* **Digestive System Part 2**
* Accessory digestive organs
  + Salivary glands
  + Liver
  + Gallbladder
  + Pancreas
* Liver
  + Functions: performed by hepatocyte
    - Process nutrients in blood
      * Ex: glucose (in blood plasma) <-> glycogen (stored in hepatocytes)
    - Makes blood proteins
    - Stores fat-soluble vitamins
    - Metabolizes poisons and drugs
    - Produces bile = cholesterol, bile salts, bilirubin
      * Excrete bilirubin (from broken down red blood cells)
      * Emulsify fat: keep fats in smaller globs so enzymes can digest them better -> improves fat digestion
  + Gross Anatomy:
    - Vessels connect on visceral (posterior) side
    - Hepatic veins: carry blood away, back to heart
    - Porta hepatis: region where other vessels connect to liver
      * Vessels at porta hepatis:
        + Common hepatic duct: carries bile (out of liver)
        + Hepatic arteries: blood with oxygen (into liver)
        + Hepatic portal vein: unique! (into liver)
  + Blood and lymph flow focusing on liver:
    - Sugars and amino acids:
      * Absorbed by blood capillaries
      * Go directly to liver via hepatic portal vein
    - Lipids:
      * Absorbed by lacteals of lymphatic system
      * Bypass liver
      * Enter blood of veins near heart
  + Microscopic anatomy:
    - Liver lobules:
      * Functional units = hexagonal unit with plates of liver cells (hepatocytes)
      * Each lobule has:
        + Central vein: delivers blood to hepatic veins

How blood gets to central vein:

Liver sinusoids: leaky capillaries

Fluid (plasma) flows onto hepatocytes by way of fenestrations (holes)

Also contains hepatic macrophages (Kupffer cells)

* + - * + Portal triad: group of 3 vessels

Contains:

Portal arteriole: branch of hepatic artery

Supplies O2 to liver cells

Portal venule: branch of hepatic portal vein

Brings nutrients from digestive tract for storage and processing

Bile duct:

Carries bile (from hepatocytes) out of liver

How bile gets to bile duct:

Bile canaliculi: between hepatocytes

* + Pathology:
    - Jaundice: yellowing of skin and mucosae
      * Due to excess bilirubin throughout body tissues
      * Due to liver failure
        + Ex: due to hepatitis = inflammation of liver
  + Summary of pathway of blood flow:
    - From intestines, etc.: hepatic portal vein -> portal venule -> sinusoid -> central vein -> hepatic vein
    - From heart: hepatic artery -> portal arteriole -> sinusoid -> central vein -> hepatic vein
* Gallbladder
  + General features:
    - On visceral (posterior) surface of liver
    - Stores and concentrates bile
    - Releases bile to duodenum when stimulated
    - Not essential
  + Pathway of bile flow:
    - Accumulation of bile between meals: liver -> bile ducts -> common hepatic duct -> common bile duct (closed sphincter so backs up) -> cystic duct -> gallbladder
    - Release of stored bile from gallbladder (to emulsify fats – aid digestion): gallbladder -> cystic duct -> common bile duct -> duodenum
  + Pathology:
    - Gallstones: mainly cholesterol crystals
      * If gallbladder is removed, common bile duct takes over storage function
* Pancreas
  + Functions:
    - Exocrine secretions: released into lumen of duodenum
      * Acinar cells: secrete most of body’s digestive enzymes
      * Epithelium of small ducts: secrete bicarbonate to neutralize stomach acid
    - Endocrine secretions: released into blood
      * Pancreatic islet cells: secrete insulin and glucagon
        + Hormones controlling storage of glucose and its release into the blood

For example at the liver

* + Gross anatomy:
    - Located posterior to stomach
    - Pancreatic duct(s): empties into lumen of duodenum
* **Respiratory System**
* Function
  + Respiration: exchange of gases (oxygen and carbon dioxide) with the environment
    - Consists of 4 processes:
      * Ventilation: move air in/out of lungs (active process)
      * External respiration: gas diffuses between lungs and blood (passive process)
        + Two above processes are functions of respiratory system
      * Gas transport via blood (active process)
      * Internal respiration: gas diffuses between blood and cells (passive process)
        + Two above processes are functions of cardiovascular system
* Zones
  + Conducting zone: passageways for air, no diffusion
    - Ventilation: external nose through most tubes in lungs
  + Respiratory zone: the anatomical zone where oxygen diffuses into blood
    - External respiration
      * Pulmonary alveoli
      * Respiratory bronchioles
* Walls of conducting zone
  + Layers: mucosa, submucosa (some organs have other too)
    - Mucosa contains:
      * Epithelium:
        + Areas exposed to food: nonkeratinized stratified squamous
        + Most areas: pseudostratified ciliated columnar

