Circulation

Chapter 37 Part 1
Impacts, Issues
And Then My Heart Stood Still

- Each heartbeat starts with an electrical signal; in sudden cardiac arrest, a defibrillator is needed to restart the heart
A circulatory system distributes materials throughout the vertebrate body (and some invertebrates)

A heart pumps the transport medium (blood) through vessels

Blood and interstitial fluid (fluid between cells) make up the body’s internal environment
Two Kinds of Circulatory Systems

- **Open circulatory system** (arthropods, mollusks)
  - Blood moves through hearts and large vessels, but also mixes with interstitial fluid

- **Closed circulatory system** (annelids, vertebrates)
  - Blood remains inside heart and blood vessels
  - Materials diffuse between blood and interstitial fluid at capillaries
Open and Closed Circulatory Systems

A In a grasshopper’s open system, a heart (not like yours) pumps blood through a vessel, a type of aorta. From there, blood moves into tissue spaces, mingles with interstitial fluid, then reenters the heart at openings in the heart wall.

B The closed system of an earthworm confines blood inside pairs of muscular hearts near the head end and inside many blood vessels.
A In a grasshopper’s open system, a heart (not like yours) pumps blood through a vessel, a type of aorta. From there, blood moves into tissue spaces, mingles with interstitial fluid, then reenters the heart at openings in the heart wall.

© Brooks/Cole, Cengage Learning
In a grasshopper’s open system, a heart (not like yours) pumps blood through a vessel, a type of aorta. From there, blood moves into tissue spaces, mingles with interstitial fluid, then reenters the heart at openings in the heart wall.
B The closed system of an earthworm confines blood inside pairs of muscular hearts near the head end and inside many blood vessels.
The closed system of an earthworm confines blood inside pairs of muscular hearts near the head end and inside many blood vessels.
Animation: Types of circulatory systems

- Open Circulatory System
- Closed Circulatory System
Evolution of Circulation in Vertebrates

- **Fishes**
  - Heart with two chambers
  - Single circuit of circulation

- **Amphibians**
  - Heart with three chambers
  - Two partially separated circuits

- **Birds and mammals**
  - Heart with four chambers
  - Two fully separate circuits
Circulation in Birds and Mammals

- The four-chambered heart has two separate halves, each with an atrium and a ventricle.
- Each half pumps blood in a separate circuit.
  - **Pulmonary circuit**: Blood flows from right half of heart, to lungs (gains oxygen), to left half of heart.
  - **Systemic circuit**: Blood flows from left half of heart, to body (loses oxygen), to right half of heart.
Comparison of Flow Circuits

A. In fishes, the heart has two chambers: one atrium and one ventricle. Blood flows through one circuit. It picks up oxygen in the capillary beds of the gills, and delivers it to capillary beds in all body tissues. Oxygen-poor blood then returns to the heart.

B. In amphibians, the heart has three chambers: two atria and one ventricle. Blood flows along two partially separated circuits. The force of one contraction pumps blood from the heart to the lungs and back. The force of a second contraction pumps blood from the heart to all body tissues and back to the heart.

C. In birds and mammals, the heart has four chambers: two atria and two ventricles. The blood flows through two fully separated circuits. In one circuit, blood flows from the heart to the lungs and back. In the second circuit, blood flows from the heart to all body tissues and back.

