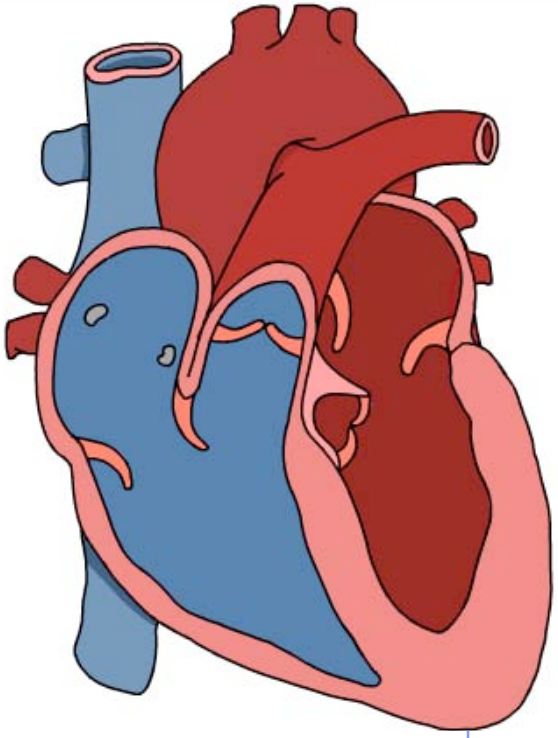
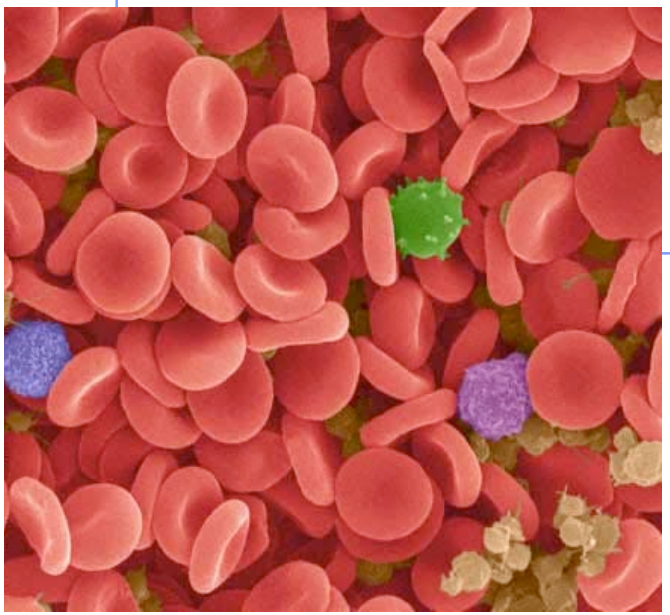
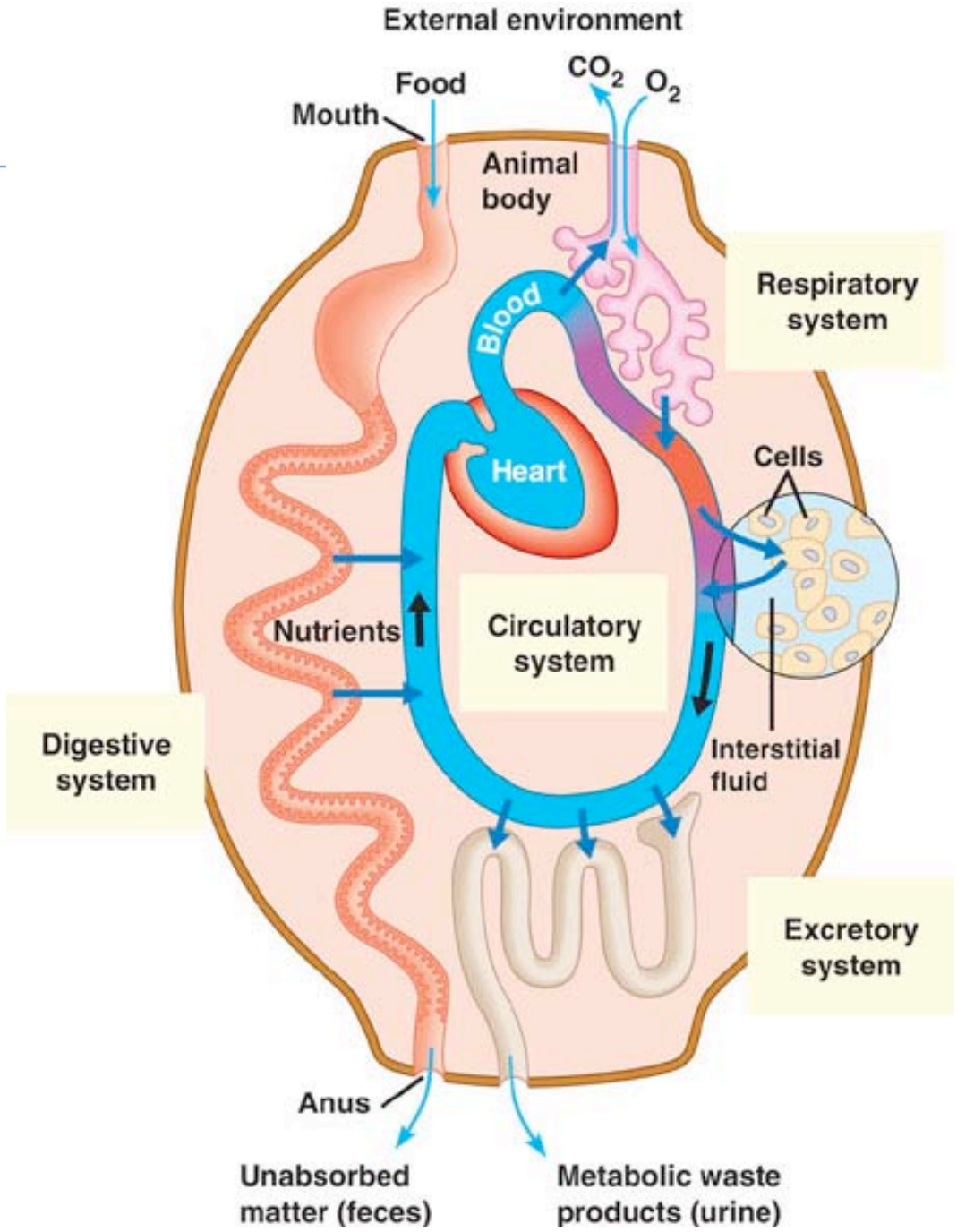
Chapter 42.

Circulation in Animals





2005-2006

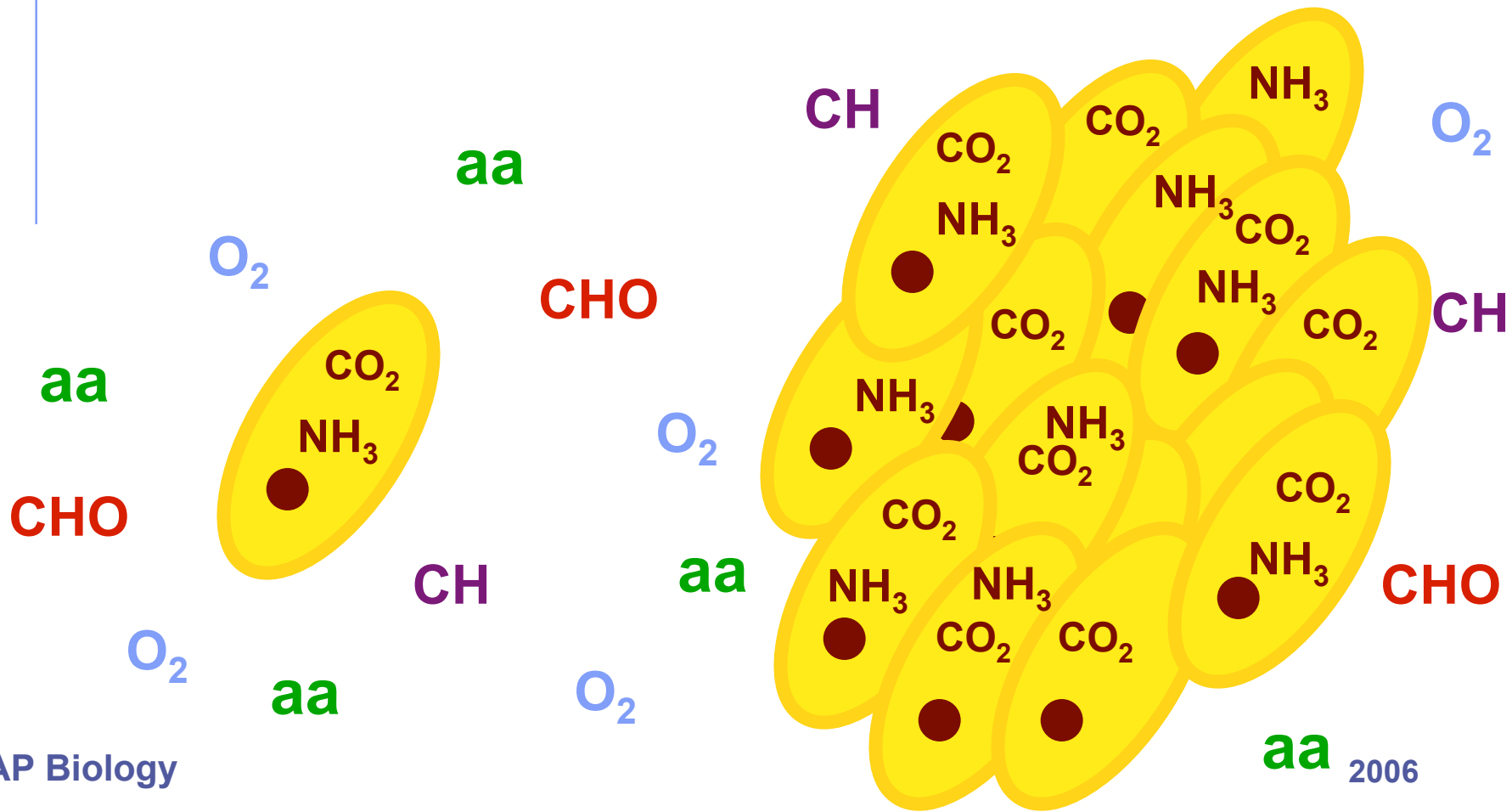

External environment
Food
Mouth
CO_2
O_2
Animal body
Blood
Respiratory system
Heart
Cells
Nutrients
Circulatory system
Digestive system
Interstitial fluid
Excretory system
Anus
Unabsorbed matter (feces)
Metabolic waste products (urine)

What are the issues

- Animal cells exchange material across the cell membrane
  - nutrients
  - fuels for energy
  - oxygen
  - waste (urea, CO_2)
- If you are a 1-cell organism that's easy!
- If you are many-celled that's harder

What are the issues?

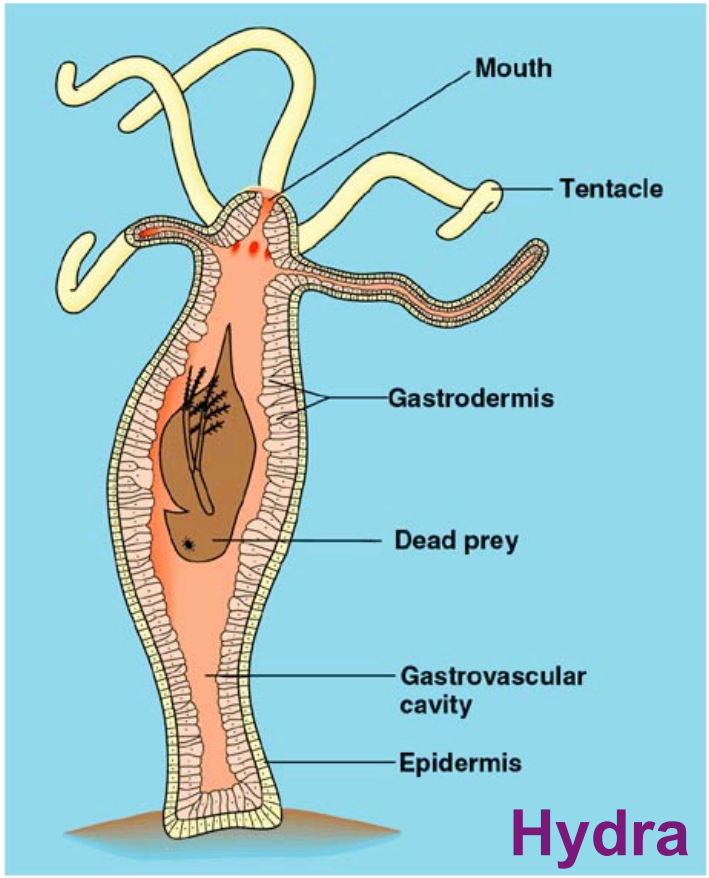
- Diffusion is not adequate for moving material across more than 1 cell barrier



Simple diffusion

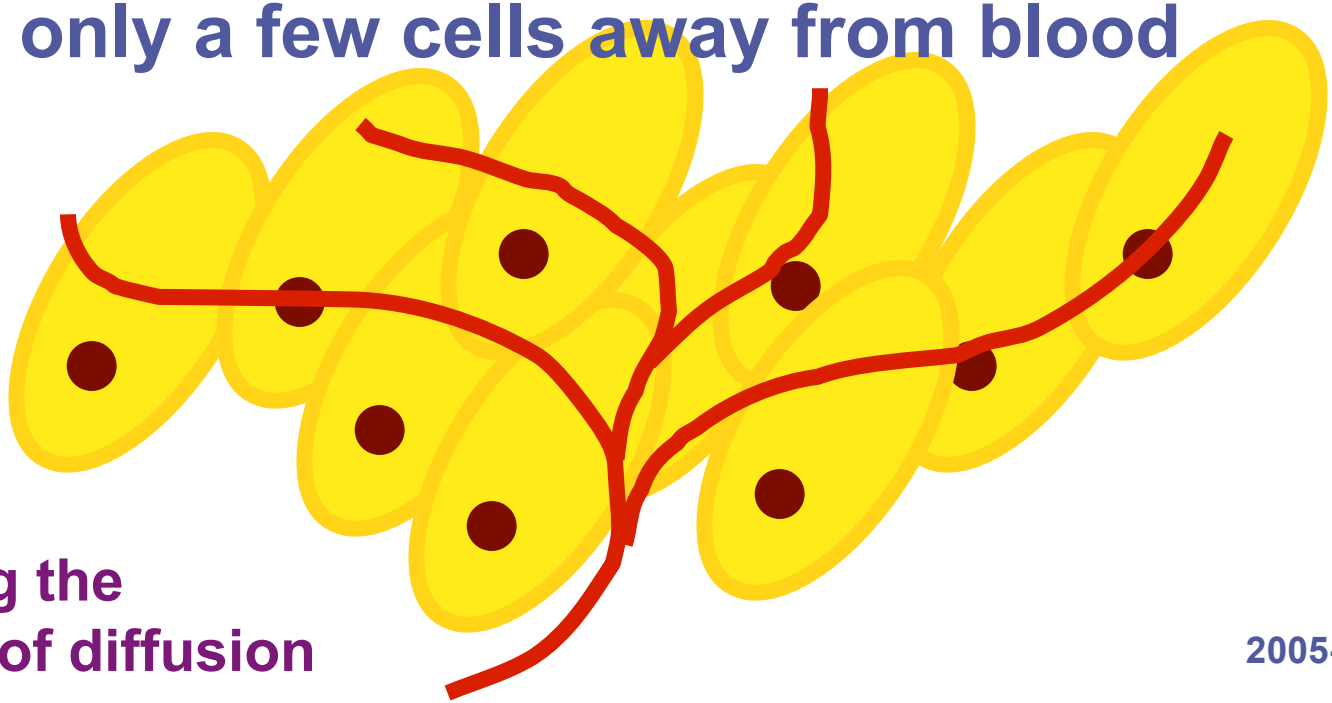
- Body cavity 2-cell layers think
  - all cells within easy reach of fluid
  - use gastrovascular cavity for exchange

Cnidarians



What are the solutions?

