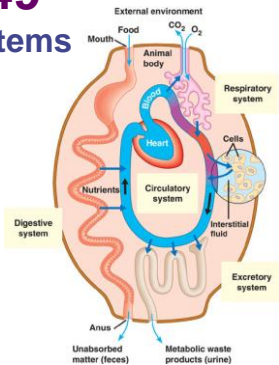
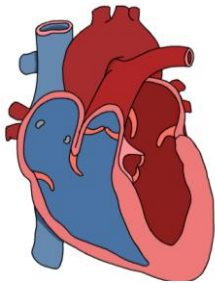


Chapter 49 Circulatory Systems



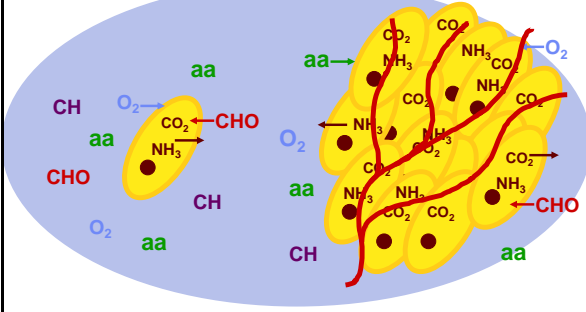
Exchange of Materials

- Animal cells exchange material across their cell membrane
 - ◆ fuels for energy
 - ◆ nutrients
 - ◆ oxygen
 - ◆ waste (urea, CO₂)
- If you are a 1-cell organism that's easy!
- If you are many-celled that's harder...



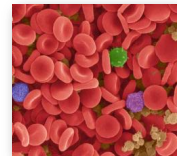
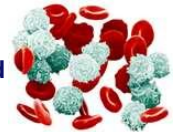
Overcoming Limitations of Diffusion

- Diffusion is not adequate for moving material across more than 1-cell barrier



In Circulation...

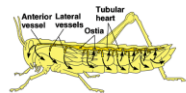
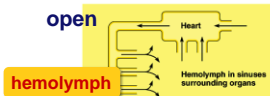
- What needs to be transported
 - ◆ **nutrients & fuels**
 - from digestive system
 - ◆ **respiratory gases**
 - O₂ & CO₂ from & to gas exchange systems: lungs, gills
 - ◆ **intracellular waste**
 - waste products from cells
 - ◆ water, salts, nitrogenous wastes (urea)
 - ◆ **protective agents**
 - immune defenses
 - ◆ white blood cells & antibodies
 - blood clotting agents
 - ◆ **regulatory molecules**
 - hormones



Circulatory Systems

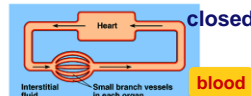
- All animals have:
 - ◆ circulatory fluid = **"blood"**
 - ◆ tubes = **blood vessels**
 - ◆ muscular pump = **heart**

open



(a) Open circulatory system

closed



(b) Closed circulatory system

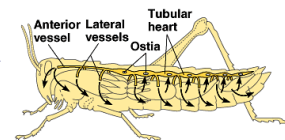
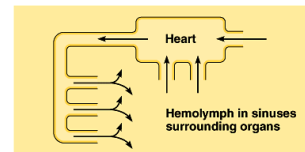
Open Circulatory System

- Taxonomy

- ◆ **invertebrates**
 - insects, arthropods, mollusks

- Structure

- ◆ no separation between blood & **interstitial** fluid
 - **hemolymph**



(a) Open circulatory system

Closed Circulatory System

- Taxonomy
 - ◆ **invertebrates**
 - earthworms, squid, octopuses
 - ◆ **vertebrates**
- Structure
 - ◆ blood confined to vessels & separate from **interstitial fluid**
 - 1 or more hearts
 - material diffuses between vessels & interstitial fluid

(b) Closed circulatory system

Vertebrate Circulatory System

- Adaptations in closed system
 - ◆ number of heart chambers differs

(a) Fish: low pressure to body
 (b) Amphibian: low O₂ to body
 (c) Mammal: high pressure & high O₂ to body