D. Why flow slows in capillaries. Picture a volume of water in two fast rivers flowing into and out of a lake. The flow rate is constant, with an identical volume moving from points 1 to 3 in the same interval. However, flow velocity decreases in the lake. Why? The volume spreads out through a larger cross-sectional area and flows forward a shorter distance during the specified interval.
A In fishes, the heart has two chambers: one atrium and one ventricle. Blood flows through one circuit. It picks up oxygen in the capillary beds of the gills, and delivers it to capillary beds in all body tissues. Oxygen-poor blood then returns to the heart.
In fishes, the heart has two chambers: one atrium and one ventricle. Blood flows through one circuit. It picks up oxygen in the capillary beds of the gills, and delivers it to capillary beds in all body tissues. Oxygen-poor blood then returns to the heart.
B  In amphibians, the heart has three chambers: two atria and one ventricle. Blood flows along two partially separated circuits. The force of one contraction pumps blood from the heart to the lungs and back. The force of a second contraction pumps blood from the heart to all body tissues and back to the heart.
In amphibians, the heart has three chambers: two atria and one ventricle. Blood flows along two partially separated circuits. The force of one contraction pumps blood from the heart to the lungs and back. The force of a second contraction pumps blood from the heart to all body tissues and back to the heart.
C In birds and mammals, the heart has four chambers: two atria and two ventricles. The blood flows through two fully separated circuits. In one circuit, blood flows from the heart to the lungs and back. In the second circuit, blood flows from the heart to all body tissues and back.
In birds and mammals, the heart has four chambers: two atria and two ventricles. The blood flows through two fully separated circuits. In one circuit, blood flows from the heart to the lungs and back. In the second circuit, blood flows from the heart to all body tissues and back.
D Why flow slows in capillaries. Picture a volume of water in two fast rivers flowing into and out of a lake. The flow rate is constant, with an identical volume moving from points 1 to 3 in the same interval. However, flow velocity decreases in the lake. Why? The volume spreads out through a larger cross-sectional area and flows forward a shorter distance during the specified interval.
D Why flow slows in capillaries. Picture a volume of water in two fast rivers flowing into and out of a lake. The flow rate is constant, with an identical volume moving from points 1 to 3 in the same interval. However, flow velocity decreases in the lake. Why? The volume spreads out through a larger cross-sectional area and flows forward a shorter distance during the specified interval.
Animation: Circulatory systems

- Capillary beds in gills
- Heart
- Capillary beds in body
Animation: Flow velocity
Many animals have either an open or a closed circulatory system that transports substances to and from all body tissues.

All vertebrates have a closed circulatory system, in which blood is always contained within the heart or blood vessels.
Blood consists mainly of plasma, a protein-rich fluid that carries wastes, gases and nutrients.

Blood cells and platelets form in bone marrow and are transported in plasma.

- Platelets are fragments of megakaryocytes, active in clotting.
Blood Cells

- **Red blood cells** (erythrocytes)
  - Contain hemoglobin that carries oxygen from lungs to tissues
  - Quantified in cell count

- **White blood cells** (leukocytes)
  - Defend the body from pathogens
  - Neutrophils, basophils, eosinophils, monocytes, and lymphocytes (B and T cells)
## Components of Human Blood

### Plasma Portion (50-60% of total blood volume)

<table>
<thead>
<tr>
<th>Components</th>
<th>Amounts</th>
<th>Main Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Water</td>
<td>91-92% of total plasma volume</td>
<td>Solvent</td>
</tr>
<tr>
<td>2. Plasma proteins (albumins, globulins, fibrinogen, etc.)</td>
<td>7-8%</td>
<td>Defense, clotting, lipid transport, extracellular fluid volume controls</td>
</tr>
<tr>
<td>3. Ions, sugars, lipids, amino acids, hormone, vitamins, dissolved gases, etc.</td>
<td>1-2%</td>
<td>Nutrition, defense, respiration, extracellular fluid volume controls, cell communication, etc.</td>
</tr>
</tbody>
</table>