- Circulatory system solves this problem
  - carries fluids & dissolved material throughout body
  - cells are never far from body fluid
  - only a few cells away from blood



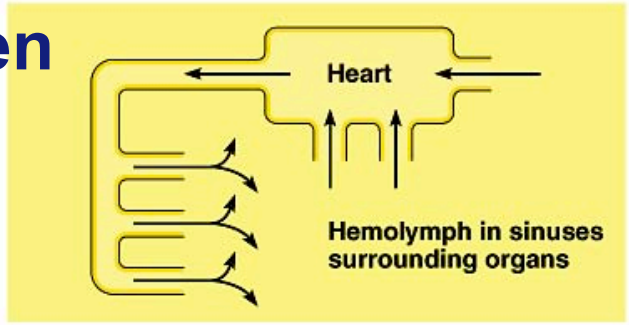
In circulation…

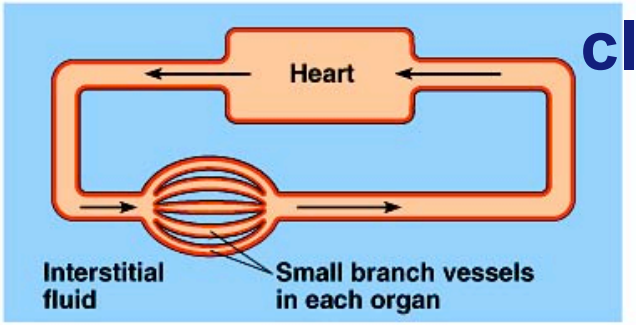
- What needs to be transported
  - nutritive
    - nutrients fuels from digestive system
  - respiratory
    - O_2 & CO_2 from & to gas exchange systems: lungs, gills
  - excretory
    - waste products from cells
      - water, salts, nitrogenous wastes (urea)
  - protection
    - blood clotting
    - immune defenses
      - white blood cells & others patrolling body
  - regulation
    - hormones

Circulatory systems

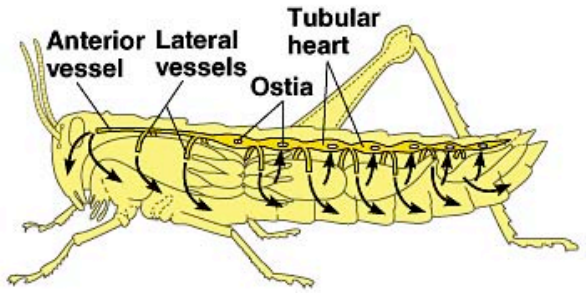
- All animals have:
  - circulatory fluid = blood
  - tubes = blood vessels
  - muscular pump = heart

open

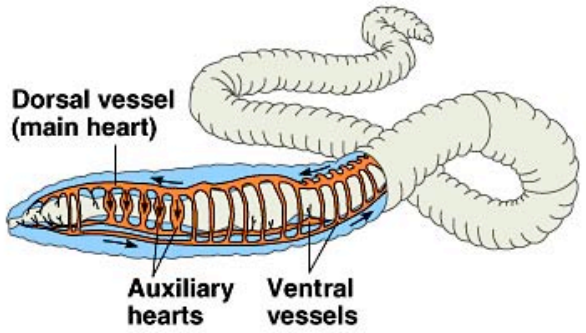




closed



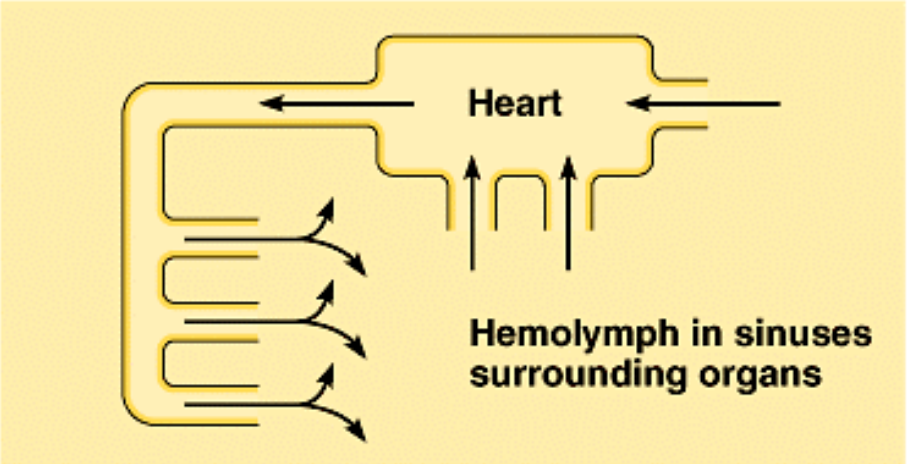
(a) Open circulatory system

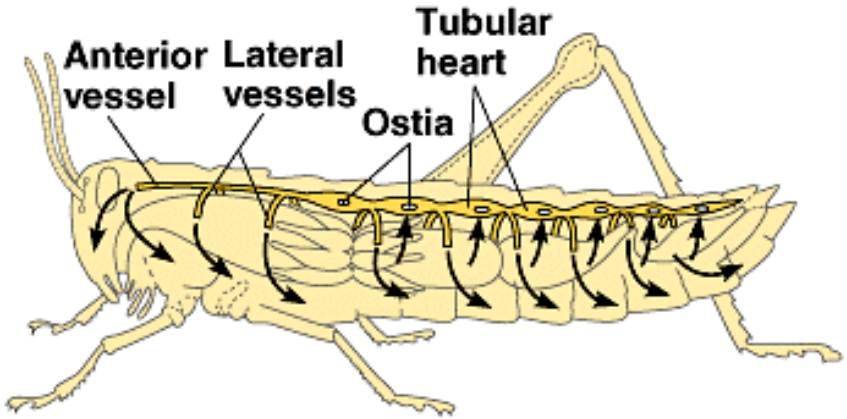


(b) Closed circulatory system

Open circulatory system

- Taxonomy
  - invertebrates
    - insects, arthropods, mollusks
- Structure
  - no distinction between blood & extracellular (interstitial) fluid
    - hemolymph

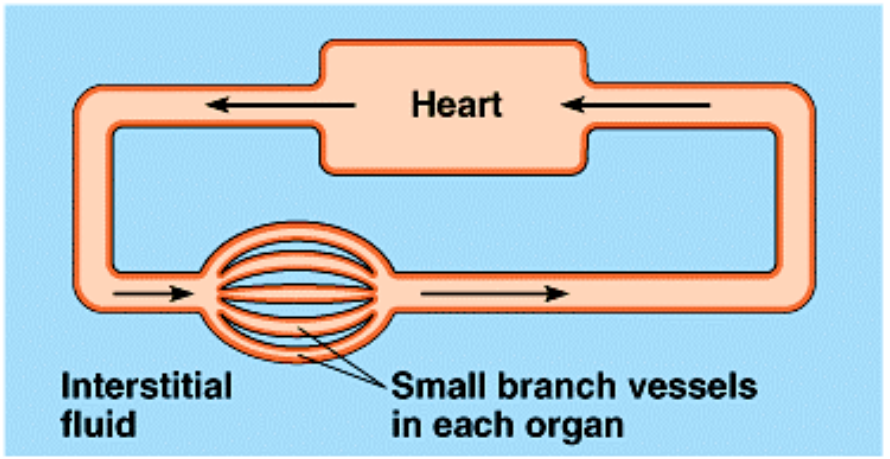


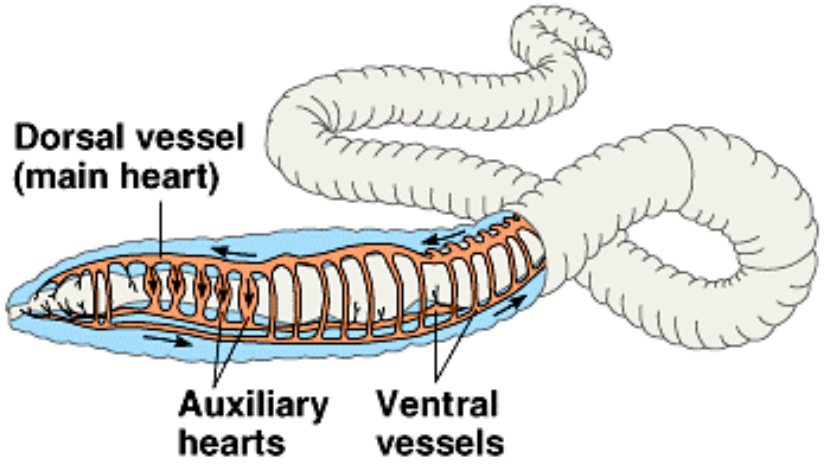


(a) Open circulatory system

Closed circulatory system

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

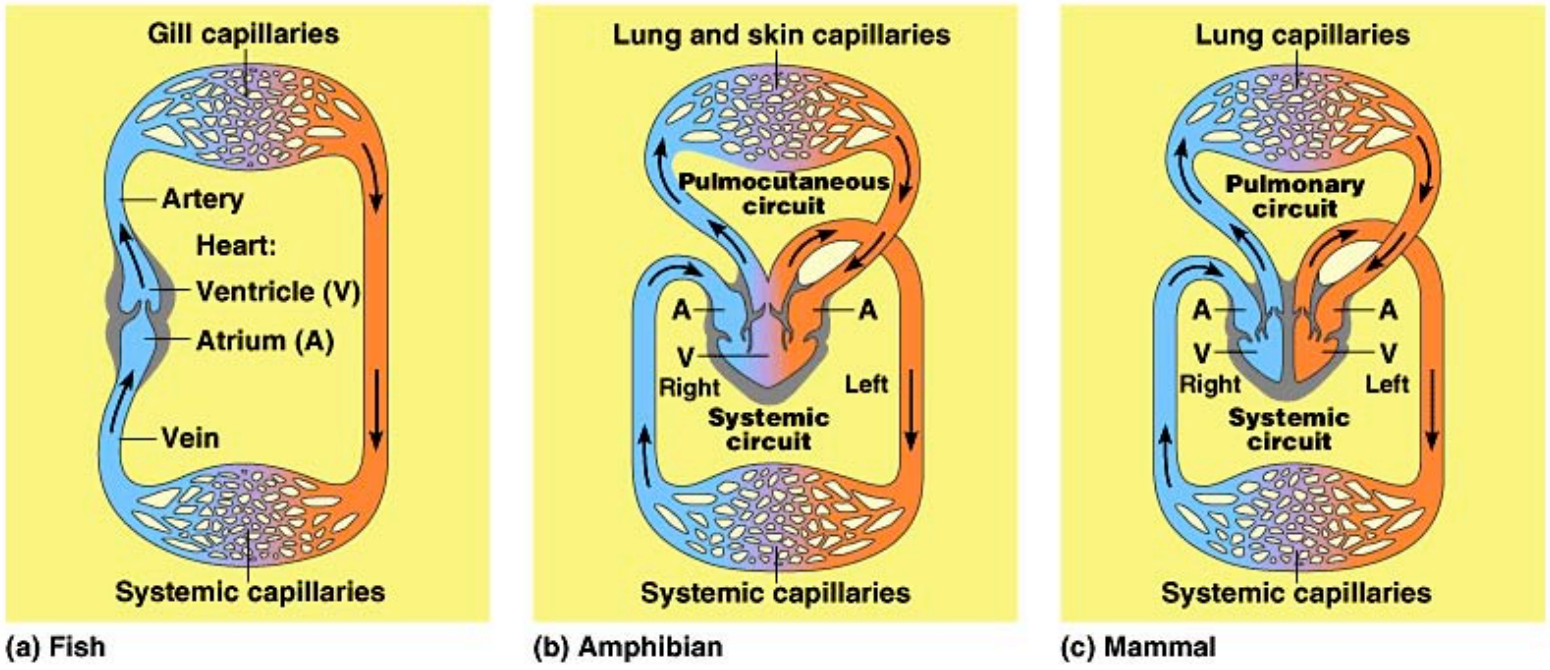




(b) Closed circulatory system

Vertebrate circulatory system

- Closed system
  - number of heart chambers differs



What's the adaptive value of a 4 chamber heart?

