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)
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 layers of muscle
• Metarterioles form branches into capillary bed
  – to bypass capillary bed, precapillary sphincters close
  – blood flows out 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
• 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 pituitary, & parathyroid gland
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

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

- Pressure exerted by blood on walls of a vessel
  - caused by contraction of the ventricles
  - highest in aorta
    - 120 mm Hg during systole & 80 mm Hg 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

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
      - dehydratation 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

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)
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 inappropriate 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

**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

**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.