Evolution of Vertebrate Circulatory System

fish 2 chamber amphibian 3 chamber reptiles 3 chamber birds & mammals 4 chamber

Evolution of 4-Chambered Heart

- Selective forces
 - ◆ **body size**
 - protection from predation
 - bigger body = bigger stomach for herbivores
 - ◆ **endothermy**
 - can colonize more habitats
 - ◆ **flight**
 - decrease predation & increase prey capture
- Effect of higher metabolic rate
 - ◆ greater need for energy, fuels, O₂, waste removal
 - endothermic animals need 10x energy
 - need to deliver 10x fuel & O₂ to cells

Vertebrate Cardiovascular System

- Chambered heart
 - ◆ **atrium** = receive blood
 - ◆ **ventricle** = pump blood out
- Blood vessels
 - ◆ **arteries** = carry blood away from heart
 - arterioles
 - ◆ **veins** = return blood to heart
 - venules
 - ◆ **capillaries** = point of exchange, thin wall
 - capillary beds = networks of capillaries

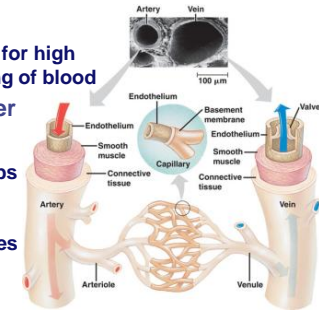
Blood Vessels

arteries → arterioles → capillaries → venules → veins

Arteries: Built for High Pressure Flow

Arteries

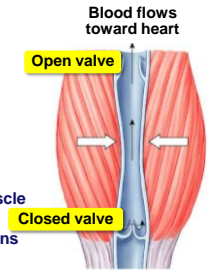
- ◆ thicker walls
 - provide strength for high pressure pumping of blood
- ◆ narrower diameter
- ◆ elasticity
 - elastic recoil helps maintain blood pressure even when heart relaxes



Veins: Built for Low Pressure Flow

Veins

- ◆ thinner-walled
- ◆ wider diameter
 - blood travels back to heart at low velocity & pressure
 - lower pressure
 - ◆ distant from heart
 - ◆ blood must flow by skeletal muscle contractions when we move
 - squeeze blood through veins

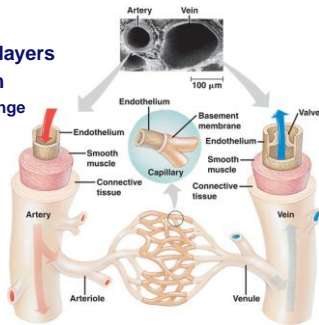


- ◆ valves
 - in larger veins **one-way valves** allow blood to flow only toward heart

Capillaries: Built for Exchange

Capillaries

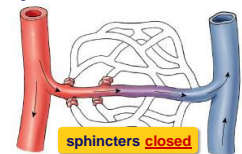
- ◆ very thin walls
 - lack 2 outer wall layers
 - only endothelium
 - ◆ enhances exchange across capillary



Controlling Blood Flow to Tissues

Blood flow in capillaries controlled by pre-capillary **sphincters**

- supply varies as blood is needed
- **after a meal**, blood supply to digestive tract increases
- **during strenuous exercise**, blood is diverted from digestive tract to skeletal muscles
- ◆ capillaries in **brain, heart, kidneys & liver** usually filled to capacity

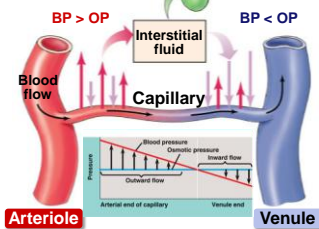


Exchange Across Capillary Walls

Fluid & solutes flows out of capillaries to tissues due to **blood pressure**
▪ "bulk flow"