4 chamber heart is double pump = separates oxygen-rich & oxygen-poor blood

Evolution of vertebrate circulatory system

heart structure & increasing body size

fish

2 chamber

amphibian

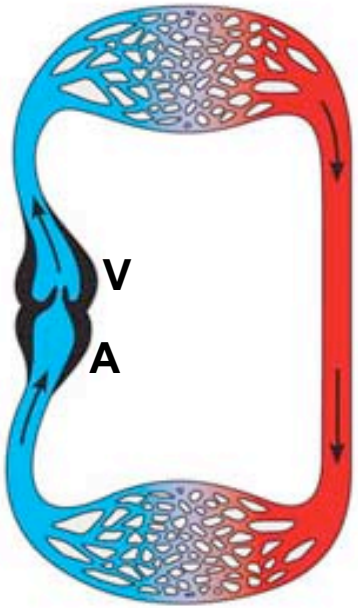
3 chamber

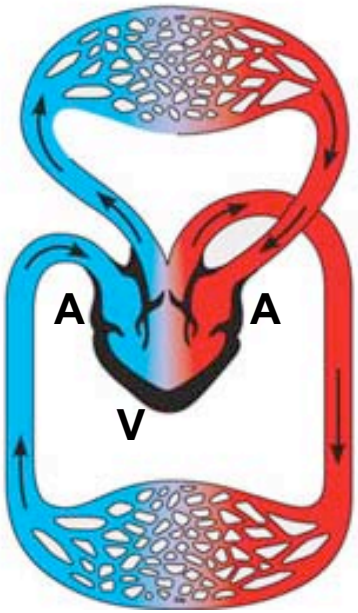
reptiles

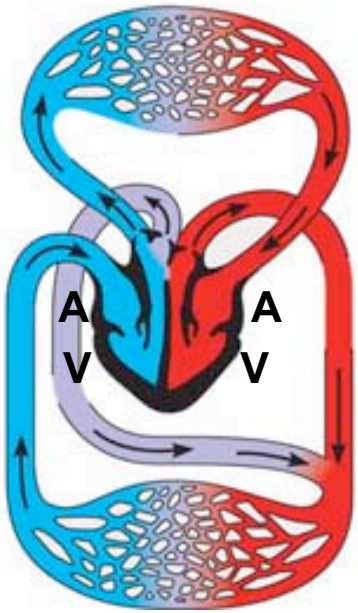
3 chamber

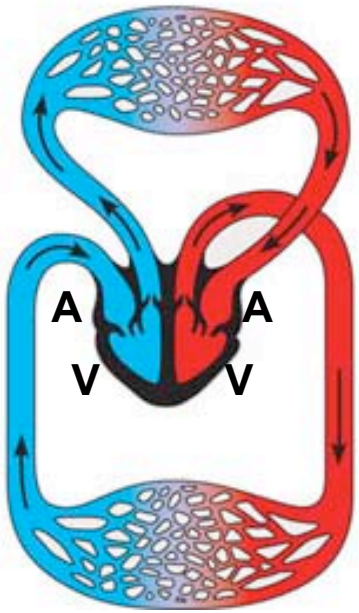
birds & mammals

4 chamber



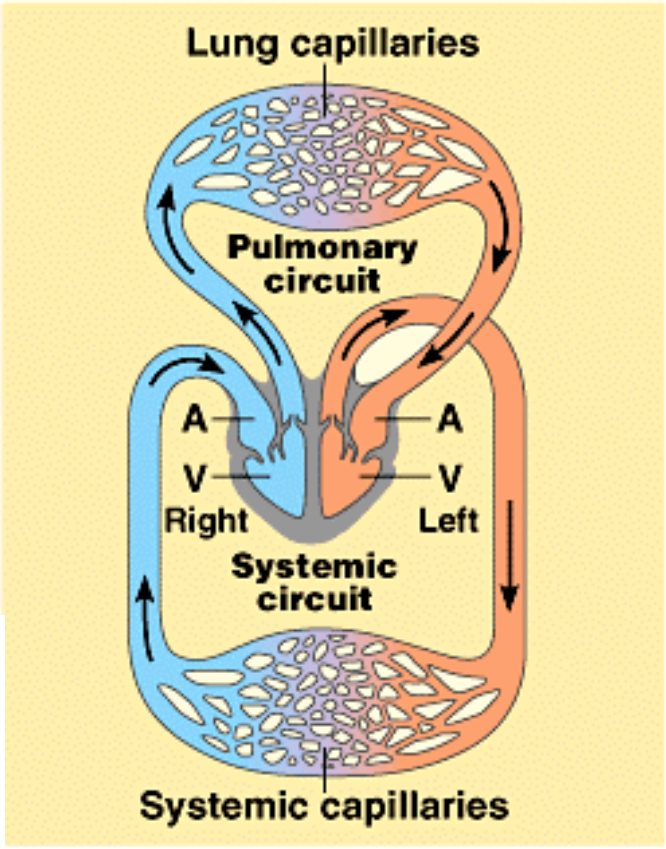






Driving evolution of CV systems

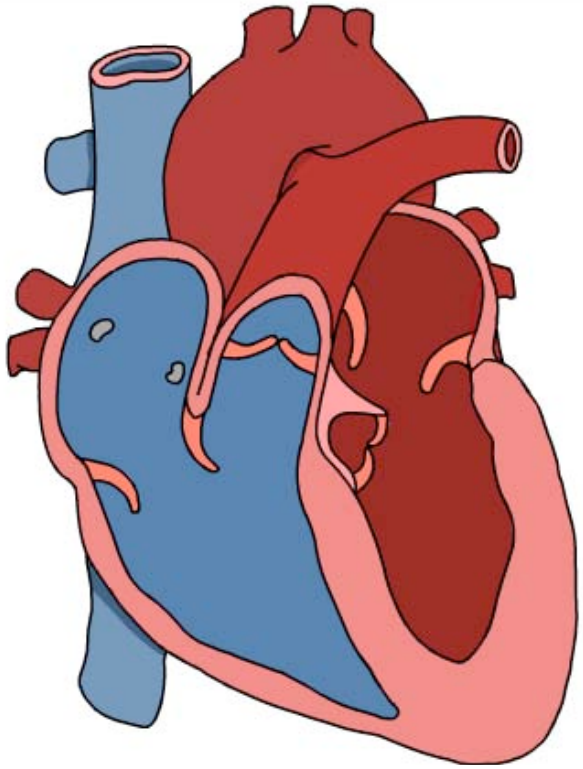
- **Metabolic rate**
  - endothermy = higher metabolic rate
    - greater need for energy, fuels, O_2, waste removal
    - more complex circulatory system
    - more powerful hearts



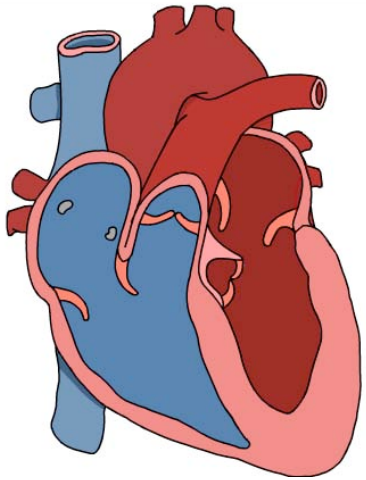
(c) Mammal

Evolution of 4 chambered heart

- **Double circulation**
  - increase pressure to systemic (body) circuit
  - prevents mixing of oxygen-rich & oxygen-poor blood
- **Powerful 4-chambered heart**
  - essential adaptation to support endothermy (warm-blooded)
  - endothermic animals need 10x energy
    - need to deliver 10x fuel & O_2
  - convergent evolution in birds & mammals

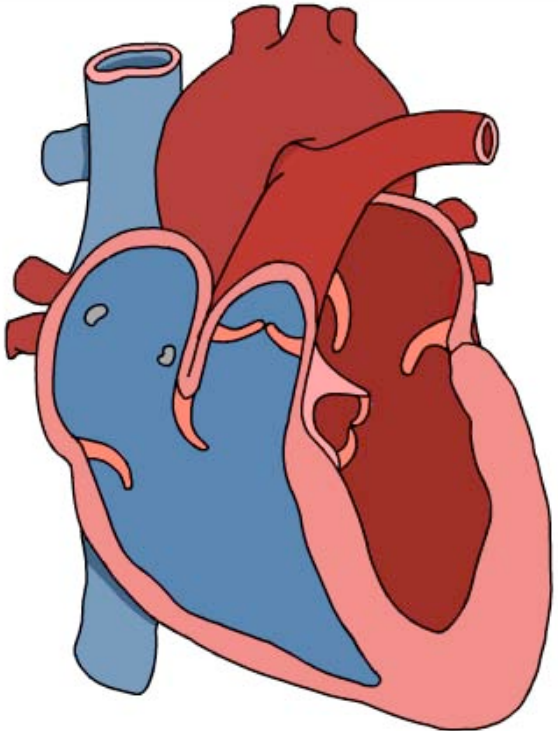


Vertebrate cardiovascular system



- Chambered heart
  - atria (atrium) = receive blood
  - ventricles = 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



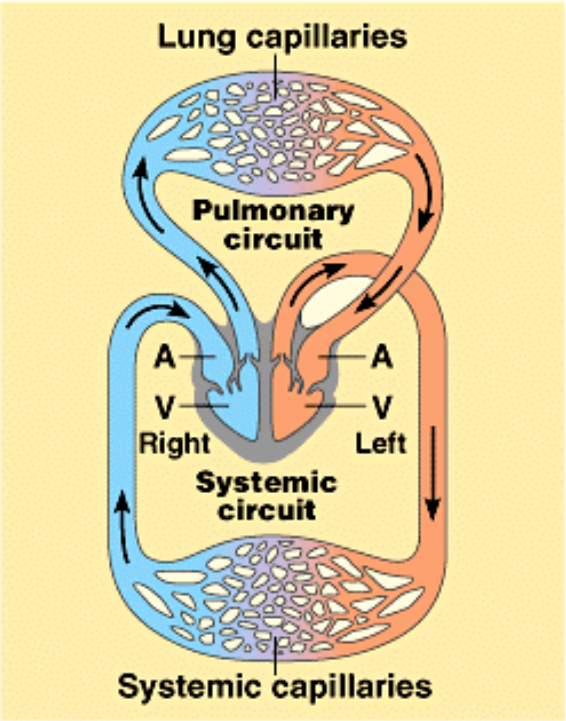
arteries

arterioles

capillaries

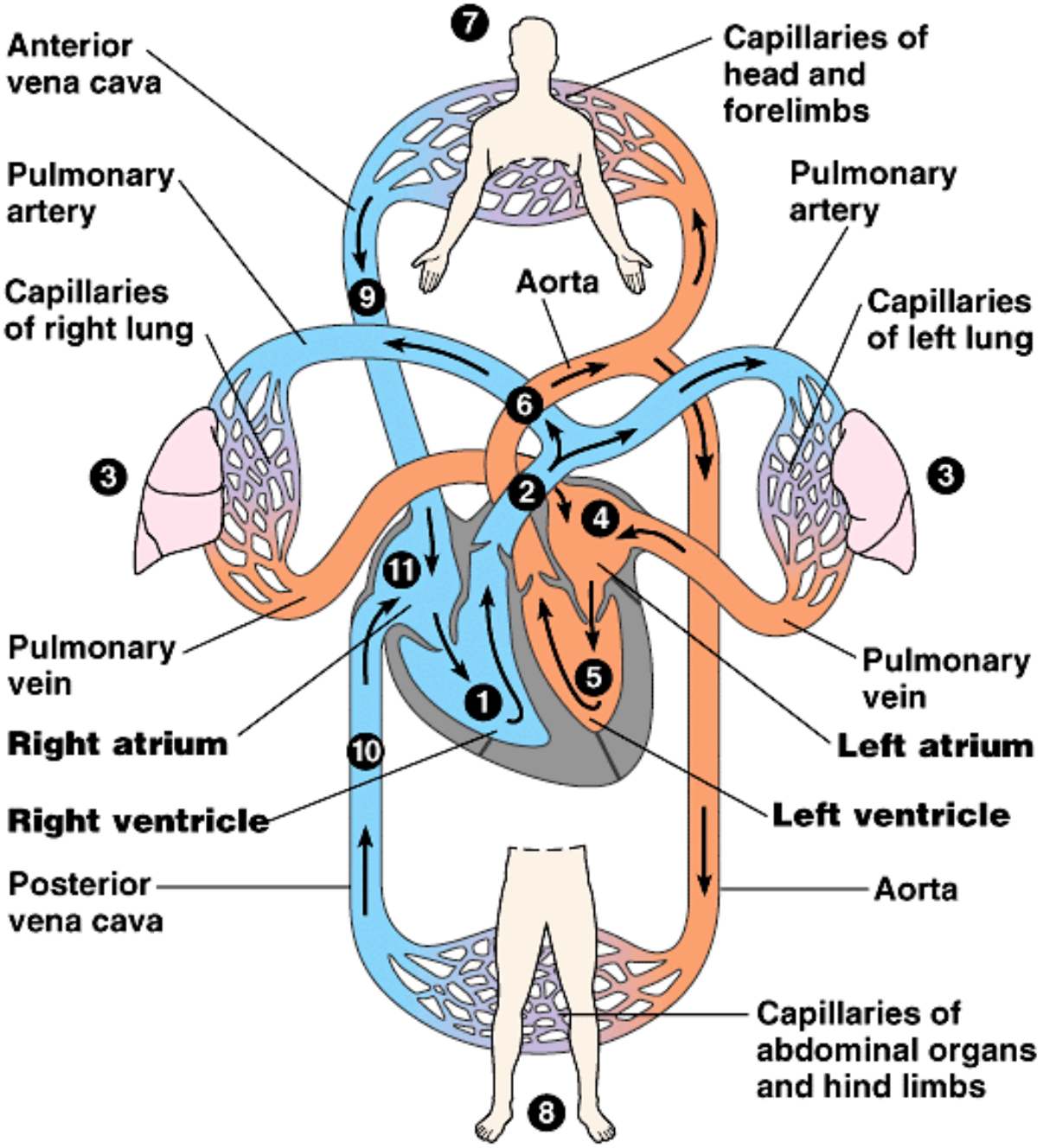
venules

veins



Mammalian circulation

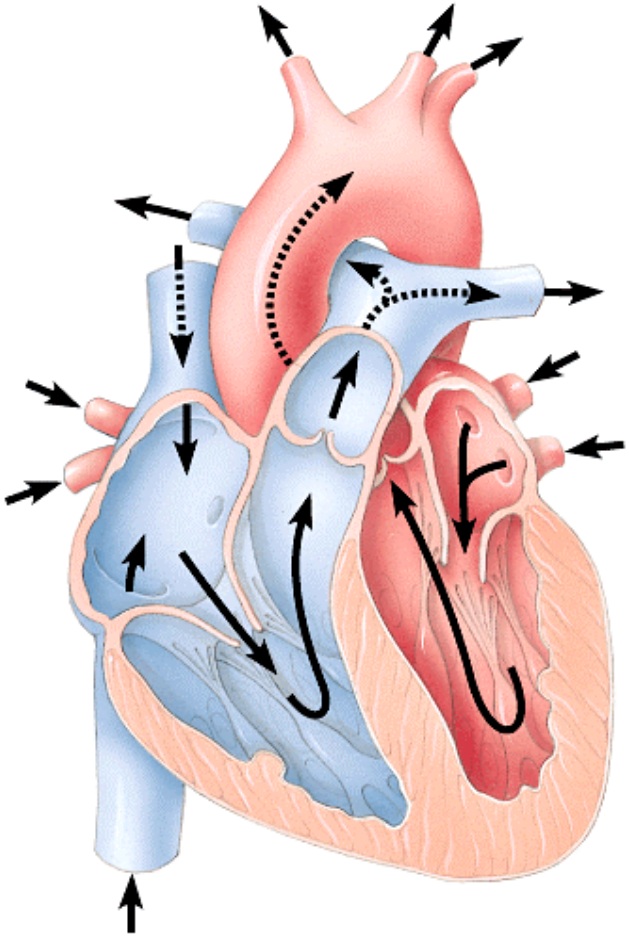
Pulmonary circuit
vs.
Systemic circuit



What do the blue vs. red areas represent?

