EXAM Notes

Human Anatomy and Physiology (University of Technology Sydney)

Conduction of the heart

•Certain cardiac muscle cells are auto rhythmic cells because they are self-excitable. They repeatedly generate spontaneous action potentials that then trigger heart contractions

•These cells located in the SA node act as a pacemaker to set the rhythm for the entire heart

•SA node: pacemaker, initiates heartbeat, sets heart rate

•Fibrous skeleton insulates atria from ventricles

•AV node: electrical gateway to ventricles

•AV bundle (bundle of His): pathway for signals from AV node

•Right and left bundle branches: divisions of AV bundle that enter inter-ventricular septum

•Purkinje fibers are located in the inner ventricular walls of the heart and stimulate myocytes: upward from apex spread throughout ventricular myocardium

•Auto rhythmic Cells

–Cells fire spontaneously, act as pacemaker and form conduction system for the heart

•SA node

–cluster of cells in wall of Right Atria

–begins heart activity that spreads to both atria

–excitation spreads to AV node

•AV node

–in atrial septum, transmits signal to bundle of His

•AV bundle of His

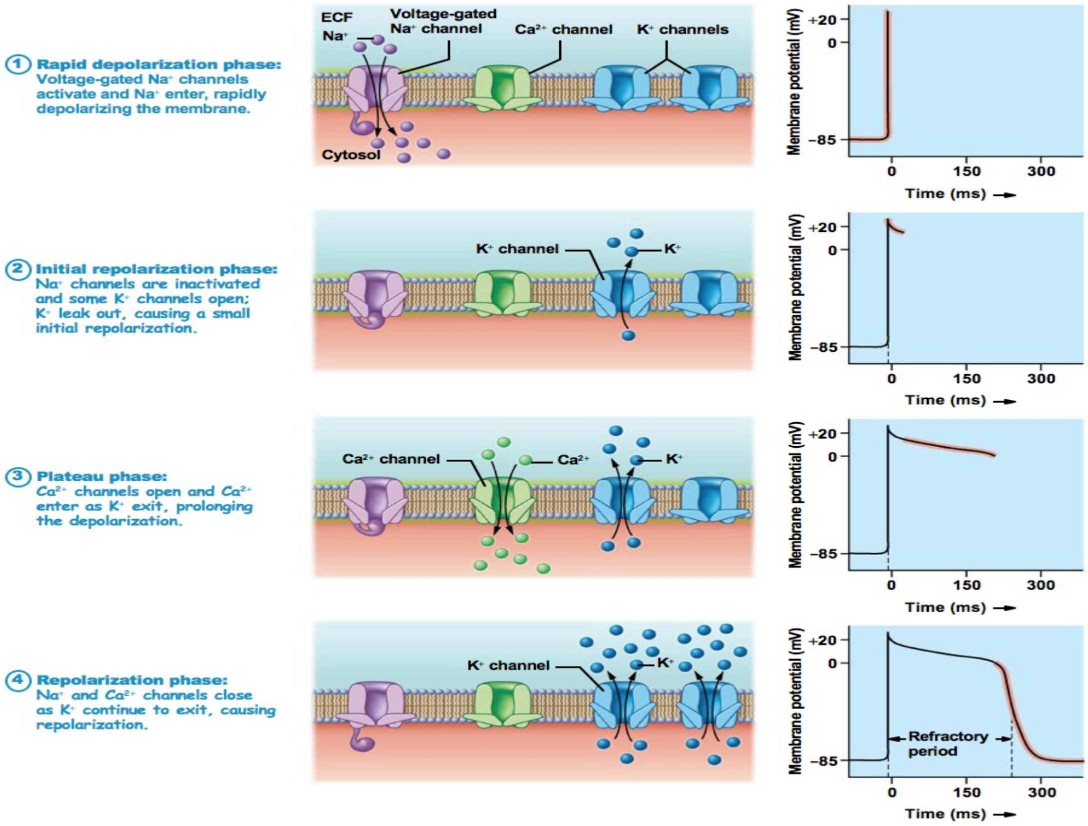
–the connection between atria and ventricles

–divides into bundle branches (left and right) & finally Purkinje fibers, large diameter fibers that conduct signals quickly

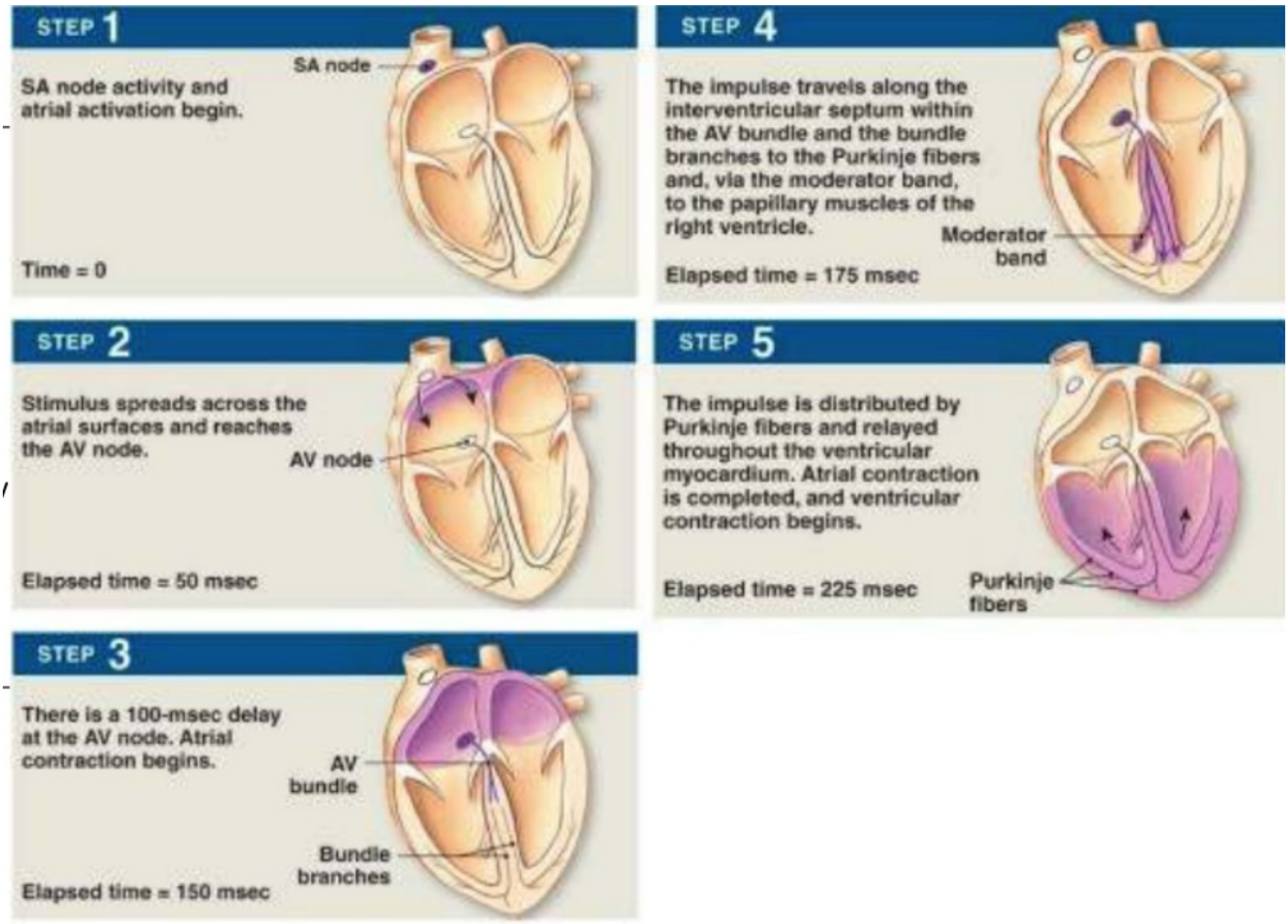
•SA node fires spontaneously 70 times per minute at rest

•AV node fires at 40-50 times per minute

•If both nodes are suppressed fibers in ventricles by themselves fire only 20-40 times per minute

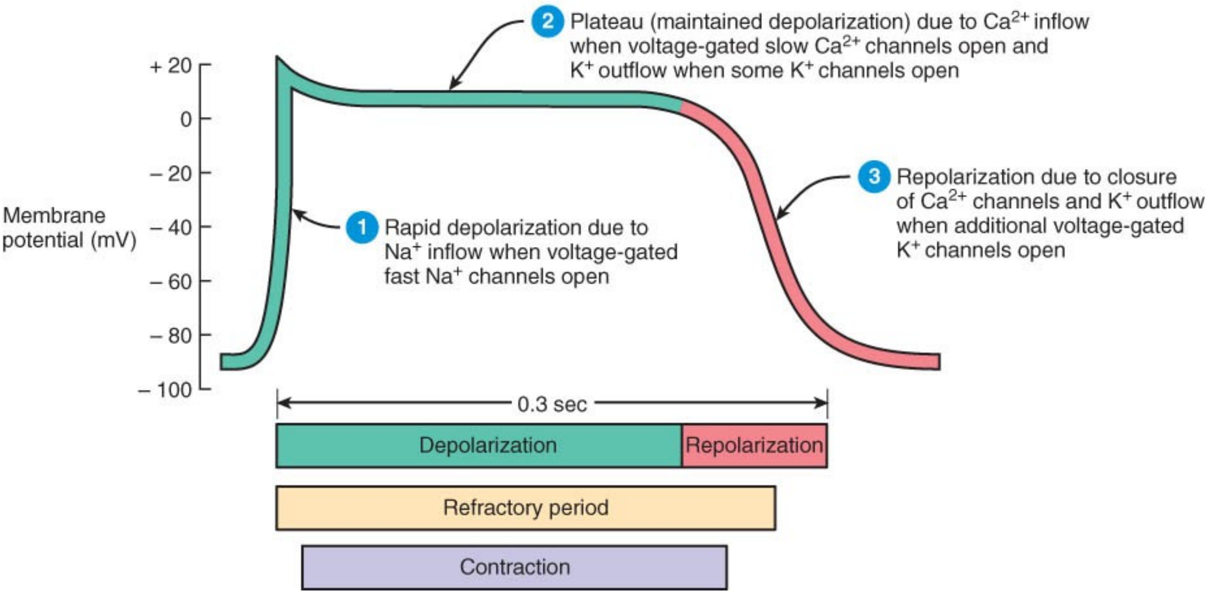


1 Rapid depolarization phase: Voltage-gated Na^+ channels activate and Na^+ enter, rapidly depolarizing the membrane.
2 Initial repolarization phase: Na^+ channels are inactivated and some K^+ channels open; K^+ leak out, causing a small initial repolarization.
3 Plateau phase: Ca^{2+} channels open and Ca^{2+} enter as K^+ exit, prolonging the depolarization.
4 Repolarization phase: Na^+ and Ca^{2+} channels close as K^+ continue to exit, causing repolarization.
ECF
Na^+
Voltage-gated Na^+ channel
Ca^{2+} channel
K^+ channels
Cytosol
K^+ channel
K^+
Ca^{2+}
Membrane potential (mV)
+20
0
−85
0
150
300
Time (ms)
Refractory period



STEP 1
SA node activity and atrial activation begin.
SA node
Time = 0
STEP 2
Stimulus spreads across the atrial surfaces and reaches the AV node.
AV node
Elapsed time = 50 msec
STEP 3
There is a 100-msec delay at the AV node. Atrial contraction begins.
AV bundle
Bundle branches
Elapsed time = 150 msec
STEP 4
The impulse travels along the interventricular septum within the AV bundle and the bundle branches to the Purkinje fibers and, via the moderator band, to the papillary muscles of the right ventricle.
Moderator band
Elapsed time = 175 msec
STEP 5
The impulse is distributed by Purkinje fibers and relayed throughout the ventricular myocardium. Atrial contraction is completed, and ventricular contraction begins.
Purkinje fibers
Elapsed time = 225 msec

Physiology of Contraction



•Depolarization

–Cardiac cell resting membrane potential is -90mv

–excitation spreads through gap junctions

–fast Na+ channels open for rapid depolarization

•Plateau phase

–250 msec

–slow Ca^{2+} channels open, let Ca^{2+} enter from outside cell and from storage in Sarcoplasmic Reticulum (SR), while Na^+ channels close

