Lecture 15
The Circulatory System

Evolution of Circulatory Systems

Gastrovascular cavity
Cnidarians and flatworms have a cavity that functions in both digestion and circulation

Open circulatory system
In mollusks and arthropods there is no distinction between circulating fluid (blood) and fluid of the body tissues (lymph) Hemolymph

Closed circulatory system
In annelids and vertebrates circulating fluid (blood) is always enclosed within vessels that transport blood away from, and back to a pump (heart)

The Vertebrate Circulatory System

- In vertebrates, blood vessels from a tubular network
  - Arteries carry blood away from the heart
  - Veins return blood to the heart
  - Capillaries connect arteries to veins
    - As blood plasma passes through capillaries, pressure forces fluid out of the capillary walls
    - Some of this interstitial fluid returns directly to capillaries
    - Some enters lymph vessels and is returned to venous blood at specific sites
Circulatory System Functions

- **Transportation**
  - Respiratory
    - Transport O₂ to cells for aerobic respiration
  - Nutritive
    - Transport of absorbed products of digestion to cells
  - Excretory
    - Metabolic wastes and excessive water are filtered in the kidney and excreted in urine

- **Regulation**
  - Hormones are transported from endocrine glands to distant target organs
  - Help maintain a constant body temperature

- **Protection**
  - Blood clotting protects against blood loss
  - White blood cells provide immunity against many-disease causing agents

Arteries: Highways from the Heart

- Blood comes from the heart in large pulses
- Thus the artery must be able to expand
- Arterial walls are made up of three layers

Arterioles are smaller in diameter than arteries
Their surrounding muscle layer can be relaxed to enlarge diameter

Veins: Returning Blood to the Heart

- Walls have thinner layers of muscle and elastic fiber than arteries

When empty, walls collapse
Veins: Returning Blood to the Heart

Blood flow back to the heart is aided by
1. Low pressure in veins
2. Skeletal muscles
3. Unidirectional valves

The capillary network connects arteries with veins

- Individual capillaries have high resistance to flow
  - But the total cross-sectional area of capillaries is greater than that of arteries leading to it
  - Blood loses most of its pressure and velocity as it passes through the vast capillary network

Capillaries: Where Exchange Takes Place

- Transport oxygen and nutrients from blood to body’s cells and pick up carbon dioxide
  - They have thin walls to allow diffusion to take place
The Lymphatic System: Recovering Lost Fluid

The cardiovascular system is very leaky.

To collect and recycle leaked fluid, the body uses a second circulatory system called the lymphatic system.

Blood pressure forces fluid out of capillaries

- Most of this interstitial fluid returns by osmosis.
  - Excess fluid is drained into lymphatic capillaries in the lymphatic system, the fluid is called lymph.
- Lymphatic vessels contain a series of one-way valves.
  - Permit movement only in the direction of the neck.

Functions of the Lymphatic System

- The lymphatic system has three important functions:
  1. Returns proteins to circulation.
     - If proteins are not returned to the blood, a condition called edema (body swelling) results.
  2. Transports fats absorbed from the intestine.
     - Lymph capillaries, called lacteals, absorb fats from the small intestine.
  3. Aids in the body’s defense.
     - Lymph nodes are filled with white blood cells.
Components of Whole Blood

Withdraw blood and place in tube

1. Centrifuge

Plasma (55% of whole blood)

Buffy coat: leukocytes and platelets (<1% of whole blood)

Erythrocytes (45% of whole blood)

Blood is the body’s only fluid tissue

- Blood is a sticky, opaque fluid with a metallic taste
- Color varies from scarlet (oxygen-rich) to dark red (oxygen-poor)
- The pH of blood is 7.35–7.45
- Temperature is 38°C, slightly higher than “normal” body temperature
- Blood accounts for approximately 8% of body weight
- Average volume of blood is 5–6 L for males, and 4–5 L for females