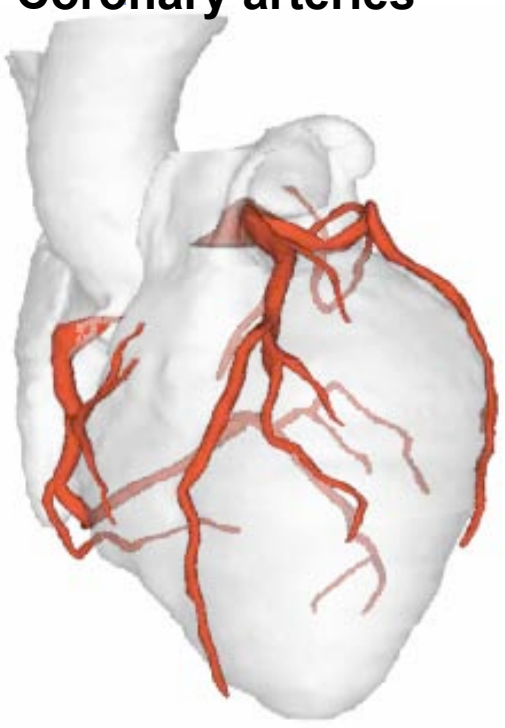
Mammalian circulation

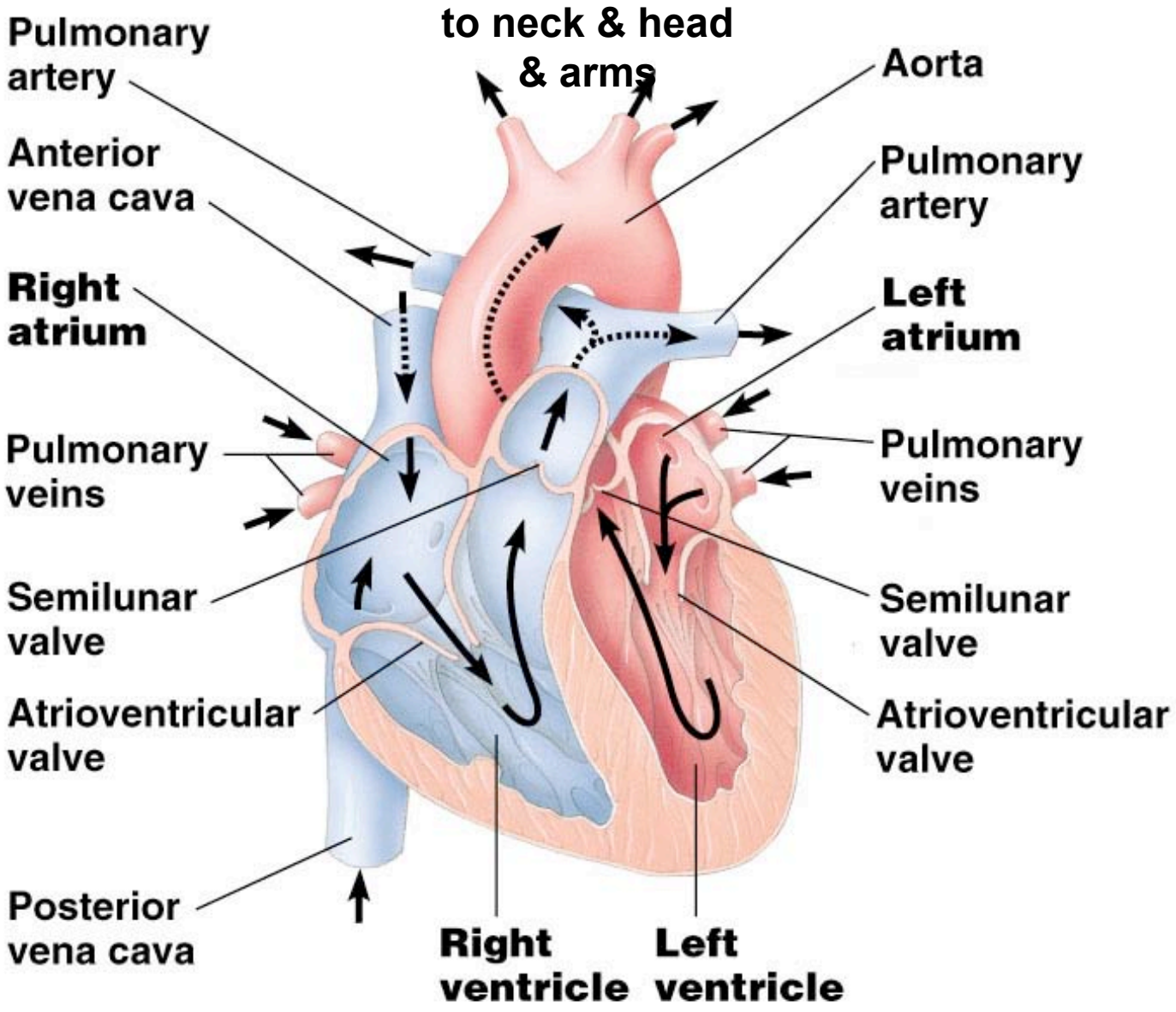
- 2 circulations
  - pulmonary = lungs
  - systemic = body
  - operate simultaneously
- 4 chambered heart
  - 2 atria = thin-walled collection chambers
  - 2 ventricles = thick-walled pumps
  - ventricles pump almost in unison
- Vessels
  - veins carry blood to heart
  - arteries carry blood away from heart



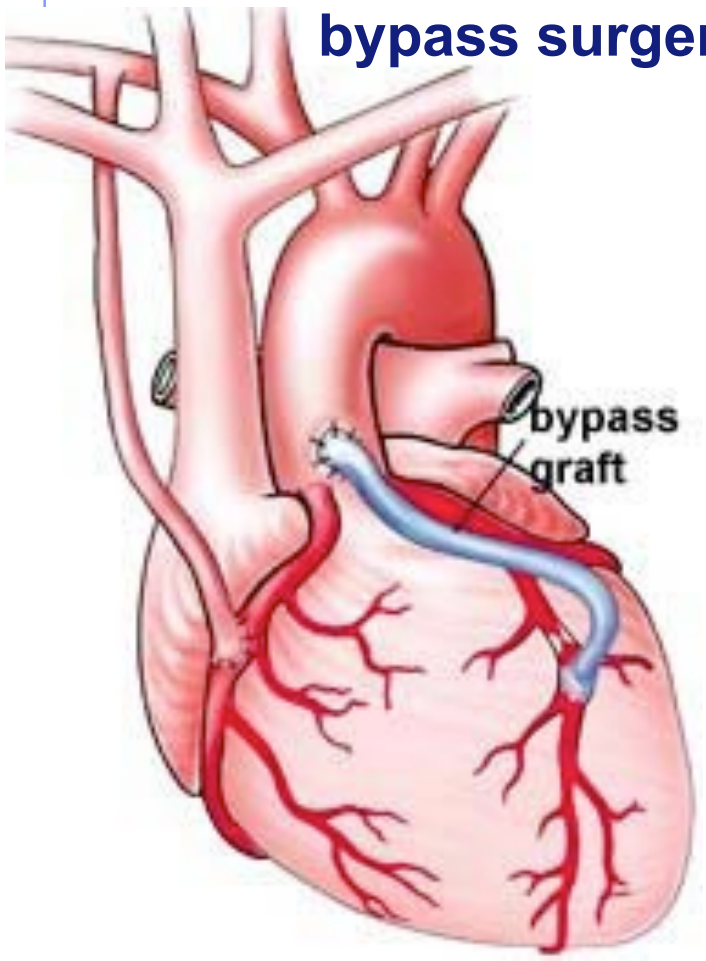
Mammalian heart

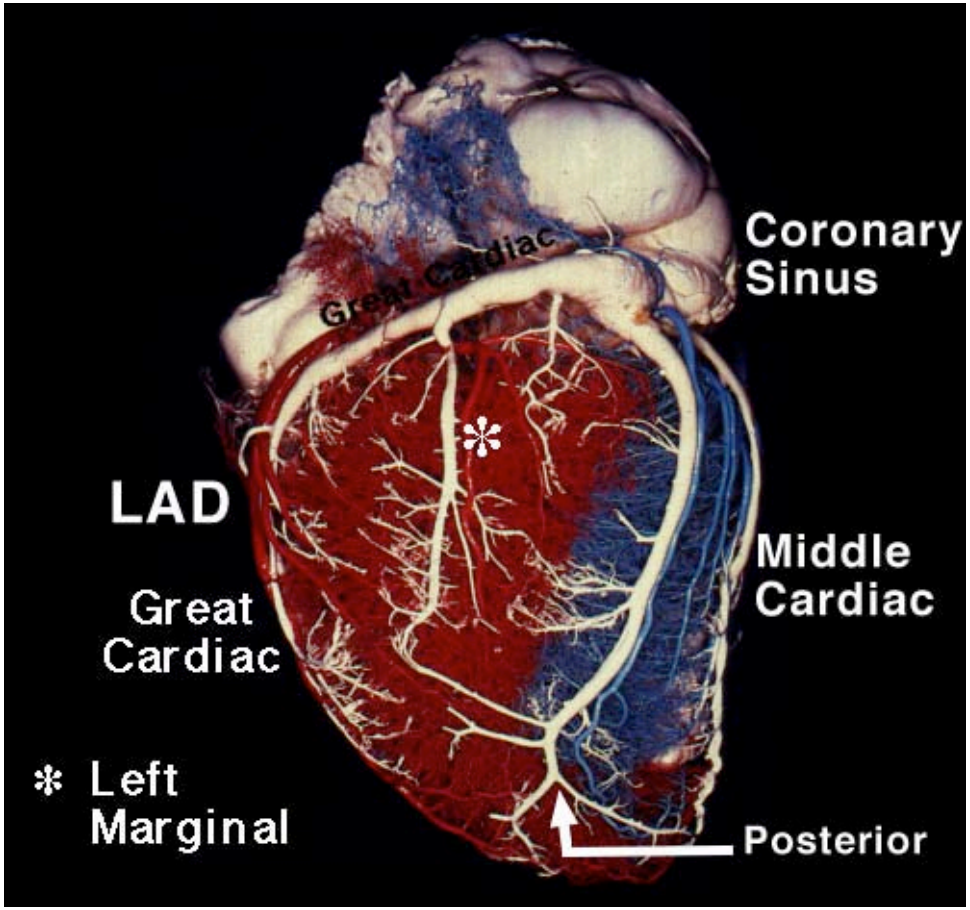
Coronary arteries





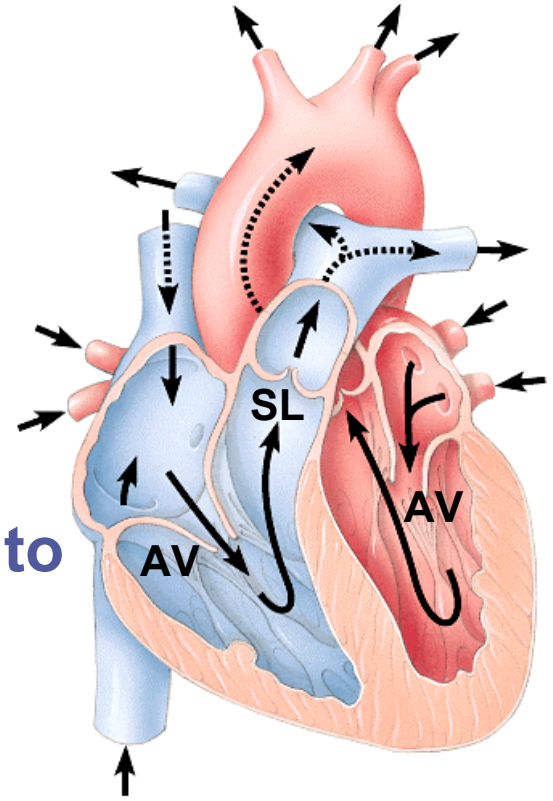
Coronary arteries





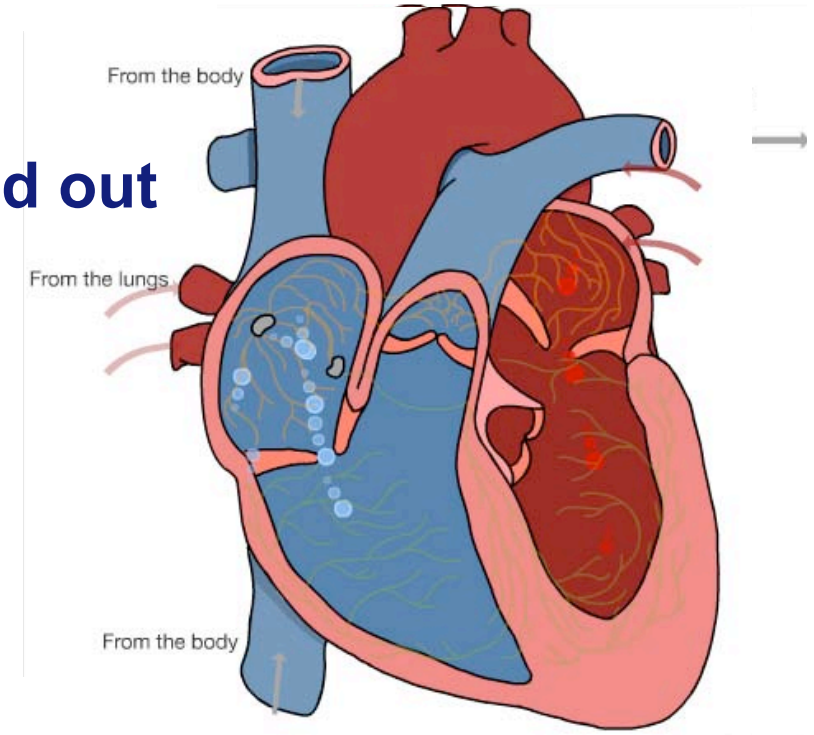
Heart valves

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



Cardiac cycle

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



Cardiac Cycle

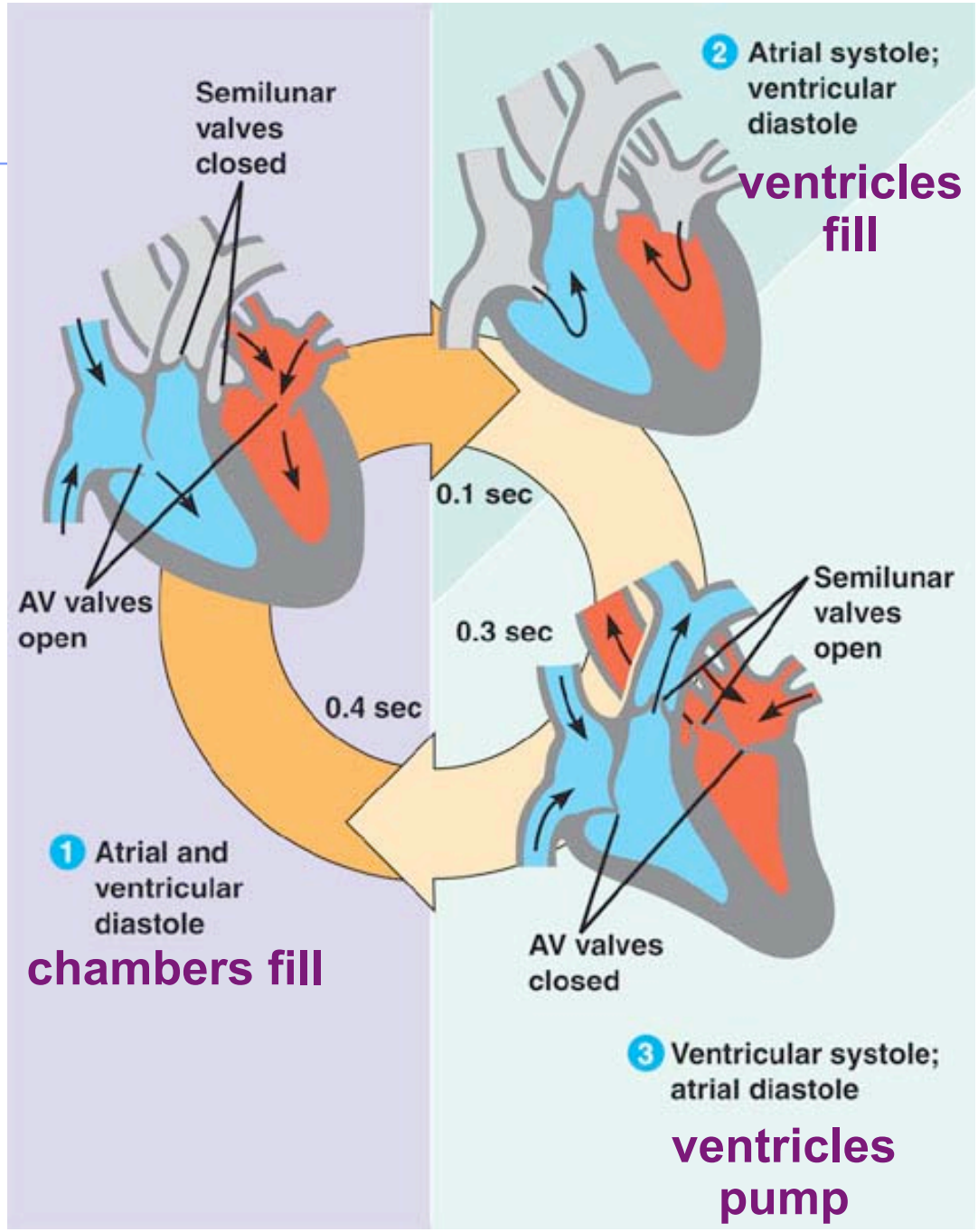
How is this reflected in blood pressure measurements?