Major function: removing debris

* + CT: lamina propria
  + Glands secrete mucus to trap debris:
    - Goblet cells (1 celled glands): in mucosal epithelium
    - Seromucous glands: in lamina propria and submucosa
* Organs of respiratory system
  + External nose:
    - External nares: nostrils (entrance/exit)
  + Nasal cavity:
    - Nasal septum separates left and right nasal cavities
    - Epithelium: pseudostratified ciliated columnar
    - Debris are swept posteriorly to be swallowed
    - Highly vascularized lamina propria: warms and moistens the inspired air
  + Paranasal sinuses: paired air spaces in the bones of the skull
    - Connect to nasal cavities by drainage ducts
    - Warm and moisten the inspired air
    - Sinusitis: sinus infection
  + Pharynx: where respiratory/digestive tracts intersect
    - Divisions of pharynx:
      * Nasopharynx: nasal cavity (pseudostratified ciliated columnar)
      * Oropharynx: oral cavity (stratified squamous)
      * Laryngopharynx: larynx and esophagus (stratified squamous)
    - During swallowing soft palate folds upward to seal of nasopharynx
  + Larynx:
    - Functions:
      * Gateway to the lungs
      * Speech (voicebox)
    - Structures: most are hyaline cartilage
      * Thyroid cartilage:
        + Laryngeal prominence: Adam’s apple (larger in males)
      * Cricoid cartilage: inferior to thyroid cartilage
      * Arytenoid cartilage: attached to back of cricoid cartilage (A like shape of cartilage)
      * Epiglottis: swallowing elevates the larynx -> epiglottis passively tilts down -> laryngeal inlet (opening) closes
        + Elastic cartilage
      * Vocal folds: true vocal cords
        + Vibrated by the air to produce sound
        + Rima glottides: opening between vocal folds
        + Glottis: rima glottides + vocal folds
        + Attached directly to thyroid cartilage (at anterior end) and arytenoid cartilages (at posterior end)

Open/close by moving arytenoid cartilages in transverse plane

* + - * + Control of pitch: cricoid cartilage moves in sagittal plane (around joint between cricoid and thyroid)

Carries arytenoid cartilages along

Increases tension in vocal folds -> higher pitch

* + - * Vestibular folds: false vocal cords
        + Superior to vocal folds
        + No direct role in most sound production
        + Important for holding breath against pressure in the thoracic cavity
      * Epithelium:
        + Superior larynx: occasional contact with food

Stratified squamous

* + - * + Inferior larynx (below vocal folds):

Pseudostratified ciliated columnar

* + Trachea:
    - Location: in mediastinum
    - Tissues:
      * Epithelium: pseudostratified cilated columnar
      * Rings of hyaline cartilage to prevent collapse
      * Smooth muscle
      * Elastic CT: for elastic recoil (more efficient ventilation)
      * NOTE: Same tissues continue through most of the conducting zone
  + Primary bronchi:
    - First part of the bronchial tree
    - The only bronchi outside the lungs
    - Location: in mediastinum
  + Lungs:
    - Contains:
      * Most of bronchial tree (except for primary bronchi): part of the conducting zone
      * Pulmonary alveoli: most of the respiratory zone
    - Pleurae: serous membranes surrounding the lungs (superficial to deep)
      * Parietal pleura (outer pleura)
      * Pleural cavity: space
        + Contains pleural fluid
        + Slight vacuum is important for breathing
      * Visceral pleura: inner pleura
    - Divisions of the lungs:
      * Lobes:
        + Left lung: 2 lobes
        + Right lung: 3 lobes
      * Bronchopulmonary segments (parts of lobes):
        + About 10 per lung
    - Bronchial tree:
      * Connects trachea to alveoli
      * Right and left primary (main) bronchi (outside lung)
      * Second lobar bronchi (1 per lobe)
      * Tertiary (segmental) bronchi (1 per bronchopulmonary segment)
      * Bronchioles (<1mm wide)
        + Terminal bronchioles: end of conducting zone
        + Respiratory bronchioles: start of respiratory zone (attached to alveoli)
      * Pathologies:
        + Asthma: allergic inflammation

