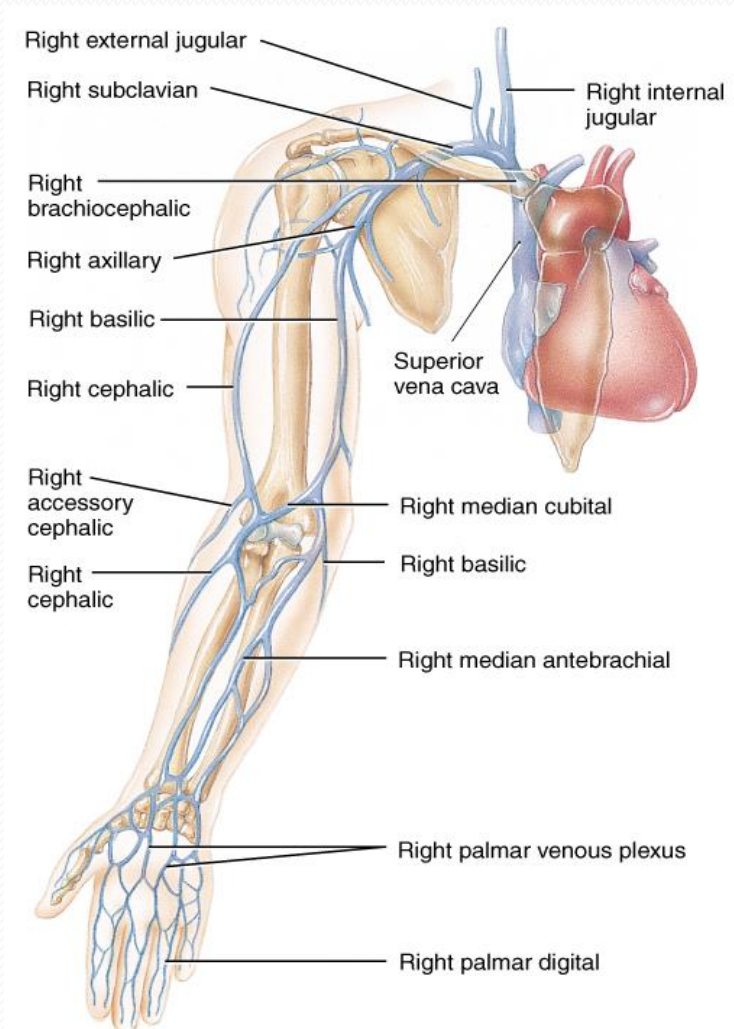


Chapter 21_ The Cardiovascular System:

Blood Vessels and Hemodynamics



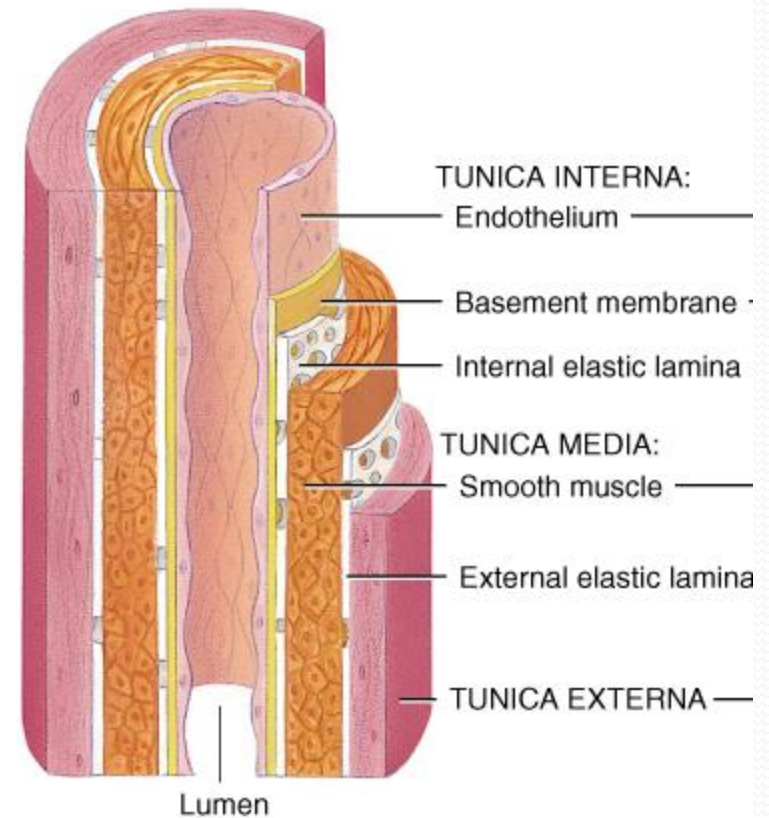
- Structure and function of blood vessels
- Hemodynamics
 - forces involved in circulating blood
- Major circulatory routes

Anatomy of Blood Vessels

- Closed system of tubes that carries blood
- Arteries carry blood from heart to tissues
 - elastic arteries
 - muscular arteries
 - arterioles
- Capillaries are thin enough to allow exchange
- Venules merge to form veins that bring blood back to the heart
- Vasa vasorum is vessels in walls of large vessel

Arteries

- Tunica interna (intima)
 - simple squamous epithelium known as endothelium
 - basement membrane
 - internal elastic lamina
- Tunica media
 - circular smooth muscle & elastic fibers
- Tunica externa
 - elastic & collagen fibers

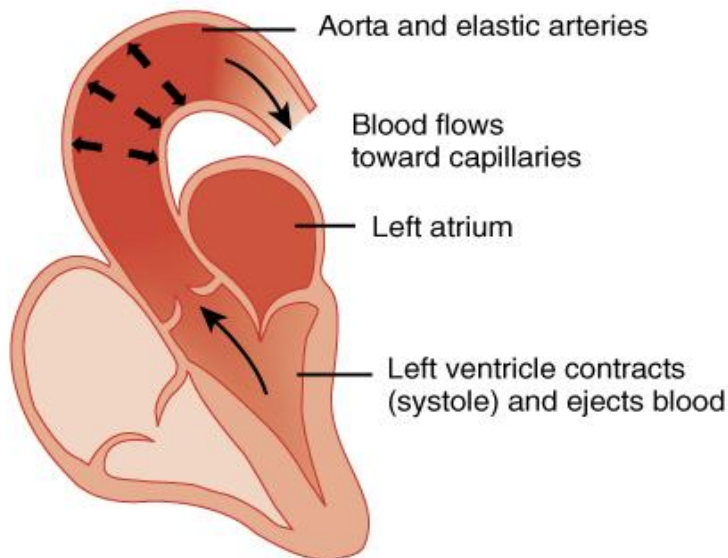


Sympathetic Innervation

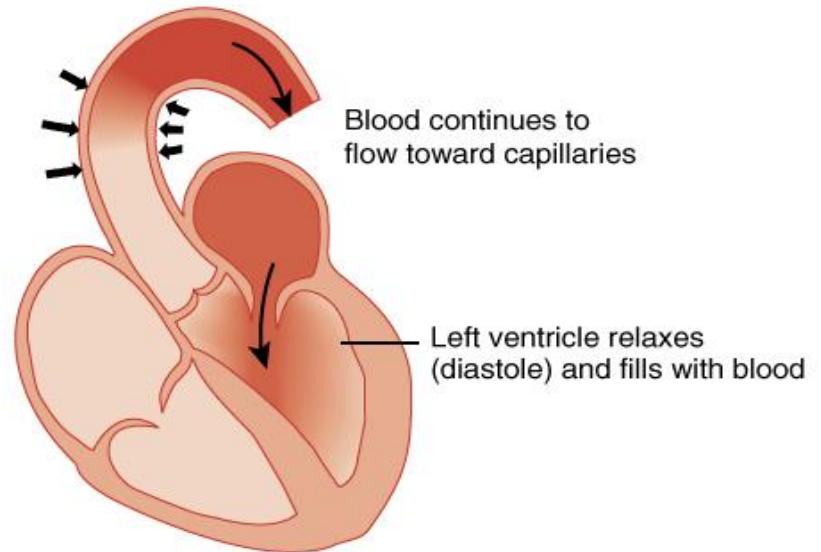
- Vascular smooth muscle is innervated by sympathetic nervous system
 - increase in stimulation causes muscle contraction or vasoconstriction
 - decreases diameter of vessel
 - injury to artery or arteriole causes muscle contraction reducing blood loss (vasospasm)
 - decrease in stimulation or presence of certain chemicals causes vasodilation
 - increases diameter of vessel
 - nitric oxide, K^+ , H^+ and lactic acid cause vasodilation

Elastic Arteries

- Largest-diameter arteries have lot of elastic fibers in tunica media
- Help propel blood onward despite ventricular relaxation (stretch and recoil -- pressure reservoir)



(a) Elastic aorta and arteries stretch during ventricular contraction



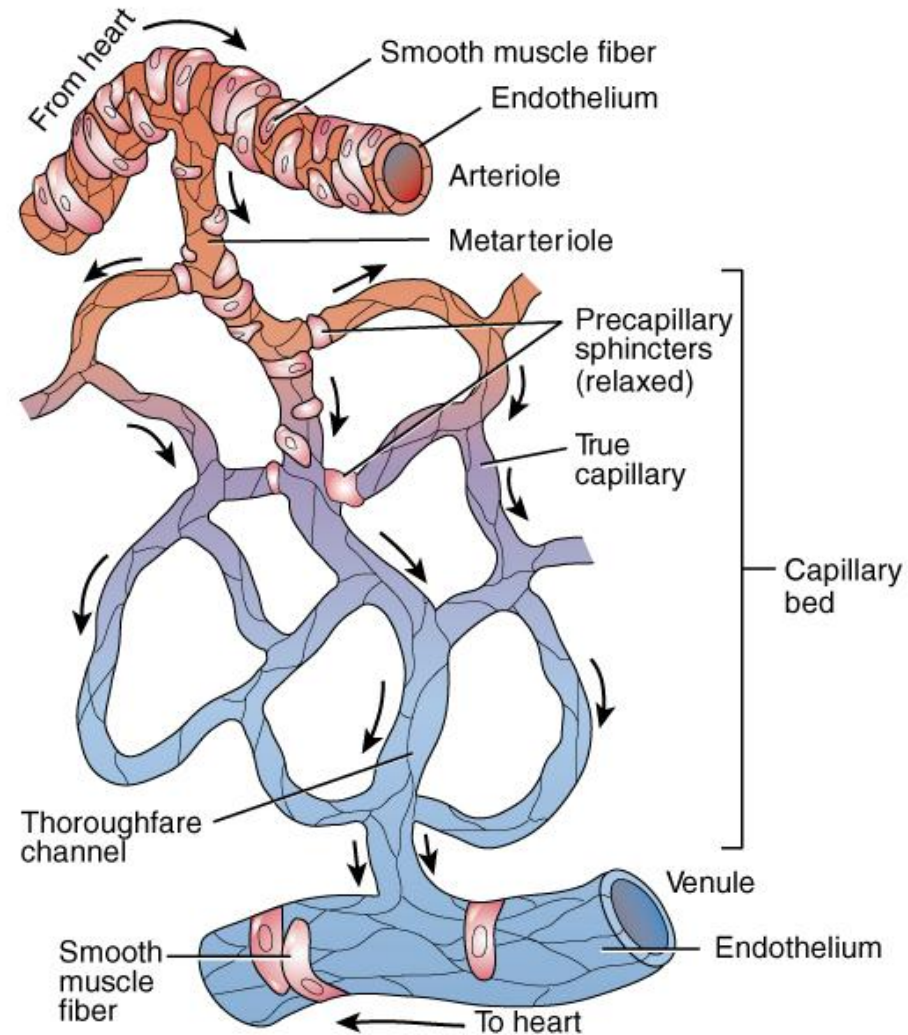
(b) Elastic aorta and arteries recoil during ventricular relaxation

Muscular Arteries

- Medium-sized arteries with more muscle than elastic fibers in tunica media
- Capable of greater vasoconstriction and vasodilation to adjust rate of flow
 - walls are relatively thick
 - called distributing arteries because they direct blood flow

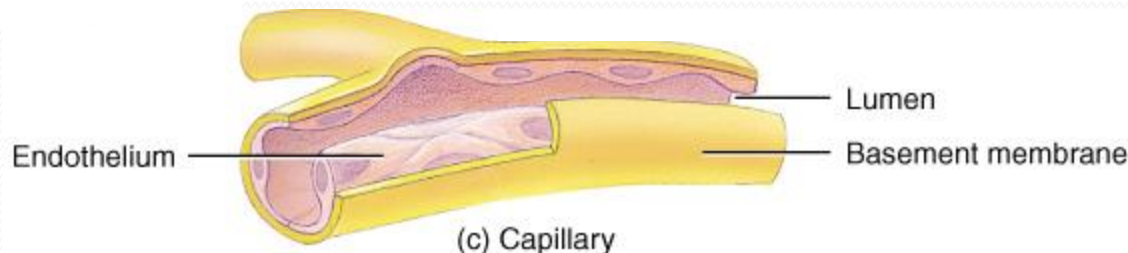
Arterioles

- Small arteries delivering blood to capillaries
 - tunica media containing few layer of muscle
- Metarterioles form branches into capillary bed
 - to bypass capillary bed, precapilla sphincters close & blood flows ou of bed in thoroughfare channel
 - vasomotion is intermittent contraction & relaxation of sphincters that allow filling of capillary bed 5-10 times/minute



Capillaries form Microcirculation

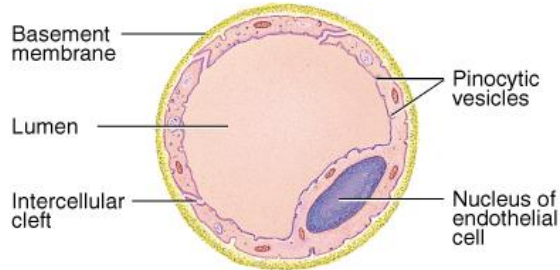
- Microscopic vessels that connect arterioles to venules
- Found near every cell in the body but more extensive in highly active tissue (muscles, liver, kidneys & brain)
 - entire capillary bed fills with blood when tissue is active
 - lacking in epithelia, cornea and lens of eye & cartilage
- Function is exchange of nutrients & wastes between blood and tissue fluid
- Structure is single layer of simple squamous epithelium and its basement membrane



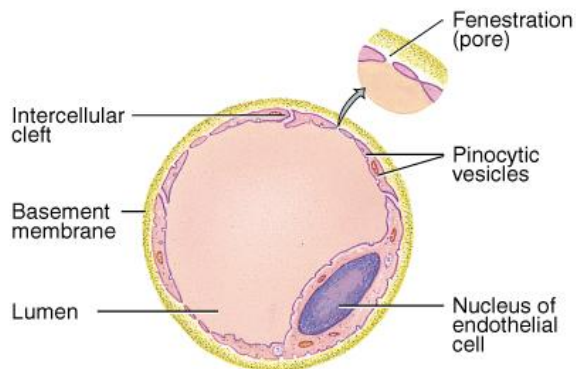
Types of Capillaries

- Continuous capillaries

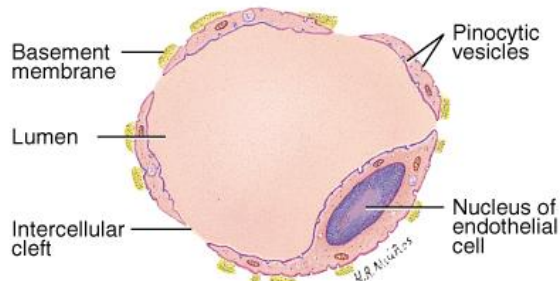
- intercellular clefts are gaps between neighboring cells
- skeletal & smooth, connective tissue and lungs