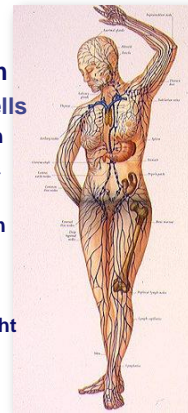
Interstitial fluid flows back into capillaries due to **osmosis**
▪ plasma proteins ↑ osmotic pressure in capillary

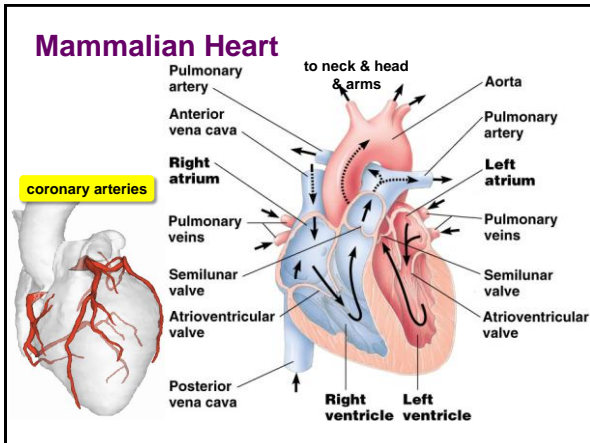
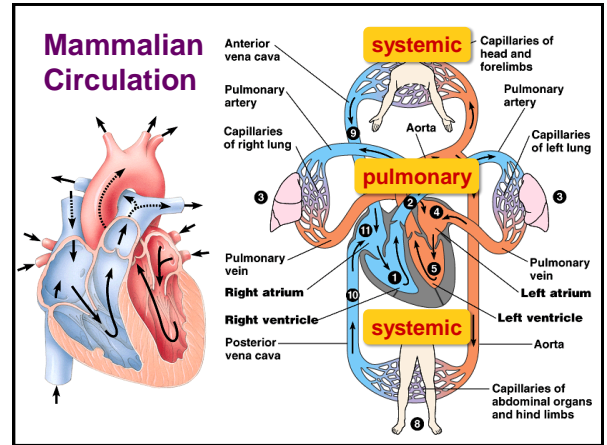
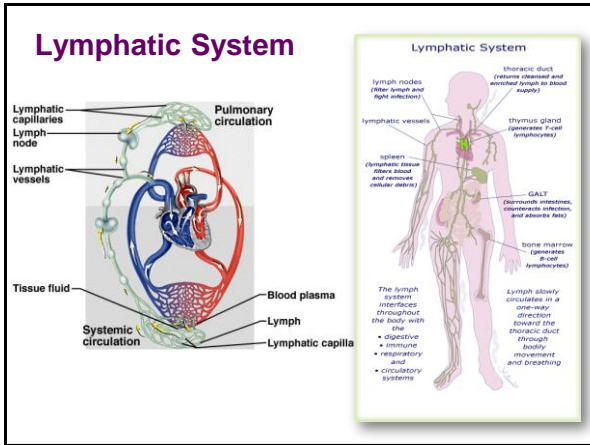


Lymphatic System

Parallel circulatory system

- ◆ transports white blood cells
 - defending against infection
- ◆ collects interstitial fluid & returns to blood
 - maintains volume & protein concentration of blood
 - **thoracic ducts** drains into circulatory system near junction of vena cava & right atrium





Heart Valves

- 4 valves in the heart
 - flaps of connective tissue
 - prevent backflow
- Atrioventricular (AV) valve**
 - between atrium & ventricle
 - keeps blood from flowing back into atria when ventricles contract
 - "lub"
- Semilunar valves**
 - between ventricle & arteries
 - prevent backflow from arteries into ventricles while they are relaxing
 - "dup"

lub-dup, lub-dup

- Heart sounds**
 - closing of valves
 - "Lub"
 - recoil of blood against closed AV valves
 - "Dup"
 - recoil of blood against semilunar valves
- Heart murmur**
 - defect in valves causes hissing sound when stream of blood squirts backward through valve