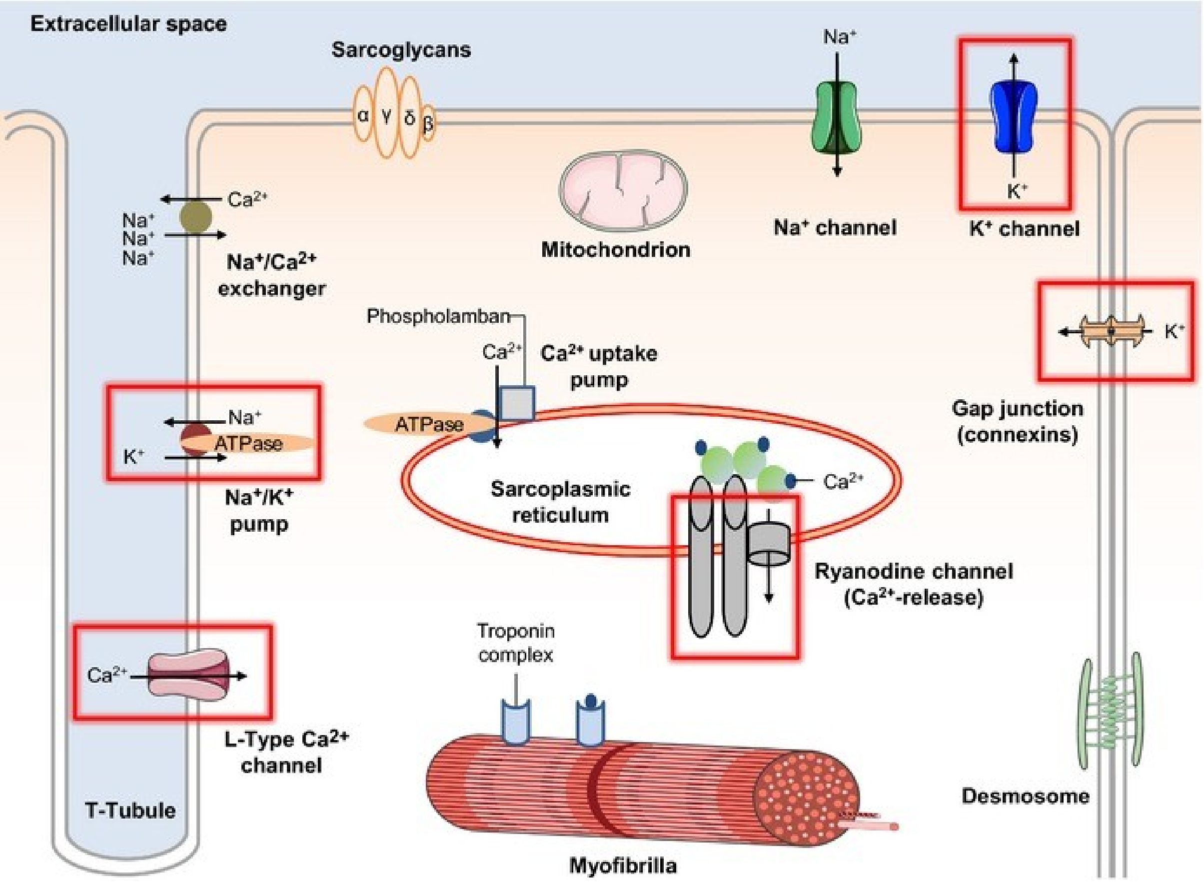
–Ca^{2+} binds to muscle proteins allowing for tension development and muscle contraction

•Repolarization

–Ca^{2+} channels close and K^+ channels open and -90mv is restored as potassium leaves the cell. Ca^{2+} pumped back into SR by Ca^{2+} ATPase pumps

•Refractory period

–Heart cannot be stimulated during this very long-time interval so heart can fill



Heart

-Heart wall and tissue

•Layers of heart wall

Epicardium (Visceral pericardium)

•Serous membrane consisting of simple squamous epithelium (these epithelial cells produce a lubricating fluid that is released between layers providing a slippery, non-adhesive and protective surface) and underlying connective tissue (attaching to myocardium)

–Parietal pericardium

•Not a heart wall layer but is continuous with serous membrane of the visceral pericardium

•Pericardial cavity - space inside the pericardial sac filled with 5 - 30 mL of pericardial fluid

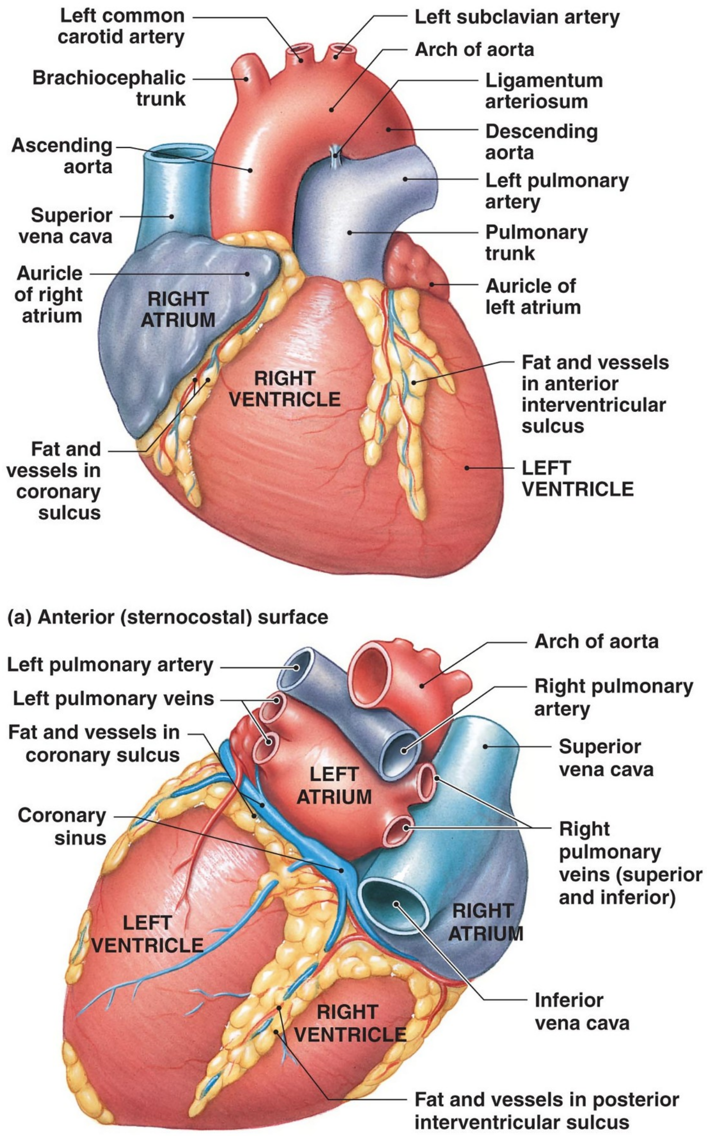
•Pericarditis – inflammation of the membranes

–painful friction rubs with each heartbeat

-Intercalated discs

•Desmosomes are molecular complexes of cell adhesion proteins and linking proteins that attach the cell surface adhesion proteins to intracellular keratin cytoskeletal filaments

•Linked by gap junctions which allow ions to move directly between cells



(a) Anterior (sternocostal) surface

(b) Posterior (diaphragmatic) surface

•The Right Atrium

–Superior vena cava

•Receives blood from head, neck, upper limbs, and chest

–Inferior vena cava

•Receives blood from trunk, viscera, and lower limbs

– Coronary sinus

•Cardiac veins return blood to coronary sinus

•Coronary sinus opens into right atrium

•The Pulmonary Circuit

–Conus arteriosus (superior end of right ventricle) leads to pulmonary trunk

–Pulmonary trunk divides into left and right pulmonary arteries

–Blood flows from right ventricle to pulmonary trunk through pulmonary valve

–Pulmonary valve has three semilunar cusps

•The Left Atrium

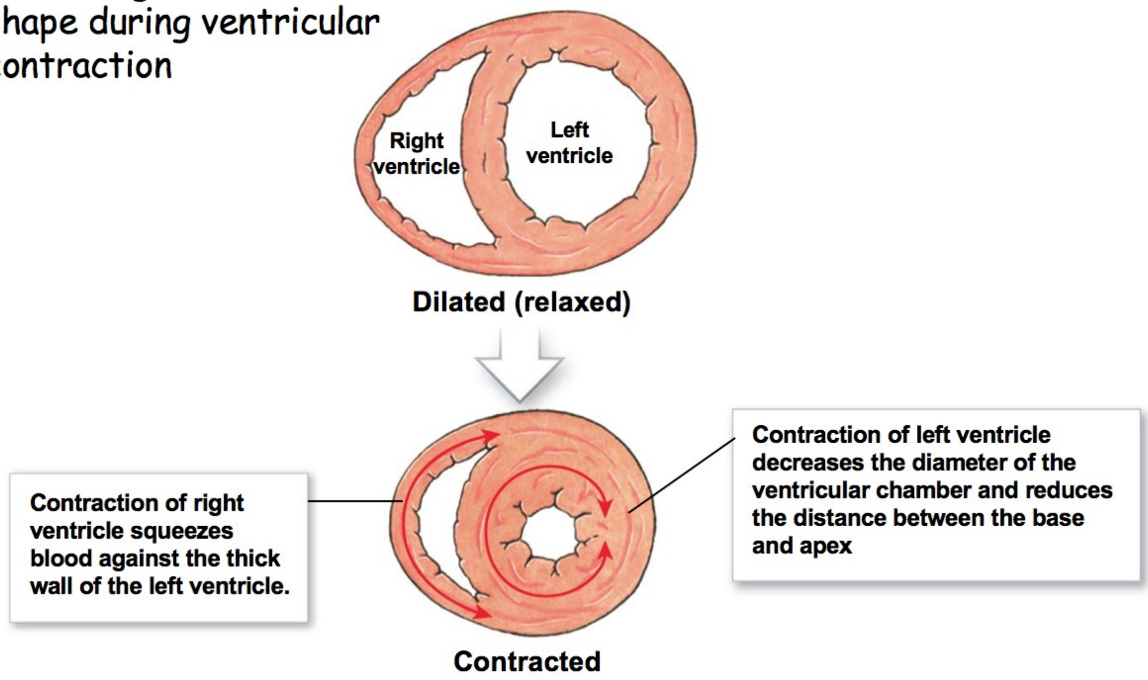
–Blood gathers into left and right pulmonary veins

–Pulmonary veins deliver to left atrium
–Blood from left atrium passes to left ventricle through left atrioventricular (AV) valve
–A two-cusped bicuspid valve or mitral valve

•The Left Ventricle

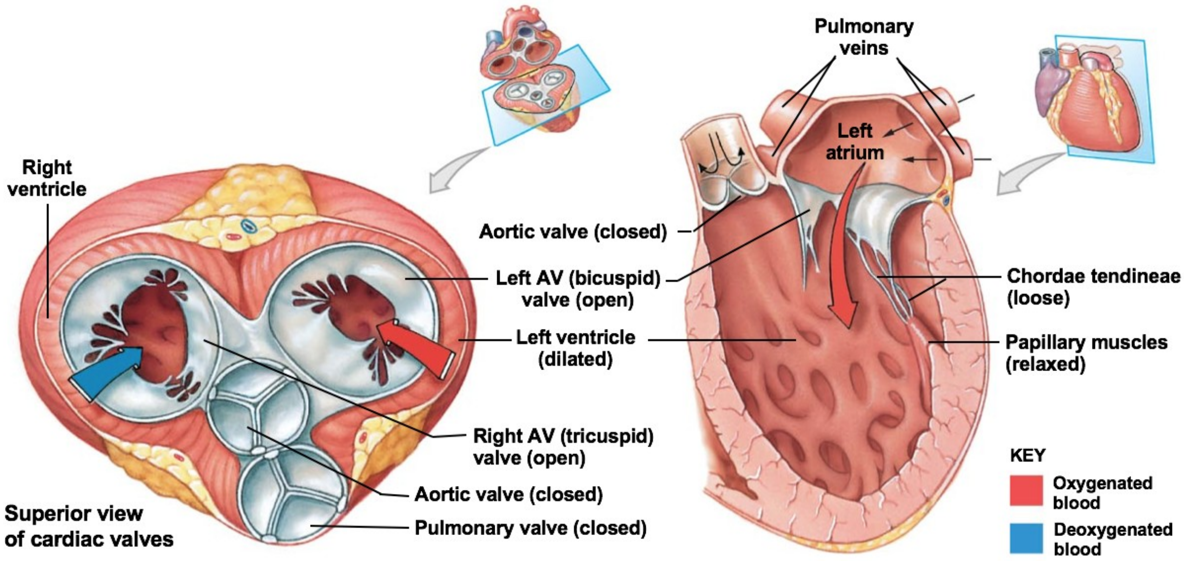
–Holds same volume as right ventricle
–Is larger and muscle is thicker and more powerful
–Similar internally to right ventricle but does not have moderator band
–Systemic circulation
•Blood leaves left ventricle through aortic semilunar valve into ascending aorta
•Ascending aorta turns (aortic arch) and becomes descending aorta