(a) Continuous capillary formed by endothelial cells



(b) Fenestrated capillary



(c) Sinusoid

- Fenestrated capillaries

- plasma membranes have many holes
- kidneys, small intestine, choroid plexuses, ciliary process & endocrine glands

- Sinusoids

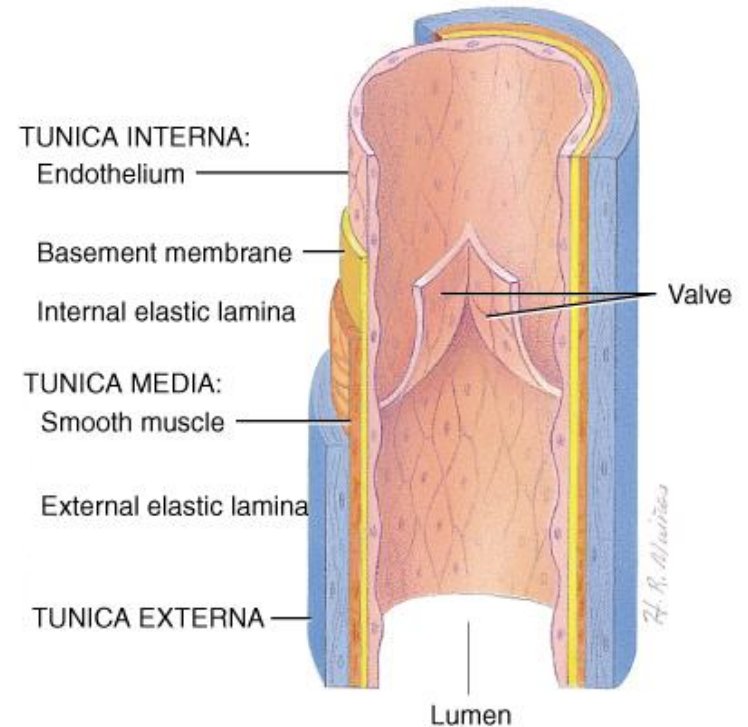
- very large fenestrations
- incomplete basement membrane
- liver, bone marrow, spleen, anterior

Venules

- Small veins collecting blood from capillaries
- Tunica media contains only a few smooth muscle cells & scattered fibroblasts
 - very porous endothelium allows for escape of many phagocytic white blood cells
- Venules that approach size of veins more closely resemble structure of vein

Veins

- Proportionally thinner walls than same diameter artery
 - tunica media less muscle
 - lack external & internal elastic lamina
- Still adaptable to variations in volume & pressure
- Valves are thin folds of tunica interna designed to prevent backflow
- Venous sinus has no muscle at all
 - coronary sinus or dural venous sinuses



Varicose Veins

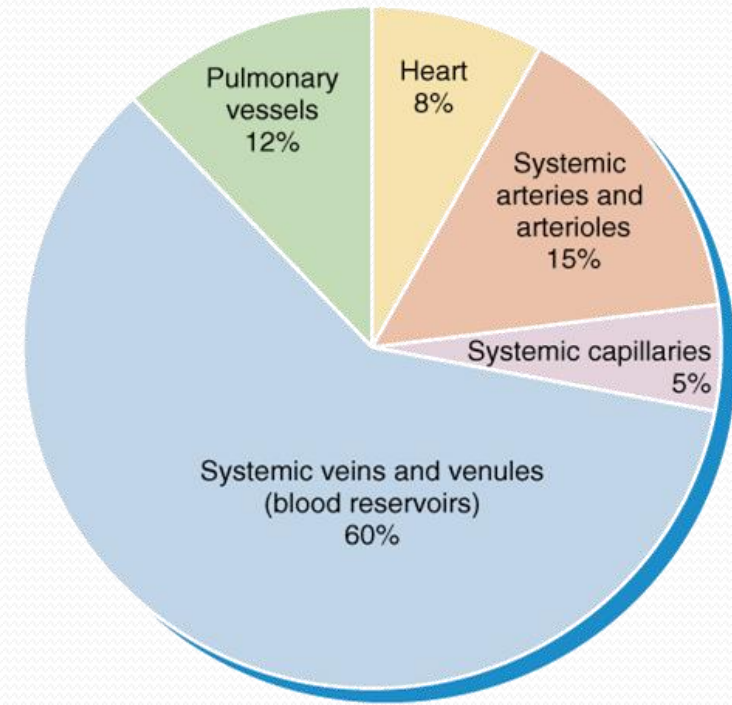
- Twisted, dilated superficial veins
 - caused by leaky venous valves
 - congenital or mechanically stressed from prolonged standing or pregnancy
 - allow backflow and pooling of blood
 - extra pressure forces fluids into surrounding tissues
 - nearby tissue is inflamed and tender
- Deeper veins not susceptible because of support of surrounding muscles

Anastomoses

- Union of 2 or more arteries supplying the same body region
 - blockage of only one pathway has no effect
 - circle of willis underneath brain
 - coronary circulation of heart
- Alternate route of blood flow through an anastomosis is known as collateral circulation
 - can occur in veins and venules as well
- Alternate routes to a region can also be supplied by nonanastomosing vessels

Blood Distribution

- 60% of blood volume at rest is in systemic veins and venules
 - function as blood reservoir
 - veins of skin & abdominal organs
 - blood is diverted from it in times of need
 - increased muscular activity produces vasoconstriction
 - hemorrhage causes vasoconstriction to help maintain blood pressure
- 15% of blood volume in arteries & arterioles



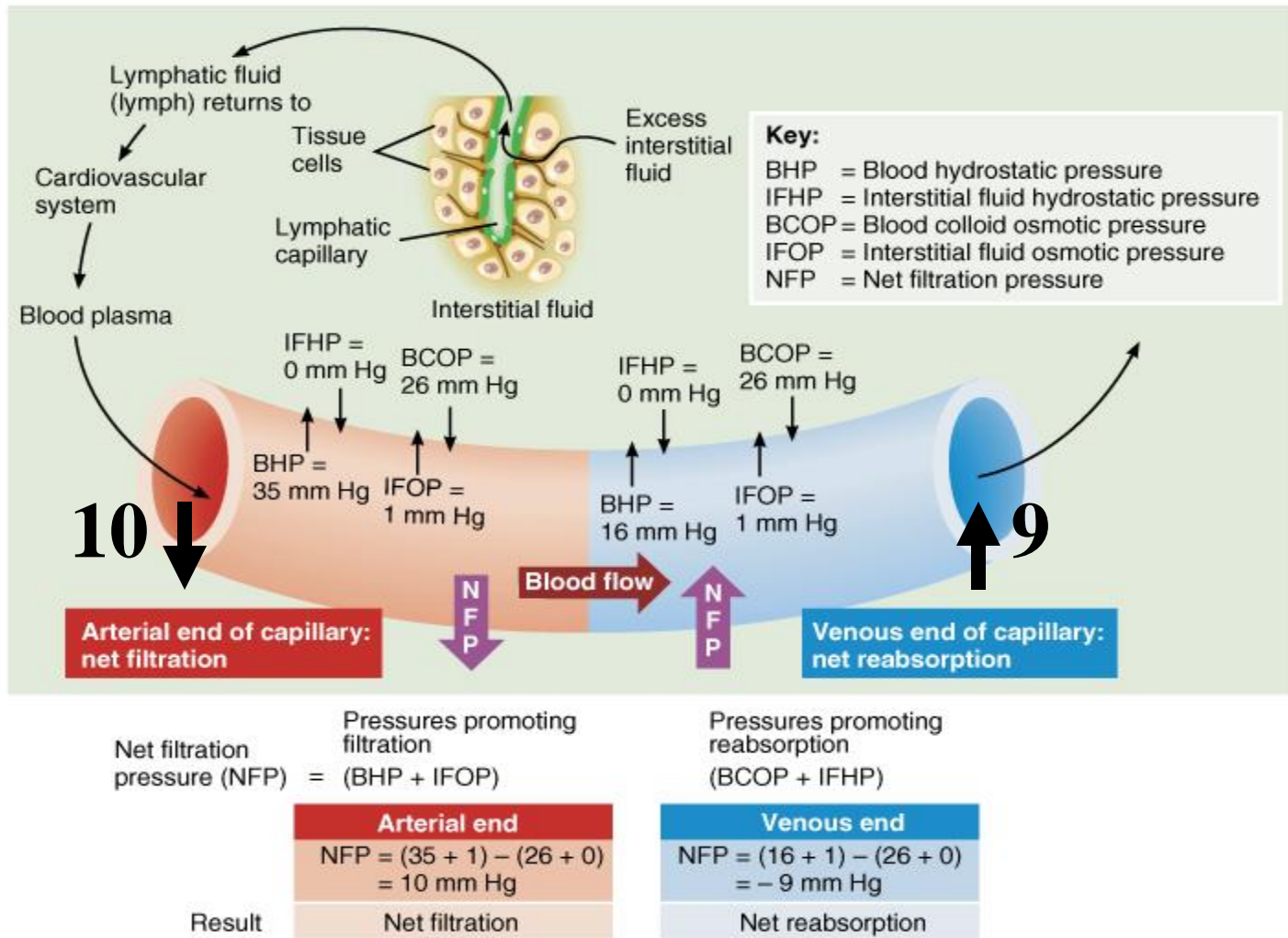
Capillary Exchange

- Movement of materials in & out of a capillary
 - diffusion (most important method)
 - substances move down concentration gradient
 - all plasma solutes except large proteins pass freely across
 - through lipid bilayer, fenestrations or intercellular clefts
 - blood brain barrier does not allow diffusion of water-soluble materials (nonfenestrated epithelium with tight junctions)
 - transcytosis
 - passage of material across endothelium in tiny vesicles by endocytosis and exocytosis
 - large, lipid-insoluble molecules such as insulin or maternal antibodies passing through placental circulation to fetus
 - bulk flow see next slide

Bulk Flow: Filtration & Reabsorption

- Movement of large amount of dissolved or suspended material in same direction
 - move in response to pressure
 - from area of high pressure to area of low
 - faster rate of movement than diffusion or osmosis
- Most important for regulation of relative volumes of blood & interstitial fluid
 - filtration is movement of material into interstitial fluid
 - promoted by blood hydrostatic pressure & interstitial fluid osmotic pressure
 - reabsorption is movement from interstitial fluid into capillaries
 - promoted by blood colloid osmotic pressure
 - balance of these pressures is net filtration pressure

Dynamics of Capillary Exchange



- Starling's law of the capillaries is that the volume of fluid & solutes reabsorbed is almost as large as the volume filtered

Net Filtration Pressure

- Whether fluids leave or enter capillaries depends on net balance of pressures
 - net outward pressure of 10 mm Hg at arterial end of a capillary bed
 - net inward pressure of 9 mm Hg at venous end of a capillary bed
- About 85% of the filtered fluid is returned to the capillary
 - escaping fluid and plasma proteins are collected by lymphatic capillaries (3 liters/day)

Edema

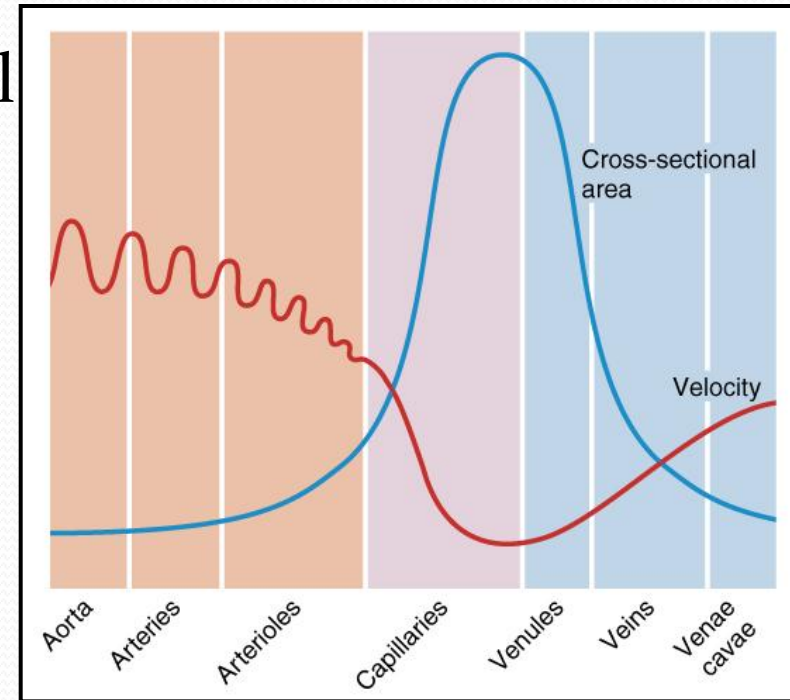
- An abnormal increase in interstitial fluid if filtration exceeds reabsorption
 - result of excess filtration
 - increased blood pressure (hypertension)
 - increased permeability of capillaries allows plasma proteins to escape
 - result of inadequate reabsorption
 - decreased concentration of plasma proteins lowers blood colloid osmotic pressure
 - inadequate synthesis or loss from liver disease, burns, malnutrition or kidney disease
- Not noticeable until 30% above normal

Hemodynamics

- Factors affecting circulation
 - pressure differences that drive the blood flow
 - velocity of blood flow
 - volume of blood flow
 - blood pressure
 - resistance to flow
 - venous return
- An interplay of forces result in blood flow

Velocity of Blood Flow

- Speed of blood flow in cm/sec is inversely related to cross-sectional area
 - blood flow is slower in the arterial branches
 - flow in aorta is 40 cm/sec while flow in capillaries is .1 cm/sec
 - slow rate in capillaries allows for exchange
- Blood flow becomes faster when vessels merge to form veins
- Circulation time is time it takes a drop of blood to travel from right atrium back to right atrium



Volume of Blood Flow

- Cardiac output = stroke volume x heart rate
- Other factors that influence cardiac output
 - blood pressure
 - resistance due to friction between blood cells and blood vessel walls
 - blood flows from areas of higher pressure to areas of lower pressure

• Pressure exerted by blood on walls of a vessel

- caused by contraction of the ventricles
- highest in aorta
 - 120 mm Hg during systole & 80 during diastole

