Heart, Vessels, and Lymphatics

Introduction

1. Heart Description/Location/Stats
   a. Size of a person’s fist-250-350 g
   b. Found in mediastinum-medial cavity of larger thoracic cavity
   c. Anterior to vertebrae; posterior to sternum
   d. Extends 2nd-5th ribs; apex tips left towards left hip

2. Heart Coverings
   a. Heart is enclosed in a double-layer membrane called the pericardium
      1) Fibrous pericardium
         a) Description
         b) Function
      2) Serous pericardium
         a) Description:
         b) Function:
         c) Divided into:
            i. Parietal layer-lines inner surface of fibrous pericardium
            ii. Visceral layer-covers surface of heart and is also known as the epicardium
      3) Pericardial cavity-space between parietal and visceral layers
         a) Filled with a lubricating serous fluid (5-30 ml)

3. Heart Wall
   a. Heart has 3 layers: epicardium, myocardium, and endocardium
   b. Epicardium-outermost layer of heart wall
      1) Same as visceral layer
   c. Myocardium
      1) Mostly cardiac muscle
      2) Bound together by collagen and elastic fibers-called the fibrous skeleton
      3) Fibrous skeleton provides insulation of AP’s traveling through heart, elastic recoil, and support of valves
   d. Endocardium-continuous with endothelium lining blood vessels

4. Heart Chambers
   a. 4
      1) 2 upper thin-walled chambers called atria
      2) 2 lower thick-walled chambers called ventricles
   b. Atria
      1) Externally. Atria have outer flap-like coverings called auricles
2) Interatrial septum—wall of muscle and CT that separates RA from LA
3) Internally, ridges of muscles in atrial wall are musculi pectinati
c. Ventricles
   1) Interventricular septum—muscle and CT that separates RV from LV
   2) Folds or columns in walls of ventricles are called trabeculae carneae
5. Major Heart Vessels
   a. Vena Cavae
      1) Superior VC drains upper body and returns oxygen-poor blood to RA
      2) Inferior VC drains lower body and returns oxygen-poor blood to RA
   b. Coronary Sinus
      1) Collection area for venous blood returning from heart’s myocardium
      2) Empties into RA
   c. Pulmonary trunk
      1) Divides into rt and left pulmonary arteries going to rt and left lungs
      2) Only artery to carry oxygen-poor blood
d. Pulmonary veins
   1) Usually 4, 2 rt and 2 left
   2) Carry oxygen-rich blood to LA
e. Aorta
   1) Carries oxygen-rich blood from LV
   2) Ascending aorta
      a) Coronary arteries emerge from base, but are hidden by rt and left auricles and pulmonary trunk
      b) Left coronary artery (LCA) divides into:
         i. Left Anterior Descending branch (= anterior interventricular artery) going down between ventricles-supplying blood to both ventricles
         ii. Circumflex branch—goes around left side in coronary sulcus eventually servicing LA and posterior wall of LV
      c) Right coronary artery (RCA) divides into:
         i. Rt marginal branch going to apex of heart
         ii. Posterior interventricular artery supplying posterior walls of both ventricles and eventually anastomoses with LCA
      d) Turns left at about 5 cm to become:
3) Aortic arch
   a) Gives rise to 3 vessels: Brachiocephalic, Left common carotid, and L subclavian
   b) Brachiocephalic divides into:
      i. R Common carotid—goes up neck to head
      ii. R Subclavian—goes into arm; gives rise to axillary, then brachial
   c) L Common carotid—goes up left neck and to head
   d) L Subclavian—goes out to arm becoming axillary, then brachial

4) Descending aorta
   a) Descending thoracic aorta—inside thoracic cavity
   b) Descending abdominal aorta—when aorta penetrates diaphragm into abdominal cavity

6. Heart Valves
   a. Atrioventricular (AV)
      1) Tricuspid—found between RA and RV; has 3 cusps
      2) Mitral (bicuspid)—found between LA & LV; has two cusps
   b. Semilunar (SLV)
      1) Pulmonary—found at base of pulmonary trunk
      2) Aortic—found at base of ascending aorta
   c. All valves regulate direction of blood flow and prevent backflow (= regurgitation)
   d. Semilunar valves allow pressure buildup-enhancing blood ejection from ventricles
      1) Cup-like structures help catch returning blood to cause closure
   e. Accessory structures
      1) Chordae tendinae (Tendinous cords)—tendons of papillary muscles that attach to AV valves
      2) Papillary muscles—open and close AV valves

7. Coronary Circulation
   a. Subdivision of Systemic Circuit
   b. 2 coronary arteries emerge from base of ascending aorta
   c. After gas exchange in capillaries of myocardium, blood vessels empty into coronary veins
   d. Coronary veins converge at back of heart into the coronary sinus
   e. Coronary sinus empties into RA