Cardiac cycle

- 1 complete sequence of pumping
 - heart contracts & pumps
 - heart relaxes & chambers fill
 - contraction phase
 - systole**
 - ventricles pump blood out
 - relaxation phase
 - diastole**
 - atria refill with blood

systolic → **diastolic**

pump (peak pressure)

fill (minimum pressure)

Measurement of Blood Pressure

Artery

Rubber cuff inflated with air

Artery closed

Pressure in cuff above 120

Pressure in cuff below 120

Pressure in cuff below 70

Blood pressure reading: 120/70

Sounds audible in stethoscope

Sounds stop

High Blood Pressure (hypertension)

- if top number (**systolic** pumping) > 150
- if bottom number (**diastolic** filling) > 90

Regulation of Blood Volume / Pressure

- Hormone regulation**
 - ADH (antidiuretic hormone)**
 - from pituitary
 - causes kidneys to reabsorb more water
 - aldosterone**
 - from adrenal gland
 - causes kidneys to reabsorb Na⁺ & water
 - atrial natriuretic hormone**
 - from heart (right atrium)
 - promotes excretion of Na⁺ in urine
 - nitric oxide**
 - from blood vessel cells
 - dilates blood vessels
 - nitroglycerin & Viagra release nitric oxide

Cardiovascular Disease

- Still the leading cause of death in U.S.
 - plaques** develop in inner wall of arteries
 - narrowing channel
 - stroke, heart attack, atherosclerosis, arteriosclerosis, hypertension (high blood pressure)
 - tendency inherited, but other risk factors: smoking, lack of exercise, obesity, diet rich in fat

Control of Heart

- Evolution of system to control heart beat
 - timely delivery of O₂ to cells is critical
 - cells of cardiac muscle are "**self-excitatory**"
 - contract without any signal from nervous system
 - each cell has its own contraction rhythm, so have to coordinate them
 - cells synchronized by **sinoatrial (SA) node**
 - "**pacemaker**"
 - cells in wall of right atrium
 - sets rate & timing of cardiac cell contraction

SA node & Electrical Signals

- Pacemaker generates electrical impulses across heart
 - signal also transmitted to skin = **EKG or ECG**

1 Pacemaker generates wave of signals to contract

2 Signals delayed at AV node

3 Signals pass to heart apex

4 Signals spread throughout ventricles

SA node (pacemaker)

AV node

Bundle branches

Heart apex

allows atria to empty completely before ventricles contract

stimulates ventricles to contract from bottom to top, driving blood into arteries

ECG

Regulation of Heart Rate

- Physiological cues affect heart rate
 - nervous system**
 - speed up pacemaker
 - slow down pacemaker
 - heart rate is compromise regulated by opposing actions of these 2 sets of nerves
 - hormones**
 - epinephrine from adrenal glands increases heart rate
 - body temperature**
 - activity**
 - exercise, etc.

Thermoregulation

- Vasodilation & vasoconstriction**
 - adjusts blood flow
 - evaporative cooling

(a) Vasoconstriction (b) Vasodilation

Temperature Management

5°C environmental temperature 36°C core body temperature

Warm blood Veins Artery Veins

Cold blood

Capillary bed

Venous blood Arterial blood

33° 35°C

27° 30°

18° 20°

9° 10°

Blood & Blood Cells

- Blood is a tissue of cells in a fluid**
 - plasma = fluid (55% of volume)**
 - ions (electrolytes), plasma proteins, nutrients, waste products, gases, hormones
 - cells (45% of volume)**
 - RBC = erythrocytes**
 - transport O₂
 - WBC = leukocytes**
 - defense
 - platelets**
 - blood clotting