• If heart rate increases cardiac output, BP rises

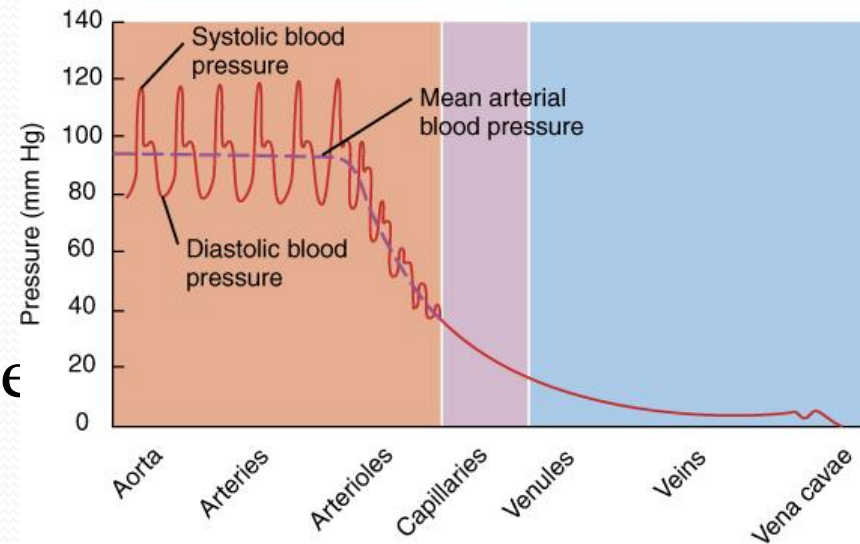
• Pressure falls steadily in systemic circulation with distance from left ventricle

- 35 mm Hg entering the capillaries
- 0 mm Hg entering the right atrium

• If decrease in blood volume is over 10%, BP drops

• Water retention increases blood pressure

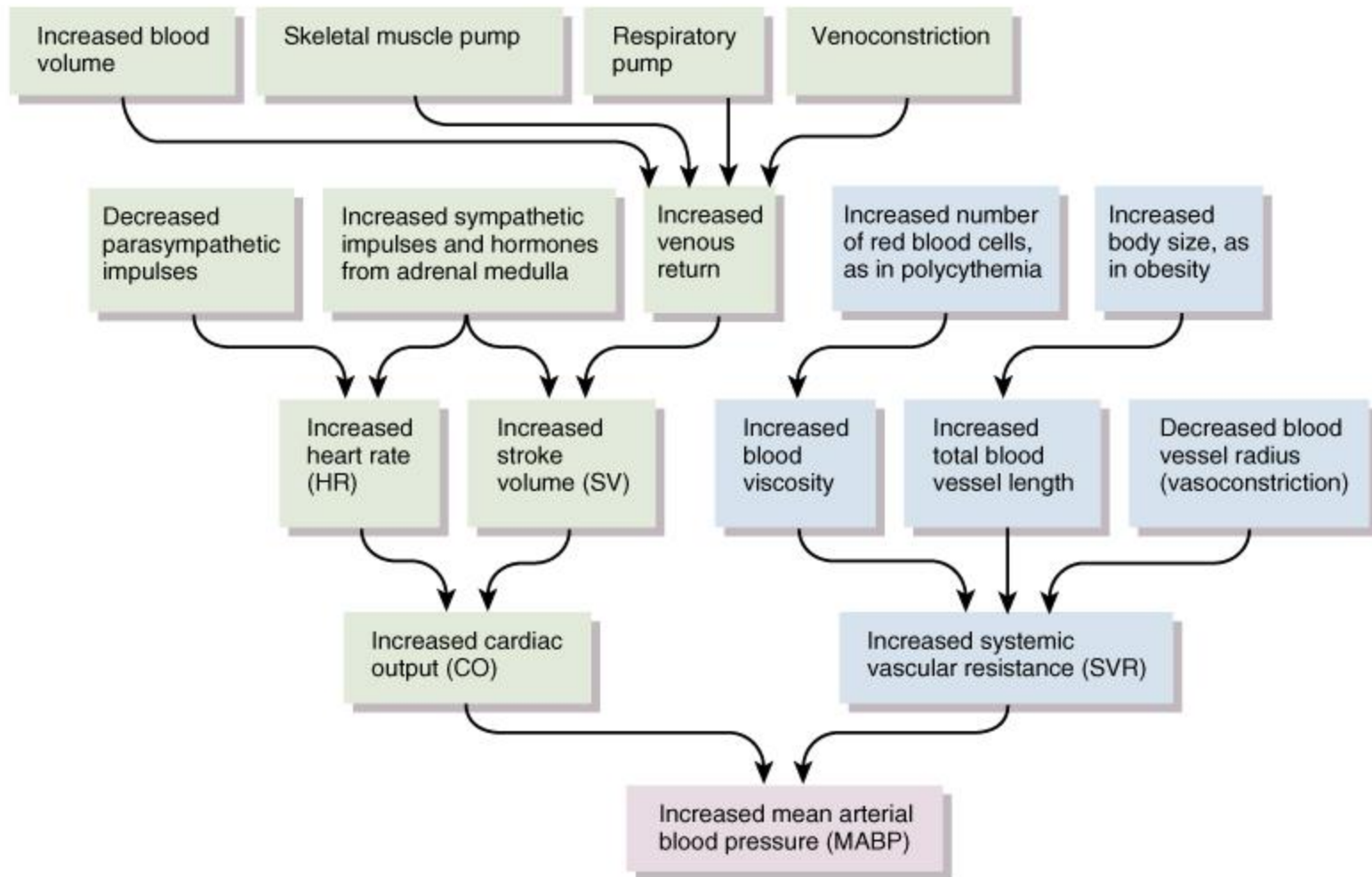
Blood Pressure



Resistance

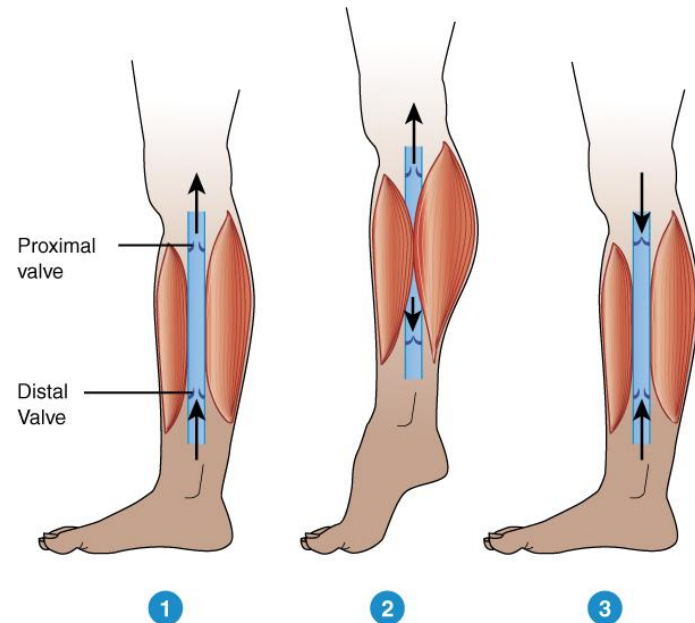
- Friction between blood and the walls of vessels
 - average blood vessel radius
 - smaller vessels offer more resistance to blood flow
 - cause moment to moment fluctuations in pressure
 - blood viscosity (thickness)
 - ratio of red blood cells to plasma volume
 - increases in viscosity increase resistance
 - dehydration or polycythemia
 - total blood vessel length
 - the longer the vessel, the greater the resistance to flow
 - 200 miles of blood vessels for every pound of fat
 - obesity causes high blood pressure
- Systemic vascular resistance is the total of above
 - arterioles control BP by changing diameter

Factors that Increase Blood Pressure



Venous Return

- Volume of blood flowing back to the heart from the systemic veins
 - depends on pressure difference from venules (16 mm Hg) to right atrium (0 mm Hg)
 - tricuspid valve leaky and buildup of blood on venous side of circulation
- Skeletal muscle pump
 - contraction of muscles & presence of valves
- Respiratory pump
 - decreased thoracic pressure and increased abdominal pressure during inhalation, moves blood into thoracic veins and the right atrium

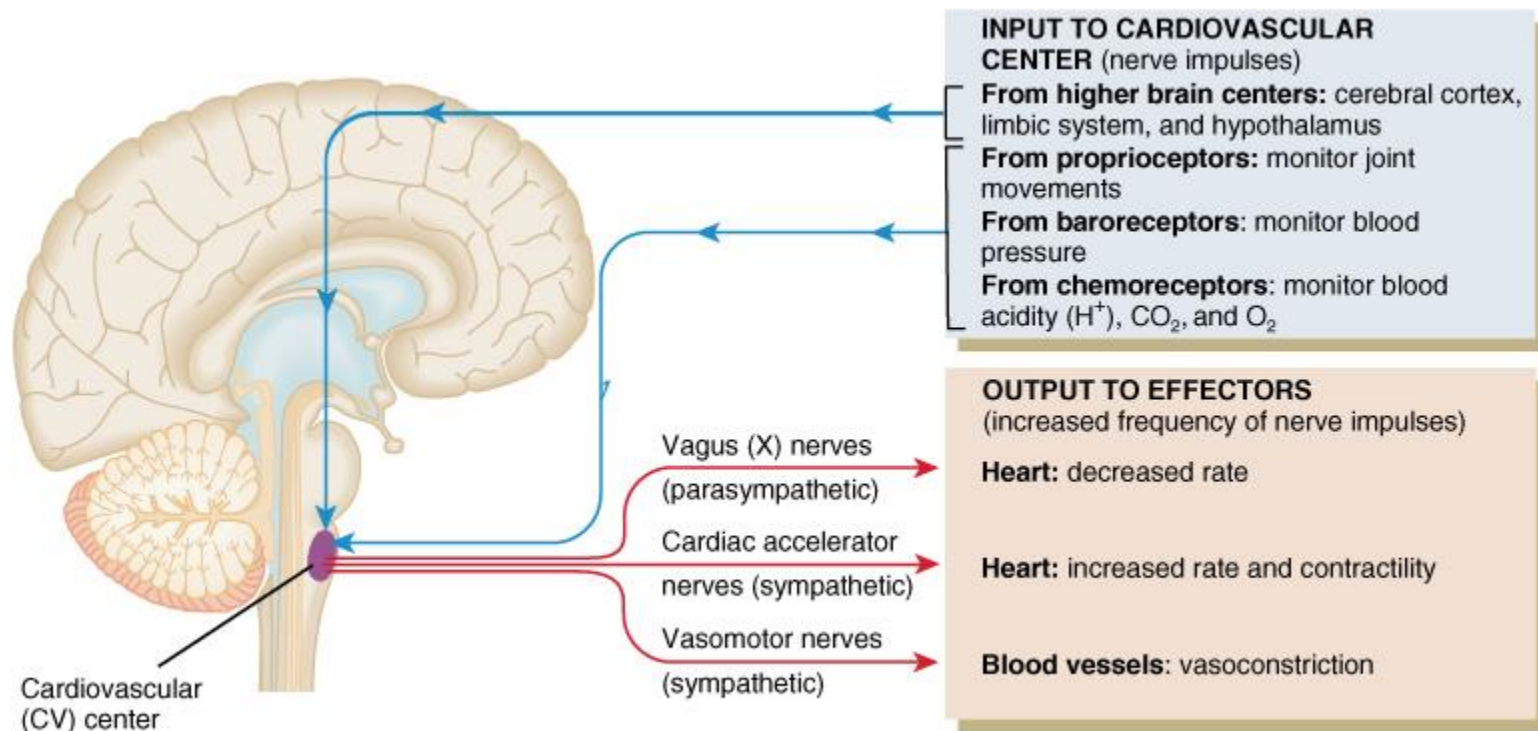


Syncope

- Fainting or a sudden, temporary loss of consciousness not due to trauma
 - due to cerebral ischemia or lack of blood flow to the brain
- Causes
 - vasodepressor syncope = sudden emotional stress
 - situational syncope = pressure stress of coughing, defecation, or urination
 - drug-induced syncope = antihypertensives, diuretics, vasodilators and tranquilizers
 - orthostatic hypotension = decrease in BP upon standing

Control of Blood Pressure & Flow

- Role of cardiovascular center
 - help regulate heart rate & stroke volume
 - specific neurons regulate blood vessel diameter



Input to the Cardiovascular Center

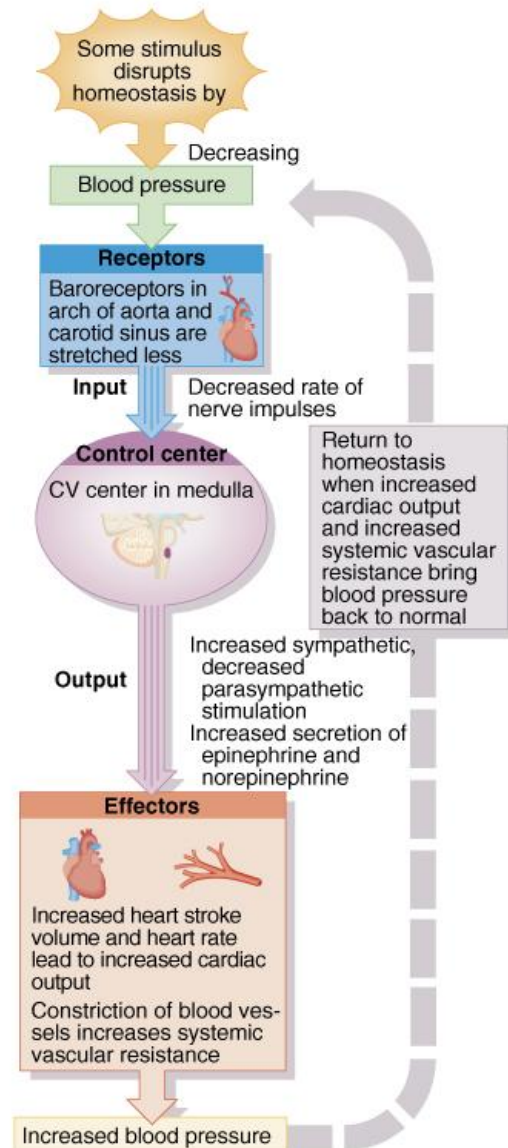
- Higher brain centers such as cerebral cortex, limbic system & hypothalamus
 - anticipation of competition
 - increase in body temperature
- Proprioceptors
 - input during physical activity
- Baroreceptors
 - changes in pressure within blood vessels
- Chemoreceptors
 - monitor concentration of chemicals in the blood