The changes in ventricle shape during ventricular contraction



–Tricuspid (Right side) – three cusps and between the right atrium and right ventricle
–Bicuspid (Left side) – two cusps and between the left atrium and left ventricle
•A-V valves open and allow blood to flow from atria into ventricles when ventricular pressure is lower than atrial pressure
–open when ventricles are relaxed, chordae tendineae are slack and papillary muscles are relaxed
–close when ventricles are contracting, chordae tendineae are taut and papillary muscles are contracted

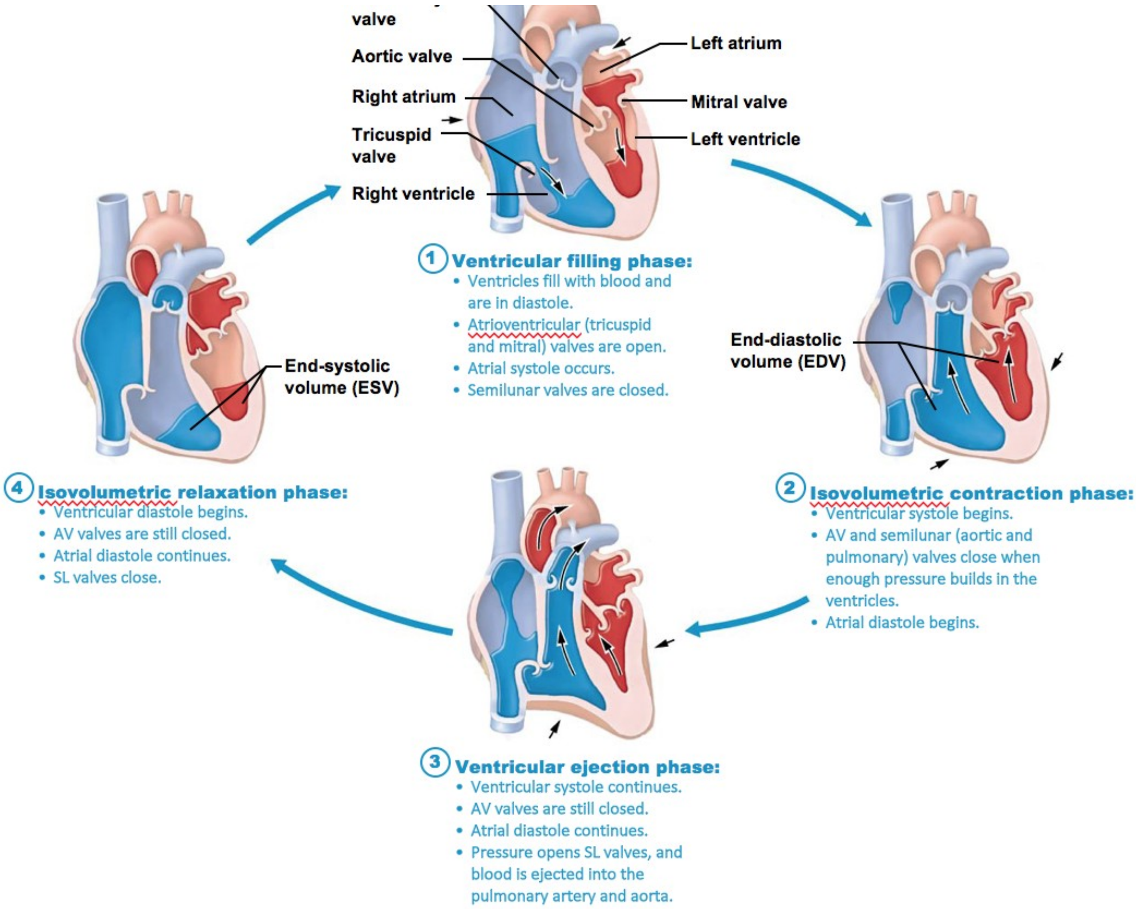
The positions of the valves and associated structures when the ventricles are relaxed

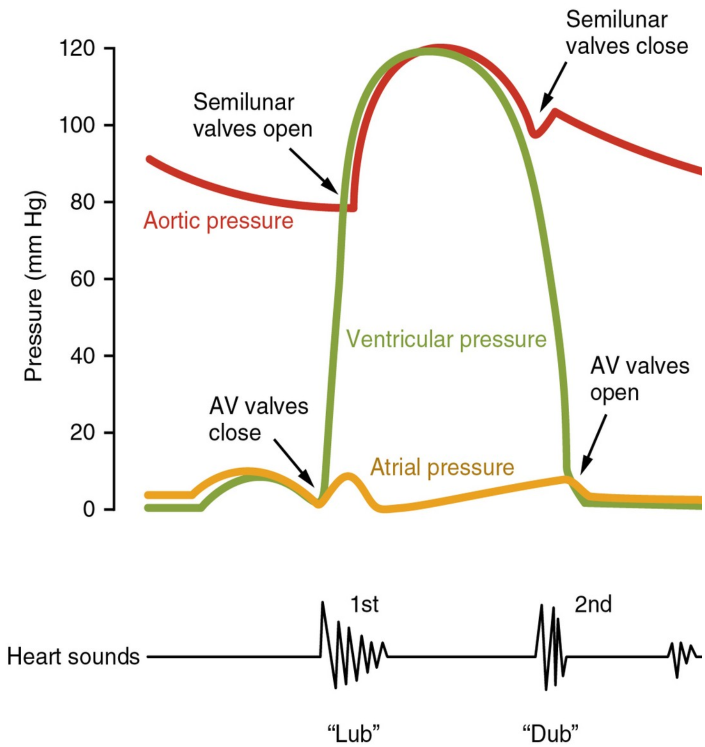


•Ventricles relax
–pressure drops inside the ventricles
–semilunar valves close as blood attempts to back up into the ventricles from the vessels
–AV valves open
–blood flows from atria to ventricles
–
•Ventricles contract
–AV valves close as blood attempts to back up into the atria
–pressure rises inside of the ventricles
–semilunar valves open and blood flows into great vessels

- Coronary Artery Disease
- •Heart muscle receiving insufficient blood supply
- –narrowing of vessels---atherosclerosis, artery spasm or clot
- –atherosclerosis--smooth muscle & fatty deposits in walls of arteries
- •Treatment
- –drugs, bypass graft, angioplasty, stent

Cardio dynamics
•Includes both contraction and relaxation
•Phases of the Cardiac Cycle
•Within any one chamber
•Systole (contraction)
•Diastole (relaxation)





–S_1
- Loud sounds
- Produced by AV valves closing

–S_2
- Loud sounds
- Produced by semilunar valves closing

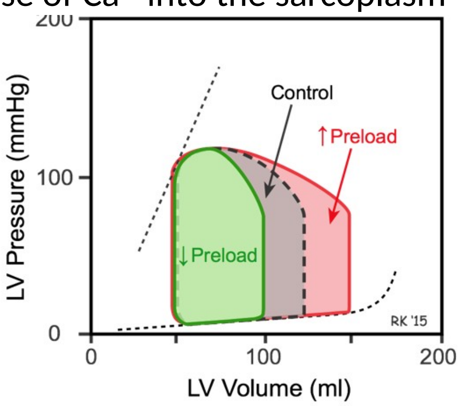
Cardiac Output

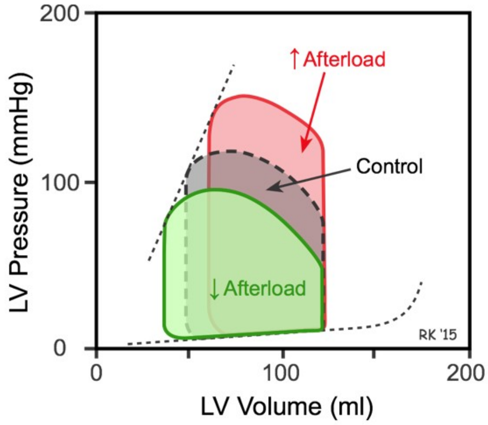
- CO is the amount of blood pumped by each ventricle in one minute
- CO is the product of heart rate (HR) and stroke volume (SV) CO = HR x SV

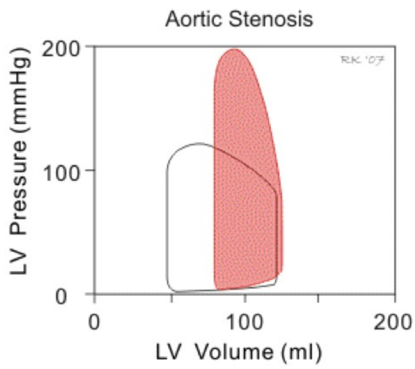
(ml/min)
•HR is the number of heart beats per minute (beats/min)
•SV is the amount of blood pumped out by a ventricle with each beat (ml/beat)
•SV = end diastolic volume (EDV) minus end systolic volume (ESV)
SV = EDV - ESV
•EDV = amount of blood collected in a ventricle during diastole
•ESV = amount of blood remaining in a ventricle after contraction

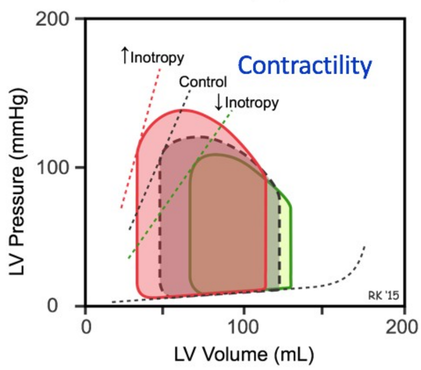
Contractility

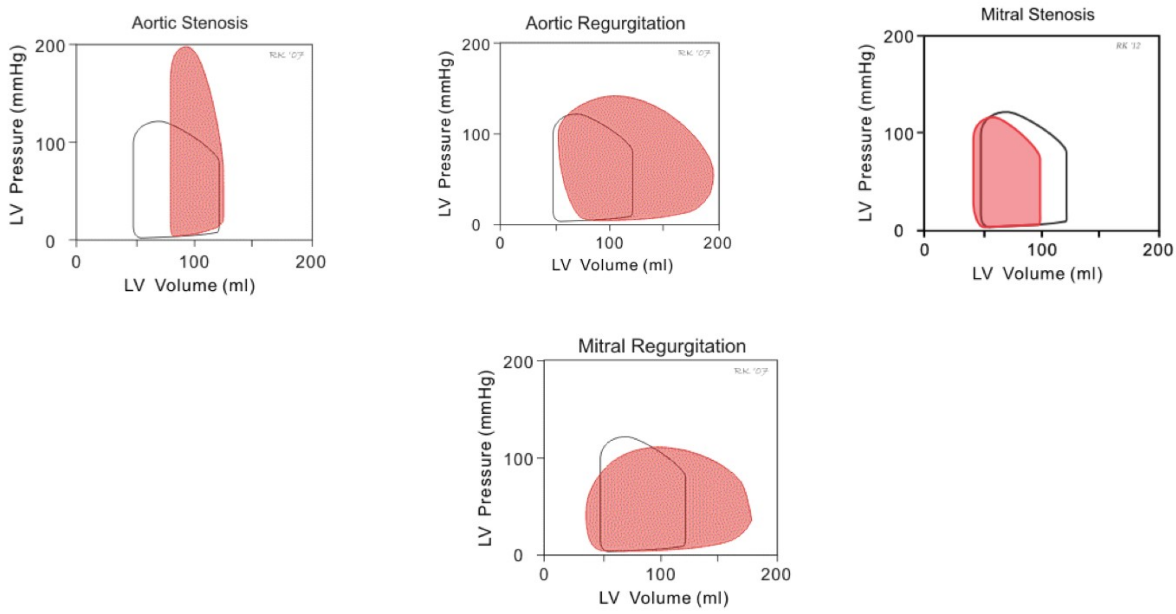
•Positive inotropic agents increase contractility
•hypercalcemia can cause strong, prolonged contractions and even cardiac arrest in systole
•catecholamine’s increase calcium levels
•glucagon stimulates cAMP production
•digitalis raises intracellular calcium levels and contraction strength
•Negative inotropic agents reduce contractility
•hypocalcemia can cause weak, irregular heartbeat and cardiac arrest in diastole
•hyperkalemia reduces strength of myocardial action potentials and the release of Ca^{2+} into the sarcoplasm