### Cellular Portion (40-50% of total blood volume; numbers per microliter)

<table>
<thead>
<tr>
<th>Components</th>
<th>Amounts</th>
<th>Main Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Red blood cells</td>
<td>4,600,000-5,400,000</td>
<td>Oxygen, carbon dioxide transport to and from lungs</td>
</tr>
<tr>
<td>2. White blood cells: Neutrophils</td>
<td>3,000-6,750</td>
<td>Fast-acting phagocytosis</td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>1,000-2,700</td>
<td>Immune responses</td>
</tr>
<tr>
<td>Monocytes (macrophages)</td>
<td>150-720</td>
<td>Phagocytosis</td>
</tr>
<tr>
<td>Eosinophils</td>
<td>100-380</td>
<td>Killing parasitic worms</td>
</tr>
<tr>
<td>Basophils</td>
<td>25-90</td>
<td>Anti-inflammatory secretions</td>
</tr>
<tr>
<td>3. Platelets</td>
<td>250,000-300,000</td>
<td>Roles in blood clotting</td>
</tr>
</tbody>
</table>

© Brooks/Cole, Cengage Learning
<table>
<thead>
<tr>
<th>Components</th>
<th>Amounts</th>
<th>Main Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Plasma Portion (50-60% of total blood volume)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Water</td>
<td>91-92% of total plasma volume</td>
<td>Solvent</td>
</tr>
<tr>
<td>2. Plasma proteins (albumins, globulins, fibrinogen, etc.)</td>
<td>7-8%</td>
<td>Defense, clotting, lipid transport, extracellular fluid volume controls</td>
</tr>
<tr>
<td>3. Ions, sugars, lipids, amino acids, hormones, vitamins, dissolved gases, etc.</td>
<td>1-2%</td>
<td>Nutrition, defense, respiration, extracellular fluid volume controls, cell communication, etc.</td>
</tr>
<tr>
<td><strong>Cellular Portion (40-50% of total blood volume; numbers per microliter)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Red blood cells</td>
<td>4,600,000-5,400,000</td>
<td>Oxygen, carbon dioxide transport to and from lungs</td>
</tr>
<tr>
<td>2. White blood cells:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutrophils</td>
<td>3,000-6,750</td>
<td>Fast-acting phagocytosis</td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>1,000-2,700</td>
<td>Immune responses</td>
</tr>
<tr>
<td>Monocytes (macrophages)</td>
<td>150-720</td>
<td>Phagocytosis</td>
</tr>
<tr>
<td>Eosinophils</td>
<td>100-380</td>
<td>Killing parasitic worms</td>
</tr>
<tr>
<td>Basophils</td>
<td>25-90</td>
<td>Anti-inflammatory secretions</td>
</tr>
<tr>
<td>3. Platelets</td>
<td>250,000-300,000</td>
<td>Roles in blood clotting</td>
</tr>
</tbody>
</table>

Stepped Art
Fig. 37-4, p. 640
Cellular Components of Human Blood

stem cell in bone marrow

myeloid stem cell

- red blood cell precursor
  - megakaryocytes
    - platelets
  - red blood cells (erythrocytes)
  - neutrophils
  - eosinophils
  - basophils

- granulocyte precursor

- monocyte precursor
  - monocytes (immature phagocytes)
  - B lymphocytes (mature in bone marrow)
  - T lymphocytes (mature in thymus)

lymphoid stem cell
Fig. 37-5, p. 641

stem cell in bone marrow

myeloid stem cell

- granulocyte precursor
  - neutrophils
  - eosinophils
  - basophils

- monocyte precursor
  - monocytes (immature phagocytes)

lymphoid stem cell

B lymphocytes (mature in bone marrow)

T lymphocytes (mature in thymus)
Hemostasis is a three-phase process that stops blood loss, constructs a framework for repairs

- Damaged vessel constricts
- Platelets accumulate
- Cascading enzyme reactions involving plasma proteins cause clot formation
Three-Phase Process of Hemostasis

**Stimulus**
A blood vessel is damaged.

**Phase 1 response**
A vascular spasm constricts the vessel.

**Phase 2 response**
Platelets stick together plugging the site.

**Phase 3 response**
Clot formation starts:
1. Enzyme cascade results in activation of Factor X.
2. Factor X converts prothrombin in plasma to thrombin.
3. Thrombin converts fibrinogen, a plasma protein, to fibrin threads.
4. Fibrin forms a net that entangles cells and platelets, forming a clot.
**Stimulus**
A blood vessel is damaged.