Output from the Cardiovascular Center

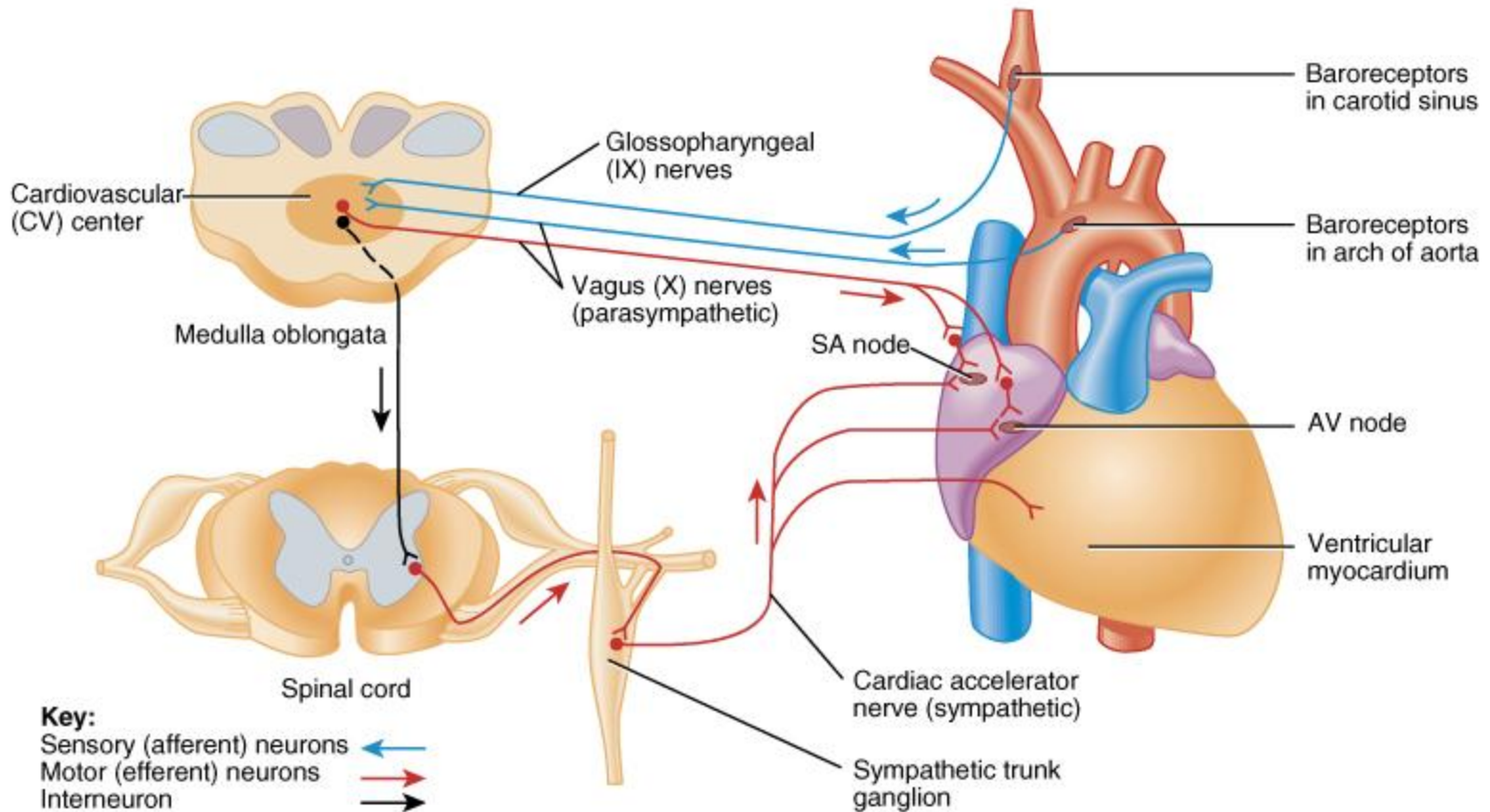
- Heart
 - parasympathetic (vagus nerve)
 - decrease heart rate
 - sympathetic (cardiac accelerator nerves)
 - cause increase or decrease in contractility & rate
- Blood vessels
 - sympathetic vasomotor nerves
 - continual stimulation to arterioles in skin & abdominal viscera producing vasoconstriction (vasomotor tone)
 - increased stimulation produces constriction & increased BP

Neural Regulation of Blood Pressure

- Baroreceptor reflexes
 - carotid sinus reflex
 - swellings in internal carotid artery wall
 - glossopharyngeal nerve to cardiovascular center in medulla
 - maintains normal BP in the brain
 - aortic reflex
 - receptors in wall of ascending aorta
 - vagus nerve to cardiovascular center
 - maintains general systemic BP
- If feedback is decreased, CV center reduces parasympathetic & increases sympathetic stimulation of the heart



Innervation of the Heart



- Speed up the heart with sympathetic stimulation
- Slow it down with parasympathetic stimulation (X)
- Sensory information from baroreceptors (IX)

Carotid Sinus Massage & Syncope

- Stimulation (careful neck massage) over the carotid sinus to lower heart rate
 - paroxysmal supraventricular tachycardia
 - tachycardia originating from the atria
- Anything that puts pressure on carotid sinus
 - tight collar or hyperextension of the neck
 - may slow heart rate & cause carotid sinus syncope or fainting

Chemoreceptor Reflexes

- Carotid bodies and aortic bodies
 - detect changes in blood levels of O₂, CO₂, and H⁺ (hypoxia, hypercapnia or acidosis)
 - causes stimulation of cardiovascular center
 - increases sympathetic stimulation to arterioles & veins
 - vasoconstriction and increase in blood pressure
- Also changes breathing rates as well

Hormonal Regulation of Blood Pressure

- Renin-angiotensin-aldosterone system
 - decrease in BP or decreased blood flow to kidney
 - release of renin / results in formation angiotensin II
 - systemic vasoconstriction
 - causes release aldosterone (H₂O & Na⁺ reabsorption)
- Epinephrine & norepinephrine
 - increases heart rate & force of contraction
 - causes vasoconstriction in skin & abdominal organs
 - vasodilation in cardiac & skeletal muscle
- ADH causes vasoconstriction
- ANP (atrial natriuretic peptide) lowers BP
 - causes vasodilation & loss of salt and water in the urine

Local Regulation of Blood Pressure

- Local factors cause changes in each capillary bed
 - autoregulation is ability to make these changes as needed by demand for O₂ & waste removal
 - important for tissues that have major increases in activity (brain, cardiac & skeletal muscle)
- Local changes in response to physical changes
 - warming & decrease in vascular stretching promotes vasodilation
- Vasoactive substances released from cells alter vessel diameter (K⁺, H⁺, lactic acid, nitric oxide)
 - systemic vessels dilate in response to low levels of O₂
 - pulmonary vessels constrict in response to low levels of O₂

Shock and Homeostasis

- Shock is failure of cardiovascular system to deliver enough O₂ and nutrients
 - inadequate perfusion
 - cells forced to switch to anaerobic respiration
 - lactic acid builds up
 - cells and tissues become damaged & die

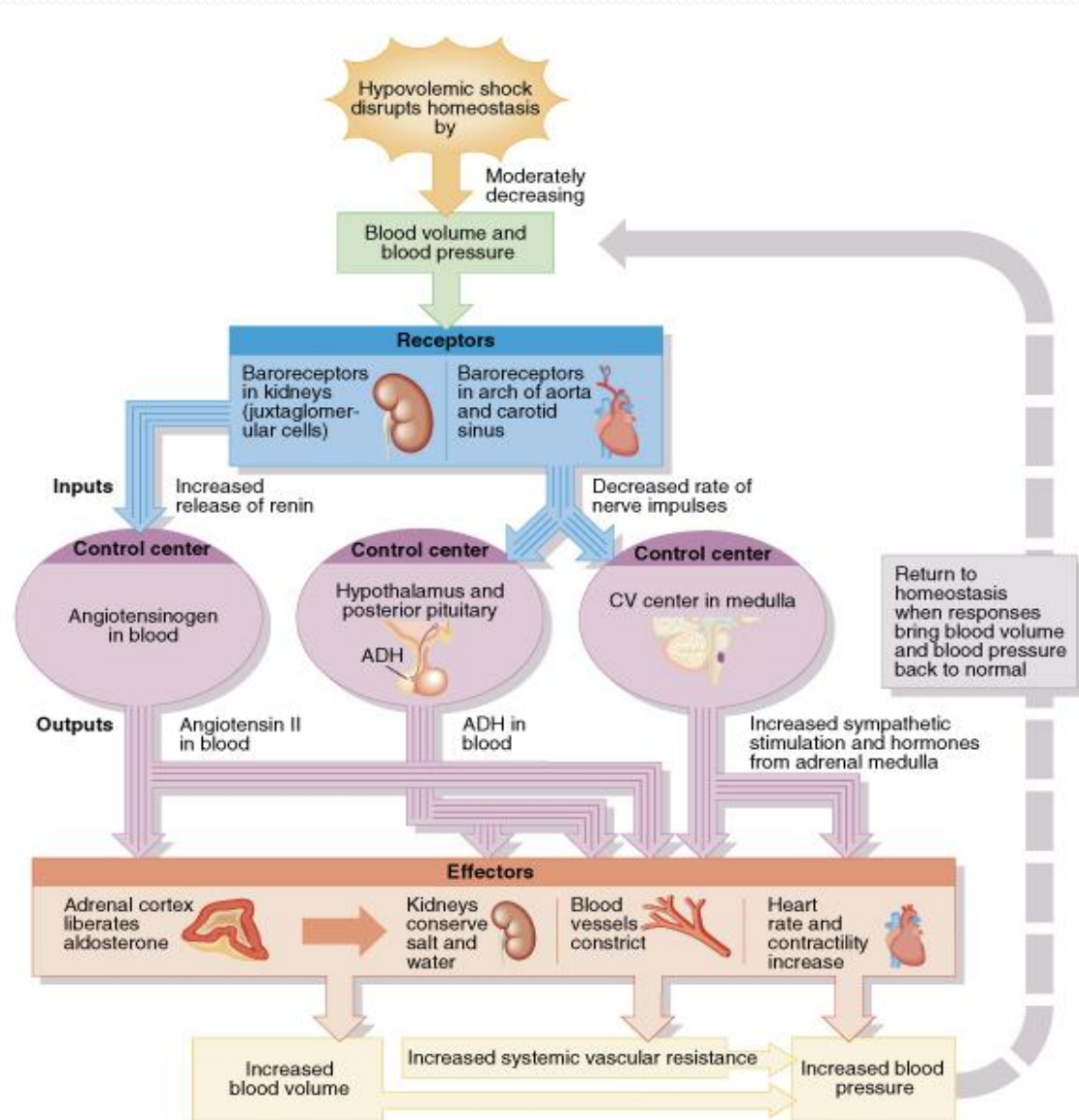
Types of Shock

- Hypovolemic shock due to loss of blood or body fluids (hemorrhage, sweating, diarrhea)
 - venous return to heart declines & output decreases
- Cardiogenic shock caused by damage to pumping action of the heart (MI, ischemia, valve problems or arrhythmias)
- Vascular shock causing drop in appropriate vasodilation -- anaphylactic shock, septic shock or neurogenic shock (head trauma)
- Obstructive shock caused by blockage of circulation (pulmonary embolism)

Homeostatic Responses to Shock

- Mechanisms of compensation in shock attempt to return cardiac output & BP to normal
 - activation of renin-angiotensin-aldosterone
 - secretion of antidiuretic hormone
 - activation of sympathetic nervous system
 - release of local vasodilators
- If blood volume drops by 10-20% or if BP does not rise sufficiently, perfusion may be inadequate -- cells start to die

Restoring BP during Hypovolemic Shock



Signs & Symptoms of Shock

- Rapid resting heart rate (sympathetic stimulation)
- Weak, rapid pulse due to reduced cardiac output & fast heart rate
- Clammy, cool skin due to cutaneous vasoconstriction
- Sweating -- sympathetic stimulation
- Altered mental state due to cerebral ischemia
- Reduced urine formation -- vasoconstriction to kidneys & increased aldosterone & antidiuretic hormone
- Thirst -- loss of extracellular fluid
- Acidosis -- buildup of lactic acid
- Nausea -- impaired circulation to GI tract

Evaluating Circulation

- Pulse is a pressure wave
 - alternate expansion & recoil of elastic artery after each systole of the left ventricle
 - pulse rate is normally between 70-80 beats/min
 - tachycardia is rate over 100 beats/min/bradycardia under 60
- Measuring blood pressure with sphygmomanometer
 - Korotkoff sounds are heard while taking pressure
 - systolic blood pressure from ventricular contraction
 - diastolic blood pressure during ventricular contraction
 - provides information about systemic vascular resistance
 - pulse pressure is difference between systolic & diastolic
 - normal ratio is 3:2:1 -- systolic/diastolic/pulse pressure

Pulse Points



(a) Superficial temporal artery

Lateral to orbit of eye.



(e) femoral artery

Inferior to inguinal ligament.



(b) Facial artery

Mandible (lower jawbone) on a line with the corners of the mouth.



(f) Popliteal artery

Posterior to the knee.



(c) Common carotid artery

Lateral to larynx (voice box).



(g) Radial artery

Distal half of wrist.



(d) Brachial artery

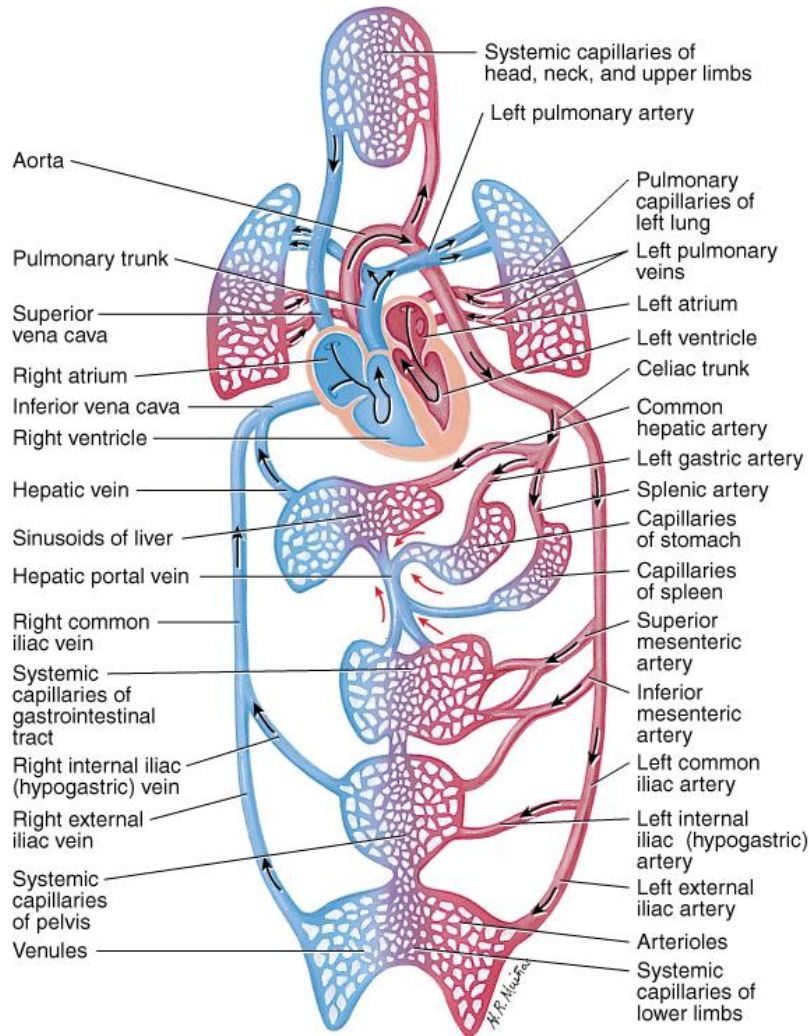
Medial side of biceps brachii muscle.