8. Blood Flow Sequence
   a. Oxygen-poor blood enters RA via Superior/Inferior Vena Cavae and coronary sinus
   b. Blood passes through Tricuspid valves into RV
c. Oxygen-poor blood exits pulmonary semilunar valves using pulmonary trunk
   1) Pulmonary trunk divides into R and L pulmonary arteries
      going to R and L lungs
d. Oxygen poor blood becomes oxygen rich blood in lungs
e. Oxygen rich blood returns to heart using pulmonary veins
f. Pulmonary veins empty into LA
g. Blood passes through mitral valves into LV
h. Oxygen rich blood exits through aortic semilunar valve to aorta
i. Branches of aorta deliver oxygen rich blood to body tissues where gases are exchanged
j. Oxygen poor blood returns to heart using numerous smaller veins
   that empty into the vena cavae

   a. Pulmonary circuit-blood flow between heart and lungs = RV-
      Pulmonary trunk (arteries)-lungs-Pulmonary veins-LA
   b. Systemic circuit-blood flow between heart and body tissues = LV-
      Aorta-tissues-vena cavae-RA
   c. Coronary circuit is subdivision of systemic circuit

10. Heart Sounds
   a. Two main heart sounds: Lubb (S1)-Dupp (S2) pause
   b. Lubb is caused by closure of AV valves; onset of systole
c. Dupp is caused by closure of semilunar valves; onset of diastole
d. Any abnormal heart sound is a murmur
   1) Can be harmless
      2) Or indicators of valve malfunction, a foramen between atria/ventricles, or general roughness of myocardium

11. Fetal Heart
   a. Modifications of fetal heart shunt blood away from inactive lungs
      back to main circulation for eventual gas exchange in placenta
   b. Ductus arteriosus-vessel that joins pulmonary trunk and aorta
      1) Collapses after birth and becomes ligamentum arteriosus
   c. Foramen ovale-opening between atria allowing oxygen poor blood
      to move from RA to LA
      1) Usually closes after birth leaving a scar-like depression in interatrial septum called the fossa ovalis
d. Septal defects
   1) Atrial-foramen ovale does not close after birth; sometimes
closes on its own or is closed by surgery
   2) Ventricular-congenital defect where opening occur in interventricular septum; serious and must be closed surgically
   3) Both cause infant’s skin to take on ‘blue’ appearance (Blue Baby) because of poor oxygenation.
4) Ventricular defect is much more serious because of higher pressures involved causing greater mixing

e. Heart disorders: Valves
1) Murmur- any abnormal or extra heart sound
2) Valvular insufficiency allows regurgitation, or backflow, of blood
   a) Valvular prolapse-AV valve billows back into atria during systole; ventricles lose pressure
   b) Valvular stenosis-valve cusps are stiffened by scar tissue (rheumatic fever) or age; may resist opening and cause buildup of pressure in atria

12. Cardiac Muscle
a. Both skeletal and cardiac muscles are striated because of similar actin-myosin alignments
b. Unique features of cardiac muscle:
   1) Anastomosing fibers
   2) Uninucleate
   3) Endomysium is loaded with capillaries
   4) Cells united by intercalated discs
      a) Desmosomes
      b) Gap junctions
   5) Large numbers of mitochondria (30-40% of volume)
   6) Myofibrils vary in diameter and fuse together; therefore striations are less distinct than in skeletal muscle
   7) T system: T tubules are wider and fewer entering cells at intercalated discs
   8) SR is less elaborate; therefore Ca++ comes from ECF
   9) Depends totally on aerobic respiration using mainly fatty acids when very active
      a) 60% fatty acids, 35% glucose, 5% other
   10) All or none Law applies to whole muscle, not individual cells as in skeletal muscle
   11) Myogenic tissue-pacemake sets rhythm of contraction; caused by leaky Na+ GC
   12. Refractory period very long (250 ms) making cardiac muscle less likely to experience tetany
      a) Refractory period in skeletal muscle???

Cardiophysiology
1. Conduction System
a. Two main types of modified cardiac muscle cells
   1) Conduction (1%)-carry AP's throughout heart
   2) Contraction (99%)-generate force of contractions
b. Initiated by pacemaker; also called sinoatrial node

c. ANS controls via vagus (X) nerve; also sympathetic fibers present
d. Components: Sinoatrial node (SA node), Atrioventricular Node (AV Node), Bundle of His (AV Bundle), Purkinje fibers
e. SA node
   1) Located near entrance of SVC in upper R atria wall
   2) Depolarizes at rate of 80-90 times/min (in absence of hormonal and neural controls)
   3) CT between atria and ventricles prevents AP’s from reaching ventricles too soon
f. AV node
   1) Located in lower floor of RA near opening of coronary sinus
   2) Self-depolarizes at rate of 40-50 beats/min (SA node sets AV node pace.)
g. Bundle of His
   1) Located in interventricular septum; splits into R and L bundle branches
h. Purkinje fibers
   1) Bundle branches give off numerous branches near heart’s apex, spreading throughout wall of outer ventricular myocardium
i. Conduction and Contraction Sequence
   1) SA node fires sending AP out and down atria towards AV node
      a) Atria contract from the top-down driving blood downward into the ventricles
      b) Ventricles receive 30% of their blood volume from atria
   2) AV node now fires; AP travels down Bundle of His in interventricular septum toward heart’s apex
   3) From apex, AP enters Purkinje fibers which disperse the AP along the outer ventricular wall from the apex
      a) When ventricles contract, they contract from the apex-up diving blood up and out pulmonary trunk and aorta