**Phase 1 response**
A vascular spasm constricts the vessel.

**Phase 2 response**
Platelets stick together plugging the site.

**Phase 3 response**
Clot formation starts:

1. Enzyme cascade results in activation of Factor X.

2. Factor X converts prothrombin in plasma to thrombin

3. Thrombin converts fibrinogen, a plasma protein, to fibrin threads.

4. Fibrin forms a net that entangles cells and platelets, forming a clot.
37.4 Blood Typing

- **Blood type**
  - Genetically determined differences in molecules on the surface of red blood cells

- **Agglutination**
  - Clumping of foreign cells by plasma proteins
  - When blood of incompatible types mixes, the immune system attacks the unfamiliar molecules
Agglutination
# ABO Blood Typing

<table>
<thead>
<tr>
<th>ABO Type</th>
<th>Glycolipid(s) on Red Cells</th>
<th>Antibodies Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>Anti-B</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>Anti-A</td>
</tr>
<tr>
<td>AB</td>
<td>Both A and B</td>
<td>None</td>
</tr>
<tr>
<td>O</td>
<td>Neither A nor B</td>
<td>Anti-A, Anti-B</td>
</tr>
</tbody>
</table>

- Blood type O is a universal donor; blood type AB can receive blood from any donor.
Mixing ABO Blood Types
<table>
<thead>
<tr>
<th>Blood Type of Donor</th>
<th>O</th>
<th>A</th>
<th>B</th>
<th>AB</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>A</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
<tr>
<td>B</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
</tr>
<tr>
<td>AB</td>
<td><img src="image13" alt="Image" /></td>
<td><img src="image14" alt="Image" /></td>
<td><img src="image15" alt="Image" /></td>
<td><img src="image16" alt="Image" /></td>
</tr>
</tbody>
</table>
Animation: ABO compatibilities

Select Recipient Blood Type:
- A
- B
- AB
- O

Select Donor Blood Type:
- A
- B
- AB
- O

Do Transfusion
Rh Blood Typing

- An Rh- mother may develop Rh+ antibodies if blood from an Rh+ child enters her bloodstream during childbirth

- These antibodies may attack the red blood cells of the next Rh+ fetus
Rh Complications of Pregnancy

Rh⁰ markers on the red blood cells of a fetus

anti-Rh⁰ antibody molecules

any subsequent Rh⁰ fetus
An Rh+ man and an Rh– woman carrying his Rh+ child. This is the mother’s first Rh+ pregnancy, so she has no anti-Rh+ antibodies. But during birth, some of the child’s Rh+ cells get into her blood.
The foreign marker stimulates antibody formation. If this woman gets pregnant again and if her second fetus (or any other) carries the Rh+ protein, her anti-Rh+ antibodies may attack the fetal red blood cells.
Animation: Rh factor and pregnancy
Vertebrate blood is a fluid connective tissue.

It consists of red blood cells, white blood cells, platelets, and plasma (the transport medium).

Red blood cells function in gas exchange; white blood cells defend tissues, and platelets function in clotting.
The term “cardiovascular” comes from the Greek *kardia* (for heart) and Latin *vasculum* (vessel).

In a cardiovascular circuit, blood flows from the heart through arteries, arterioles, capillaries, venules, veins, and back to the heart.
Two Circuits of the Human Cardiovascular System

- **Pulmonary circuit**
  - Oxygen-poor blood flows from the heart, through a pair of lungs, then back to the heart
  - Blood takes up oxygen in the lungs

- **Systemic circuit**
  - Oxygenated blood flows from the heart (through the aorta) into capillary beds where it gives up O\(_2\) and takes up CO\(_2\), then flows back to the heart
Pulmonary and Systemic Circuits of the Human Cardiovascular System