(h) Dorsalis pedis artery

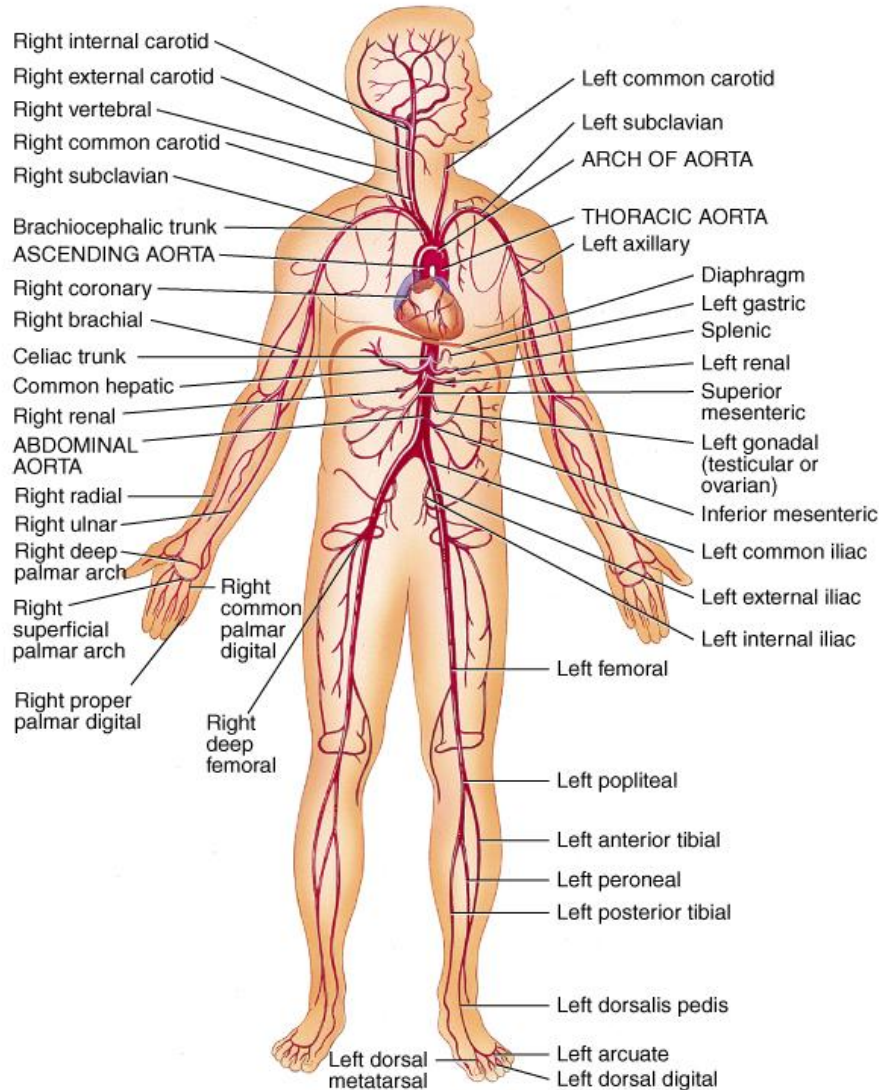
Superior to instep of foot.

Systemic Circulation



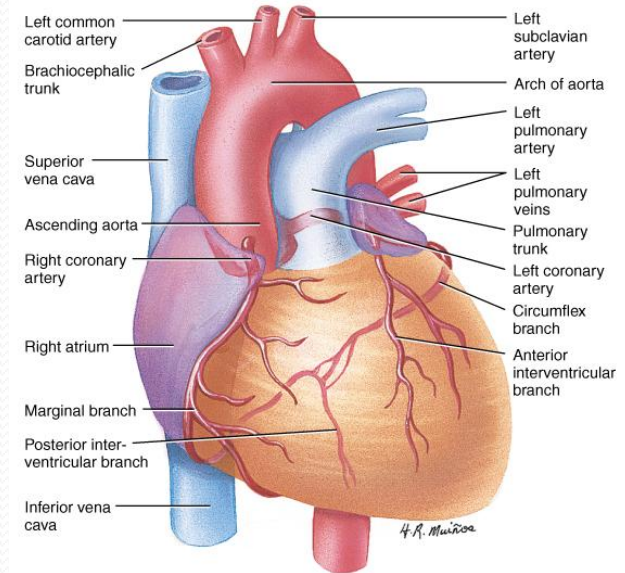
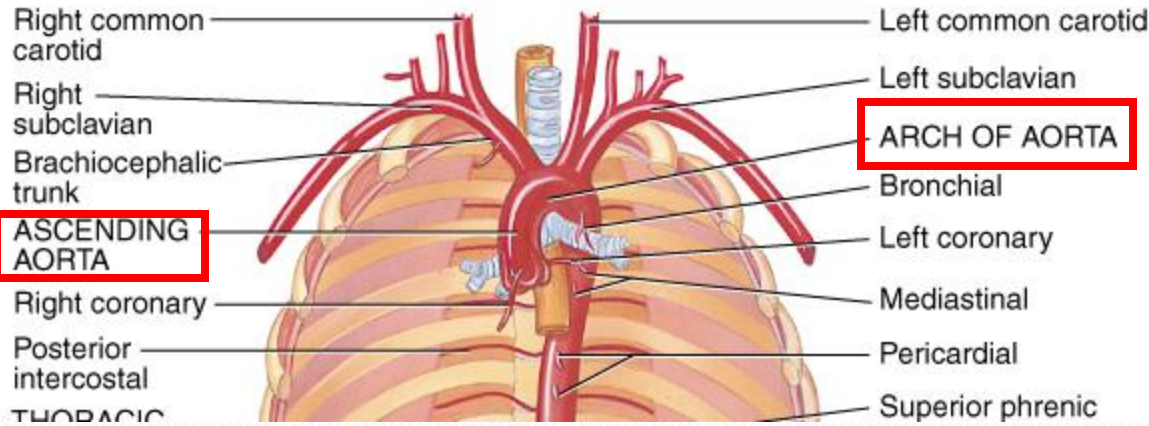
- All systemic arteries branch from the aorta
- All systemic veins drain into the superior or inferior vena cava or coronary sinus to return to the right-side of heart

Arterial Branches of Systemic Circulation



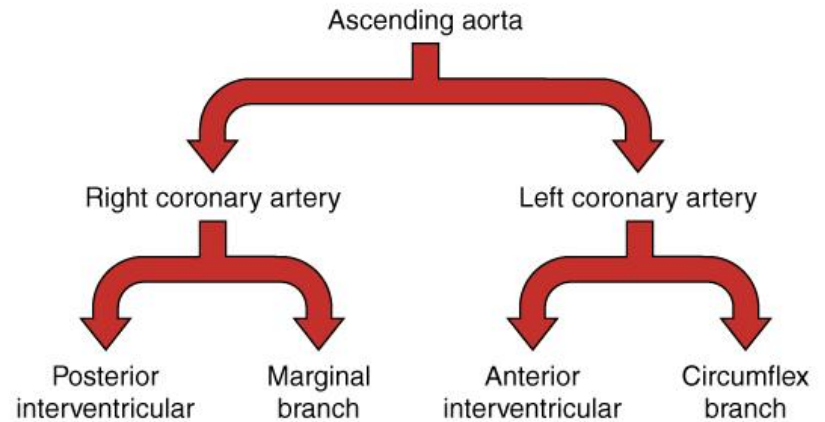
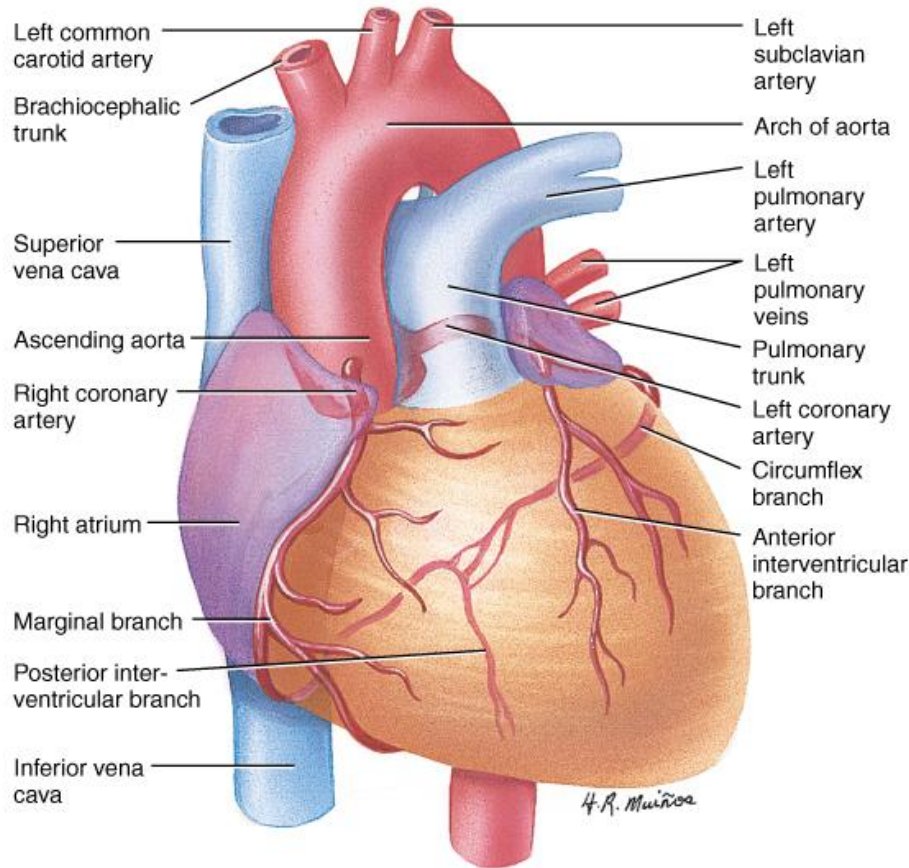
- All are branches from aorta supplying arms, head, lower limbs and all viscera with O₂ from the lungs
- Aorta arises from left ventricle (thickest chamber)
 - 4 major divisions of aorta
 - ascending aorta
 - arch of aorta
 - thoracic aorta
 - abdominal aorta

Aorta and Its Superior Branches



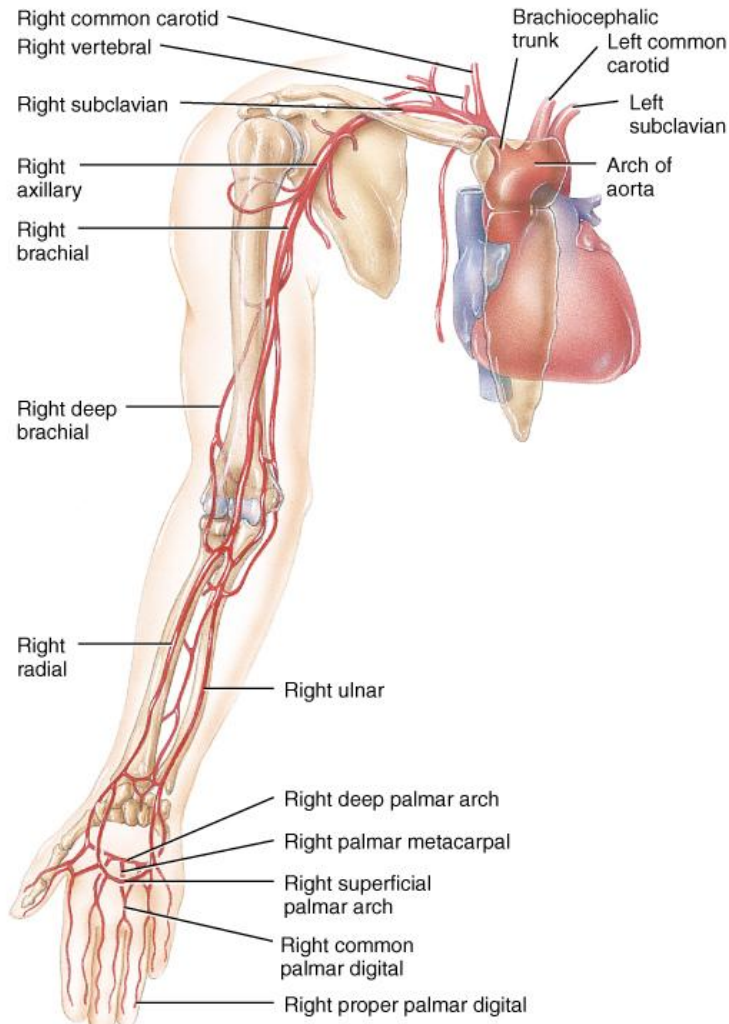
- Aorta is largest artery of the body
 - ascending aorta
 - 2 coronary arteries supply myocardium
 - arch of aorta -- branches to the arms & head
 - brachiocephalic trunk branches into right common carotid and right subclavian
 - left subclavian & left carotid arise independently
 - thoracic aorta supplies branches to pericardium, esophagus, bronchi, diaphragm, intercostal & chest muscles, mammary gland, skin, vertebrae and spinal cord

Coronary Circulation



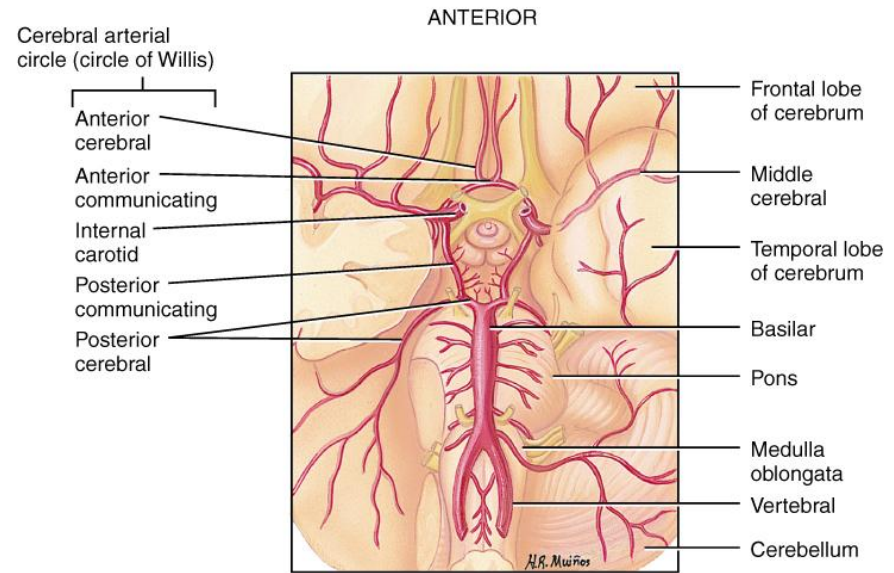
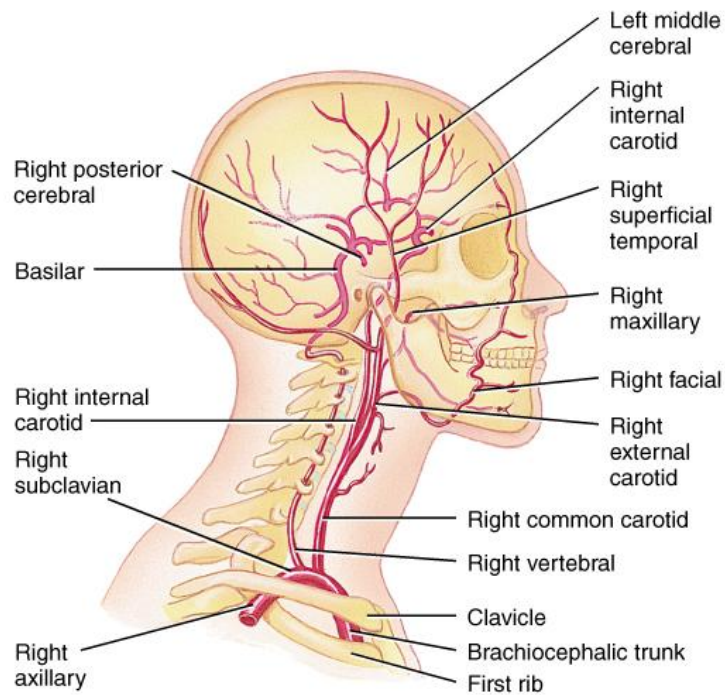
- Right & left coronary arteries branch to supply heart muscle
 - anterior & posterior interventricular aa.