2. Electrokardiogram (ECG or EKG)
   a. Graphical recording of the electrical changes in the heart muscle
   b. 3 deflection waves: P, QRS, and T
      1) P wave-smallest (0.1 mV) and first (0.08 s)
         a) Represents depolarization from SA node along atria
      2) QRS-largest (1.4 mV) and second (0.08 s)
         a) Represents ventricular depolarization
      3) T wave-longest (0.16 s) and last; 0.2 mV
         a) Represents ventricular repolarization
   c. Intervals
1) P-R (P-Q) interval-time (~0.16 s) from atrial excitation to beginning of ventricular excitation (Atrial depolarization, AV depolarization, and Bundles)
2) Q-T (S-T) interval time (~0.14 s) from ventricular depolarization through repolarization
3) Presence, durations, and sizes are important in diagnosing heart problems
d. Electrical activity of myocardium
   1) Atria begin to depolarize
   2) Atria depolarize
   3) Ventricles begin to depolarize at apex; atria repolarize
   4) Ventricles depolarize
   5) Ventricles begin to depolarize at apex
   6) Ventricles repolarize
e. Abnormal EKG’s
   1) P wave absent or inverted-no SA node pacemaker
   2) Lengthened P-R interval-AV node block or inflammation due to heart disease or rheumatic fever
   3) Damage to conduction pathways is called heart block
   4) Enlarged R-enlarged ventricles (either athlete’s heart or heart disease
   5) Premature ventricular contraction (PVC)-region(s) outside normal pacemaker become more excitable than usual
      a) Ectopic heart beat-A Purkinje cell or myocardial cell generates a second AP leading to arrhythmic heart beat
f. Abnormal heart rates
   1) Tachycardia-presistent, resting heart rate above 100 beats/min
      a) Elevated body temperature, fever or toxins
      b) Excessive stimulation by SNS
   2) Bradycardia-presistent, resting heart rate below 60 beats/min
      a) Observed in athletes
      b) Excessive Vagus nerve activity
   3) Ectopic heart beat-see earlier
   4) Atrial flutter-180-200 beats/min; AV block; contractions coordinated
   5) Fibrillation-400-500 beats/min; muscle quivers instead of contracting and beats are asynchronous
      a) Atrial-not immediately life threatening because atria only contribute 30% of blood pumped by ventricles
      b) Ventricular-AP’s travel to parts of ventricle at different rates because of coronary occlusion, imminent cardiac arrest
c) Both dramatically raise risk of blood clots by activating intrinsic pathway
d) Corrected by a defibrillator where a large electrical charge stops fibrillation and lets SA node reset pace

6) Palpitation-fluttering or any abnormal heart rate or rhythm

3. Cardiac Cycle
   a. All the events associated with flow of blood through the heart during one heartbeat
   b. Major divisions
      1) Systole-contraction of heart muscle
         a) Atrial
         b) Ventricular
      2) Diastole-relaxation of heart muscle
         a) Atrial
         b) Ventricular
      3) These divisions overlap and are correlated with important pressures changes that drive blood flow
   c. Steps of:
      1) Heart is completely relaxed (0.4 s)
         a) Both atrial and ventricular diastoles overlap
         b) Pressure in LV is very low (~ 0mmHg)
            i. RV side pressure of heart is ~ 1/5 of LV
         c) Blood is returning passively filling ventricles and then atria
         d) Ventricles expand from relaxation-decreases pressure
         e) AV valves open at beginning, but as ventricles fill, AV valves closes allowing atria to fill
         f) Semilunar valves closed
         g) 30& of ventricular filling occurs here
      2) Atrial systole (0.1 s)
         a) SA node depolarizes
         b) Wave of depolarization spread out and down
         c) Atria contract from top-down forcing blood down through AV valves into ventricles (add 30% of blood to ventricles)
         d) Ventricles bulge (~10-20 mmHg) and force AV valves shit tight
         e) At end of atrial systole, ventricles contain maximum blood volume (120 ml) called End Diastolic Volume (EDV)
      3) Atrial diastole-persists through rest of cycle
      4) Ventricular systole, VS (0.3 s)
         a) AV node fires
         b) AP moves down Bundle His to Purkinje fibers in apex
c) AV valves remain close; semilunar valves closed for first part of VS; therefore ventricles bulge briefly and no blood flows, a period called isovolumetric contraction
d) At ~ 80-90 mmHg, semilunar valves burst open allowing blood to exit ventricles, an event called ventricular ejection phase (pressure peaks at 120 mmHg)
e) At end of VS, ventricles contain smallest volume of blood (~50 ml) called End Systolic Volume (ESV)
f) The difference between EDV and ESV is called stroke volume (SV)
g) SV is the amount of blood ejected from each ventricle during one contraction
   i. Ejection fraction = SV/EDV
h) Atrial have started filling with blood