Smooth muscle of bronchioles contracts

Increased mucus secretion

* + - Respiratory zone:
      * Pulmonary alveoli: where gas exchange occurs by diffusion
      * Covered with pulmonary capillaries
      * Very short diffusion distance
      * Very large surface area
      * No mucus! (would slow down diffusion)
      * Pathologies:
        + Emphysema: walls between alveoli break down -> decreased surface area
      * Alveolar macrophages: trap dust
      * Cells of alveolar wall:
        + Type I cells: main component of alveolar lining

Simple squamous epithelium

Thinnest for diffusion

* + - * + Type II cells:

Simple cuboidal epithelial cells

Secrete surfactant: molecule that decreases surface tension of water (allows alveoli to expand)

Respiratory Distress Syndrome:

Common in premature infants

Insufficient surfactant produced

Difficult to expand alveoli

* Ventilation
  + Breathing
  + Inspiration:
    - Active process
    - Diaphragm and external intercostals contract -> increase thoracic volume -> decrease pressure in lungs -> air enters
  + Expiration:
    - Passive process: muscles relax
    - Tissues recoil (elastic CT)
  + Pathologies:
    - Pneumothorax: presence of air in the pleural cavity
      * Causes lung collapse
* **Cardiovascular System**
* Function
  + Transport and deliver (via the blood):
    - Nutrients and metabolic waste
    - O2 and CO2
    - Hormones
    - Heat, etc.
* Circulatory routes
  + Pulmonary circuit:
    - Delivers blood to and from the lungs
      * For external respiration
  + Systemic circuit:
    - Delivers blood to and from the rest of the body
      * For internal respiration
* General circulatory principles
  + Capillary beds: where exchange takes place
  + Artery: delivers blood from the hear to the capillary beds
    - Most arteries have oxygenated blood but not all
  + Vein: delivers blood from capillary beds
    - Back to the heart (most veins)
    - Or to another capillary bed
      * Portal veins
    - Most veins have deoxygenated blood but not all
    - Hepatic portal system
* The heart
  + A muscular pump that circulates the blood
  + Four-chambered
  + Surrounded by pericardial cavity
  + Coverings of heart (superficial to deep):
    - Enclosed in pericardium
    - Fibrous pericardium (outer): not serosa
    - Parietal layer of serous pericardium
    - Pericardial cavity: contains serous fluid
    - Visceral layer of serous pericardium (epicardium)
  + Pathologies:
    - Cardiac tamponade: compression of the heart due to excess fluid in pericardial cavity
  + Wall of heart (outer to inner):
    - Epicardium (visceral layer of serous pericardium)
    - Myocardium: cardiac muscle
    - Endocardium:
      * Epithelium: simple squamous (endothelium)
      * Lines inner heart (including valves)
  + Chambers and vessels:
    - Overview of heart, chambers, valves, and vessels (diagram)
    - Atria: receive blood from veins
      * Right atrium: receives deoxygenated blood from:
        + Inferior and superior vena cava
        + Coronary sinus: returns blood from heart tissue
      * Left atrium: receives oxygenated blood from:
        + Pulmonary veins
    - Ventricles: eject blood from heart
      * Right ventricle: pumps deoxygenated blood to:
        + Pulmonary trunk -> pulmonary arteries
      * Left ventricle: pumps oxygenated blood to:
        + Aorta