Subclavian Branches



- Subclavian aa. pass superior to the 1st rib
 - gives rise to vertebral a. that supplies blood to the Circle of Willis on the base of the brain
- Become the axillary artery in the armpit
- Become the brachial in the arm
- Divide into radial and ulnar branches in the forearm

Common Carotid Branches

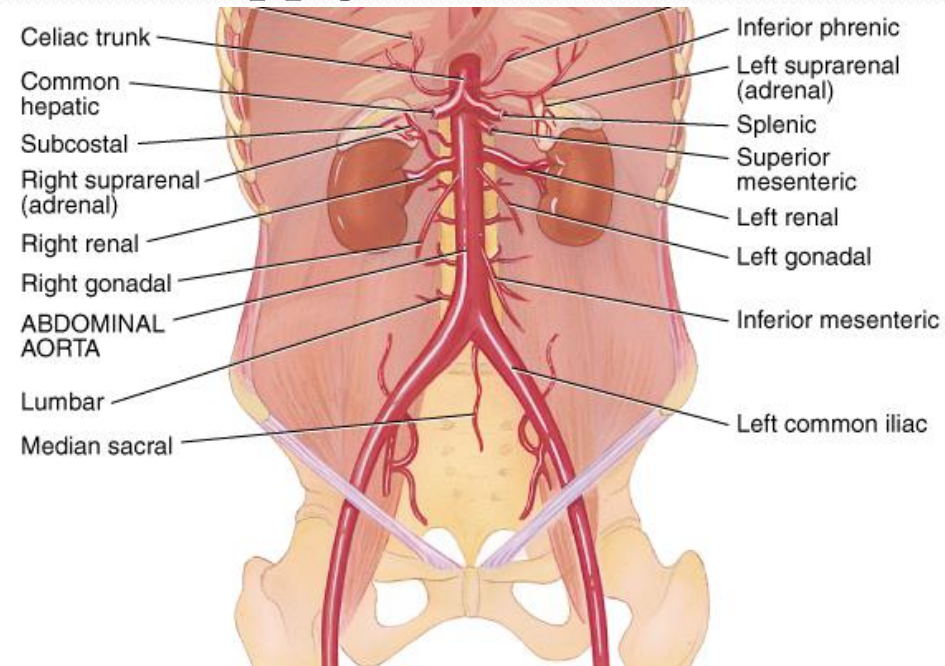


Circle of Willis

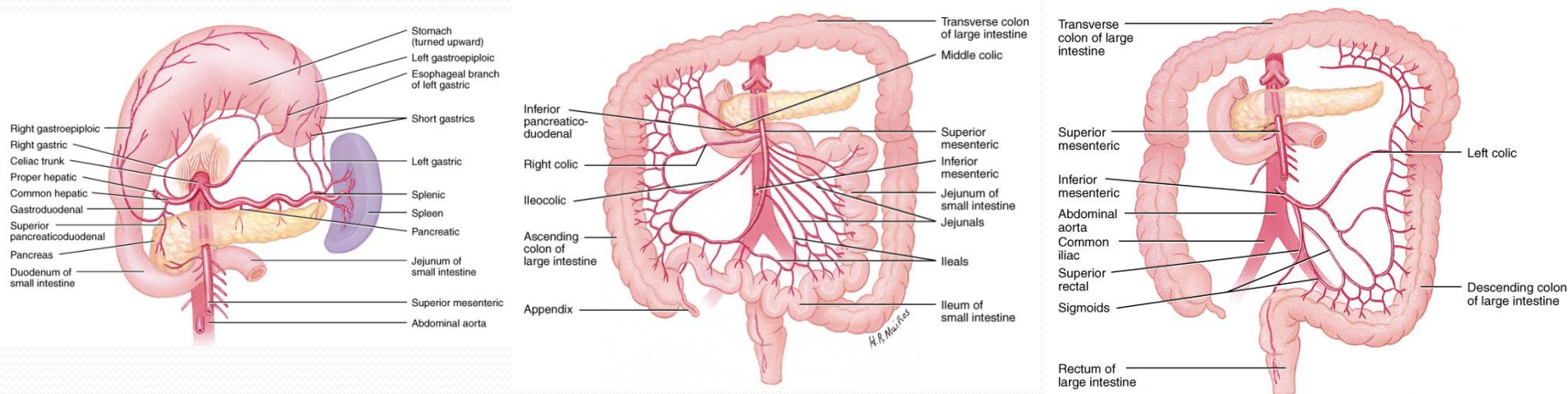
- External carotid arteries
 - supplies structures external to skull as branches of maxillary and superficial temporal branches
- Internal carotid arteries (contribute to Circle of Willis)
 - supply eyeballs and parts of brain

Abdominal Aorta and Its Branches

- Supplies abdominal & pelvic viscera & lower extremities
 - celiac aa. supplies liver, stomach, spleen & pancreas
 - superior & inferior mesenteric aa. supply intestines
 - renal aa supply kidneys
 - gonadal aa. supply ovaries and testes
- Splits into common iliac aa at 4th lumbar vertebrae
 - external iliac aa supply lower extremity
 - internal iliac aa supply pelvic viscera

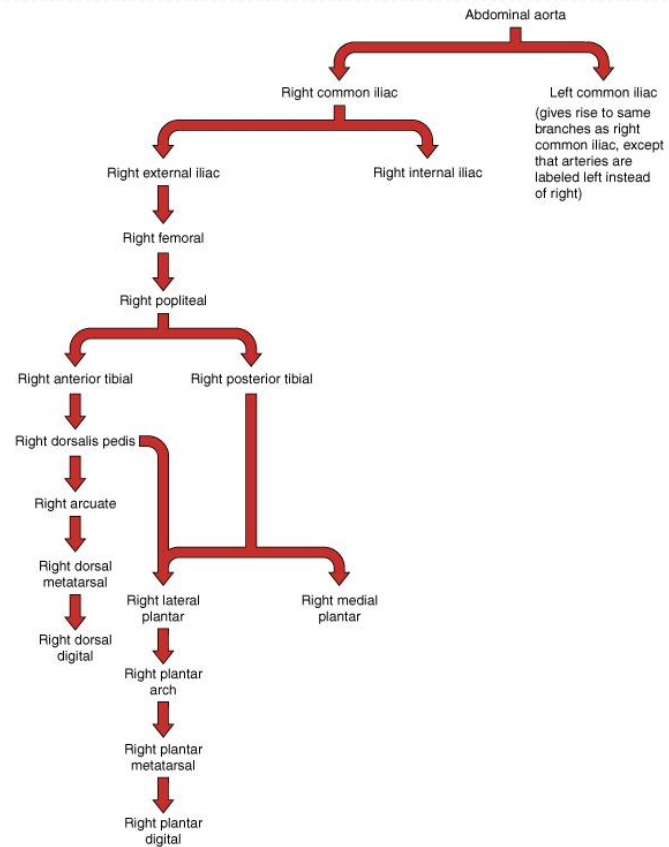
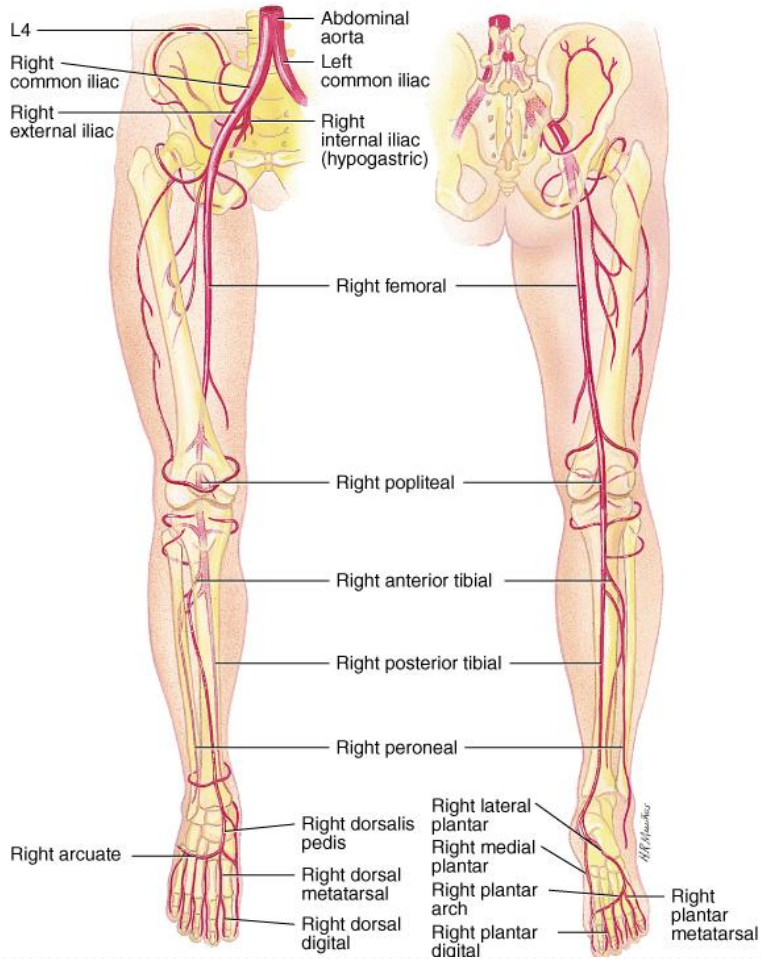


Visceral Branches off Abdominal Aorta



- Celiac artery is first branch inferior to diaphragm
 - left gastric artery, splenic artery, common hepatic artery
- Superior mesenteric artery lies in mesentery
 - pancreaticoduodenal, jejunal, ileocolic, ascending & middle colic aa.
- Inferior mesenteric artery
 - descending colon, sigmoid colon & rectal aa

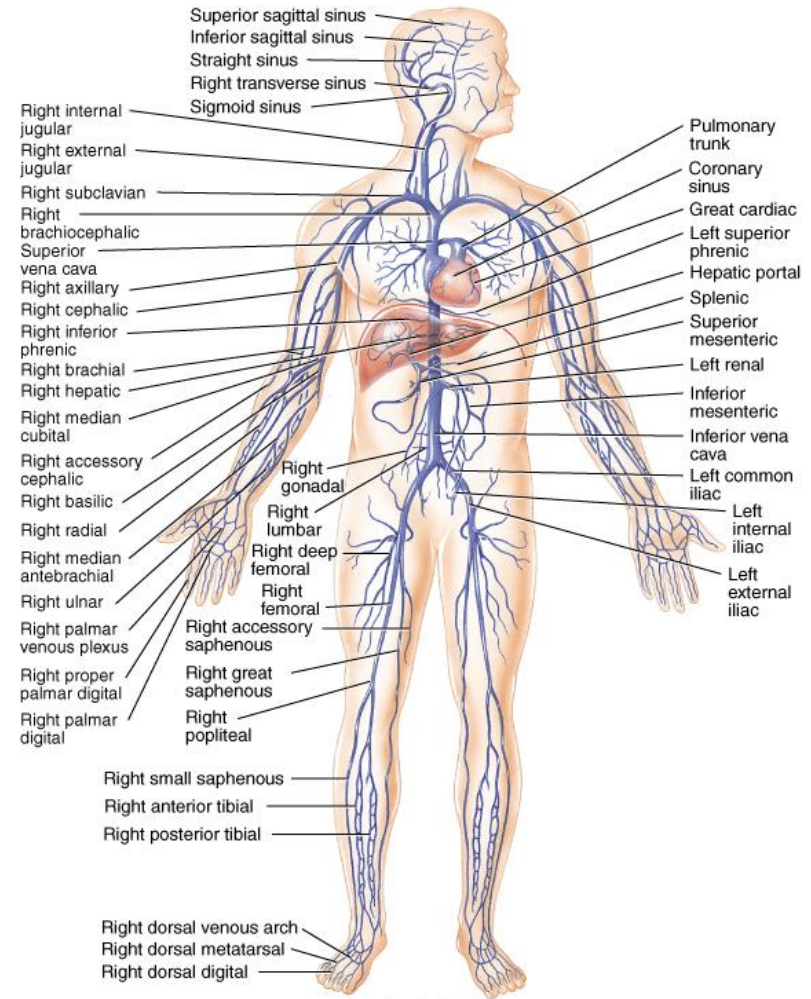
Arteries of the Lower Extremity



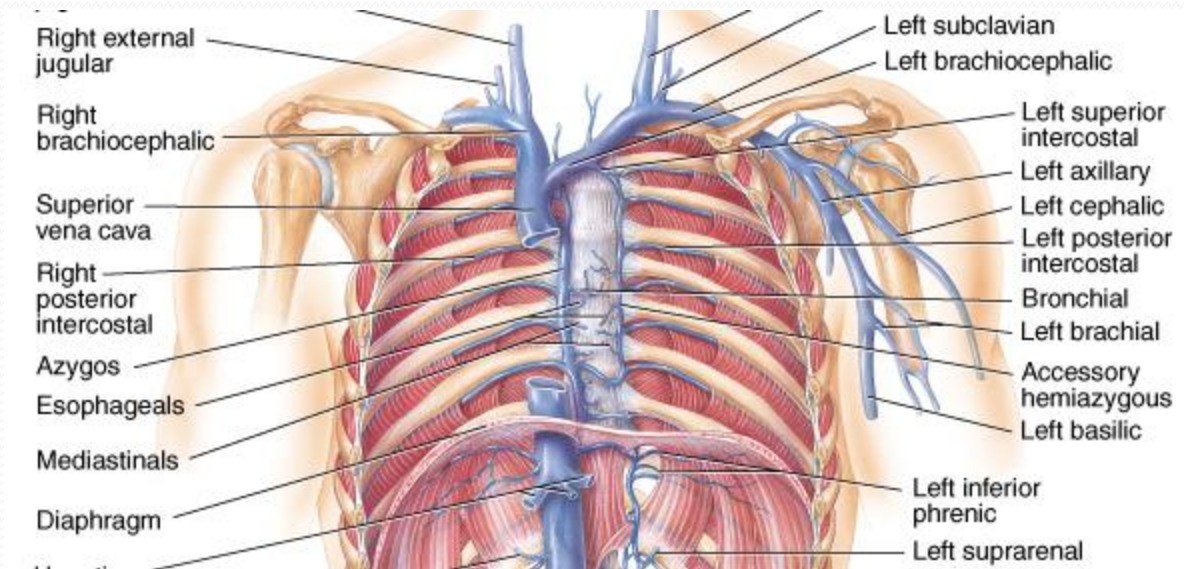
- External iliac artery become femoral artery when it passes under the inguinal ligament & into the thigh
 - femoral artery becomes popliteal artery behind the knee