Blood Plasma

- Blood plasma contains over 100 solutes, including:
  - Proteins – albumin, globulins, clotting proteins, and others
  - Nonprotein nitrogenous substances – lactic acid, urea, creatinine
  - Organic nutrients – glucose, carbohydrates, amino acids
  - Electrolytes – sodium, potassium, calcium, chloride, bicarbonate
  - Respiratory gases – oxygen and carbon dioxide

Formed Elements

- Erythrocytes, leukocytes, and platelets make up the formed elements
  - Only WBCs are complete cells
  - RBCs have no nuclei or organelles, and platelets are just cell fragments
  - Most formed elements survive in the bloodstream for only a few days
  - Most blood cells do not divide but are renewed by cells in bone marrow
Erythrocytes (RBCs)

- Biconcave discs, anucleate, essentially no organelles
- Filled with hemoglobin (Hb), a protein that functions in gas transport
- Contain the plasma membrane protein spectrin and other proteins that:
  - Give erythrocytes their flexibility
  - Allow them to change shape as necessary
- Hematocrit – the percentage of RBCs out of the total blood volume (in humans about 45%)

Life Cycle of Red Blood Cells

- The life span of an erythrocyte is 100–120 days
- Old erythrocytes become rigid and fragile, and their hemoglobin begins to degenerate

Anemias: Insufficient erythrocytes or hemoglobin

- **Hemorrhagic anemia** – result of acute or chronic loss of blood
- **Hemolytic anemia** – prematurely ruptured erythrocytes
- **Aplastic anemia** – destruction or inhibition of red bone marrow
- **Iron-deficiency anemia**
  - A secondary result of hemorrhagic anemia
  - Inadequate intake of iron-containing foods
  - Impaired iron absorption
- **Pernicious anemia**
  - Deficiency of vitamin B₁₂
  - Lack of intrinsic factor needed for absorption of B₁₂
  - Treatment is intramuscular injection of B₁₂, application of Nascobal
- **Sickle-cell anemia** – results from a defective gene coding for an abnormal hemoglobin called hemoglobin S (HbS)
  - HbS has a single amino acid substitution in the beta chain
  - This defect causes RBCs to become sickle-shaped in low oxygen situations
- **Thalassemias** – absent or faulty globin chain in hemoglobin
  - Erythrocytes are thin, delicate, and deficient in hemoglobin
**Polycythemia**

- **Polycythemia** – excess RBCs that increase blood viscosity
- Three main polycythemias are:
  - **Polycythemia vera**
    - Generally result of bone marrow cancer
  - **Secondary polycythemia**
    - Less oxygen available – normal at high altitudes
  - **Blood doping**
    - Artificially induced

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**Human ABO Blood Groups**

- RBC membranes have glycoprotein antigens on their external surfaces
- These antigens are:
  - Unique to the individual
  - Recognized as foreign if transfused into another individual
  - Promoters of agglutination and are referred to as agglutinogens
- Presence or absence of these antigens is used to classify blood groups

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**Rh-Based Hemolytic Disease of the Newborn**

- Hemolytic disease of the newborn – Rh\(^{+}\) antibodies of a sensitized Rh\(^{-}\) mother cross the placenta and attack and destroy the RBCs of an Rh\(^{+}\) baby
- Rh\(^{-}\) mother becomes sensitized when Rh\(^{+}\) blood (from a previous pregnancy of an Rh\(^{-}\) baby or a Rh\(^{+}\) transfusion) causes her body to synthesize Rh\(^{+}\) antibodies
- The drug RhoGAM can prevent the Rh\(^{-}\) mother from becoming sensitized
- Treatment of hemolytic disease of the newborn involves pre-birth transfusions and exchange transfusions after birth
Platelets

- Platelets are fragments of megakaryocytes with a blue-staining outer region and a purple granular center.
- They do not contain a nucleus.
- Their granules contain serotonin, Ca^{2+}, enzymes, ADP, and platelet-derived growth factor (PDGF).
- Platelets function in the clotting mechanism by forming a temporary plug that helps seal breaks in blood vessels.
- They also play a key role in blood formation of fibrin from fibrinogen.
- Platelets not involved in clotting are kept inactive by NO and prostaglandin I_2.