systolic

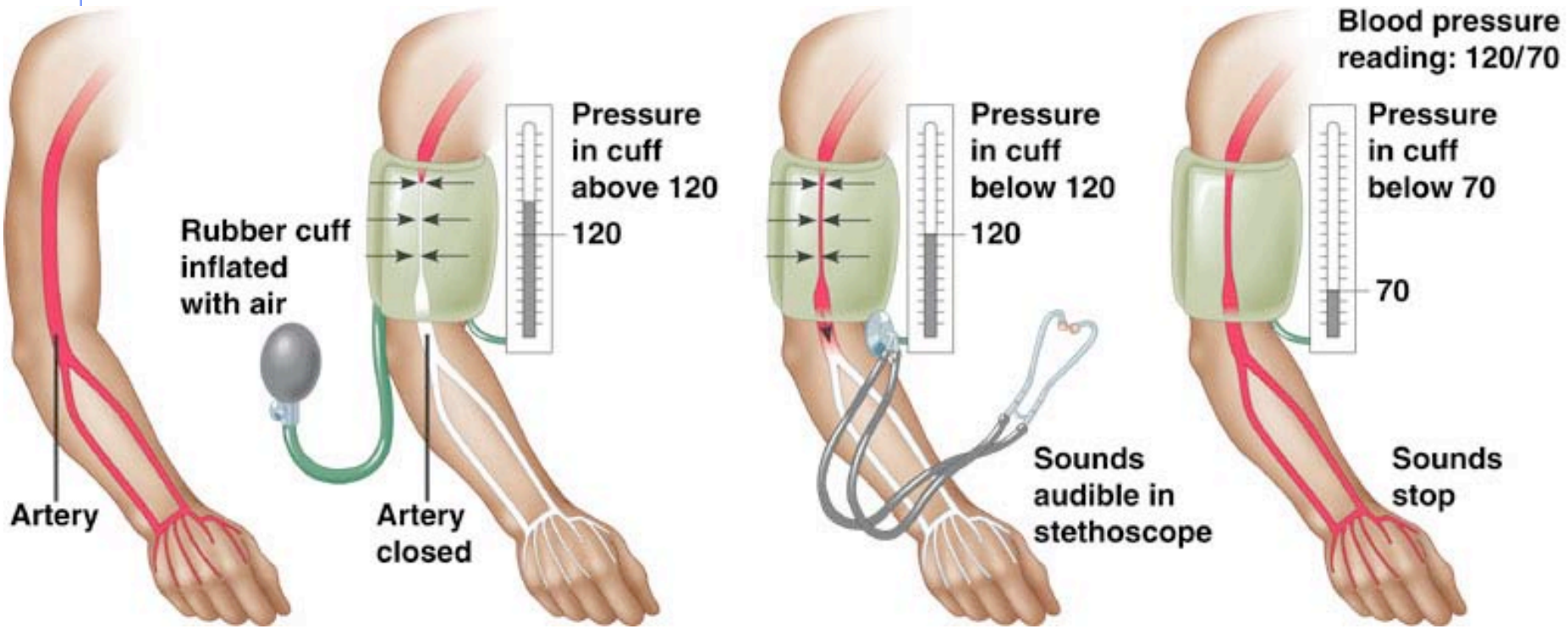
diastolic

pump

fill

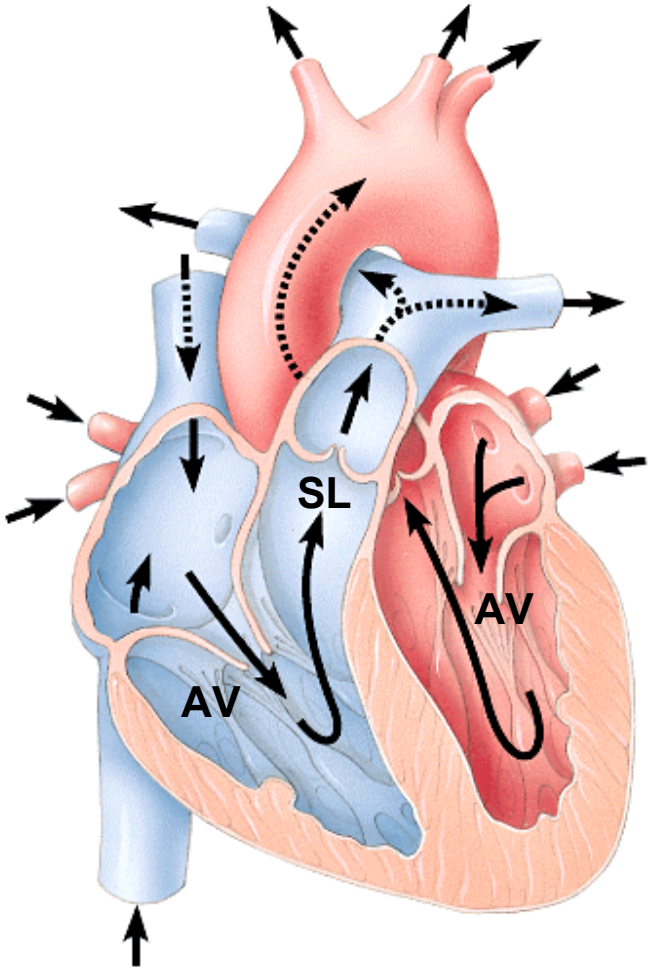


Measurement of blood pressure



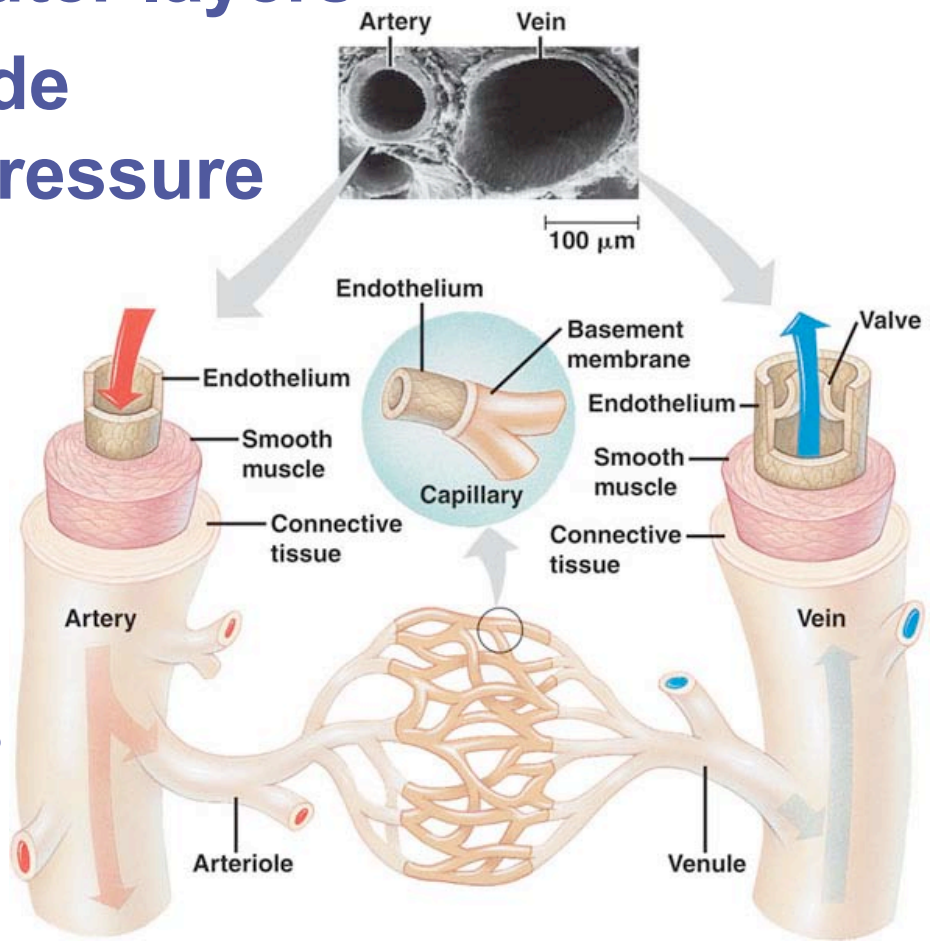
Lub-dup, lub-dup

- **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



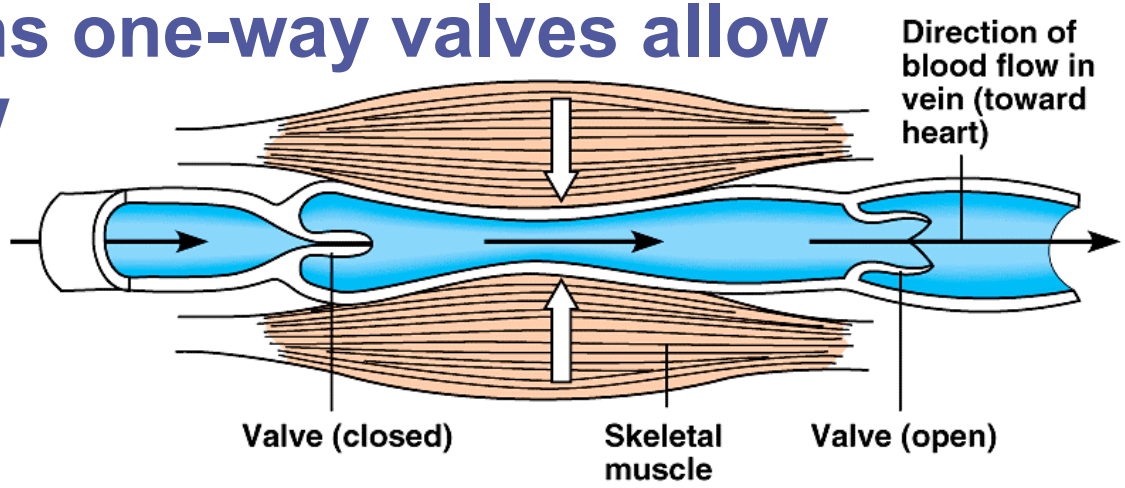
Form follows function

- **Arteries**
  - thicker middle & outer layers
  - thicker walls provide strength for high pressure pumping of blood
  - elasticity (elastic recoil) helps maintain blood pressure even when heart relaxes



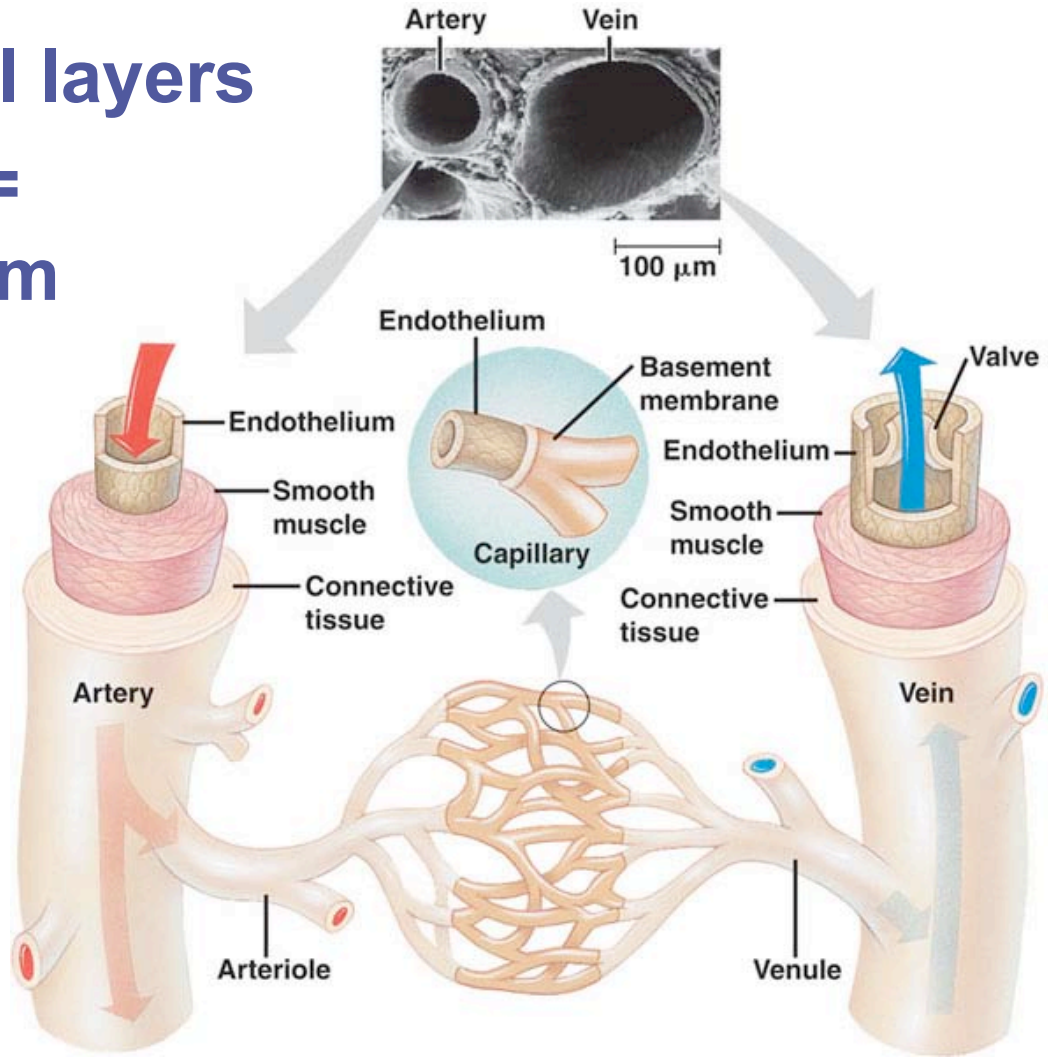
Form follows function

- Veins
  - thinner-walled
  - blood travels back to heart at low velocity & pressure
  - blood flows due to skeletal muscle contractions when we move
    - squeeze blood in veins
  - in larger veins one-way valves allow blood to flow only toward heart