Veins of the Systemic Circulation

- Drain blood from entire body & return it to right side of heart
- Deep veins parallel the arteries in the region
- Superficial veins are found just beneath the skin
- All venous blood drains to either superior or inferior vena cava or coronary sinus

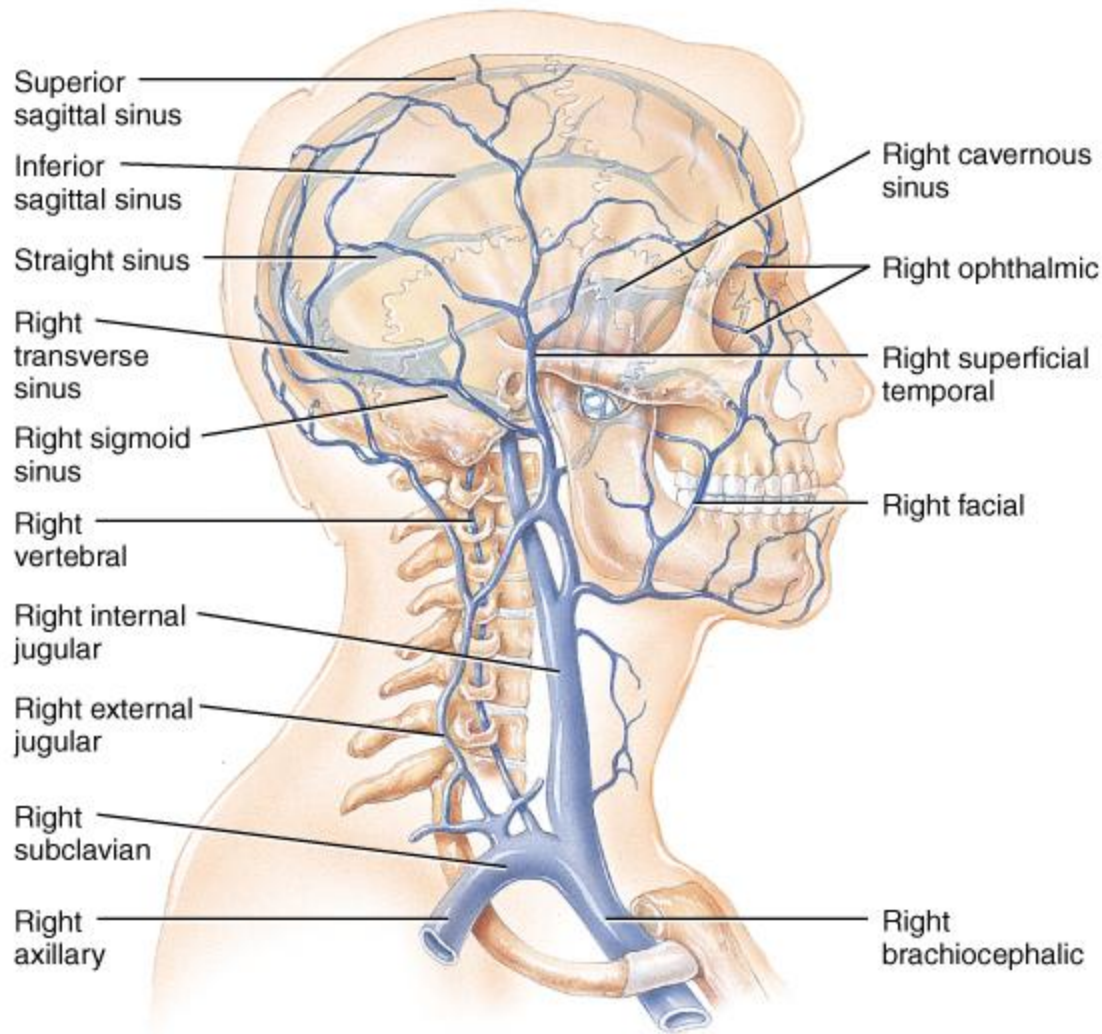


Major Systemic Veins



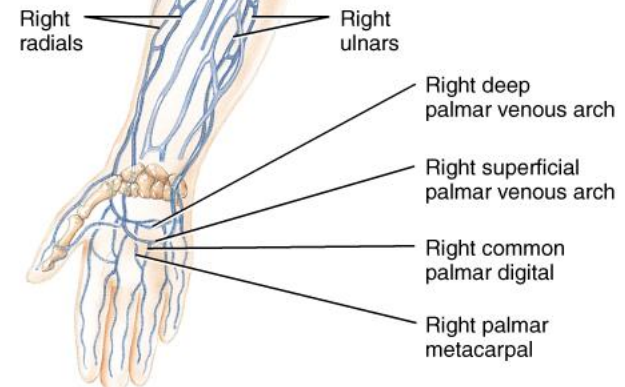
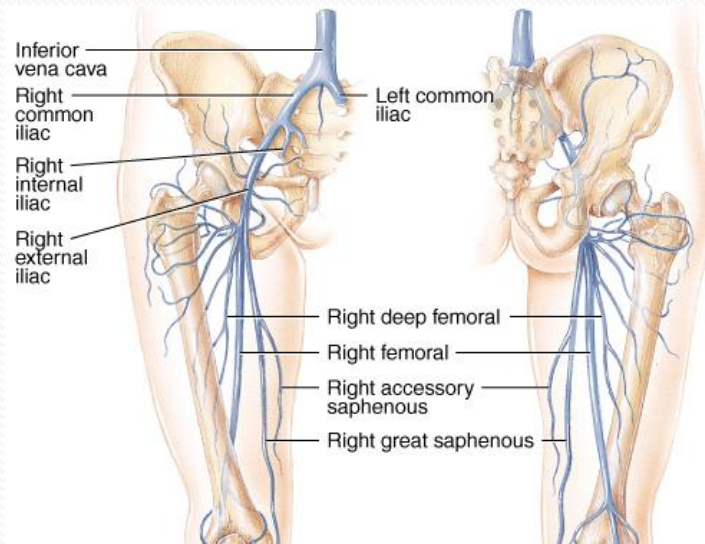
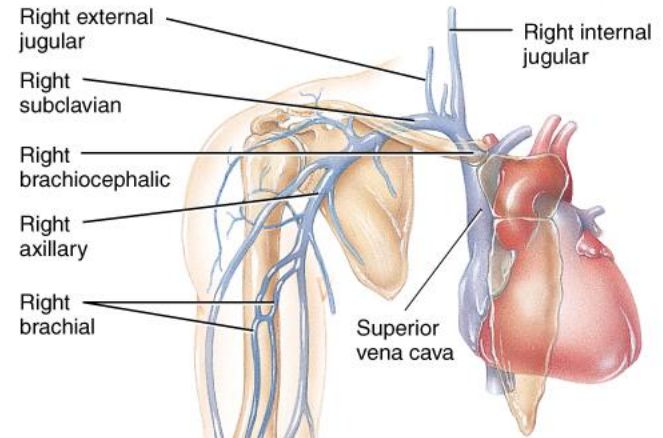
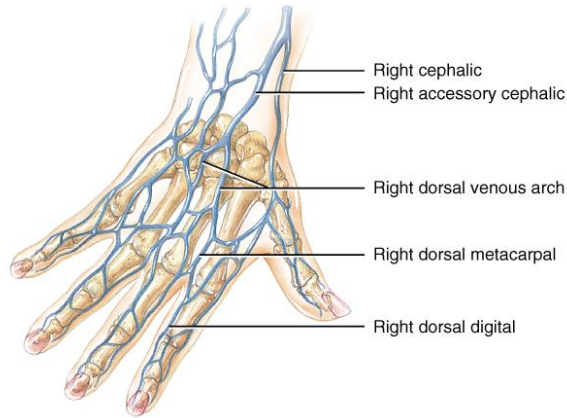
- All empty into the right atrium of the heart
 - superior vena cava drains the head and upper extremities
 - inferior vena cava drains the abdomen, pelvis & lower limbs
 - coronary sinus is large vein draining the heart muscle back into the heart

Veins of the Head and Neck



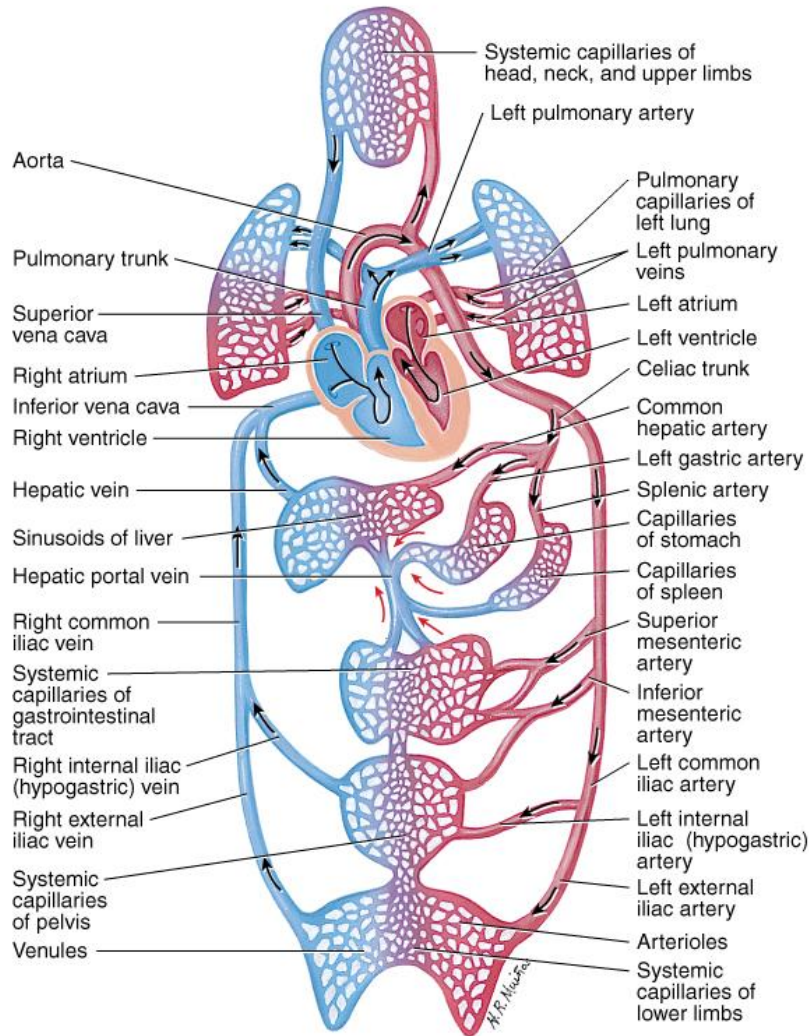
- External and Internal jugular veins drain the head and neck into the superior vena cava
- Dural venous sinuses empty into internal jugular vein

Venipuncture



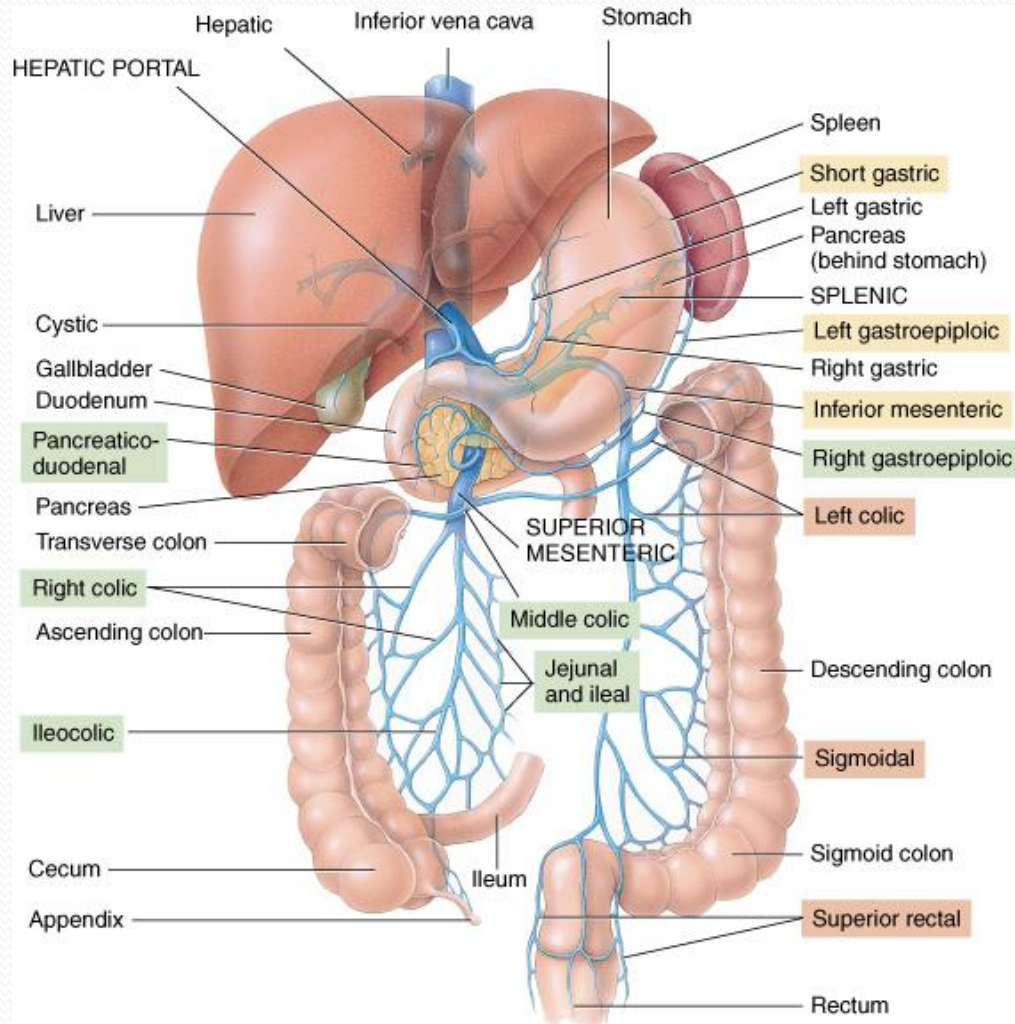
- Venipuncture is normally performed at cubital fossa, dorsum of the hand or great saphenous vein in infants