5) Ventricular diastole (VD)
a) As pressure drops to ~ 80 mmHg in aorta, some blood returns towards semilunar valves; cusps of valve catch blood and close, but some blood richochets into aorta causing a slight (2-5 mmHg) pressure rise, a event called the dicrotic notch

4. Cardiac Output
   a. Amount of blood pumped out by each ventricle in 1 minute
   b. Calculations:
      1) EDV = 120 ml
      2) ESV = 50 ml
      3) SV = EDV − ESV = 70 ml
      4) Heart Rate (HR) = 75 beats/min
      5) CO = HR × SV = 75 beats/min × 70 ml = 5250 ml/min
      6) 5250 ml = 5.250 L/min
c. Heart's ability to push CO above resting levels is called cardiac reserve.
   1) Nonathletes 4X or 21 L/min
   2) Athletes 7-8X or 42 L/min

5. Regulation of CO
   a. Two factors affect: HR and SV
   b. HR greatest force affecting CO because it can vary 3X; SV only varies 1.5 X
   c. Autonomic controls of HR
      1) Carotid sinus reflex
         a) located at jct of internal and external carotids
         b) Houses baroreceptors sensitive to stretch
         c) Baroreceptors detect stretch, a reflection of how much blood is flowing and therefore a measure of HR
d) AP’s sent to cardioregulatory center in medulla
e) Cardioregulatory center has 2 neuronal pools:
   i. Cardioacceleratory center-responds to low blood flow (therefore less stretch, low HR & low blood pressure (BP) sending signals to heart using sympathetic nerve fibers terminating at SA & AV nodes; NE is released which increases HR which raises blood flow & BP
   ii. Cardioinhibitory center-responds to increased blood flow (more stretch, high HR & BP) sending signals to heart using vagus nerve; releases ACh which slows HR, lowers blood flow & BP

2) Aortic reflex
   a) Located in aortic arch
   b) Houses baroreceptors sensitive to stretch
   c) Works similar to carotid sinus reflex
d. Besides autonomic controls, several other factors adjust HR
1) Chemicals
   a) Hormones
      i. E & NE increase
      ii. Thyroid Hormone=slower than E/NE, but more sustained HR
      iii. Glucagon (see Endocrine System)
   b) Ions
      i. These are unusual and associated with other homeostatic problems
      ii. A study of cardiomyocyte helps understand effects
      iii. Cardiomyocyte AP
      iv. A-voltage sensitive Na+ GC open & leak Na+ in towards threshold
      v. B-Na+ influx depolarizes membrane triggering opening of next Na+ GC
      vi. C-Na+ GC close as voltage approaches 30mV
      vii. D-Positive interior is extended, and therefore depolarization, by opening of slow Ca++ channels; Ca++ enters cell; some K+ leaks out causing voltage to decrease gradually
      viii. E-Ca++ GC close and Ca++ gets transported back out of cell; K+ GC open returning interior to original negative voltage of -90 to -80 mV
      ix. F-Membrane is hyperpolarized, but K+ channels close; next cycle is started
x. Hypercalcemia-ECF high in Ca++ extending plateau phase of AP and slowing HR; drugs like digitalis and dopamine increase Ca++ levels
xi. Hypocalcemia-ECF low in Ca++ shortening plateau phase of AP and increasing HR
xii. Ca++ imbalances are relatively rare and their primary effect is on contraction strength; hypercalcemia increases, hypocalcemia decreases

c) Temperature
i. Hot increases HR because of increased metabolism of cardiomyocytes
ii. Cold lowers HR which is reasoning behind lowering temperatures during surgeries

d) Exercise
i. Increases HR via SNS and feedback from proprioceptors in joints and muscles
ii. Resting HR decreases with training because heart enlarges & increases SV

e) Emotions-increases via SNS

f) Sex
i. Females 72-78 beats/min
ii. Males 64-72 beats/min
iii. Males are larger on average than females

g) Age-From birth to adult size, HR slows, remains stable for 10-15 years (your prime) then gradually increases after prime
i. Inverse correlation between body size and HR

d. Stroke volume
1) HR and SV are two most important variables affecting CO
2) SV defined:
3) Three factors govern:
   a) Preload
      i. Amt of tension in ventricular myocardium before it contracts
      ii. Increase preload causes increased contraction strength
      iii. Exercise increases venous return, stretches myocardium (Increase preload), myocytes generate more tension during contraction, increase CO matches increased venous return
      iv. Frank-Starling Law of the Heart: SV is directly proportional to EDV
v. Ventricles eject as much blood as they receive, more they are stretched (increase preload) the more they contract

b) Contractility
i. Contraction force for a given preload
ii. Tension caused by factors that adjust myocyte’s responsiveness to stimulation
iii. Factors that increase contractility are positive ionotropic agents-hypercalcemia
iv. Factors that decrease contractility are negative ionotropic agents-hypocalcemia