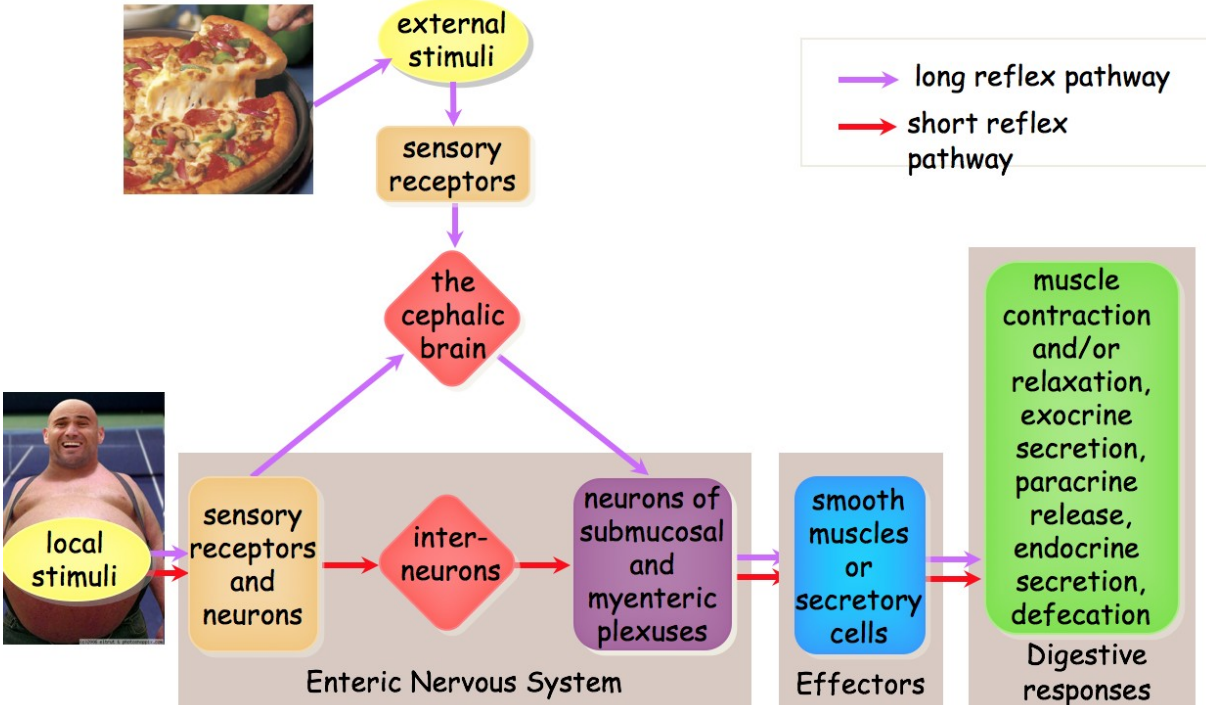




Digestion

•Five stages of digestion
–ingestion - selective intake of food
–digestion – mechanical and chemical breakdown of food into a form usable by the body
–absorption - uptake of nutrient molecules into the epithelial cells of the digestive tract and then into the blood and lymph
–compaction - absorbing water and consolidating the indigestible residue into feces
–defecation - elimination of feces
•Composed of two networks of neurons
–Submucosal (Meissner) plexus – in submucosa
•controls glandular secretion of mucosa
•controls movements of muscular is mucosae (thin layer of smooth muscle) dislodges food particles that have adhered to the mucosa
–Myenteric (Auerbach) plexus – parasympathetic ganglia and nerve fibers between the two layers of the muscularis externa
•controls peristalsis and other contractions of muscularis externa

Regulation of GI Function
Long & Short Reflexes



•Hormones

–gastrin (stimulates secretion of HCl) by the parietal cells of the stomach and aids in gastric motility)

–Secretin - controls the environment in the duodenum by regulating secretions of the stomach and pancreas. Its effect is to regulate the pH of the duodenal contents via inhibiting gastric acid secretion by the parietal cells of the stomach, and by stimulating bicarbonate production by the pancreas. Produced in the S cells of the duodenum, which are located in the intestinal glands

•Paracrine secretions

–chemical messengers that diffuse through the tissue fluids to stimulate nearby target cells

–Histamine stimulates HCl secretion

–Prostaglandins inhibit gastric secretions

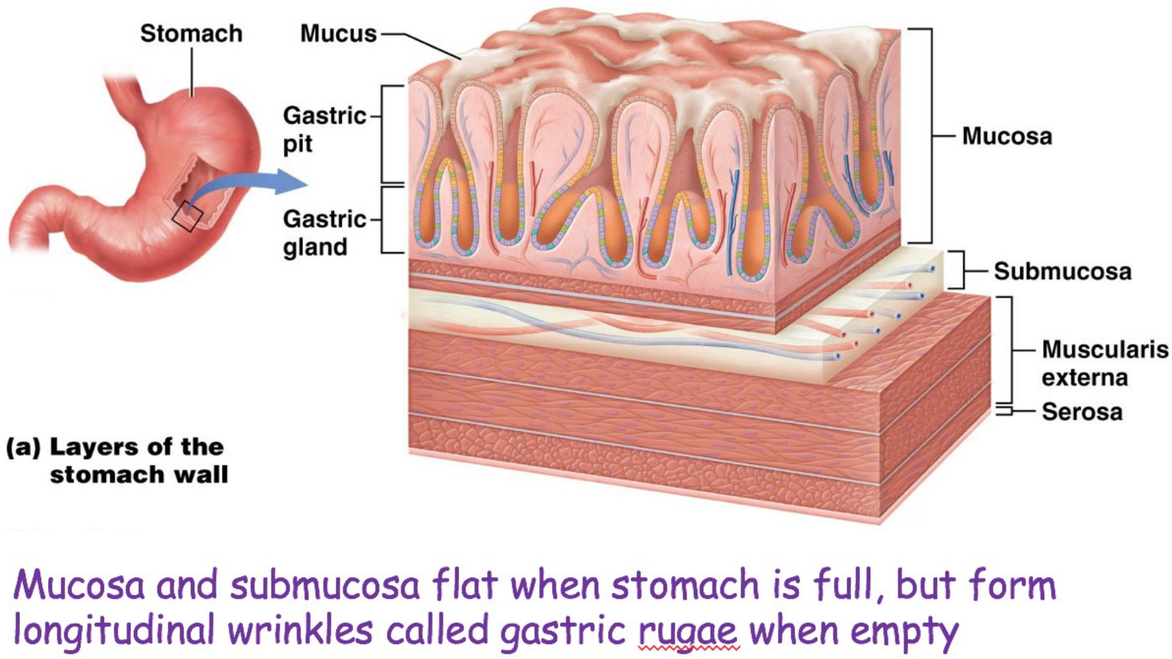
•Major Functions of the Stomach

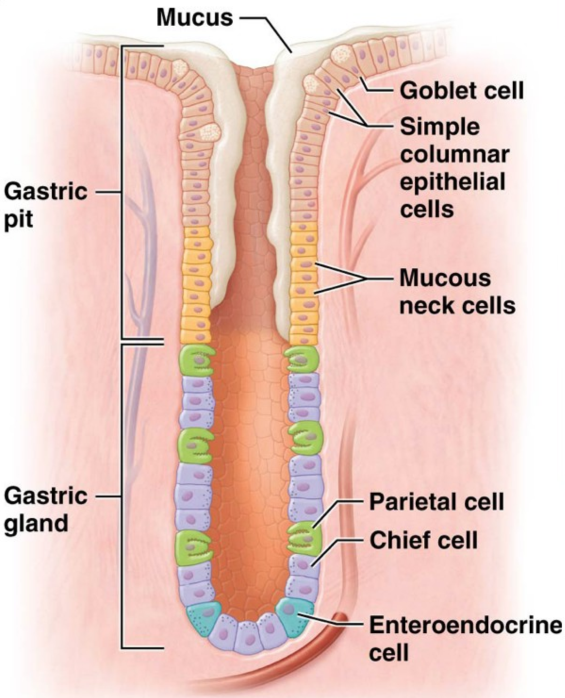
–Forms HCl which contributes to nonspecific disease resistance by destroying most ingested pathogens

–Disruption of chemical bonds in food material by hydrochloric acid (e.g. plant material and connective tissues) and enzymes (pepsin and lipase (digests 10 – 15% of dietary fats) which are activated by HCl

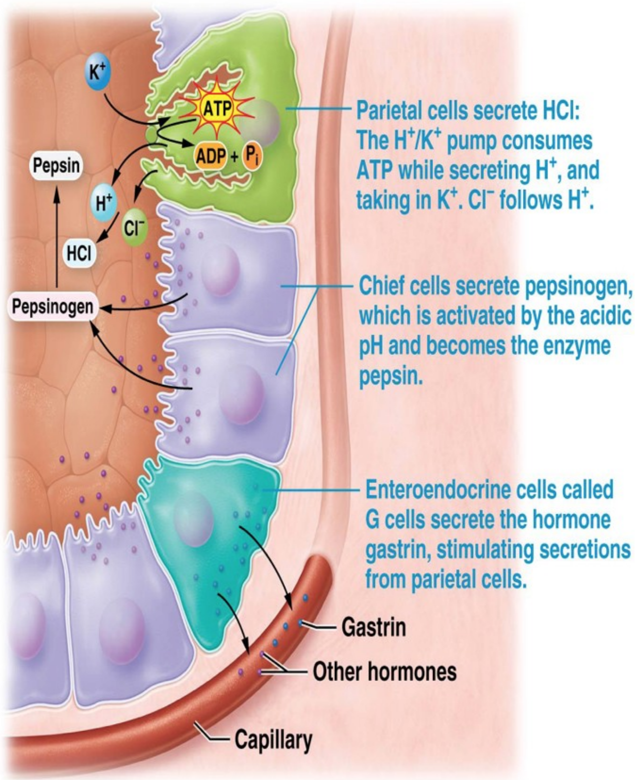
–Converts ingested ferric ions Fe^{3+} to ferrous iron Fe^{2+} which can be easily

absorbed and used for Haemoglobin synthesis
–Production of intrinsic factor, a glycoprotein required for absorption of vitamin B_{12} in small intestine
–Divided into four regions
•cardiac region (cardia) – small area within about 3 cm of the cardiac orifice
•fundic region (fundus) – dome-shaped portion superior to esophageal attachment
•body (corpus) – makes up the greatest part of the stomach
•pyloric region – narrower pouch at the inferior end
–subdivided into the funnel-like antrum
–and narrower pyloric canal that terminates at pylorus
–pylorus – narrow passage to duodenum





(b) Section through a gastric pit and gastric gland



(c) Functions of gastric gland cells

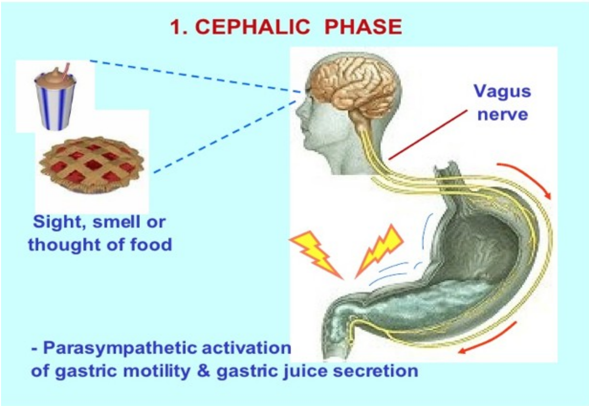
•Mucous cells – secrete mucus
–predominate in cardiac and pyloric glands
–in gastric glands, called mucous neck cells since they are concentrated at the neck of the gland
•Regenerative (stem) cells – found in the base of the pit and in the neck of the gland
–divide rapidly and produce a continual supply of new cells to replace cells that die
•Parietal cells – found mostly in the upper half of the gland
–secrete hydrochloric acid (HCl), intrinsic factor (essential for Vit B12 absorption)
•Chief cells – most numerous
–secrete gastric lipase and pepsinogen
–dominate lower half of gastric glands
–absent in pyloric and cardiac glands
•G cells – release gastrin which stimulates gastric glands to secrete HCl and enzymes. Stimulates intestinal motility and relaxes ileocecal valve (separating small intestine from large intestine)