Circulatory Routes



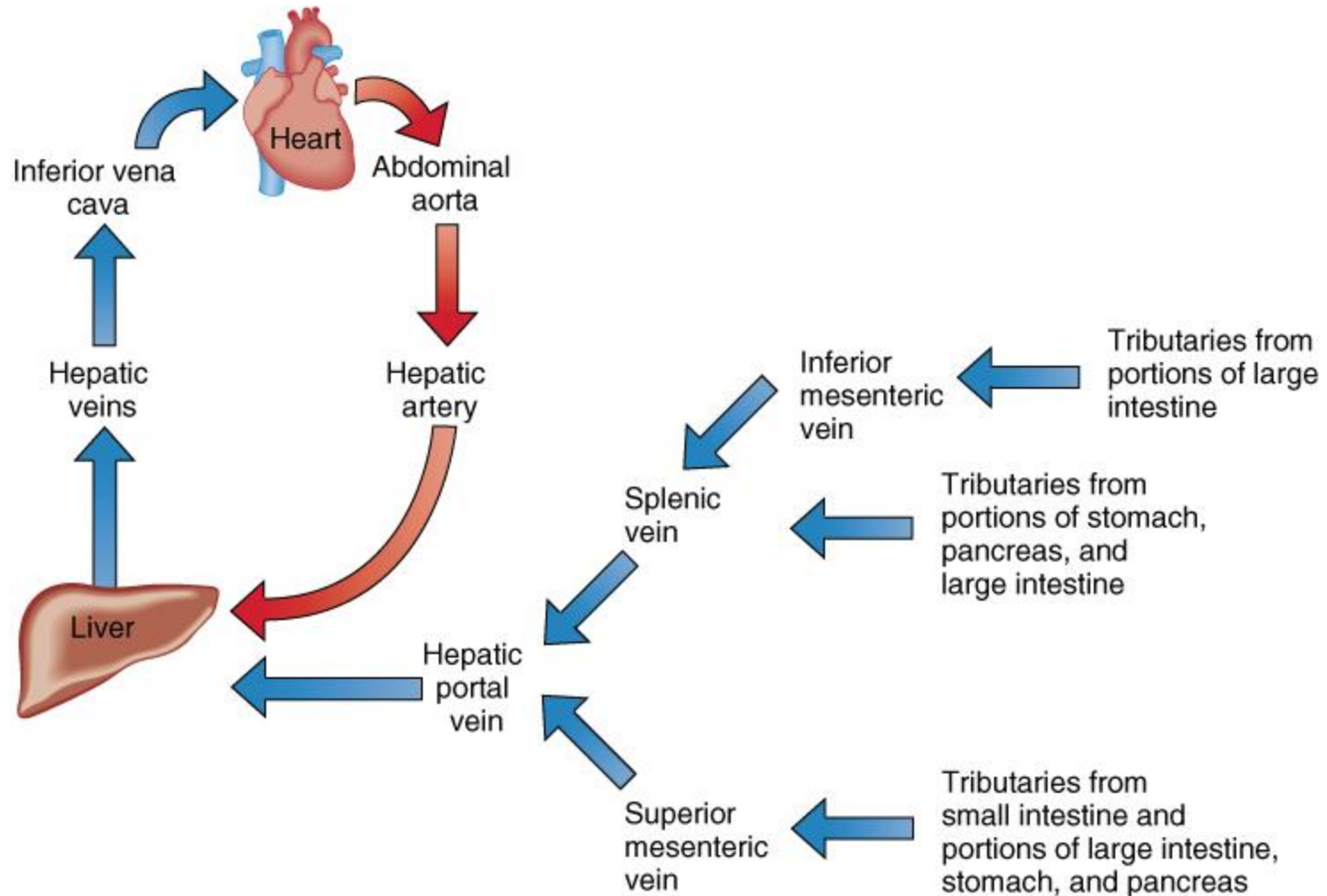
- Systemic circulation is left side heart to body & back to heart
- Hepatic Portal circulation is capillaries of GI tract to capillaries in liver
- Pulmonary circulation is right-side heart to lungs & back to heart
- Fetal circulation is from fetal heart through umbilical cord to placenta & back

Hepatic Portal System

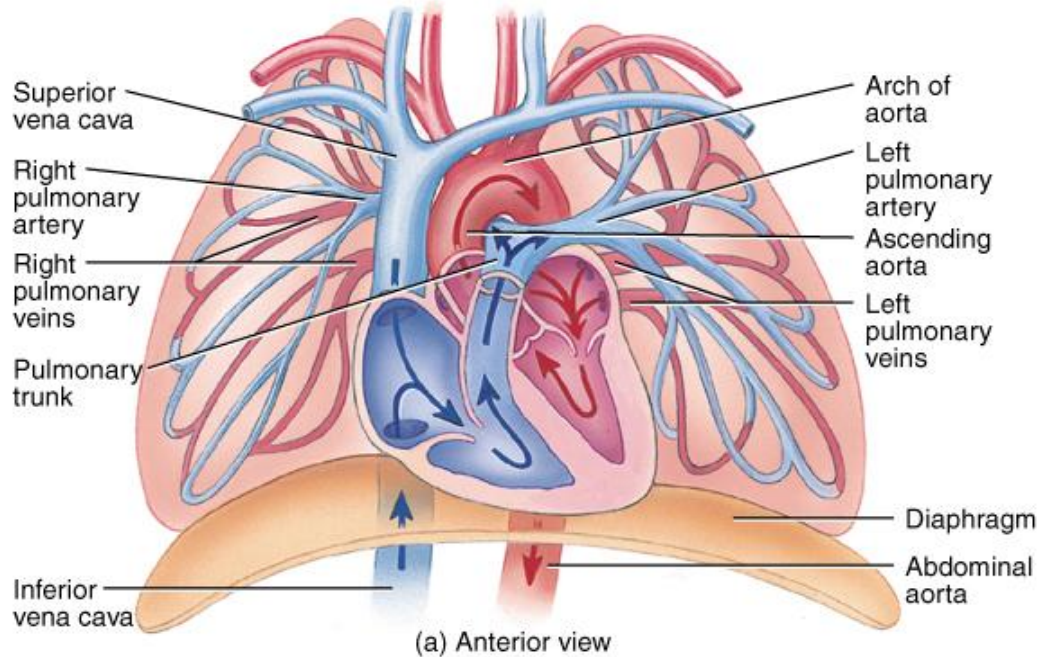


- Subdivision of systemic circulation
- Detours venous blood from GI tract to liver on its way to the heart
 - liver stores or modifies nutrients
- Formed by union of splenic, superior mesenteric & hepatic veins

Arterial Supply and Venous Drainage of Liver

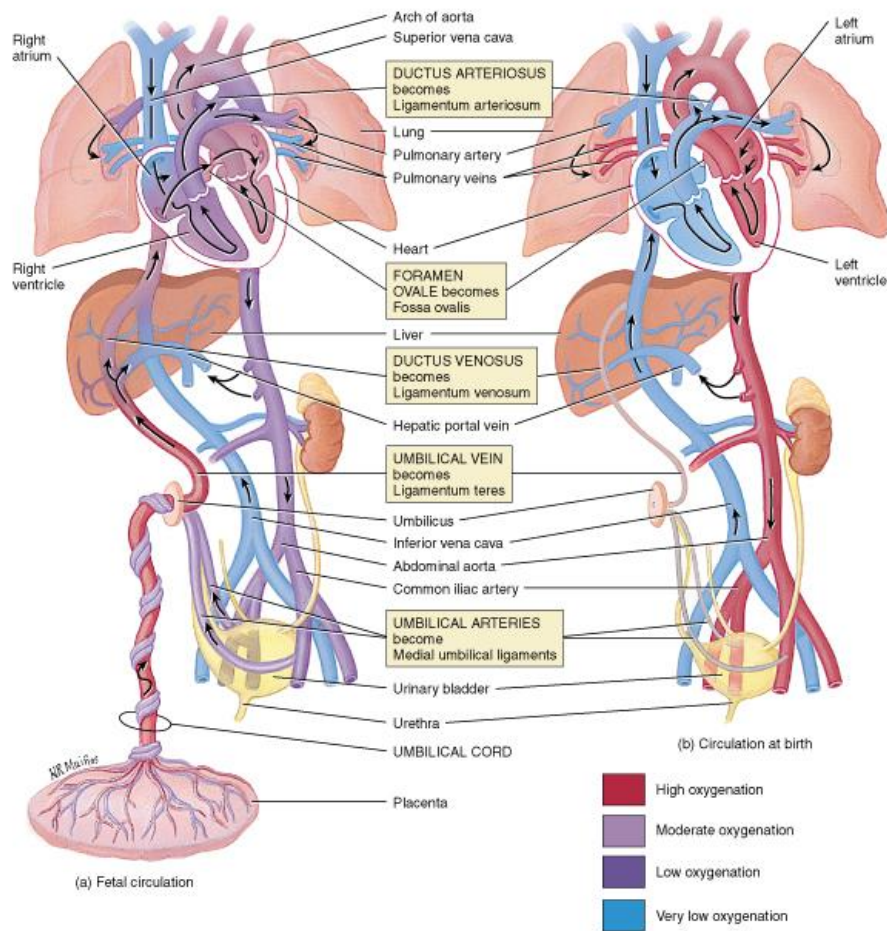


Pulmonary Circulation



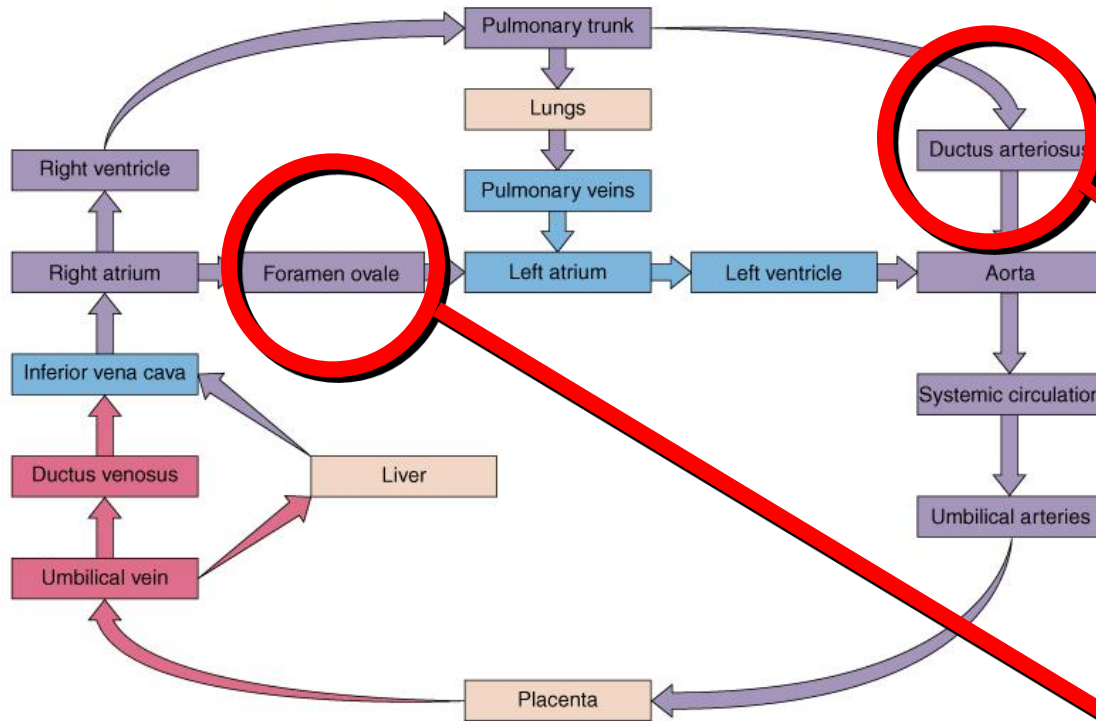
- Carries deoxygenated blood from right ventricle to air sacs in the lungs and returns it to the left atria
- Vessels include pulmonary trunk, arteries and veins
- Differences from systemic circulation
 - pulmonary aa. are larger, thinner with less elastic tissue
 - resistance to is low & pulmonary blood pressure is reduced

Fetal Circulation



- Oxygen from placenta reaches heart via fetal veins in umbilical cord.
 - bypasses liver
- Heart pumps oxygenated blood to capillaries in all fetal tissues including lungs.
- Umbilical aa. Branch off iliac aa. to return blood to placenta.

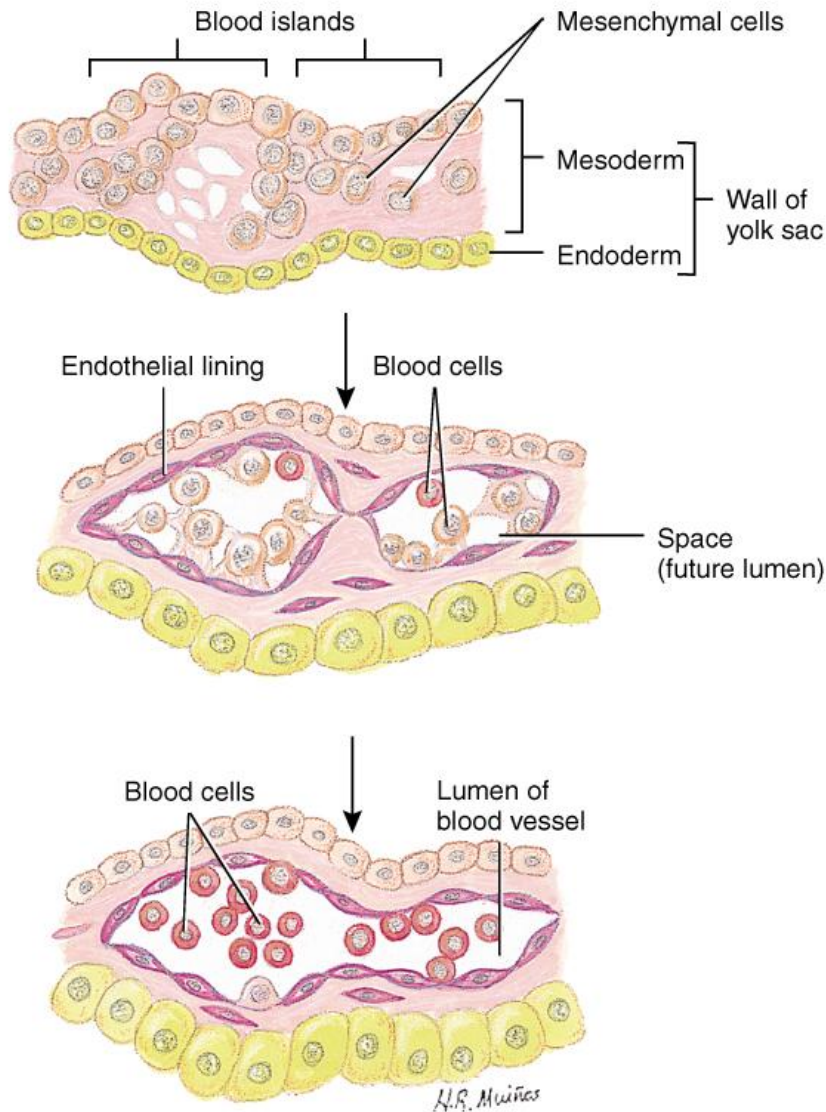
Lung Bypasses in Fetal Circulation



Ductus arteriosus is shortcut from pulmonary trunk to aorta bypassing the lungs.

Foramen ovale is shortcut from right atria to left atria bypassing the lungs.

Developmental Anatomy of Blood Vessels



- Begins at 15 days in yolk sac, chorion & body stalk
- Masses of mesenchyme called blood islands develop a “lumen”
- Mesenchymal cells give rise to endothelial lining and muscle
- Growth & fusion form vascular networks
- Plasma & cells develop from endothelium

Aging and the Cardiovascular System

- General changes associated with aging
 - decreased compliance of aorta
 - reduction in cardiac muscle fiber size
 - reduced cardiac output & maximum heart rate
 - increase in systolic pressure
- Total cholesterol & LDL increases, HDL decreases
- Congestive heart failure, coronary artery disease and atherosclerosis more likely