A. Pulmonary Circuit for Blood Flow

B. Systemic Circuit for Blood Flow
Pulmonary Circuit for Blood Flow

- **Right Pulmonary Artery**
- **Capillary Bed of Right Lung**
- **Pulmonary Trunk**
- **Capillary Bed of Left Lung**
- **To Systemic Circuit**
- **From Systemic Circuit**
- **Pulmonary Veins**
- **Heart**

Fig. 37-10a, p. 644
A Pulmonary Circuit for Blood Flow

- right pulmonary artery
- left pulmonary artery
- capillary bed of right lung
- capillary bed of left lung
- pulmonary trunk
- from systemic circuit
- to systemic circuit
- pulmonary veins
- heart
Systemic Circuit for Blood Flow

- Capillary beds of head, upper extremities
- Aorta
- To pulmonary circuit
- From pulmonary circuit
- Heart
- Capillary beds of other organs in thoracic cavity
- Diaphragm, the muscular partition between thoracic and abdominal cavities
- Capillary bed of liver
- Capillary beds of intestines
- Capillary beds of other abdominal organs and lower extremities

Fig. 37-10b, p. 644
Systemic Circuit for Blood Flow

- Capillary beds of head, upper extremities to pulmonary circuit
- Capillary beds of other organs in thoracic cavity
- Capillary bed of liver
- Capillary beds of intestines
- Capillary beds of other abdominal organs and lower extremities
Animation: Human blood circulation
Major Blood Vessels of the Human Cardiovascular System

- **Jugular Veins**: Receive blood from brain and from tissues of head.
- **Superior Vena Cava**: Receives blood from veins of upper body.
- **Pulmonary Veins**: Deliver oxygenated blood from the lungs to the heart.
- **Hepatic Vein**: Carries blood that has passed through small intestine and then liver.
- **Renal Vein**: Carries processed blood away from kidneys.
- **Inferior Vena Cava**: Receives blood from all veins below diaphragm.
- **Iliac Veins**: Carry blood away from the pelvic organs and lower abdominal wall.
- **Femoral Vein**: Carries blood away from the thigh and inner knee.
- **Carotid Arteries**: Deliver blood to neck, head, brain.
- **Ascending Aorta**: Carries oxygenated blood away from heart; the largest artery.
- **Pulmonary Arteries**: Deliver oxygen-poor blood from the heart to the lungs.
- **Coronary Arteries**: Service the incessantly active cardiac muscle cells of heart.
- **Brachial Artery**: Delivers blood to upper extremities; blood pressure measured here.
- **Renal Artery**: Delivers blood to kidneys, where its volume, composition are adjusted.
- **Abdominal Aorta**: Delivers blood to arteries leading to the digestive tract, kidneys, pelvic organs, lower extremities.
- **Iliac Arteries**: Deliver blood to pelvic organs and lower abdominal wall.
- **Femoral Artery**: Delivers blood to the thigh and inner knee.
Animation: Major human blood vessels

- Jugular veins
- Carotid arteries
- Superior vena cava
- Ascending aorta
- Pulmonary veins
- Pulmonary arteries
- Coronary arteries
- Brachial artery
- Hepatic portal vein
The Circulatory System and Homeostasis

- **Digestive System**
  - Food, water intake
  - Nutrients, water, salts
  - Elimination of food residues

- **Respiratory System**
  - Oxygen intake
  - Oxygen
  - Carbon dioxide

- **Circulatory System**
  - Rapid transport to and from all living cells

- **Urinary System**
  - Elimination of excess water, salts, wastes
Fig. 37-12, p. 645

- **Food, water intake**
  - DIGESTIVE SYSTEM
    - Nutrients, water, salts
  - RESPIRATORY SYSTEM
    - Oxygen
  - CIRCULATORY SYSTEM
    - Oxygen
    - Rapid transport to and from all living cells
  - URINARY SYSTEM
    - Water, solutes
    - Elimination of excess water, salts, wastes

- **Oxygen intake**
  - RESPIRATORY SYSTEM
    - Elimination of carbon dioxide
37.6 The Human Heart

- A sac of connective tissue (pericardium) surrounds the heart muscle (myocardium)

- Endothelium lines heart chambers and blood vessels

- Heart valves keep blood moving in one direction
  - AV valves separate atria and ventricles
  - Semilunar valves separate ventricles and arteries
The Human Heart

A cutaway view shows the heart’s internal organization.