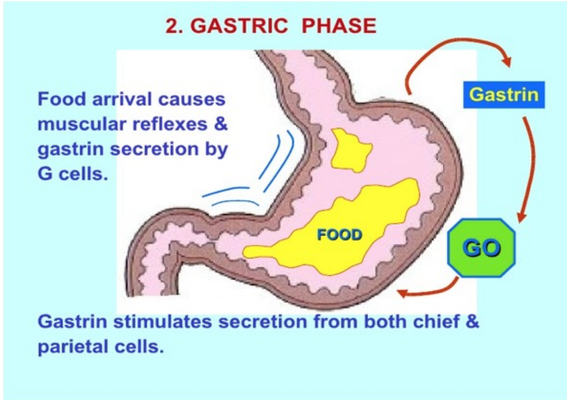
Hydrochloric acid

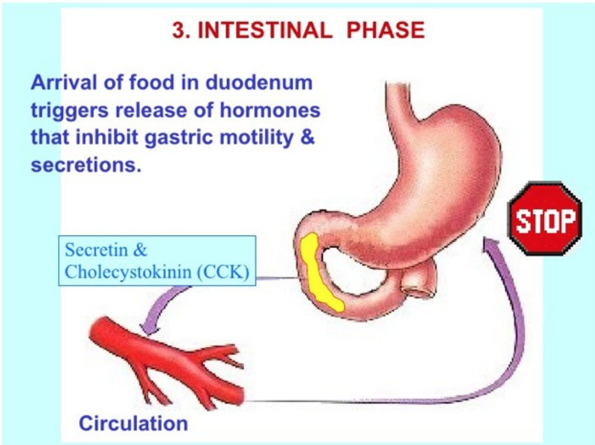
•Parietal cells produce HCl and contain carbonic anhydrase (CAH)

CAH

–$CO_2 + H_2O$ ® H_2CO_3 ® $HCO_3^- + H^+$
–H^+ is pumped into gastric gland lumen by H^+- K^+ ATPase pump
•antiporter uses ATP to pump H^+ out and K^+ in
–HCO_3^- exchanged for Cl^- (chloride shift) from blood plasma
•Cl^- (chloride ion) pumped into the lumen of gastric gland to join H^+ forming HCl
•Intrinsic factor – a glycoprotein secreted by parietal cells
•Essential to absorption of Vitamin B_{12} by the small intestine
–binds vitamin B_{12} and intestinal cells absorb this complex by receptor-mediated endocytosis
•Vitamin B_{12} is needed to synthesize RBCs/hemoglobin and involved in DNA synthesis in cells
–prevents pernicious anemia (production of large immature nonfunctioning RBCs)
•Secretion of intrinsic factor is the only indispensable function of the stomach
–digestion can continue if stomach is removed (gastrectomy), but B_{12} supplements will be needed
•Gastric activity is divided into three phases:
–cephalic phase – stomach being controlled by brain
–gastric phase – stomach controlling itself
–intestinal phase – stomach being controlled by small intestine







Function of the liver

•Carbohydrate metabolism (maintenance of blood glucose level: glycogenesis, glycogenolysis, gluconeogenesis). Between meals, hepatocytes break down stored glycogen and releases glucose into the blood
•Processing and excretion of bilirubin (breakdown product of Haemoglobin) into bile
•Synthesis of bile salts (for digestion and absorption of lipids)
•Storage (e.g. glycogen, iron, some vitamins)
•Phagocytosis (via Kupffer cells)
•Activation of Vitamin D taken in food
•Filters toxins from blood

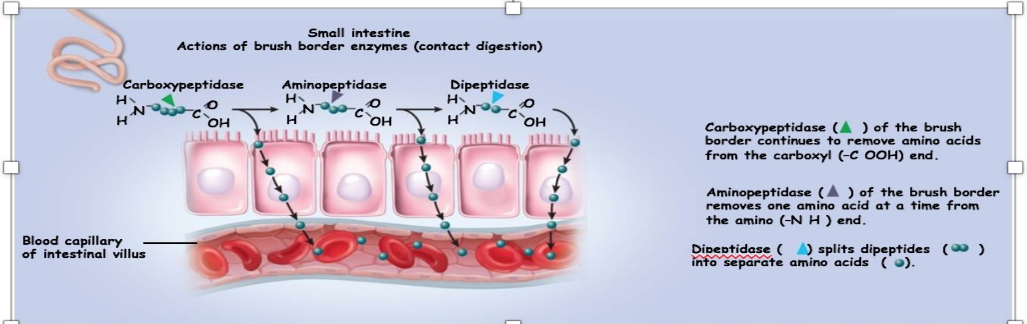
–Digestive enzymes

•pancreatic amylase à carbohydrate starch breakdown
•trypsin and chymotrypsin à protein breakdown
•pancreatic lipase à fat (triglyceride) breakdown
•deoxy ribonuclease and ribonuclease à digest DNA and RNA respectively
•Three stimuli are chiefly responsible for the release of pancreatic juice and bile

–Acetylcholine (ACh) - from vagus and enteric nerves

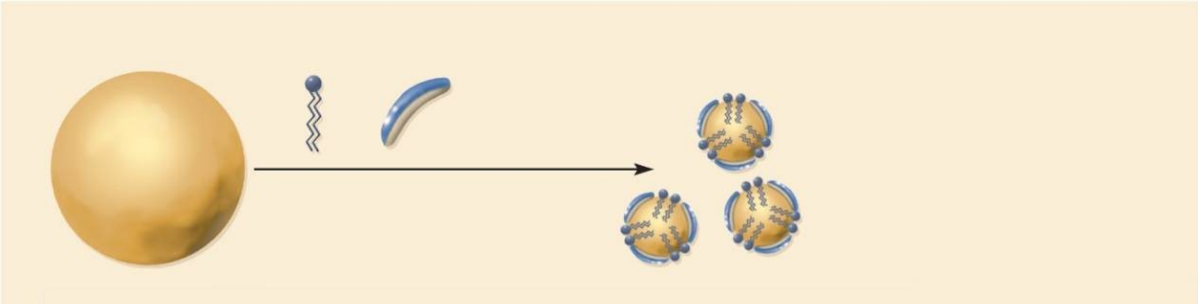
•stimulates acini to secrete their enzymes during the cephalic phase of gastric

control even before food is swallowed
–enzymes remain in acini and ducts until chyme enters the duodenum
–Cholecystokinin (CCK) - secreted by mucosa of duodenum in response to arrival of fats in small intestine
•stimulate pancreatic acini to secrete enzymes
•strongly stimulates gall bladder
•induces contractions of the gallbladder and relaxation of hepatopancreatic sphincter causing discharge of bile into the duodenum
–Secretin - released from duodenum in response to acidic chyme arriving from the stomach
•stimulates ducts of both liver and pancreas to secrete more sodium bicarbonate
•raising pH to level pancreatic and intestinal digestive enzymes require
•Decreases acid production in stomach
•Duodenum
–The segment of small intestine closest to stomach
–25 cm (10 in.) long
–"Mixing bowl" that receives **chyme** from stomach and digestive secretions from pancreas (trypsinogen, chymotrypsinogen, procarboxypeptidase, amylase, lipase, ribonuclease, deoxyribonuclease) and liver (**bile**)
–Functions of the duodenum – produces copious amounts of mucus
•To receive chyme from stomach
•To neutralize acids before they can damage the absorptive surfaces of the small intestine



Brush border enzymes finish task, producing free amino acids that are absorbed into intestinal epithelial cells

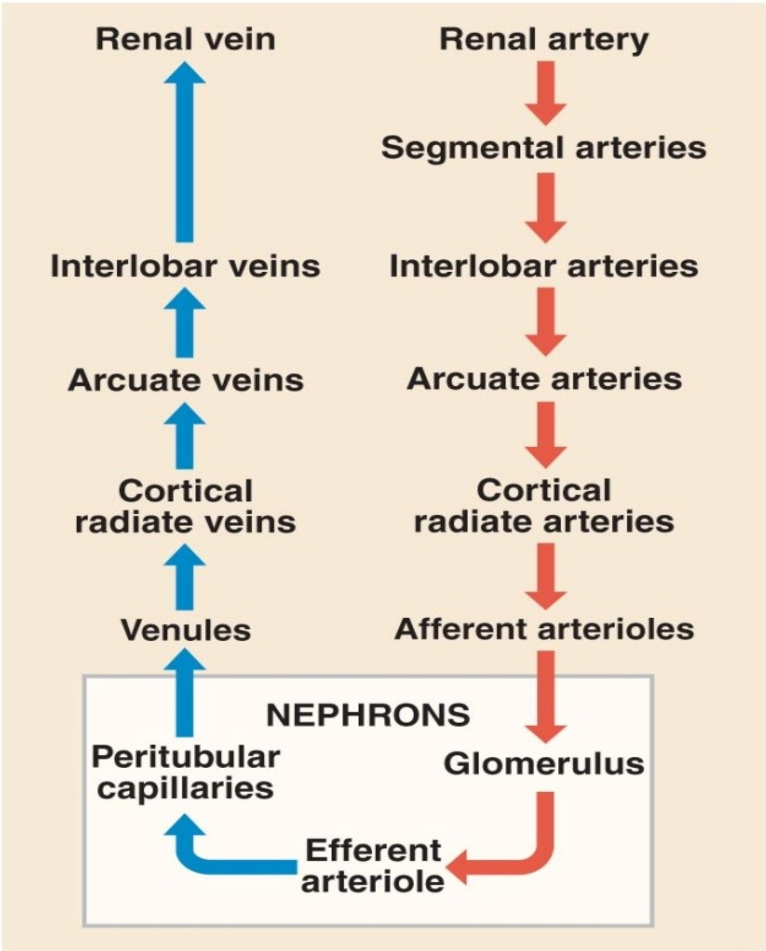
- sodium-dependent amino acid co-transporters move amino acids into epithelial cells
- facilitated diffusion moves amino acids out into blood stream
- monosaccharides: facilitated diffusion and active transport
- amino acids and electrolytes: secondary active transport
- monoglycerides, fatty acids: simple diffusion
- Water: osmosis via aquaporins and intercellular osmotic drag



Renal

Functions of the Kidneys

•Regulation of extracellular fluid volume and blood pressure
•Regulation of osmolarity
•Maintenance of ion balance
•Homeostatic regulation of pH
•Excretion of wastes
•Production of hormones
•Conserve nutrients
•Secrete erythropoietin – regulates RBC synthesis



(c)

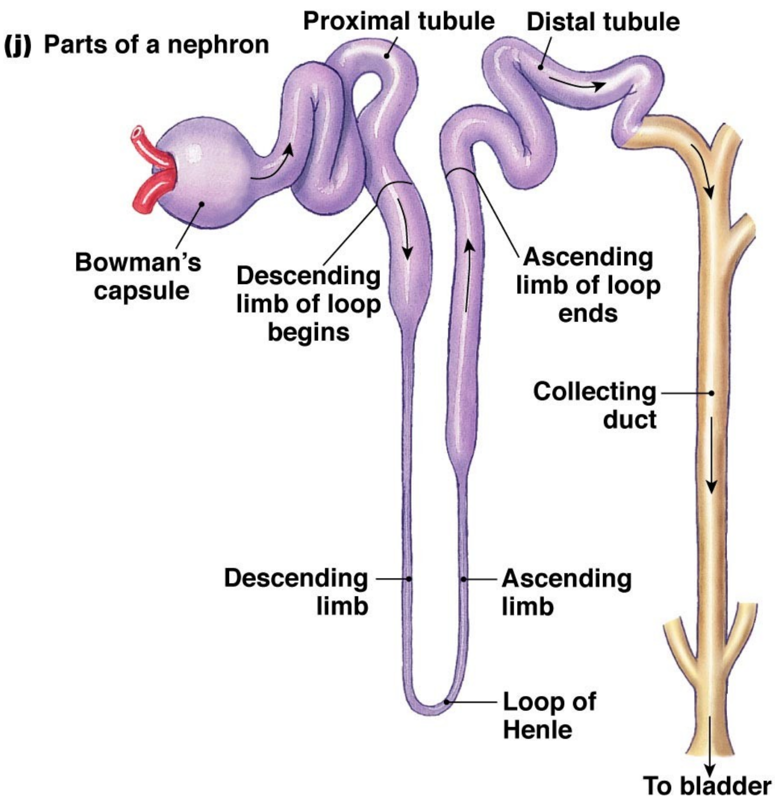
Nephron

Cortical nephrons do not participate in producing a urine more concentrated than the body fluid. However, are involved in glomerular filtration and tubular reabsorption plus excretion of some substances. Juxta-Medullary nephrons are involved in producing concentrated urine