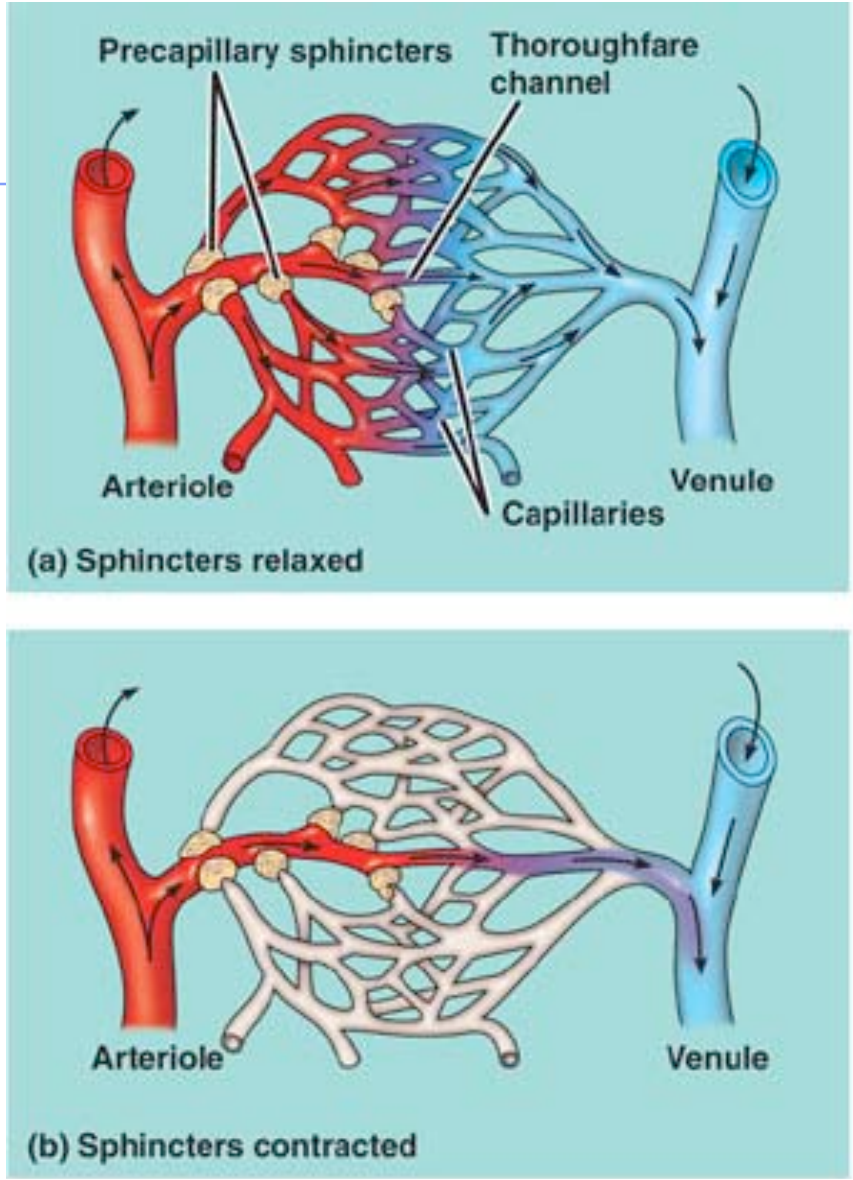
Form follows function

- **Capillaries**
  - lack 2 outer wall layers
  - very thin walls = only endothelium
    - enhancing exchange



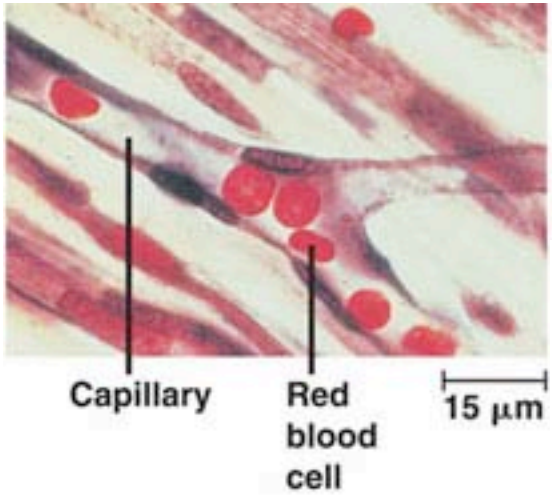
Capillary Beds

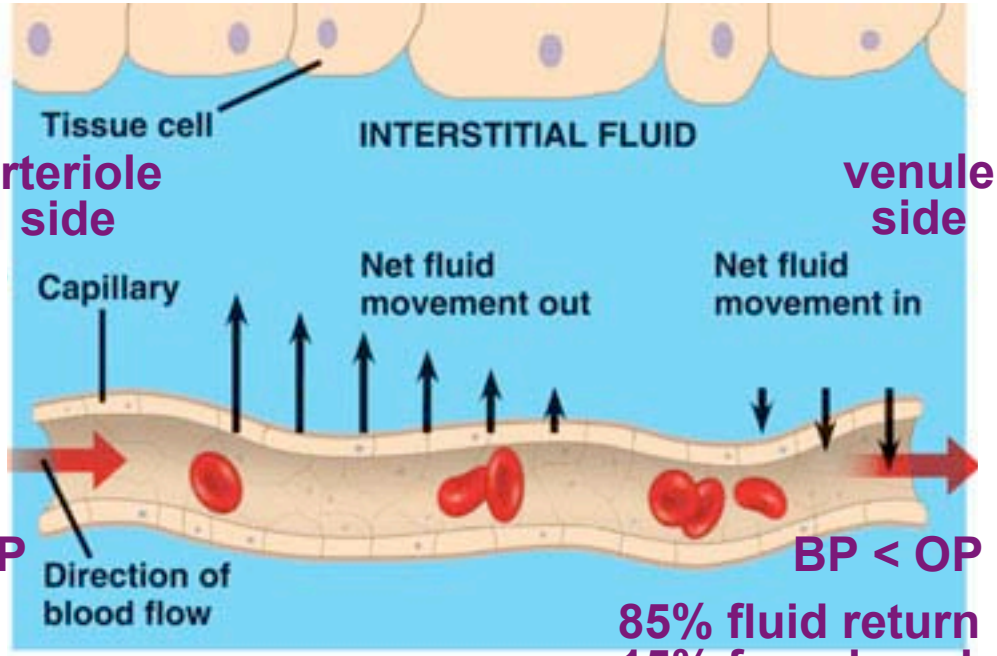
- **Blood flow**
  - at any given time, only ~5-10% of body's capillaries have blood flowing through them
  - capillaries in brain, heart, kidneys & liver usually filled to capacity
  - for other sites, blood supply varies over times as blood is needed
    - after a meal blood supply to digestive tract increases
    - during strenuous exercise, blood is diverted from digestive tract to skeletal muscles



pre-capillary sphincters regulate flow into capillary beds

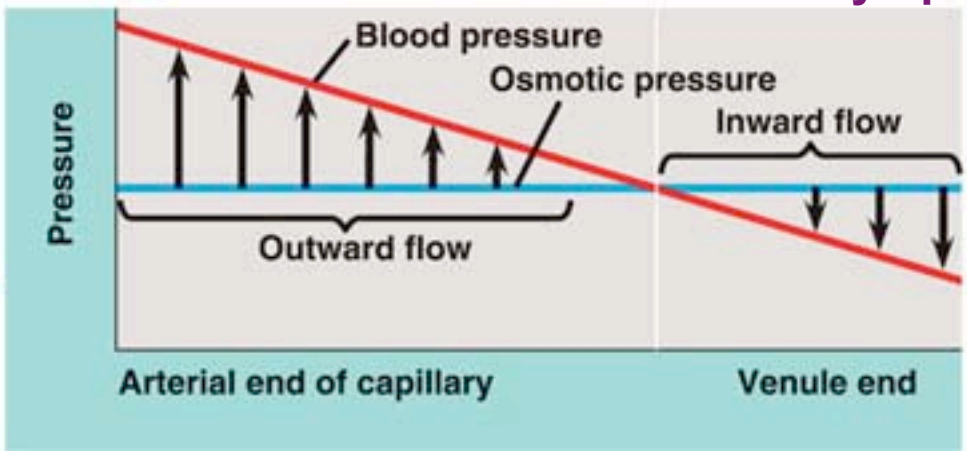
Exchange across capillary walls





85% fluid return
15% from lymph

Direction of movement of fluid between blood & interstitial fluids depends on blood pressure & osmotic pressure

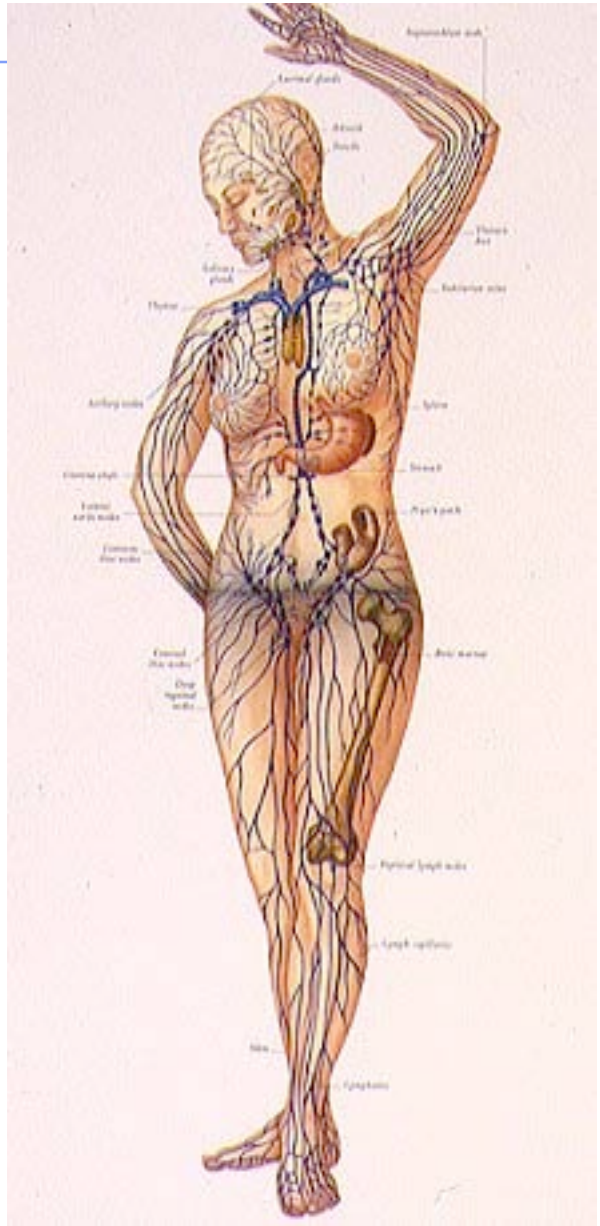


Exchange across capillary walls

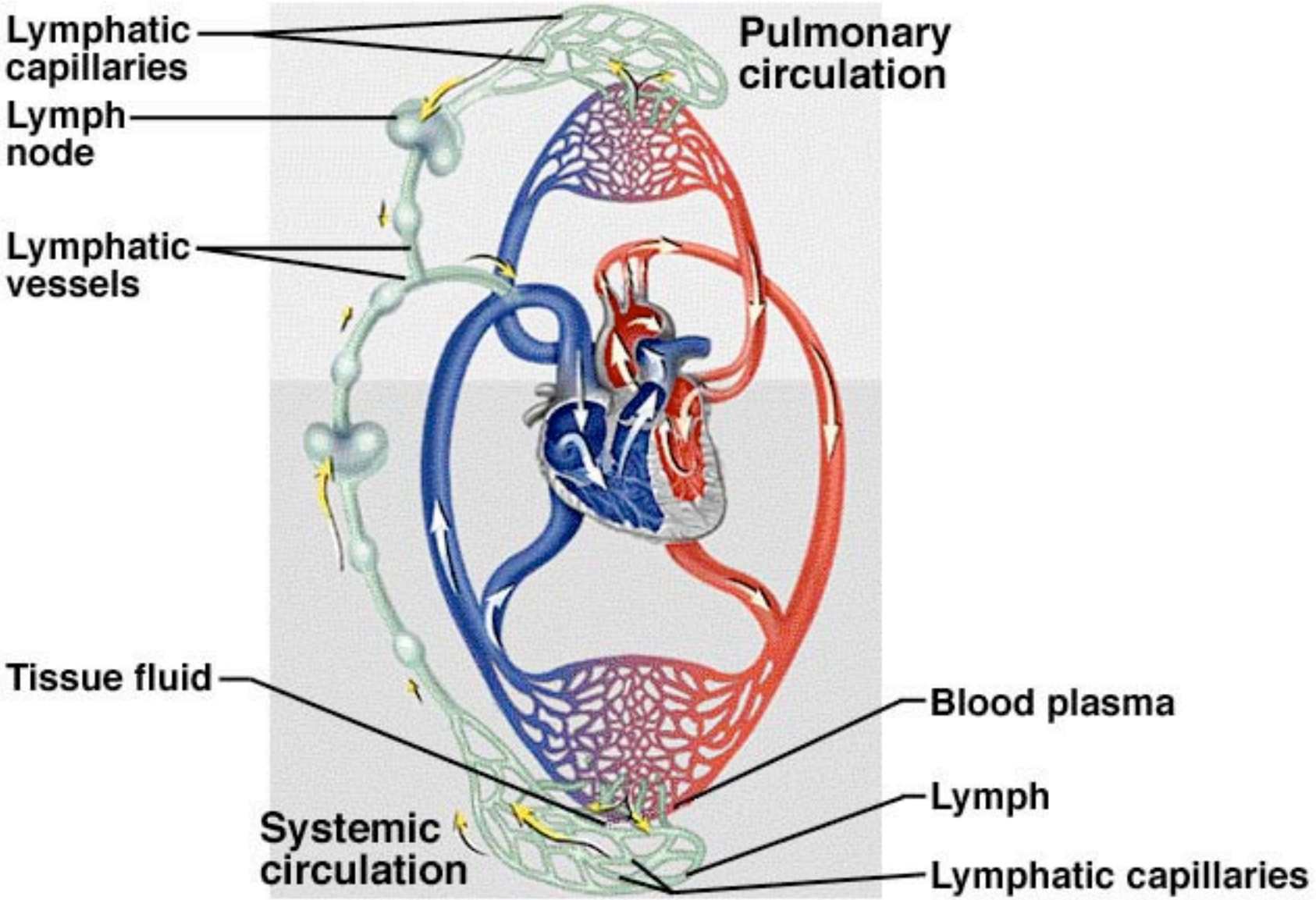
- **Diffusion**
  - bulk flow transport due to fluid pressure
  - blood pressure within capillary pushes fluid – water & small solutes – through capillary wall
    - causes net loss of fluid at upstream end of capillary
- **Endocytosis & exocytosis**
  - larger molecules
- **Left behind**
  - blood cells & most proteins in blood are too large to pass through, so remain in capillaries