B The heart is located between the lungs in the thoracic cavity.

C Outer appearance. Pads of fat on the heart’s surface are normal.
B The heart is located between the lungs in the thoracic cavity.
The heart is located between the lungs in the thoracic cavity.
C Outer appearance. Pads of fat on the heart’s surface are normal.
C Outer appearance. Pads of fat on the heart’s surface are normal.
Animation: The human heart
The Cardiac Cycle

- **Cardiac cycle**: Heart muscle alternates between *diastole* (relaxation) and *systole* (contraction)
  - Blood collects in *atria*
  - **AV valves** open, blood flows into *ventricles*
  - Contraction of ventricles drives blood circulation
  - Ventricles contract with a wringing motion from bottom to top
**The Cardiac Cycle**

**A** Atria fill. Fluid pressure opens the AV valves, blood flows into the ventricles.

**B** Next, atria contract. As fluid pressure rises in the ventricles, AV valves close.

**C** Ventricles contract. Semilunar valves close as atria begin filling for the next cardiac cycle.

A Atria fill. Fluid pressure opens the AV valves, blood flows into the ventricles.

B Next, atria contract. As fluid pressure rises in the ventricles, AV valves close.


D Ventriles relax. Semilunar valves close as atria begin filling for the next cardiac cycle.
A Atria fill. Fluid pressure opens the AV valves, blood flows into the ventricles.

B Next, atria contract. As fluid pressure rises in the ventricles, AV valves close.

D Ventricles relax. Semilunar valves close as atria begin filling for the next cardiac cycle.

Animation: Cardiac cycle
Cardiac Muscle

- Cardiac muscle cells are striated (divided into sarcomeres) and have many mitochondria.

- Cells attach end to end at intercalated discs.

- Neighboring cells communicate through gap junctions that conduct waves of excitation.
Cardiac Muscle Cells and Gap Junctions

- intercalated disk
- a branching cardiac muscle cell (part of one cardiac muscle fiber)

**b** Part of a gap junction across the plasma membrane of a cardiac muscle cell. The junctions connect cytoplasm of adjoining cells and allow electrical signals that stimulate contraction to spread swiftly between them.
a branching cardiac muscle cell (part of one cardiac muscle fiber)

b Part of a gap junction across the plasma membrane of a cardiac muscle cell. The junctions connect cytoplasm of adjoining cells and allow electrical signals that stimulate contraction to spread swiftly between them.
How the Heart Beats

- **Cardiac pacemaker** (SA node)
  - A clump of noncontracting cells in the right atrium’s wall spontaneously fires action potentials about 70 times per minute

- **Cardiac conduction system**
  - Signal spreads from SA node to AV node and junctional fibers in the septum, so heart contracts in a coordinated fashion
The Cardiac Conduction System

SA node  (cardiac pacemaker)
AV node  (the only point of electrical contact between atria and ventricles)

junctional fibers
branchings of junctional fibers (carry electrical signals through the ventricles)
SA node (cardiac pacemaker)

AV node (the only point of electrical contact between atria and ventricles)

junctional fibers

branchings of junctional fibers (carry electrical signals through the ventricles)
Animation: Cardiac conduction
37.5-37.6 Key Concepts
The Human Heart and Two Flow Circuits

- The four-chambered human heart pumps blood through two separate circuits of blood vessels

- One circuit extends through all body regions, the other through lung tissue only

- Both circuits loop back to the heart
Animation: ABO blood group genetics
Animation: Hemostasis
Animation: Waller’s experiment
Animation: White blood cells