- Cortical nephrons
- 80 - 85% of all nephrons
- Short nephron loops
- Efferent arterioles branch into peritubular capillaries around PCT and DCT
- Juxtamedullary nephrons
- 15 - 20% of all nephrons
- Very long nephron loops, maintain salinity gradient in the medulla and helps conserve water
- Efferent arterioles branch into vasa recta around long nephron loop

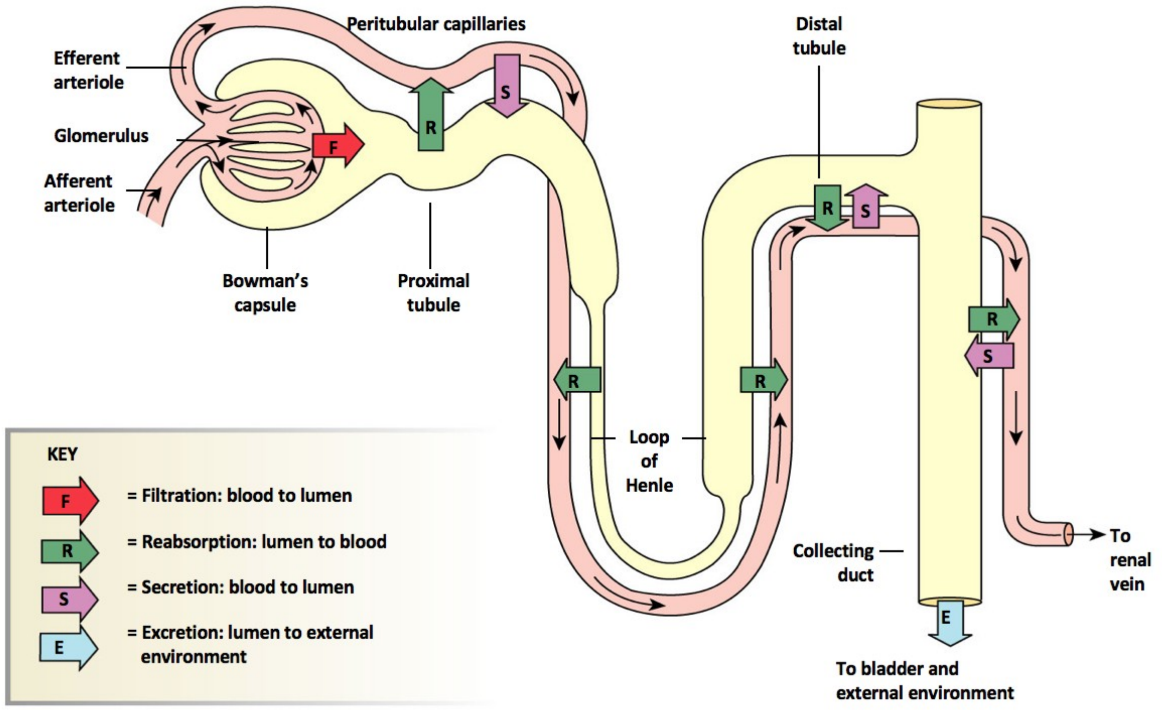
Structure of nephron

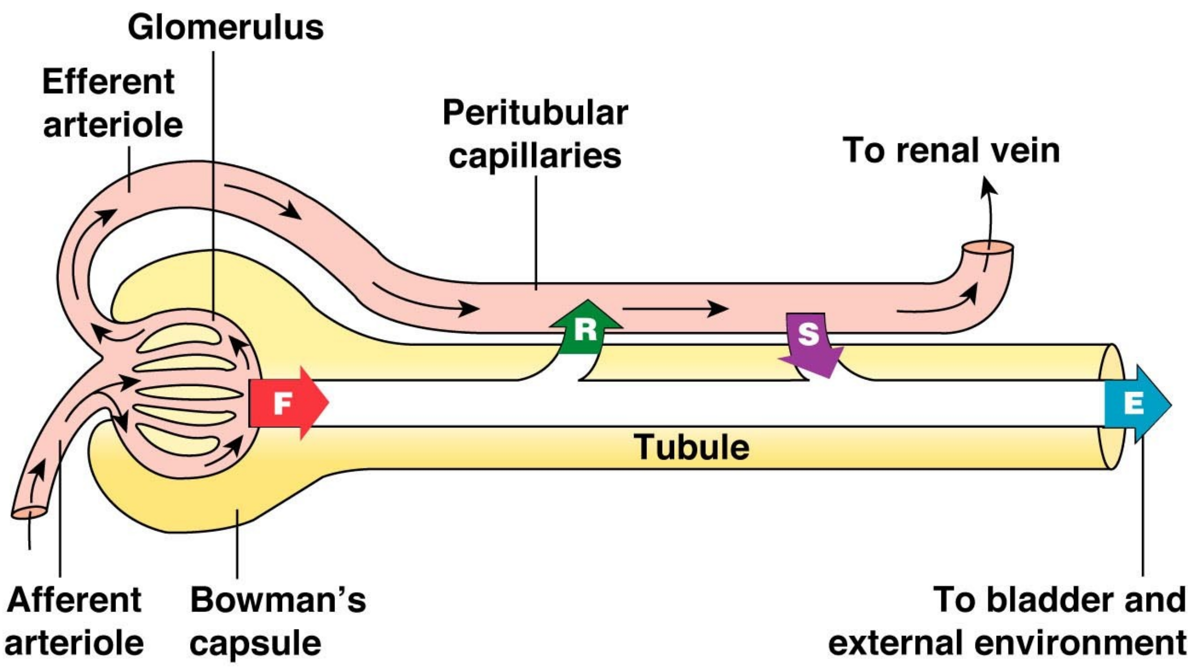
- Glomerular filtration – from glomerulus to Bowman's capsule
- Reabsorption – from tubules to peritubular capillaries
- Secretion – from peritubular capillaries to tubules
- Excretion – from tubules out of body



Kidney Function

Filtration, reabsorption, secretion, and excretion





Amount filtered	−	amount reabsorbed	+	amount secreted	=	Amount of solute excreted
F		R		S		E

Glomerular filtration rate (GFR) is a test used to check how well the kidneys are working. Specifically, it estimates how much blood passes through the glomeruli each minute. Glomeruli are the tiny filters in the kidneys that filter waste from the blood.

•Myogenic response – intrinsic ability of vascular smooth muscle to respond to pressure changes

–Similar to autoregulation in other systemic arterioles

GRF regulation

•Tubuloglomerular feedback – is a paracrine signaling mechanism through which changes in fluid flow or fluid composition through the loop of Henle influence GFR

•Glomerulus receives feedback on the status of downstream tubular fluid and adjusts filtration to regulate composition of fluid and stabilize GFR

•Three types of cells involved in this process: macula densa cells, juxtaglomerular cells and mesangial cells

Glomerular Filtration

•Autoregulation of the GFR

–Reduced blood flow or glomerular blood pressure triggers

•Dilation of afferent arteriole

•Dilation of glomerular capillaries

•Constriction of efferent arterioles

–Rise in renal blood pressure

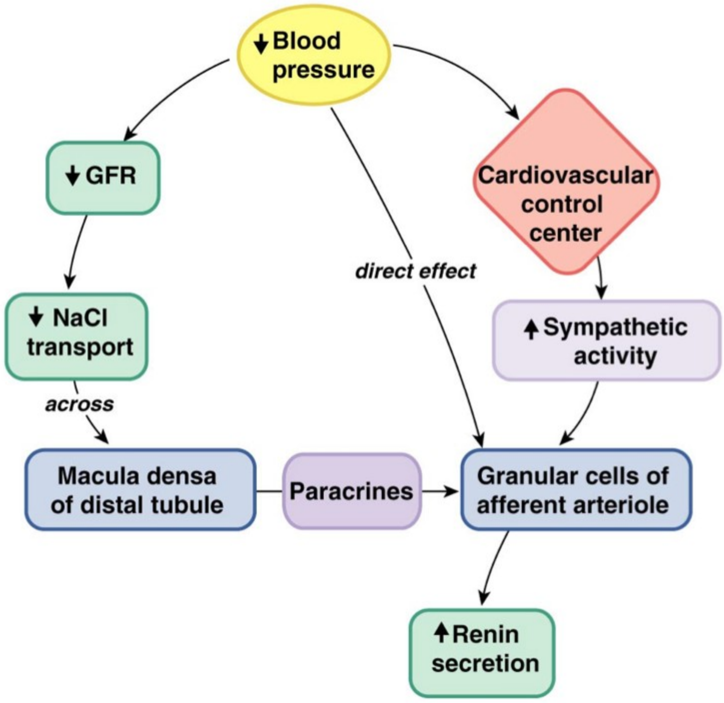
•Stretches walls of afferent arterioles

•Causes smooth muscle cells to contract

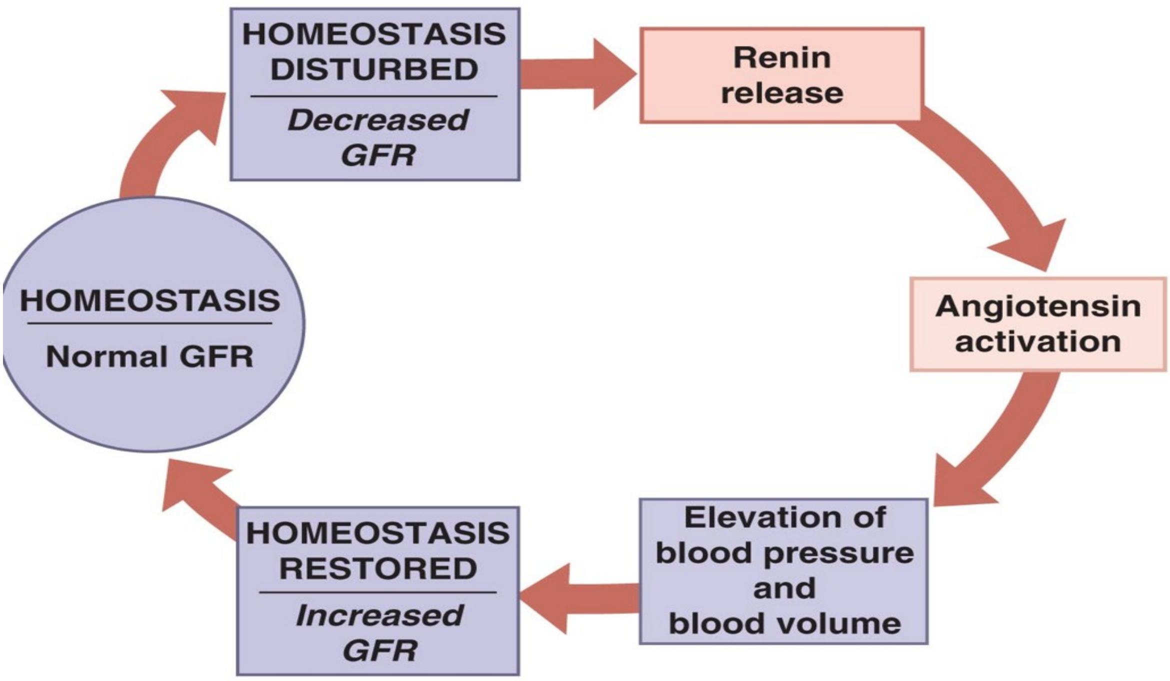
•Constricts afferent arterioles

•Decreases glomerular blood flow

Decreased blood pressure stimulates renin secretion



Response to a Reduction in GFR



(a)