Lymphatic system

- Parallel circulatory system
  - transports WBC
    - defending against infection
  - collects interstitial fluid & returns to blood
    - maintains volume & protein concentration of blood
    - drains into circulatory system near junction of venae cavae with right atrium
  - transports fats from digestive to circulatory system



Lymph System

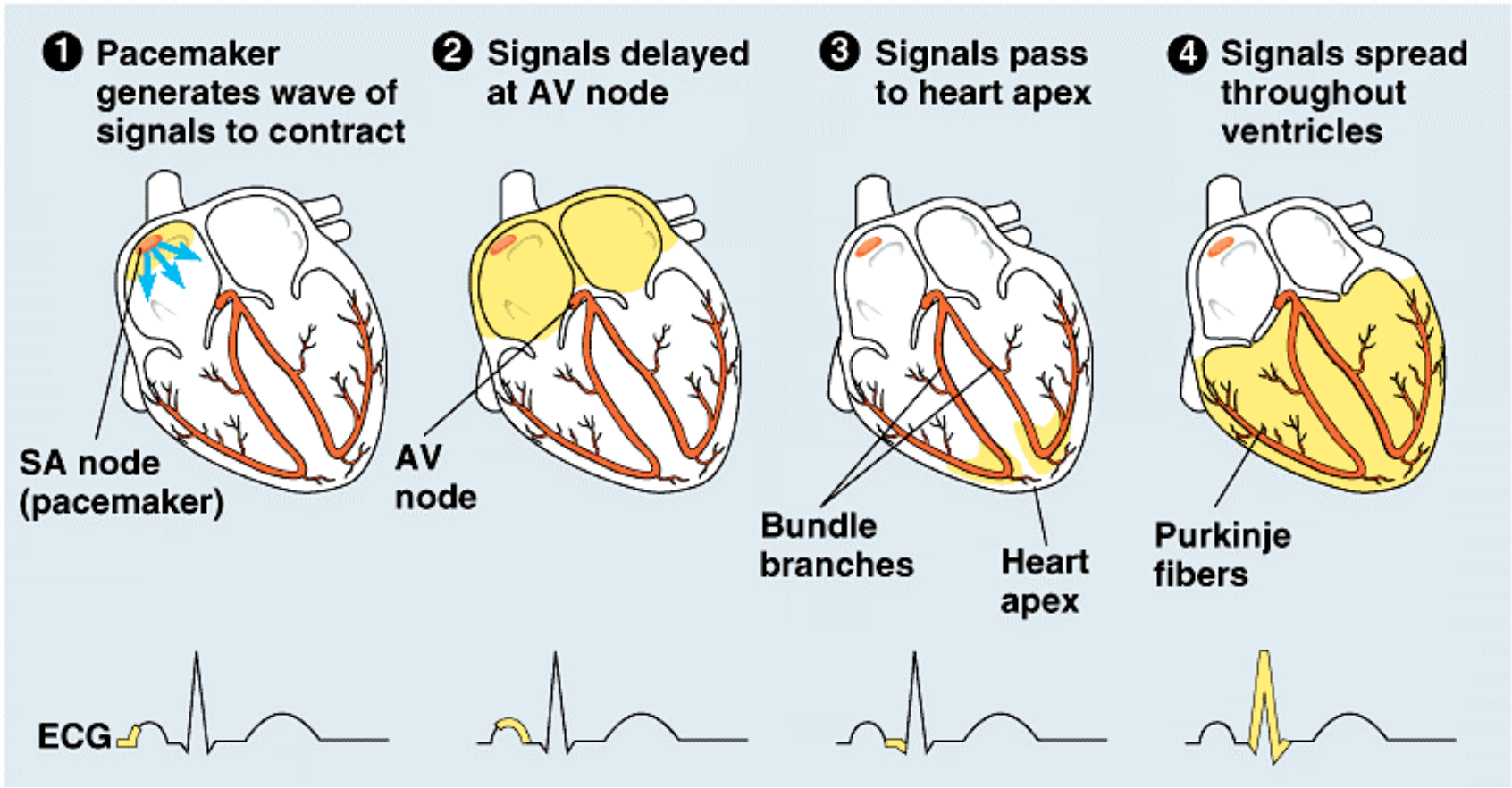


Control of heart

- Timely delivery of O_2 to body's organs is critical
  - mechanisms evolved to assure continuity & control of heartbeat
  - cells of cardiac muscle are "self-excitable"
    - contract without any signal from nervous system
    - each cell has its own contraction rhythm
  - cells are synchronized by the sinoatrial (SA) node, or pacemaker
    - sets rate & timing of cardiac muscle cell contraction
    - located in wall of right atrium

Electrical signals

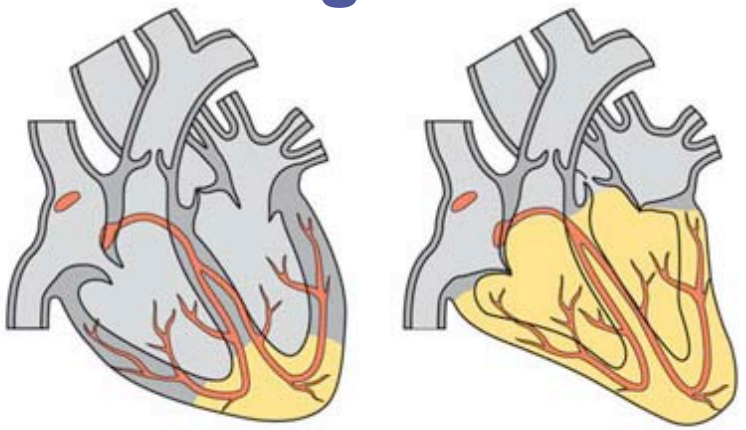
- Cardiac cycle regulated by electrical impulses that radiate across heart
  - transmitted to skin = EKG



AP

Coordinated contraction

- SA node generates electrical impulses
  - coordinates atrial contraction
  - impulse delayed by 0.1 sec at AV node
    - relay point to ventricle
    - allows atria to empty completely before ventricles contract
  - specialized muscle fibers conduct signals to apex of heart & throughout ventricular walls
    - stimulates ventricles to contract from apex toward atria, driving blood into arteries

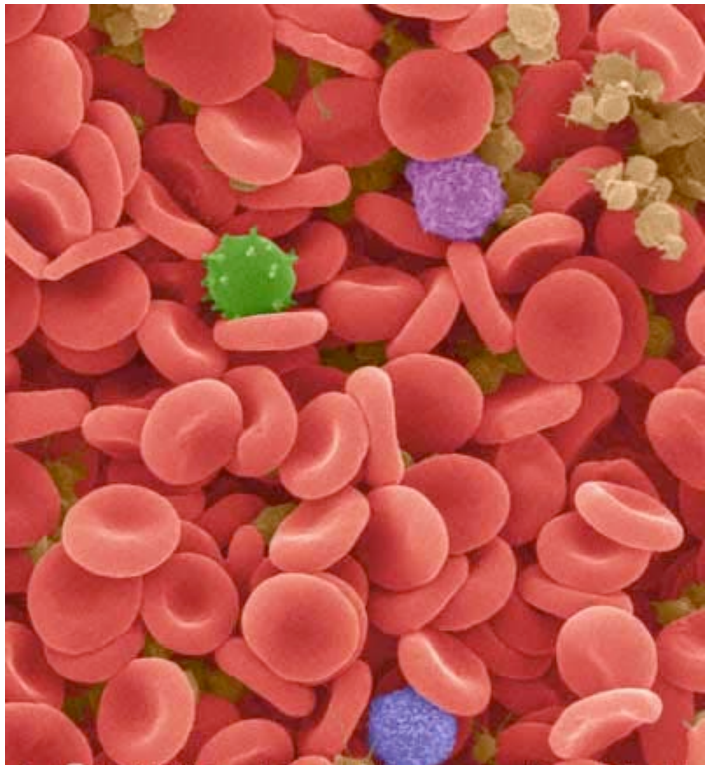


Effects on heart rate

- 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.

Blood & blood cells

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



Constituents of blood

Plasma 55%

Constituent	Major functions
Water	Solvent for carrying other substances
Ions (blood electrolytes)	
Sodium	Osmotic balance, pH buffering, and regulation of membrane permeability
Potassium	
Calcium	
Magnesium	
Chloride	
Bicarbonate	
Plasma proteins	
Albumin	Osmotic balance, pH buffering
Fibrinogen	Clotting
Immunoglobulins (antibodies)	Defense
Substances transported by blood	
Nutrients (such as glucose, fatty acids, vitamins)	
Waste products of metabolism	
Respiratory gases (O_2 and CO_2)	
Hormones	

Cellular elements 45%

Cell type	Number per μL (mm^3) of blood	Functions
Erythrocytes (red blood cells)	5–6 million	Transport oxygen and help transport carbon dioxide
Leukocytes (white blood cells)	5,000–10,000	Defense and immunity
Basophil		
Eosinophil		
Lymphocyte		
Neutrophil		
Monocyte		
Platelets	250,000–400,000	Blood clotting

