressure between contractions.

23.8 Blood pressure and velocity reflect the structure and arrangement of blood vessels

How does blood travel against gravity, up legs?
- Veins are squeezed by pressure from muscle contractions between
  - two muscles or
  - muscles and bone or skin.
- One-way valves limit blood flow to one direction, toward the heart.

23.9 CONNECTION: Measuring blood pressure can reveal cardiovascular problems

- A typical blood pressure for a healthy young adult is about 120/70.
- Blood pressure is commonly measured using a sphygmomanometer.
- Hypertension is a serious cardiovascular problem in which blood pressure is persistent at or above
  - 140 systolic and/or
  - 90 diastolic.
23.9 CONNECTION: Measuring blood pressure can reveal cardiovascular problems

- Hypertension causes
  - the heart to work harder, weakening the heart over time,
  - increased plaque formation from tiny ruptures, and
  - increased risk of blood clot formation.
- Hypertension can contribute to
  - heart attacks,
  - strokes, and/or
  - kidney failure.

23.10 Smooth muscle controls the distribution of blood

- Blood flow through capillaries is restricted by precapillary sphincters.
- By opening and closing these precapillary sphincters, blood flow to particular regions can be increased or decreased.
- Only about 5–10% of capillaries are open at one time.

23.11 Capillaries allow the transfer of substances through their walls

- Capillaries have very thin walls.
- Substances leave blood and enter interstitial fluid by
  - diffusion and
  - pressure-driven flow through clefts between epithelial cells.
- Blood pressure forces fluid out of capillaries at the arterial end.
- Osmotic pressure draws in fluid at the venous end.
STRUCTURE AND FUNCTION OF BLOOD

23.12 Blood consists of red and white blood cells suspended in plasma

- Blood consists of several types of cells suspended in a liquid called plasma, which
  - is about 90% water and
  - contains many different substances.

Figure 23.12_1

<table>
<thead>
<tr>
<th>Plasma (55%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constituent</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td>Ions (blood electrolytes)</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Potassium</td>
</tr>
<tr>
<td>Calcium</td>
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<tr>
<td>Magnesium</td>
</tr>
<tr>
<td>Chloride</td>
</tr>
<tr>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Plasma proteins</td>
</tr>
<tr>
<td>Fibrinogen</td>
</tr>
<tr>
<td>Immunoglobulins (antibodies)</td>
</tr>
</tbody>
</table>

Figure 23.12_2

<table>
<thead>
<tr>
<th>Substances transported by blood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrients (e.g., glucose, fatty acids, vitamins)</td>
</tr>
<tr>
<td>Waste products of metabolism (O2 and CO2)</td>
</tr>
<tr>
<td>Hormones</td>
</tr>
</tbody>
</table>

23.12 Blood consists of red and white blood cells suspended in plasma

- Two classes of cells are suspended in blood plasma.
  1. Red blood cells or erythrocytes transport O2 bound to hemoglobin.
  2. White blood cells, or leukocytes, function inside and outside the circulatory system and fight infections and cancer.
    - Monocytes and neutrophils are white blood cells called phagocytes, which engulf and digest bacteria and debris from our own dead cells.

Figure 23.12

<table>
<thead>
<tr>
<th>Cellular elements (45%)</th>
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</thead>
<tbody>
<tr>
<td>Cell type</td>
</tr>
<tr>
<td>Red blood cells (erythrocytes)</td>
</tr>
<tr>
<td>White blood cells (leukocytes)</td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td>Platelets</td>
</tr>
</tbody>
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    - fight infections and cancer.
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23.13 CONNECTION: Too few or too many red blood cells can be unhealthy

- Anemia can be caused by low amounts of
  - hemoglobin or
  - red blood cells.
- Anemia causes fatigue due to lack of oxygen in tissues.

- The hormone erythropoietin (EPO) regulates red blood cell production.
- Some athletes artificially increase red blood cell production by
  - training at high altitudes,
  - injecting erythropoietin, and
  - withdrawing, storing, and then reinjecting their blood cells just before a competition.
- Abuse of these methods can lead to clotting, stroke, heart failure, or even death.

23.14 Blood clots plug leaks when blood vessels are injured

- When a blood vessel is damaged
  - platelets rapidly adhere to the exposed connective tissue and
  - a cluster of sticky platelets forms a plug.
  - Clotting factors released from platelets and in the plasma help trigger the conversion of the plasma protein fibrinogen to fibrin, a threadlike protein that helps form a clot that plugs the leak.

- Within an hour after a fibrin clot forms, the platelets contract, pulling the torn edges closer together.
- Chemicals released by platelets also stimulate cell division in smooth muscle and connective tissue, initiating the healing process.
23.15 CONNECTION: Stem cells offer a potential cure for blood cell diseases

- **Multipotent stem cells**
  - are unspecialized and
  - replace themselves throughout the life of an organism.
- **Multipotent stem cells can differentiate into two main types of stem cells.**
  1. Lymphoid stem cells can in turn produce two types of lymphocytes, which function in the immune system.
  2. Myeloid stem cells can differentiate into
     - erythrocytes,
     - other white blood cells, and
     - platelets.

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You should now be able to

1. Describe the general functions of a circulatory system.
2. Compare the structures and functions of gastrovascular cavities, open circulatory systems, and closed circulatory systems.
3. Compare the cardiovascular systems of a fish, an amphibian, a reptile, a bird, and a mammal.
4. Describe the pathway of blood through the mammalian cardiovascular system.

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You should now be able to

5. Distinguish between diastole and systole.
6. Explain how heartbeats are controlled.
7. Define a heart attack and cardiovascular disease.
8. Relate the structure of blood vessels to their function.
9. Explain how and why blood pressure changes as blood moves away from the heart.
10. Explain how blood is moved back to the heart.
You should now be able to

11. Explain how blood pressure is measured. Give examples of normal and high blood pressure readings.
12. Explain how blood flow through capillaries is regulated.
13. Explain how the structure of a capillary relates to its functions.
14. Describe the components of blood and their functions.

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You should now be able to

15. Describe the structure, function, and production of red blood cells.
16. Describe the process of blood clotting.
17. Define leukemia and describe the most common forms of treatment.

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