Natriuretic Peptides
•Are released by the heart in response to stretching walls due to increased blood volume or pressure
•Atrial natriuretic peptide (ANP) is released by atria
•Brain natriuretic peptide (BNP) is released by ventricles
Urine Formation: Tubular Reabsorption and Secretion
•Conversion of glomerular filtrate to urine involves the removal and addition of chemicals by tubular reabsorption and secretion
–occurs through PCT to DCT
–tubular fluid is modified
•Steps involved include:
–tubular reabsorption
–tubular secretion
–water conservation
•Reabsorption and Secretion at the PCT
–PCT cells normally reabsorb 60–70% of filtrate produced in renal corpuscle
•Proximal convoluted tubule Na^+ transporters promote reabsorption of 100% of most organic solutes, such as glucose and amino acids; 80-90% of bicarbonate ions; 65% of water, Na^+, and K^+; 50% of Cl^-; and a variable amount of Ca^{+2}, Mg^{+2}, and HPO_4^{-2}
Uptake by the peritubular capillaries
•Three factors promote osmosis into the capillaries
–accumulation of reabsorbed fluid around the basolateral sides of epithelial cell creates high interstitial fluid pressure that drives water into the capillaries
–narrowness of efferent arterioles lowers blood hydrostatic pressure in peritubular capillaries so there is less resistance to absorption
–proteins remain in blood after filtration, which elevates colloid osmotic pressure
•high COP and low BHP in the capillaries and high hydrostatic pressure in the tissue fluid, the balance of forces in the peritubular capillaries favors absorption
Tubular Secretion
•process in which the renal tubule extracts chemicals from the capillary blood and secretes them into tubular fluid
–waste removal
•urea, uric acid, bile acids, ammonia, catecholamines, prostaglandins and a little creatinine are secreted into the tubule
•secretion of uric acid compensates for its reabsorption earlier in PCT
•clears blood of pollutants, morphine, penicillin, aspirin, and other drugs
–explains why need to take prescriptions 3 to 4 times/day to keep pace with

the rate of clearance
–acid-base balance
•secretion of hydrogen and bicarbonate ions help regulate the pH of the body fluids

Tubular Reabsorption and Secretion

•PCT reabsorbs 65% of glomerular filtrate and returns it to peritubular capillaries
–much reabsorption by osmosis & cotransport mechanisms linked to active transport of sodium
•Nephron loop reabsorbs another 25% of filtrate
•DCT reabsorbs Na^+, Cl^- and water under hormonal control, especially aldosterone, ADH and ANP
•The tubules also extract drugs, wastes, and some solutes from the blood and secrete them into the tubular fluid
•DCT completes the process of determining the chemical composition of urine
•Collecting duct conserves water

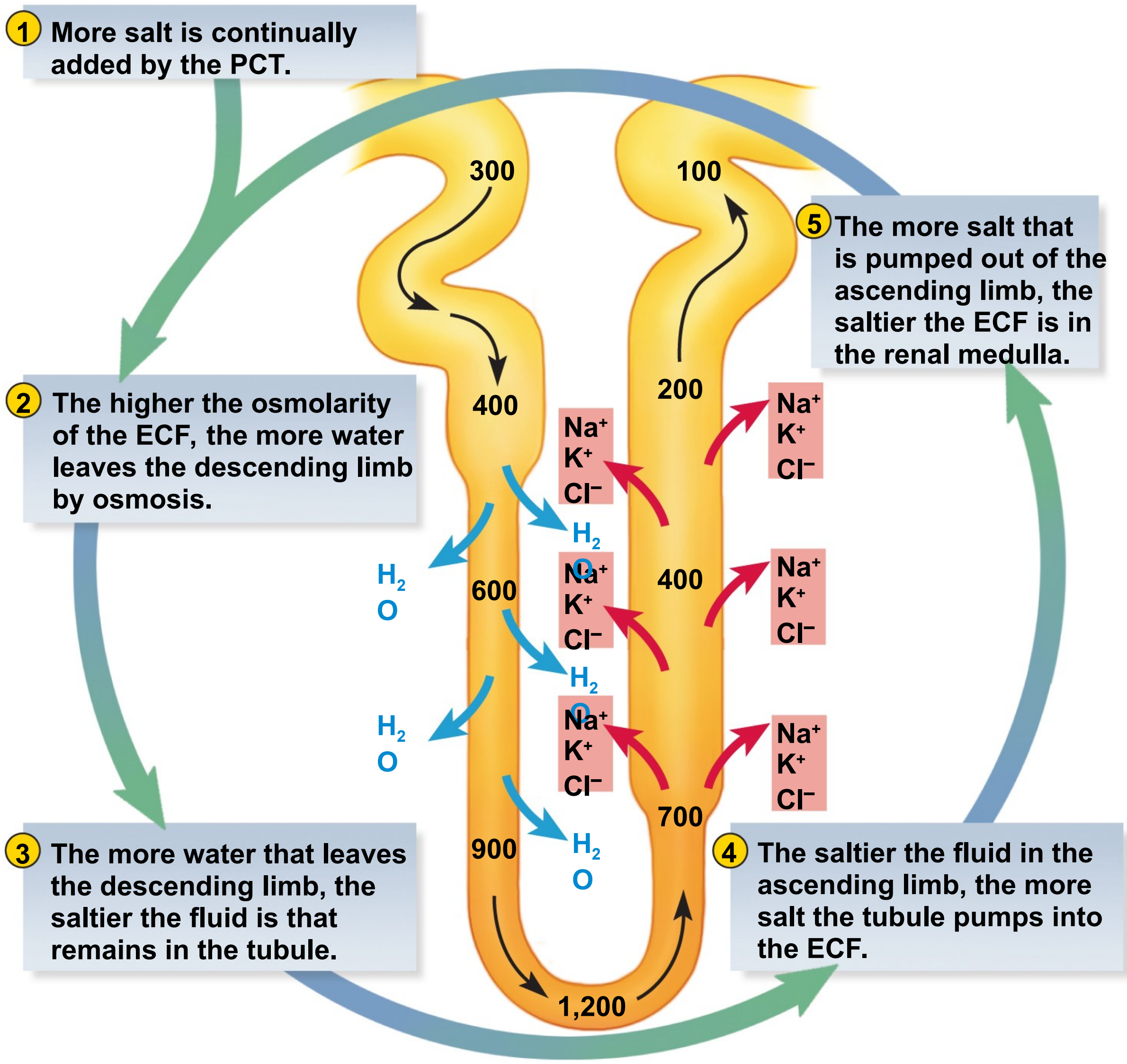
Nephrons

•Two types of Nephrons
–Cortical –80% of nephrons
•Short loops of Henle (produce dilute urine)
•Glomerulus in outer Cortex
•It keeps the solute load of body fluids constant at the osmotic concentration of blood plasma
–Juxtamedullary –20% of nephrons
•Long loops of Henle (essential for concentrating urine)
•Large Glomerulus (near medullary border), high GFR

Countercurrent Multiplier

•Fluid flowing downward in descending limb
–passes through environment of increasing osmolarity
–most of descending limb very permeable to water but impermeable to NaCl
–water passes from tubule into the ECF leaving salt behind
–concentrates tubular fluid to 1,200 mOsm/L at lower end of loop
•Fluid flowing upward in ascending limb:
–impermeable to water
–reabsorbs Na^+, K^+, and Cl^- by active transport pumps into ECF
–maintains high osmolarity of renal medulla
–tubular fluid becomes hypotonic – 100 mOsm/L at top of loop
•Recycling of urea: lower end of CD permeable to urea
–urea contributes to the osmolarity of deep medullary tissue
–continually cycled from collecting duct to the nephron loop and back

–urea remains concentrated in the collecting duct and some of it always diffuses out into the medulla adding to osmolarity



Species	Max Urine Osmolarity (mosmol/l)	Urine/Plasma Concentration ratio
Beaver	520	2
Pig	1100	4
Humans	1200	4
Cow	1400	5
Sheep	3500	11
Horse	2000	7
Dog	2500	8
Cat	3000	10
Kangaroo Rat	5500	18

•Reabsorption and Secretion at the DCT
–Composition and volume of tubular fluid
•Changes from capsular space to distal convoluted tubule:
–only 15–20% of initial filtrate volume reaches DCT
–concentrations of electrolytes and organic wastes in arriving tubular fluid no longer resemble blood plasma

Water Reabsorption in Distal Tubules and Collecting Ducts

–Water permeability dependent on water channels
•Aquaporin-3: present in basolateral membrane always
•Aquaporin-2: present in apical membrane only
when ADH present in blood

Regulation of ADH Release

–ADH stored in posterior pituitary hormone
–Primary stimulus for release
–Other stimuli
•Decrease blood pressure (baroreceptors)
•Decrease blood volume (volume receptors)

Reabsorption and Secretion

•Aldosterone – reabsorption of Na^+ ions
–Is a hormone produced by suprarenal cortex
–Controls ion pump and channels
–Stimulates synthesis and incorporation of Na^+ pumps and channels
•In plasma membranes along DCT and collecting duct
–Reduces Na^+ lost in urine

Respiration

Functions of Respiratory System

•O_2 and CO_2 exchange between blood and air

•Speech and other vocalizations

•Sense of smell

•Affects pH of body fluids by eliminating CO_2

•$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$

•Affects blood pressure by synthesis of vasoconstrictor, angiotensin II via angiotensin converting enzyme from lungs

Principal Organs of Respiratory System

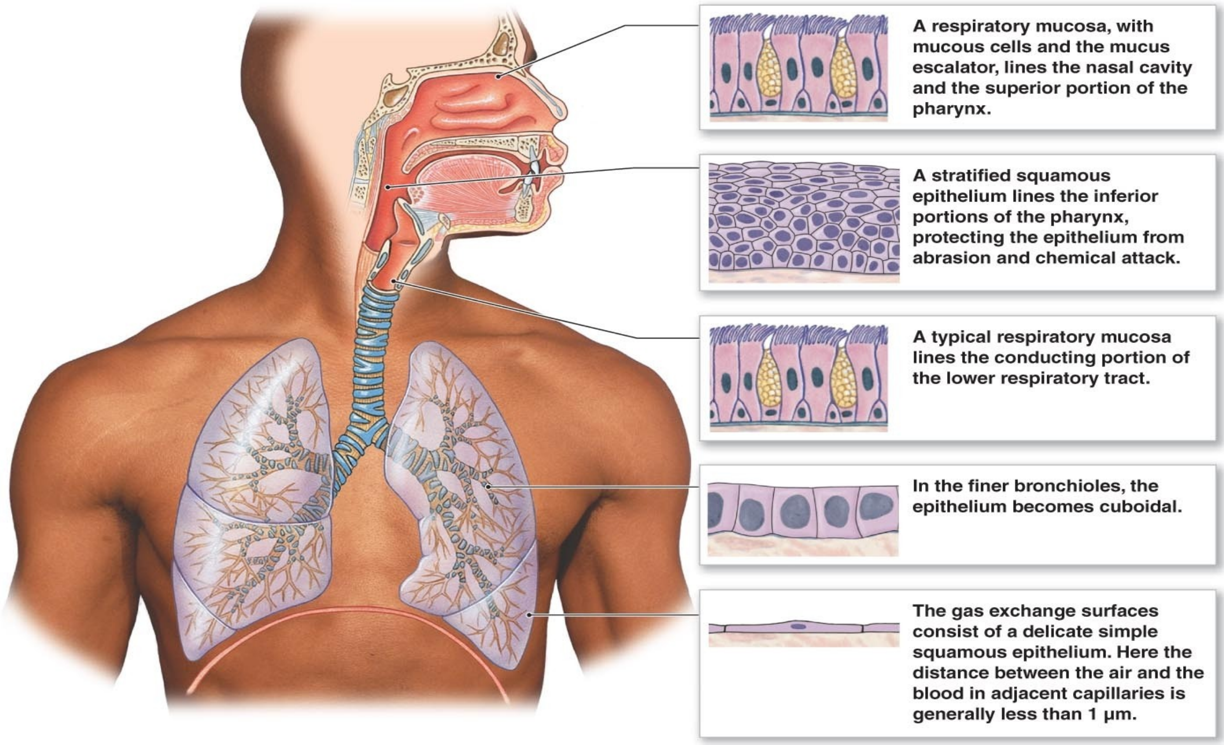
•Nose, pharynx, larynx, trachea, bronchi, bronchioles, alveoli

–incoming air stops in the alveoli

•millions of thin-walled, microscopic air sacs

•exchanges gases with the bloodstream through the alveolar wall, and then flows back out

The structure of the respiratory epithelium at different sites within the respiratory tract



Nasal Cavity

•Vestibule – beginning of nasal cavity – small dilated chamber just inside nostrils

–vibrissae – stiff guard hairs that block insects and debris from entering nose

•Occupied by three folds of tissue – nasal conchae – mucous membranes

–superior, middle, and inferior nasal conchae (turbinates)