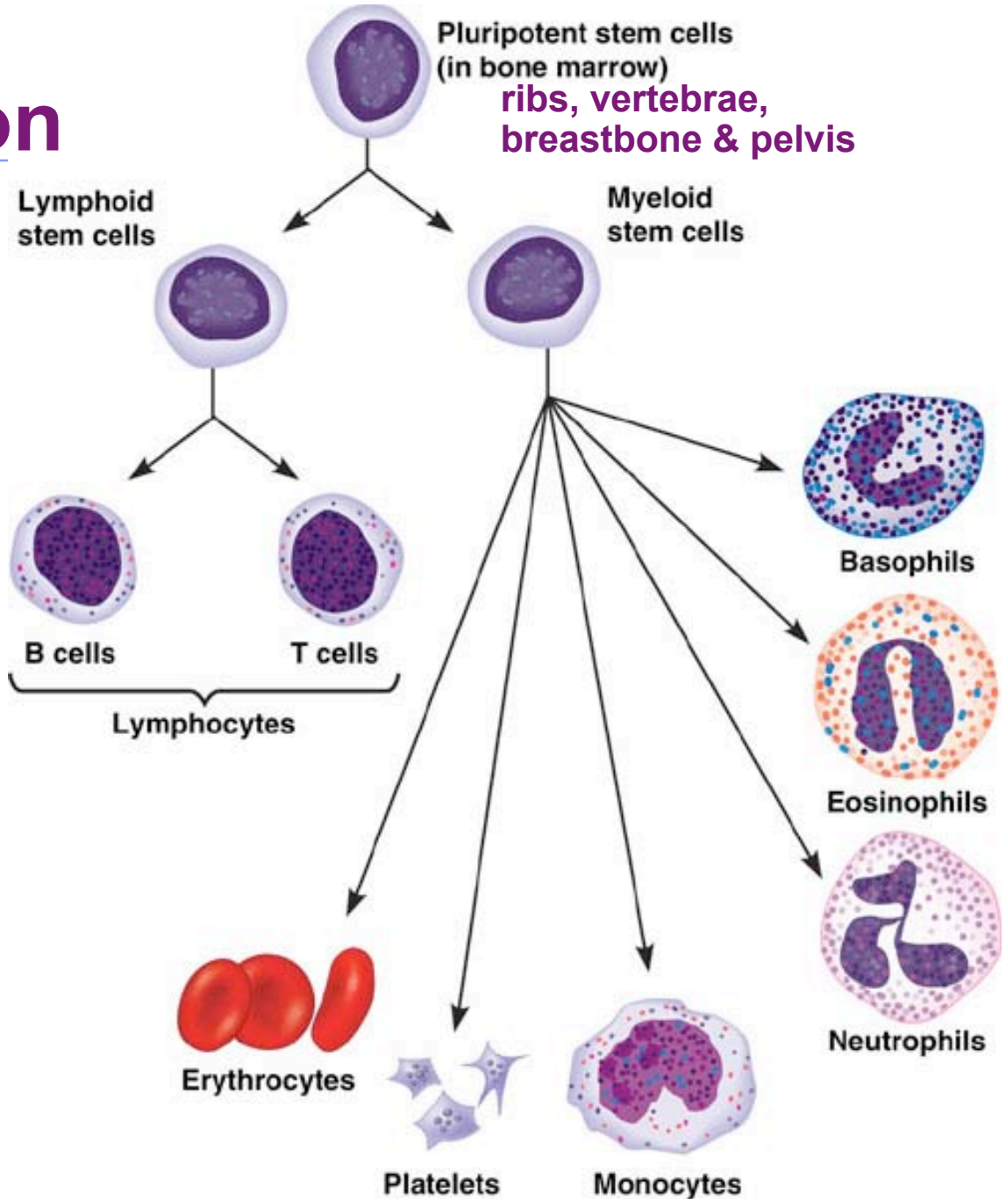
Plasma proteins

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

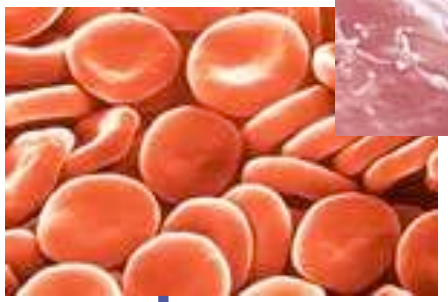
Cell production

Development from stem cells

Differentiation of blood cells in bone marrow & lymph tisssues



Red blood cells



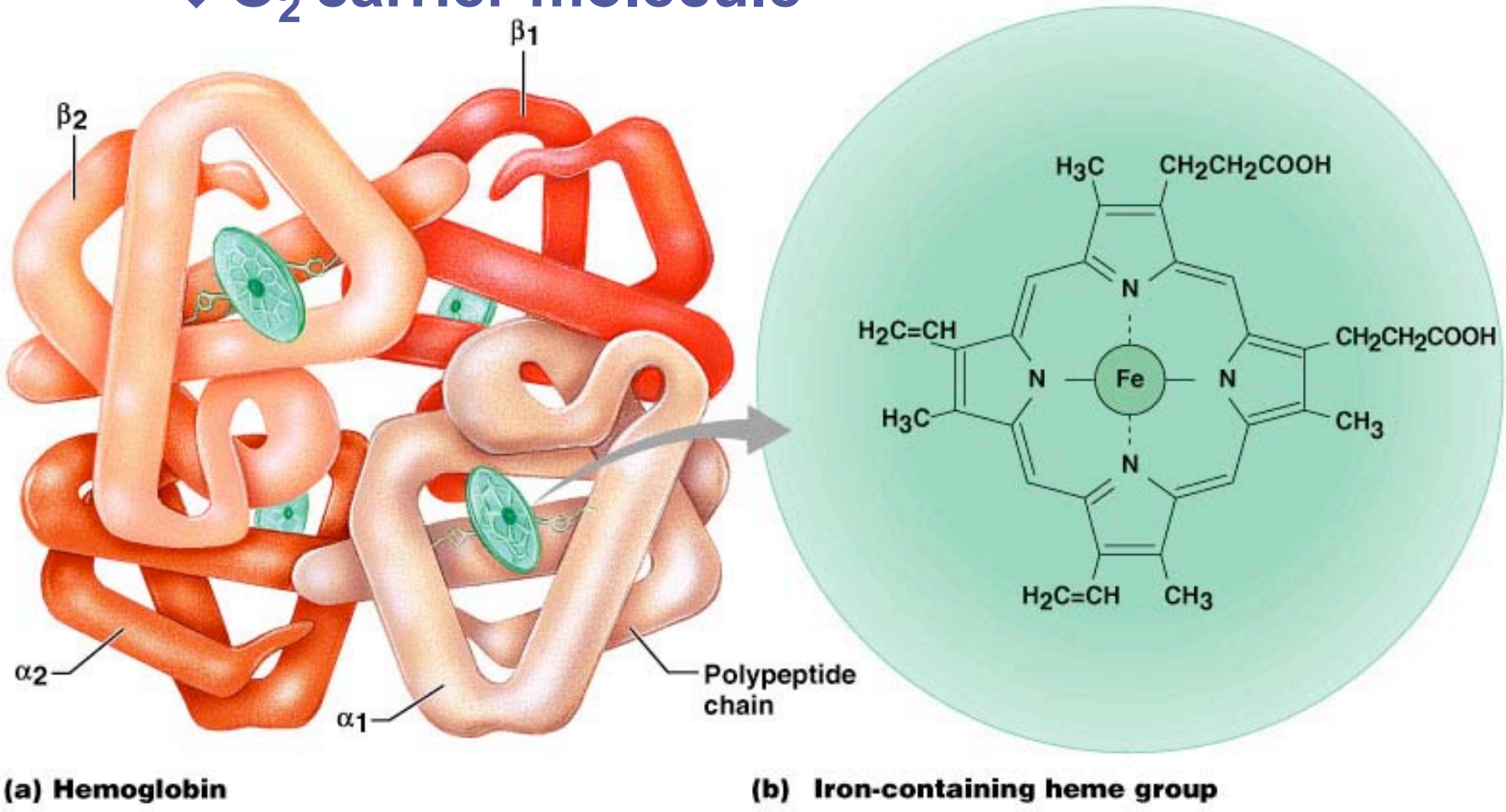
- O_2 transport
- Small biconcave disks
  - large surface area
  - produced in marrow of long bones
  - lack nuclei & mitochondria
    - more space for hemoglobin
    - iron-containing protein that transports O_2
    - generate ATP by anaerobic respiration
  - last 3-4 months (120 days)
    - ingested by phagocytic cells in liver & spleen
    - ~3 million RBC destroyed each second

Red blood cell production

- 5-6 million RBC in 1µL of human blood
- 5 L of blood in body = 25 trillion RBC
  - produce ~3 million RBC every second in bone marrow to replace cells lost through attrition
- each RBC 250,000 molecules hemoglobin
  - each Hb molecule carries 4 O_2
  - each RBC carries 1 million O_2

Hemoglobin

- **Protein with 4° structure**
  - **O_2 carrier molecule**



Blood clotting

Cascade reaction

1 Endothelium of vessel is damaged, exposing connective tissue; platelets adhere

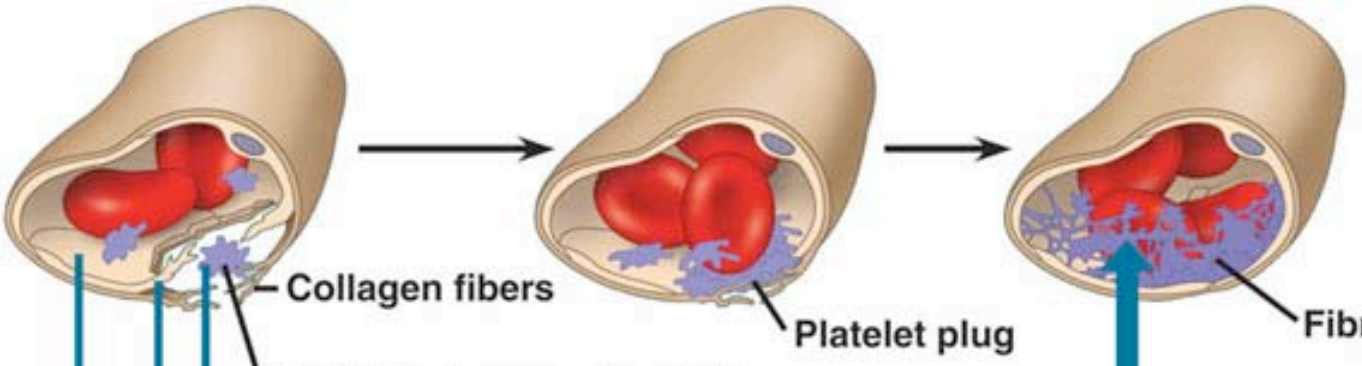
2 Platelets form a plug

self-sealing material

3 Seal is reinforced by a clot of fibrin

Powerful evolutionary adaptation

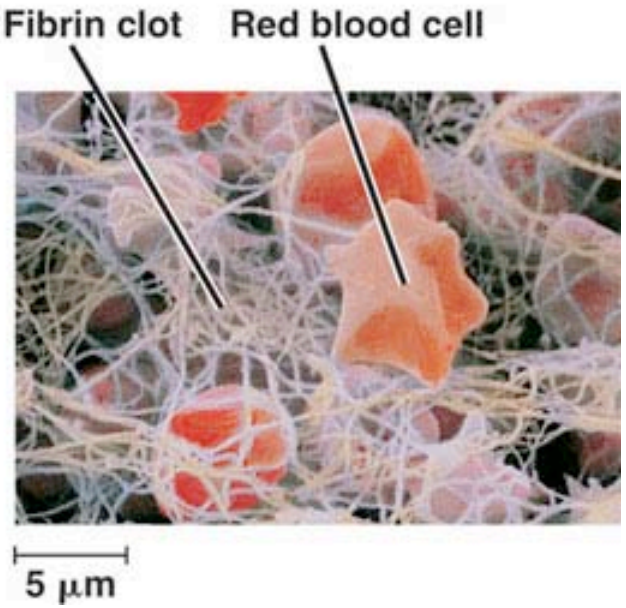
- emergency repair of circulatory system
- prevent excessive blood loss



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

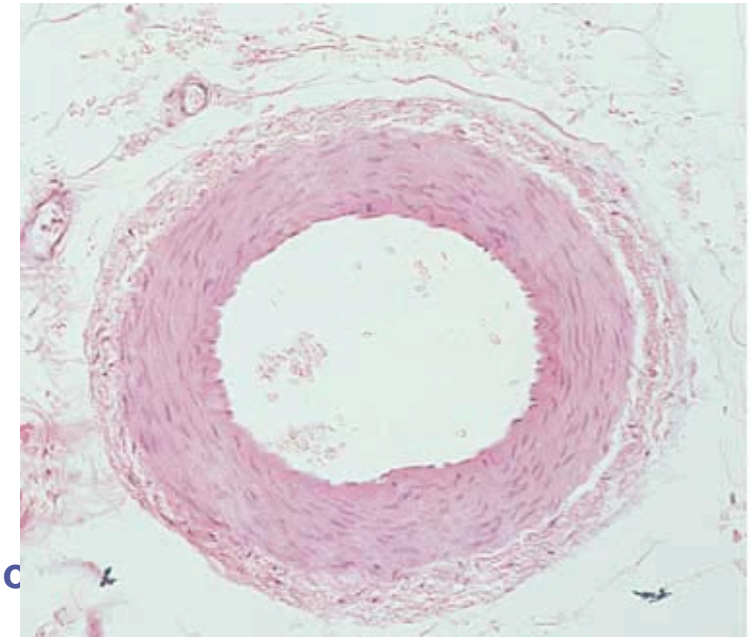
Prothrombin → Thrombin

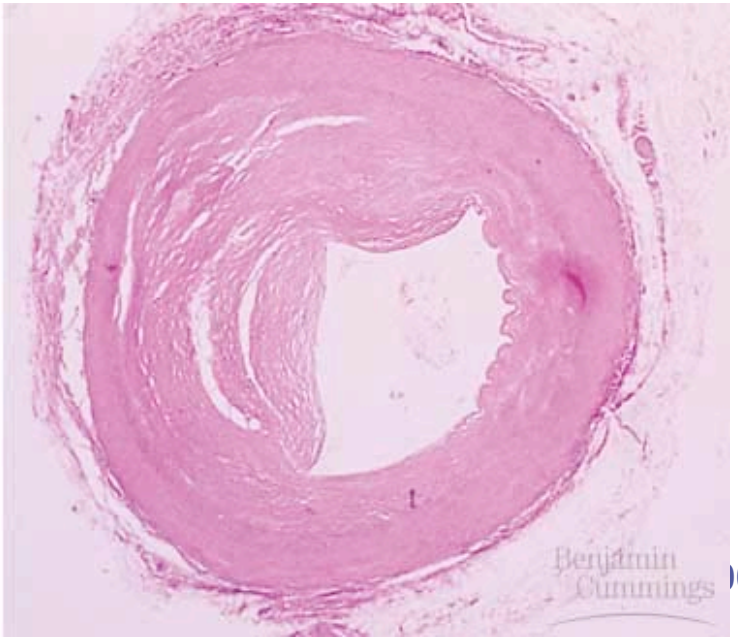
Fibrinogen → Fibrin



Cardiovascular disease

- **Leading cause of death in U.S.**
  - plaques develop in inner wall of arteries, narrowing channel
  - stroke, heart attack, atherosclerosis, arteriosclerosis, hypertension
    - tendency inherited, but other risk factors: smoking, lack of exercise, diet rich in fat

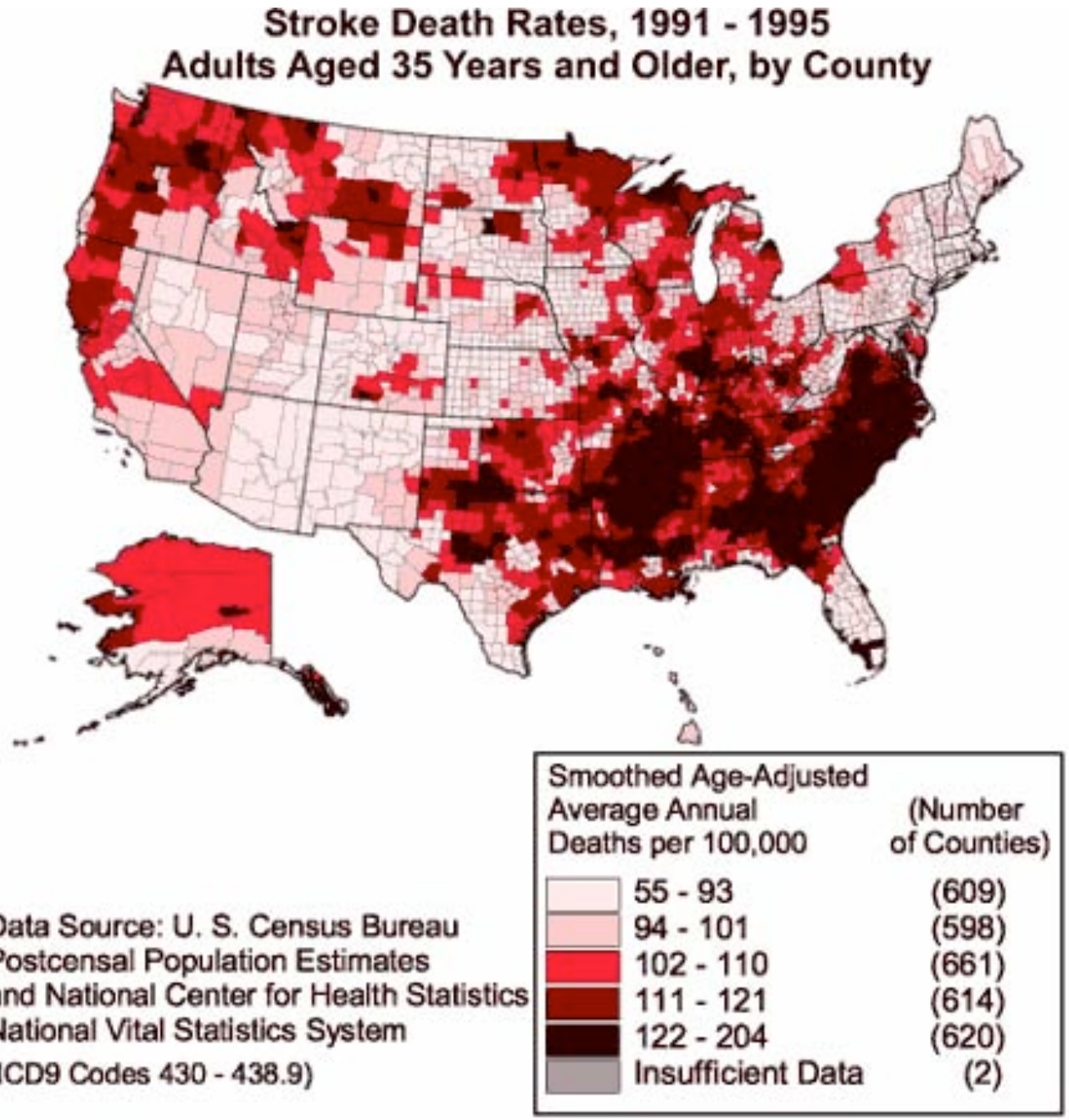




Cardiovascular health (U.S. 2001)

Heart Disease	696,947
Cancer	557,271
Stroke	162,672
Chronic lower respiratory diseases	124,816
Accidents (unintentional injuries)	106,742
Diabetes	73,249
Influenza/Pneumonia	65,681
Alzheimer's disease	58,866
Nephritis, nephrotic syndrome & nephrosis	40,974
Septicemia	33,865

Stroke Fact Sheet



Any Questions??