c) Afterload
i. Pressure in arteries above semilunar valves opposes opening of valves
ii. Increase afterload, decrease SV
iii. Anything that impedes arterial circulation will increase afterload
iv. Continuous increase in afterload (lung disease, atherosclerosis, etc) causes hypertrophy of myocardium which likely leads to weaken and cause the heart to fail

e. Exercise and CO
1) Effect of proprioceptors
   a) HR increases at beginning of exercise due to signals from joints and muscles
2) Venous return
   a) Muscle activity increases causes an increase in venous return and therefore SV
3) Increase HR, increase SV, causes increased CO
4) Ventricular hypertrophy
   a) Cause by sustained program of exercise
   b) Increased SV allows heart to beat more slowly at rest
   c) Increases Cardiac reserve allowing tolerance of more exertion

f. Congestive Heart Failure
1) Occurs when pumping action of the heart is so depressed that oxygen demands of tissues cannot be met
2) Causes: Coronary atherosclerosis, myocardial infarcts
3) Pulmonary edema-right side of heart pumps normally, but left side does not leading to buildup of fluid (edema) in lungs
4) Systemic edema-left side of heart pumps normally, but right side does not leading to buildup of fluid (edema) in body tissues/organs
Blood Vessels
1. William Harvey
   a. In 1600's, before microscopes, proposed capillaries and circulation pattern we see today
   b. Heart was thought to be a pump and organ that manufactured blood
   c. Harvey filled hearts with water, measured bpm, & showed that it was not possible to manufacture that much blood
   d. Ex: SV (70ml) X HR (75 bpm) X 60 min/hr X 24 hr/day =
2. General structure
   a. 60,000 miles of vessels
   b. Organized in 3 tunics:
      1) T. intima (interna or endothelium)-innermost layer 1 cell layer thick; includes basement membrane
      2) T. media-mostly smooth muscle, but also elastic CT that varies with vessel type; much thicker in arteries and important in vasoregulation
      3) T. externa (or adventitia)-mostly connective tissue of loosely woven collagen fibers that anchor & protect vessels
         a) Large vessels have a vasa vasorum in this layer that brings in oxygen & nutrients and removes wastes
3. Arteries
   a. Transport blood away from heart
   b. Usually carry oxygen-rich blood (O2Hb)
      1) Name exception to this rule.
   c. 3 kinds of arteries
      1) Elastic
         a) Also called conducting
         b) Thick-walled; lg diameter lumen (>1 cm)
         c) Lg amt of elastic tissue called the elastic lamina allowing vessel to withstand pressure changes & give recoil
         d) Minor role in vasoregulation
e) e.g. aorta and brachiocephalic
      2) Muscular
         a) Medium to small diameter lumen (4-10 mm)
         b) T. media is mostly smooth muscle
         c) Vessels that carry blood to specific organs such as: splenic, gastric, carotids, brachials, femorals
      3) Arterioles
a) 30 μm or less lumen diameter
b) Only 2 tunics; T. externa missing
c) Vasoregulation is most important of all vessels
d) Also called resistance vessels because of their importance in affecting peripheral resistance (PR)

4. Veins
   a. Transport blood towards the heart
   b. Usually carry oxygen-poor blood (deO2Hb)
      1) Name exception to this rule.
   c. Blood is under very low pressures
   d. Thin-walled and large lumen diameter
      1) 65% of blood volume is in veins and referred to as your venous reserve
   e. Many veins have semilunar-like valves which assist blood return from areas below heart fighting gravity
      1) Blood return is also assisted by:
         a) Skeletal muscle pump massaging veins
         b) Thoracic pump using pressure changes during breathing
   f. Usually found nearer surface than arteries
      1) What is advantage of this position?
   g. Kinds
      1) Venules have 2 tunics (T. media missing) with 20-50 μm diameter
      2) Medium-sized veins 2-9 mm diameter
      3) Vena Cavae-largest diameter with adventitia thickened by smooth muscle
   h. Vein disorders
      1) Dilated veins caused by malfunctioning valves are varicose veins
      2) Any factor that increases fluid buildup:
         a) Aging-loss of protein elasticity
         b) Obesity
         c) Pregnancy-abdominal pressure increases
         d) Long periods of standing or sitting-no muscle help in returning blood
      3) Varicose veins of the anal canal are called hemorrhoids