Components of Blood Tissue

Plasma 55%		Cellular elements 45%	
Constituent	Major functions	Cell type	Number per μL (mm ³) of blood
Water	Solvent for carrying other substances	Erythrocytes (red blood cells)	5-6 million
Ions (blood electrolytes) Sodium Potassium Calcium Magnesium Chloride Bicarbonate	Osmotic balance, pH buffering, and regulation of membrane permeability	Leukocytes (white blood cells)	5,000-10,000
Plasma proteins Albumin Fibrinogen Immunoglobulins (antibodies)	Osmotic balance, pH buffering, Clotting, Defense	Basophil	
Substances transported by blood Nutrients (such as glucose, fatty acids, vitamins) Waste products of metabolism Respiratory gases (O ₂ and CO ₂) Hormones		Lymphocyte	
		Eosinophil	
		Neutrophil	
		Monocyte	
		Platelets	250,000-400,000
			Blood clotting

Separated blood elements

Plasma Proteins

- Synthesized in liver & lymph system**
 - albumins**
 - buffer against pH changes, help maintain osmotic balance & blood's viscosity
 - globulins**
 - immunoglobulins = antibodies**
 - immune response to combat foreign invaders
 - fibrinogen**
 - clotting factor
 - blood plasma with clotting factors removed = serum

Blood Cell Production

- Stem cells**
 - pluripotent cells**
 - in bone marrow
 - produce all types of blood cells
 - cells **differentiate** in bone marrow & lymph tissue

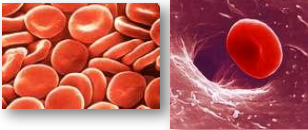
Pluripotent stem cells (in bone marrow)

Lymphoid stem cells Myeloid stem cells

B cells T cells Lymphocytes

Erythrocytes Platelets Monocytes Neutrophils Eosinophils Basophils

Red Blood Cells

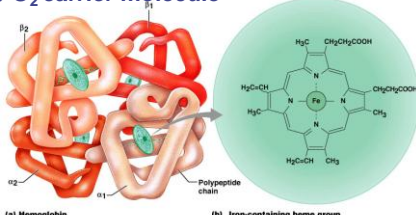


- **Function**
 - ◆ **O₂ transport**
- **Structure**
 - ◆ small biconcave disks
 - large surface area
 - ◆ lack nuclei & mitochondria
 - ◆ more space for **hemoglobin**
 - iron-containing protein that transports O₂
 - ◆ generate ATP by anaerobic respiration
 - only last 3-4 months (120 days)
 - ingested by phagocytic cells in liver & spleen
 - ~3 million RBC destroyed each second
 - produce ~3 million RBC every second to replace

5 liters of blood in body = 25 trillion RBC

Hemoglobin

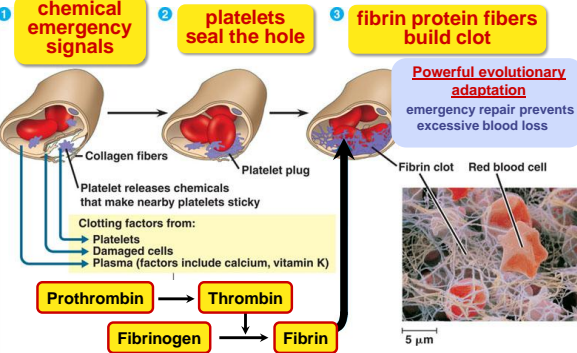
- Protein with 4^o structure
- ◆ O₂ carrier molecule



250,000 molecules hemoglobin/RBC

- each Hb molecule carries 4 O₂
- each RBC carries 1 million O₂

Blood clotting



- 1 **chemical emergency signals**
- 2 **platelets seal the hole**
- 3 **fibrin protein fibers build clot**

Collagen fibers
Platelet releases chemicals that make nearby platelets sticky
Platelet plug

Clotting factors from:

- Platelets
- Damaged cells
- Plasma (factors include calcium, vitamin K)

Prothrombin → **Thrombin**

Fibrinogen → **Fibrin**

Fibrin clot **Red blood cell**

Powerful evolutionary adaptation
 emergency repair prevents excessive blood loss

5 μm