•Functions of the nose

–warms, cleanses, and humidifies inhaled air

–detects odors in the airstream
–serves as a resonating chamber that amplifies the voice
Bronchioles
•Autonomic Control
–Regulates smooth muscle
•Controls diameter of bronchioles
•Controls airflow and resistance in lungs
•Bronchoconstriction
–Constricts bronchi
•Caused by:
–parasympathetic ANS activation
–histamine release (allergic reactions)
•Bronchodilation
–Dilation of bronchial airways
–Caused by sympathetic ANS activation
–Reduces resistance
Alveoli
•cells of the alveolus (pneumocytes)
–Squamous (type I) alveolar cells
•thin, broad cells that are involved with gas exchange and allow for rapid gas diffusion between alveolus and bloodstream
•cover 95% of alveolus surface area
–Great (type II) alveolar cells - pneumocytes type II (septal cells)
•round to cuboidal cells that cover the remaining 5% of alveolar surface
•repair the alveolar epithelium when the squamous (type I) cells are damaged
•secrete pulmonary surfactant
–a mixture of phospholipids and proteins that coats the alveoli and prevents them from collapsing when we exhale
–Alveolar macrophages (dust cells)
•most numerous of all cells in the lung
•wander the lumen and the connective tissue between alveoli
•keep alveoli free from debris by phagocytizing dust particles
Pleura
•The **pleura** is a serous membrane which folds back onto itself to form a two-layered, membrane structure
•Functions of pleurae and pleural fluid
–reduce friction
–create pressure gradient
•lower pressure than atmospheric pressure and assists lung inflation

Pulmonary Ventilation

•Respiratory airflow is governed by the same principles of flow, pressure, and resistance as blood flow

•F α DP / R equal to I = V/R

•Boyle's Law – at a constant temperature, the pressure of a given quantity of gas is inversely proportional to its volume

–if the lungs contain a quantity of a gas and the lung volume increases, their internal pressure falls

•if the pressure falls below atmospheric pressure the air moves into the lungs

Inspiration

•Charles's Law – the given quantity of a gas is directly proportional to its absolute temperature **V ~ T**

–on a cool day, 16°C air will increase its temperature by 21°C during inspiration

–inhaled air is warmed to 37°C by the time it reaches the alveoli

–inhaled volume of 500 mL will expand to 536 mL and this thermal expansion will contribute to the inflation of the lungs

Resistance to Airflow

•Three factors influencing airway resistance

–Diameter of the bronchioles

•Sympathetic stimulation leads to bronchodilation and Parasympathetic stimulation leads to bronchoconstriction

–Pulmonary compliance

•reduced by degenerative lung diseases in which the lungs are stiffened by scar tissue and increased in emphysema due to poor elastic recoil

–Surface tension of the alveoli and distal bronchioles

•surfactant – reduces surface tension of water

•infant respiratory distress syndrome (IRDS) – premature babies

Respiratory Rates and Volumes

–Respiratory system adapts to changing oxygen demands by varying

•The number of breaths per minute (**respiratory rate**)

•The volume of air moved per breath (**tidal volume**)

•The Respiratory Minute Volume

–Amount of air moved per minute and is calculated by:

Respiratory rate x Tidal volume

–Measures pulmonary ventilation

•Alveolar Ventilation

–Amount of air reaching alveoli each minute and calculated by:

Respiratory rate x (Tidal Volume - Anatomical Dead Space)

•Alveolar Ventilation

–Amount of air reaching alveoli each minute

–Calculated as:

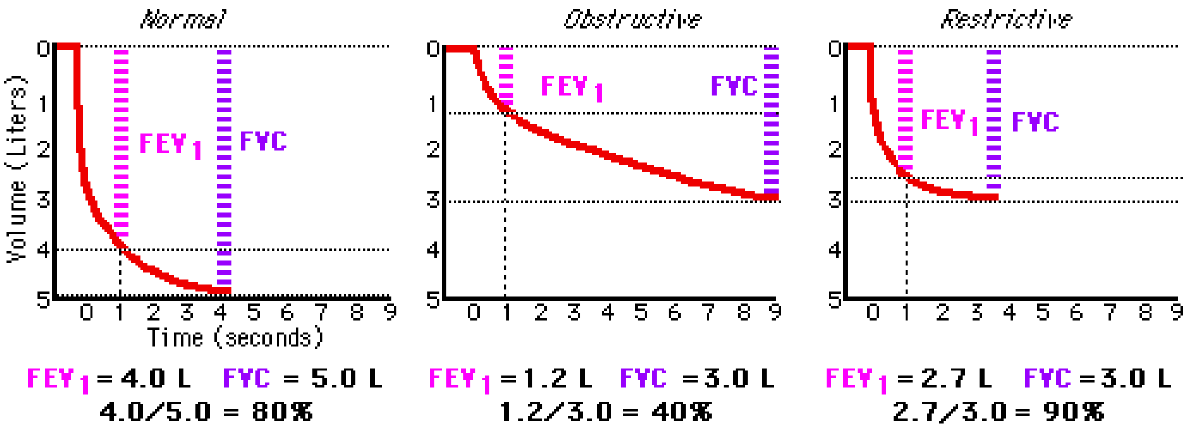
(Tidal Volume - Anatomical Dead Space) **x** Respiratory rate

The calculations of respiratory minute volume and alveolar ventilation if respiratory rate increases to 20 breaths per minute and tidal volume decreases to 300 mL

$$\begin{aligned} V_E &= f \times V_T \\ &= 20 \times 300 \text{ mL per minute} \\ &= 6.0 \text{ liters per minute} \end{aligned}$$

$$\begin{aligned} V_A &= f \times (V_T - V_D) \\ &= 20 \times (300 \text{ mL} - 150 \text{ mL}) \text{ per minute} \\ &= 3.0 \text{ liters per minute} \end{aligned}$$

FEV1/FVC



•Forced Vital capacity (FVC) is the volume of air that can forcibly be blown out after full inspiration, measured in litres

•Forced expiratory volume (FEV_1)

- percentage of the vital capacity that can be exhaled in one second
- healthy adult reading is 75 - 85% in 1 sec

Gas Exchange and Transport

•Dalton's Law – the total atmospheric pressure is the sum of the contributions of the individual gases

–partial pressure – the separate contribution of each gas in a mixture

–at sea level 1 atm. of pressure = 760 mmHg

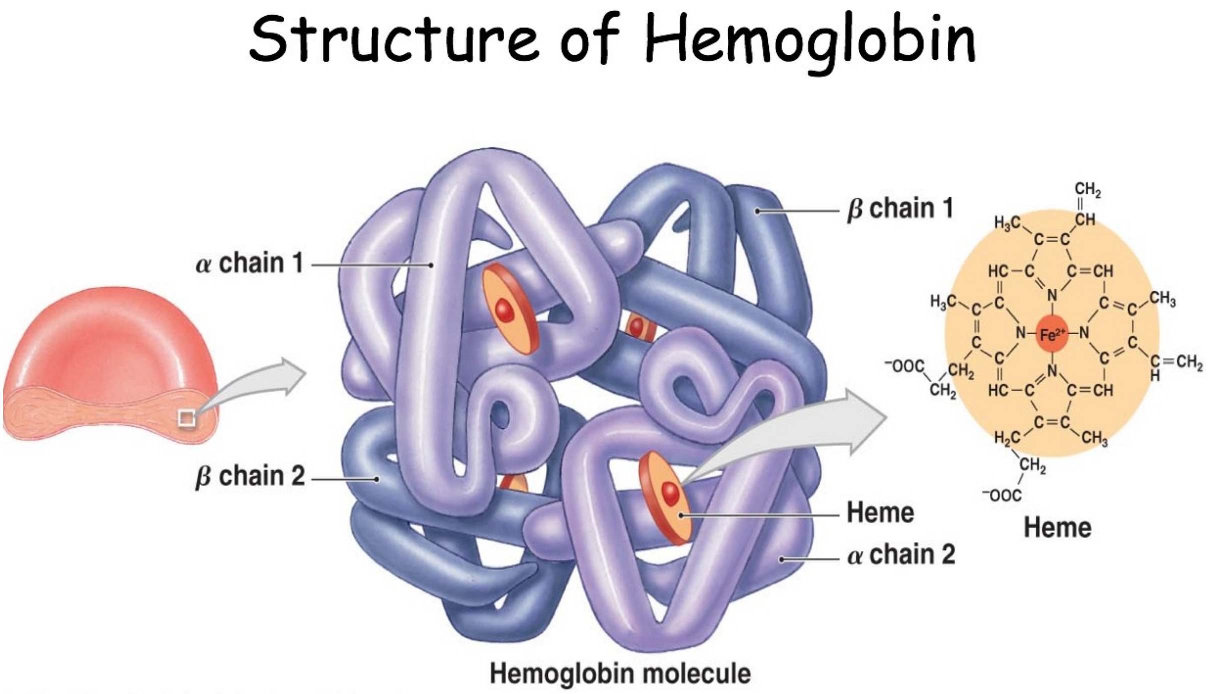
–nitrogen constitutes 78.6% of the atmosphere, thus

•PN_2 = 78.6% x 760 mm Hg = 597 mm Hg

•PO_2 = 20.9% x 760 mm Hg = 159 mm Hg

•PH_2O = 0.5% x 760 mm Hg = 3.7 mm Hg

•PCO_2 = 0.04% x 760 mm Hg = 0.3 mm Hg
•$PN_2 + PO_2 + PH_2O + PCO_2$ = 760 mmHg
Gas Transport
•Oxygen transport
–98.5% bound to Hemoglobin
– 1.5% dissolved in plasma
–four protein (globin) portions
•each with a heme group which binds one O_2 to the ferrous ion (Fe^{2+})
•Carbon dioxide transport
–75% as Bicarbonate ion
–20% bound to hemoglobin
–5% dissolved in plasma



•Partial pressure of oxygen (PaO2). This measures the pressure of oxygen dissolved in the blood and how well oxygen is able to move from the airspace of the lungs into the blood
•Partial pressure of carbon dioxide (PaCO2). This measures how much carbon dioxide is dissolved in the blood and how well carbon dioxide is able to move out of the body
Changes in oxygen-hemoglobin saturation curve
•Factors affecting oxygen-hemoglobin saturation curve
–pCO2
- pCO2 increase: saturation curve shifts to the right
- pCO2 decrease: saturation curve shifts to the left

–pH
•pH decrease: saturation curve shifts to the right
•pH increase: saturation curve shifts to the left
Bohr Effect refers to the observation that increases in the carbon dioxide partial pressure of blood or decreases in blood pH result in a lower affinity of haemoglobin for oxygen. It allows for enhanced unloading of oxygen in metabolically active peripheral tissues such as exercising skeletal muscle.

Carbon Dioxide Transport

•Carbon dioxide transported in three forms
–carbonic acid, carbamino compounds, and dissolved in plasma
•75% of CO_2 is hydrated to form carbonic acid
–$CO^2 + H_2O \rightarrow H_2CO_3 \rightarrow HCO3^- + H^+$ - this reaction is reversible and catalysed by carbonic anhydrase (enzyme)
•20% binds to the amino groups of plasma proteins and hemoglobin to form carbamino compounds – chiefly carbaminohemoglobin ($HbCO_2$)

Systemic Gas Exchange

•CO_2 loading
–CO_2 diffuses into the blood
–carbonic anhydrase in RBC catalyzes
•$CO_2 + H_2O$ ® H_2CO_3® $HCO_3^- + H^+$
–chloride shift
•keeps reaction proceeding, exchanges HCO_3^- for Cl^-
•H^+ binds to hemoglobin
•O_2 unloading
–H^+ binding to HbO_2 reduces its affinity for O_2
•tends to make hemoglobin release oxygen
•HbO_2 arrives at systemic capillaries 98% saturated, leaves 75% saturated –
–venous reserve – oxygen remaining in the blood after it passes through the capillary beds

PONS

Pneumotaxic Centre

Decrease in pneumotaxic output slows respiratory rate but increases the depth of respiration

Inhibits Apneustic centre and promotes passive exhalation

PONS

Apneustic Centre

Promotes inhalation by stimulating DRG

Medulla Oblongata

Inspiratory Centre - Dorsal Respiratory Group

Ventral Respiratory Group contain both inspiratory and expiratory centres which are stimulated when ventilation demands increase e.g. exercise

Accessory inspiratory and expiratory muscles activated

Neurons innervate external intercostal muscles and diaphragm

The effects of changes in the partial pressure of carbon dioxide on the respiratory rate