5. Capillaries
   a. Single-layer thick vessels connecting arteriole to venule
      1) ~ 1 mm long
      2) 4-10 μm diameter
      3) 500-700 m² surface area
   b. 3 Kinds
1) Continuous
   a) Abundant in all tissues except cartilage and epithelial
   b) Endothelium provides continuous lining
      i. Adjacent cells united by tight jcts
      ii. Intercellular clefts, spaces between cells, allow ions & fluid to pass in & out
      iii. Also transport larger molecules by pinocytic vesicles
2) Discontinuous or Fenestrated
   a) Structurally similar to continuous, but many more intercellular clefts and fenestrations
   b) Found in kidneys, SI, and endocrine organs
   c) Found where high rates of absorption/filtration occur
3) Sinusoid
   a) Flattened & irregular diameter
   b) Lumen is expanded and very leaky
   c) Found in liver, lymphoid tissue, bone marrow
   d) Slows blood flow to increase processing time
c. Capillary beds
   1) Interweaving, anastomosing, group of capillaries
   2) Components:
      a) Vascular shunt or thoroughfare channel
         i. No gas or nutrient exchange
         ii. True capillaries branch off of
            iii. Allows blood to pass quickly through area for use elsewhere
      b) Metarteriole-arteriole end of thoroughfare channel
      c) Precapillary sphincters-smooth muscle surrounds base of each true capillary
         i. Extremely important in vasoregulation
         ii. Precapillary sphincters relaxed, blood flows into true capillaries for gas/nutrients exchanges
         iii. Precapillary sphincters contracted, blood does not flow into true capillaries and goes directly to the venule for use elsewhere
   3) Dynamics
      a) In flight or flight response, precap sphincters would be open in skeletal muscle capillary beds and closed in the GI tract capillary beds
6. Physiology of blood flow
   a. Systemic route mainly emphasized
   b. Mean pressure (mmHg) decreases from heart outward:
      1) Aorta-80-120
2) Arteries-70-110
3) Arterioles-40-70
4) Capillary-20-40
5) Venules-15-20
6) Veins-5-15
7) Vena Cavae-2-5

7. Blood Pressure (BP)
   a. Defined: Amt of force exerted by your blood on the inside of a vessel wall
   b. Usually measured in arteries; therefore term BP is usually synonymous with arterial pressure
   c. Measured with a sphygmomanometer
   d. A more meaningful measure of BP is Mean Arterial Pressure (MAP)
      1) MAP = Diastolic pressure + Pulse pressure
      2) Pulse pressure = Systolic – diastolic pressures/3
      3) Example: BP = 120/80
      4) MAP = 80 + (120-80)/3
   e. Blood flow (BF) is directly proportional to Pressure & inversely proportional to resistance (R, or Peripheral resistance, PR)

8. Factors affecting arterial pressure
   a. PR, CO, and blood volume are important
   b. Of these 3, PR is most important
   c. PR
      1) Vessel length
         a) Increasing vessel length increases friction and therefore PR
         b) 2 vessels equal diameter, but one 2X as long provides twice the frictional SA and doubles the PR
         c) Why do overweight people have higher BP’s
            i. Fat tissue is highly vascular
            ii. With formation of fat tissue, angiogenesis (growth of new blood vessels) occurs
      2) Vessel Diameter
         a) Most important of 4 PR factors because resistance varies inversely with the 4th power of vessel radius
         b) In other words, decreasing the radius of a vessel by 1/2 results in an increase in PR 16X!!!
            i. 1/(2)4 = 1/16; since inverse PR 16X
            ii. Arterioles can constrict to 1/3 of fully relaxed state
            iii. If r = 3 mm, BF = 3^4 = 81 mm/sec; If r = 1 mm, BF = 1 mm/sec
c) Therefore, small changes in vessel diameter can cause
dramatic shifts in PR and BP
3) Viscosity-thickness of a fluid (water = 1, blood = 4.5-55)
a) Increase viscosity, increase resistance
4) Turbulence-Eddies & swirls of blood caused by irregular
surfaces
   a) Increase turbulence, increase resistance
d. CO
   1) CO = HR X SV
   2) BP = CO X PR
   3) CO and BP are directly related
e. Blood Volume
   1) Decreasing blood volume results in a decrease of BP
   2) Hemorrhage
   3) Dehydration
      a) What happens to blood viscosity if you get dehydrated?
7. Active controls of BP
   a. Autoregulation-automatic adjustments in BF to tissues in
      proportion to their requirements
      1) Natural reaction by smooth muscle to stretch
      2) No neural pathways involved, but can also be caused by
         chemicals (gases/hormones)
      3) Ex: If BF decreases, wastes (CO2, H+, K+, lactic acid, etc)
         increase; these wastes trigger vasodilation allowing wastes to
         be removed
   b. Vasomotor center in medulla
      1) Operates via reflex arc: Baroreceptor -→ sensory neuron-→
         vasomotor center-→ motor neurons-→ smooth muscle in vessel
         wall
      2) Vasomotor tone maintained by autonomic NS
c. Presso or baroreceptors
   1) Sensitive to stretch
   2) Mostly function in short-term postural changes
   3) In hypertension, receptors reset at new higher pressures
d. Chemoreceptors
   1) Located in carotid and aortic bodies
   2) Oxygen-requires very large changes
   3) pH and CO2 changes affect strongly
   4) Important in breathing rate and depth-see respiratory system
e. Higher brain centers also influence BP
   1) Cerebral cortex
   2) Hypothalamus
3) Via emotions/fight or flight
f. Chemicals
1) Angiotensin II
   a) Lowered BP \(\rightarrow\) kidney cells release rennin \(\rightarrow\) through
      a series of reactions involving liver and lungs \(\rightarrow\)
      angiotensin II
   b) Reaction in liver, lungs, & kidneys
   c) Powerful vasoconstrictor
   d) Vasoconstriction will increase BP
2) Vasopression
   a) ADH in large quantities
   b) A Vasoconstrictor, but probably not released in the
      quantities required
   c) Hemorrhage???
3) E/NE
   a) Increase BP by causing vasoconstriction in certain
      organs and also increasing CO
4) Chemical mediators: kinins, histamines, PGE, serotonin
   a) All except serotonin cause vasodilation of arterioles
   b) Mostly local effect and unlikely to decrease BP
      significantly
5) Atrial Natriuretic Peptide (ANP)
   a) Source is heart
   b) Increases excretion of Na\(^+\) by kidneys into urine \(\rightarrow\)
      increases water loss in urine \(\rightarrow\) decreases blood volume
      \(\rightarrow\) decreases BP
6) Aldosterone
   a) Causes retention of Na\(^+\) by kidneys \(\rightarrow\) increases water
      retention \(\rightarrow\) increase blood volume \(\rightarrow\) increase BP
7) Antidiuretic Hormone (ADH)
   a) Causes kidneys to conserve water \(\rightarrow\) increase blood
      volume \(\rightarrow\) increases BP
8) How many of these hormones/EZ's come from or directly
    effect kidney function?
   a) List and state effects
8. Fluid movement across capillaries
   a. Mechanisms:
      1) Diffusion
         a) Lipid-soluble substances
         b) Water via osmosis
         c) Water soluble substances
      2) Active transport: pino, phago, and exocytoses
3) Hydrostatic pressure (HP)
   a) Direct relationship to BP
   b) Force exerted by a fluid pressing against a vessel wall
   c) Because capillaries are so thin-walled, HP plays a critical role in fluid loss from the blood