Types of Blood Cells

<table>
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<tr>
<th>Blood cell</th>
<th>Life span in blood</th>
<th>Function</th>
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<th>Life span in blood</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erythrocyte</td>
<td>120 days</td>
<td>Oxygen and CO_2 transport</td>
<td>Monocyte</td>
<td>3 days</td>
<td>Immune response (monocytes)</td>
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<td>Neutrophil</td>
<td>7 hours</td>
<td>Immune defenses</td>
<td>Macrophage</td>
<td>Unknown</td>
<td>Unknown</td>
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<tr>
<td>Lymphocyte</td>
<td>Unknown</td>
<td>Defense against parasites</td>
<td>Platelet</td>
<td>Unknown</td>
<td>Cells involved in blood clotting</td>
</tr>
<tr>
<td>Basophil</td>
<td>Unknown</td>
<td>Inflammatory response</td>
<td></td>
<td>1-7 days</td>
<td>Blood clotting</td>
</tr>
</tbody>
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Mammalian and Bird Circulation

Mammals and birds have a four-chambered heart that is really two separate pumping systems.

One pumps blood to the lungs (the Pulmonary Circuit).

The other pumps blood to the rest of the body (the Systemic Circuit).

The two pumps operate together within a single unit.
Circulation Through the Heart

- Blood passes from the right atrium into the right ventricle through the one-way tricuspid valve
- Ventricle contracts forcing blood through the pulmonary valve into the pulmonary arteries
- Oxygenated blood from lungs empties into the left atrium through the pulmonary veins
- Then from the atrium to the left ventricle
  - Ventricle contracts forcing blood out in a single strong pulse
  - Bicuspid (mitral) valve prevents backflow into atrium
  - Aortic valve prevents backflow into ventricle
- Blood eventually returns to the right atrium of the heart
  - The superior vena cava drains the upper body
  - The inferior vena cava drains the lower body

Electrocardiogram (ECG or EKG)

- Like other muscle cells, heart muscle contracts when stimulated.
- An ECG shows how heart cells depolarize and repolarize
  - Depolarization causes contraction of the heart
  - Repolarization causes relaxation of the heart

How the Heart Contracts

- Heartbeat originates in the sinoatrial (SA) node
  - Its membranes spontaneously depolarize
  - This wave of depolarization spreads to the atria, causing them to contract
- The wave reaches the atrioventricular (AV) node
  - It passes to the ventricles via the Bundle of His and is conducted rapidly over the surface of the ventricles by Purkinje fibers
  - Ventricular contraction empties the heart
Monitoring the Heart’s Performance

- Simplest way is to listen to the heart at work using a stethoscope
  - If valves are not fully opening or closing, turbulence is created
    - This can be heard as a heart murmur
- Another way is to monitor blood pressure
  - A sphygmomanometer is used to record two measurements
    - Systolic pressure = High point
    - Diastolic pressure = Low point

Major Arteries and Veins

Cardiovascular Diseases

- The leading cause of deaths in the US
- Heart attacks
  - Caused by an insufficient supply of blood to one or more parts of the heart muscle
  - Also called myocardial infarctions
- Angina pectoris (“Chest pain”)
  - Warning sign of a potential heart attack
- Strokes
  - Caused by interference with blood flow to brain
Atherosclerosis & Arteriosclerosis

- **Atherosclerosis** is the accumulation of fatty materials on inner surfaces of artery
  - The lumen (interior) becomes narrower

- **Arteriosclerosis**
  - Hardening of the arteries
  - Occurs when calcium is deposited in arterial walls

Atherosclerosis is treated with:

1. Medications
   - Enzymes
   - Anticoagulants
   - Nitroglycerin

2. Invasive procedures
   - Heart transplants
   - Coronary bypass surgery
   - Angioplasty