b. Hydrostatic pressure
   1) Two kinds: HP in capillary (HPc) and HP in interstitial fluid (HPif)
   2) HPc
      a) Forces fluids out of capillary
      b) Pressure at arteriole end of capillary: 25 mmHg
      c) Pressure at venule end of capillary: 10 mmHg
      d) Therefore, fluids move out faster at arteriole end than venule end of capillary
   3) HPif
      a) Forces fluid to move into capillary if fluid volume is stable
      b) However, probably a negative value because interstitial fluid is collected or pulled away by lymphatic system
      c) HPif value at both ends of capillary: -6 mmHg
      d) – means fluids are leaving capillary

4) Net Hydrostatic pressure
   a) Arteriole end Net HP = 25 – (-6) = 31 mmHg
      i. 31 mmHg driving fluids out of capillary
   b) Venule end: Net HP = 10 – (-6) = 16 mmHg
      i. 16 mmHg driving fluids out of capillary
   c) Again, the force driving fluids out of capillary is greater at arteriole than venule end

c. Osmotic pressure (OP)
   1) Caused by nondiffusible substances in the plasma such as proteins (e.g. albumins)
   2) Interstitial fluid has few nondiffusible substances, but does have small solutes such as electrolytes
   3) The albumins in plasma pull water back into or prevent water from leaving the capillary
   4) Any solution with solutes will exhibit osmotic pressure; therefore even interstitial exhibits a small pull on water
   5) Osmotic forces will somewhat counteract the HP forces
   6) OPc = 28 mmHg
      a) The OPc will pull water back into the capillary
      b) OP in blood is sometimes called oncotic pressure
   7) OPif = 5 mmHg
      a) OPif will pull water out of the capillary
8) Net OP = OPc – OPif = 28 – 5 = 23 mmHg
9) Therefore, OP causes water to be pulled back into the capillary with greater force than it leaves (by OPif)
d. Which outcome listed do you think should occur and explain why you eliminated the other choices?
   1) Net HP > NetOP
   2) Net HP < Net OP
   3) Net HP = Net OP
e. Net HP versus Net OP
   1) Arteriole end:
      a) Net HP = 31 mmHg
      b) Net OP = 23 mmHg
      c) Net HP – Net OP = 31 – 23 = 8 mmHg
      d) Fluids are moving out of capillary with a force of 8 mmHg
   2) Veneule end:
      a) Net HP = 16 mmHg
      b) Net OP = 23 mmHg
      c) Net HP – Net OP = 16 – 23 = -7 mmHg
      d) Fluids are returning to the capillary with a force of 7 mmHg
f. There is still a net loss of fluids from capillary
   1) 8 mmHg (arteriole end) – 7 mmHg (venule end) = 1 mmHg overall
   2) Net loss of fluids works out to 1.5 ml/min or 3 L/day
   3) What happens to these ‘loss’ fluids: THEY ARE RECAPTURED BY LYMPHATIC SYSTEM!
g. Kwashiokor
   1) Disease from lack of dietary protein often seen in starving people
   2) No protein, no albumin, and no counteracting force to HP sp extreme edema forms in major organs (liver)

**Lymphatic System**
1. Components: lymphatic vessels and lymphoid organs
2. Functions:
   a. Drains tissue spaces of protein-containing fluid and returns to main circulation
   b. Transports fats from digestive tract to blood and liver
   c. Produces lymphocytes and allows us to develop immunities
3. No lymph vessels in CNS, bone, cartilage, epidermis, and teeth
4. Lymphatic vessels
   a. Interstitial fluid collected by lymph vessels is called lymph
b. Exhibits one-way transport toward heart
c. Lymphatic capillaries
   1) Composed of endothelial cells that are loosely joined and
      overlap like shingles; shingles create flap-like valves for one
      way entry
   2) Lymphatic capillaries in intestinal villi are called lacteals;
      these transport a milky-white lymph called chyle
d. Lymphatic collecting vessels
   1) Also called lymphatic veins
   2) Same 3 tunics as veins
   3) Thin-walled
   4) More internal valves
   5) Travel next to major arteries
e. Lymphatic trunks
   1) Union of largest lymphatic collecting vessels form several
      lymphatic trunks
      a) Lumbar (R and L)
      b) Intestinal
      c) Subclavian (R and L)
      d) Jugular (R & L)
      e) Intercostals
f. Lymphatic ducts
   1) Trunks drain into 2 lymphatic ducts
   2) Thoracic duct
      a) Largest and receives lymph from most (3/4) of body
      b) Arises from Ig sac called cisterna chilii located anterior
         to 2nd lumbar vertebrae
   3) R Lymphatic duct
      a) Smallest and drains upper R thorax, arm, head; thoracic
         duct drains everywhere else
      b) Each duct joins main circulation at jct of internal jugular and
         subclavian veins on respective sides
5. Lymph transport
   a. Same as veins
   b. Skeletal muscle pump
   c. Thoracic pump
   d. Valves and smooth muscle
   e. 3L enters every 24 hours = 3L lost because of HP
6. Lymphatic organs
   a. Lymph nodes
      1) 100's scattered throughout body
      2) Concentrated in axillary, cervical, & inguinal regions
      3) Lymphocytes help mount an immune response
a) Originate in marrow, migrate to lymphatic organs, and proliferate

4) Bean-shaped ~ 2.5 cm long

5) Organized into outer protective capsule, cortex, & medulla
   a) CT of capsule projects inward forming trabeculae that divide node into compartments

6) Inner matrix of node composed of reticular fibers called stroma
   a) Stroma divided into outer cortex and inner medulla
   b) Cortex
      i. Houses densely packed spherical collections of lymphocytes called follicles
      ii. Germinal centers in follicles contain & form B lymphocytes (10 mil/day)
      iii. B lymphocytes form plasma cells
      iv. Plasma cells release antibodies
      v. Free-roaming T lymphocytes also present
   c) Medulla
      i. Houses strands of lymphocytes running from cortex inward called medullary cords
      ii. Macrophages attach to reticular fibers and present antigens to lymphocytes

7) Circulation
   a) Afferent vessels outnumber efferent vessels; therefore lymph flow slows as it passes through nodes
   b) Increases filtering function
   c) Medullary sinuses-expanded capillaries which also slow flow
   d) Efferent vessels exit from hilum, or concave region of node

b. Spleen
   1) Fist-sized lymphatic organ located in left abdominal cavity (L hypochondriac) just below diaphragm
   2) Functions:
      a) Site for lymphocyte proliferation; allows an immune response
      b) Cleanses blood of old RBC’s, platelets, pathogens
      c) Stores platelets
      d) Forms RBC’s in fetus

c. Thymus
   1) Aggregation of lymphatic tissue enclosed in a capsule of CT
   2) Located in mediastinum of thoracic cavity; anterior to heart, posterior to sternum
3) Functions:
   a) Releases hormones that activate various aspects of immunity
   b) T lymphocytes become immunocompetent against specific pathogens
d. Tonsils
   1) Ring of lymphatic tissue mostly around entrance to pharynx
   2) Named according to location
      a) Palatine-each side of posterior oral cavity; largest & most often infected
      b) Lingual-at base of tongue
      c) Pharyngeal or adenoids-posterior wall of nasopharynx
   3) Traps harmful pathogens, destroys pathogens, & forms immune cells with a memory
e. Lymphatic tissue: Appendix
   1) Mass of lymphatic tissue at jct of small & lg intestines
   2) Worm-like (vermiform appendix) branch of cecum
   3) Seems to play an extremely minor role in immunity
f. Lymphatic tissue: Peyer’s patches
   1) Masses of lymphatic tissue lining ileum region of SI
7. Lymphatic obstructions
   a. Lymph nodes swell during infections as lg amts of cellular debris builds up in nodes
   b. Elephantiasis-parasitic worms clog nodes & vessels preventing return of fluids to main circulation; feet, legs, scrotum, breasts enlarge many times normal size
   c. Hodgkin’s disease-malignancy of lymph nodes; swollen & painful; treated with radiation & has a high cure rate