Coronary arteries (supplying blood to heart tissues) are branches of aorta

* \* A to V: arteries before veins, atria before ventricles
  + Heart valves: prevent backflow of blood
    - Atrioventricular valves (AV valves): between atrium and ventricle
      * Tricuspid valve (R AV): between R atrium and ventricle
      * Bicuspid valve (L AV, mitral): between L atrium and ventricle
      * Chordae tendinae:
        + Hold valved in place
        + Anchored to papillary muscles
        + Prevents eversion (prolapse)
      * Try before you buy
    - Semilunar valves (SL valves): between great arteries and ventricles
      * Aortic SL valve: between left ventricle and aorta
      * Pulmonary SL valve: between right ventricle and pulmonary trunk
    - Heart sounds in each heart beat:
      * First sound (“lub”): closing of both AV valves when ventricles begin contracting
      * Second sound (“dup”): closing of both SL valves when ventricles being relaxing
  + Conducting system:
    - Heart muscle has intrinsic rhythm
    - Conducting system: specialized cardiac muscle cells
      * Initiates electrical signal (“firing”)
      * Signals heart chambers to contract in proper sequence
      * Signal spreads from one cardiac muscle cell to another through gap junctions
    - Sequence of conduction:
      * 1. Sinoatrial node (SA node): pacemaker
        + NOTE: All cardiac muscle cells can spontaneously fire, but SA node cells have fastest rate
      * 2. Atrioventricular node (AV node)
      * 3. Bundle of His (AV node)
      * 4. Bundle of branches
      * 5. Purkinje fibers
    - Disorders of conducting system:
      * Heart block: damage to AV node or Bundle of His (only path from atria to ventricles)
        + Signal doesn’t reach ventricles: ventricles still beat but at slower pace
        + Artificial pacemaker restores normal function
* Blood
  + A type of connective tissue
  + Components of blood:
    - Plasma: fluid with dissolved nutrients, etc.
    - Erythrocytes (red blood cells): carry oxygen
    - Leukocytes (white blood cells): immune cells
    - Platelets: cell fragments for clot formation
* Blood vessels
  + Function of blood vessels:
    - Capillary: allows diffusion between blood and other tissues
    - Artery: carries blood away from heart
    - Vein: carries blood away from capillaries
      * Eventually back to heart
  + General structure of blood vessel wall:
    - Tunica intima:
      * Has endothelium: simple squamous
    - Tunica media:
      * Smooth muscle, collagen, elastin – all circularly arranged
    - Tunica externa:
      * Collagen, elastin – all longitudinally arranged
    - Arteries:
      * Structure (compared to veins and capillaries)
        + Subject to highest pressure
        + Thicker walls

Mainly due to thicker tunica media

* + - * + More elastic
      * Types of arteries:
        + Elastic arteries: conducting arteries

Largest arteries: 1 cm – 1 inch wide

Thick wall, highest elastin content

Very elastic: smoothes out pressure fluctuations

* + - * + Muscular arteries:

Most of the named arteries

0.3 mm – 1 cm

Thickest tunica media relative to vessel diameter

Regulate blood pressure and distribution

* + - * + Arterioles:

Smallest arteries: 0.1 – 0.3 mm

Regulate blood pressure and distribution

* + - Capillaries:
      * Structure: facilitates diffusion
        + Wall only has tunica intima (mostly endothelium)

Very thin wall

* + - * + Tiny: capillary diameter < 0.01 mm wide

All blood in capillary is close to wall

* + - * + Many branches: large surface area
      * Capillary beds:
        + Precapillary sphincters open when tissue is active:

Lets blood into capillaries

* + - * + Precapillary sphincters close when tissue inactive:

Shuts off exchange

Blood still travels across through metarteriole and thoroughfare channel

* + - * Types of capillaries:
        + Continuous capillaries:

Many tight junctions between endothelial cells

In brain:

Completely sealed by tight junctions

All molecules must go across membrane of endothelial cell

Least leaky of all

Blood-brain barrier

In most organs (muscles, lungs, skin, etc.):

Not completely sealed by tight junctions

Small molecules can pass through intercellular clefts (where tight junctions are absent)

* + - * + Fenestrated capillaries:

Have fenestrations: holes through endothelial cells (in other aspects, similar to continuous capillaries)

Allows more rapid exchange of small molecules

Kidney, endocrine glands, intestines, synovial membrane (places where filtration most important)

* + - * + Discontinuous capillaries:

Have fenestrations

Intercellular clefts are large (very few tight junctions)

Allows exchange of proteins and cells, lots of fluid

Liver, lymphoid organs (spleen, bone marrow)

* + - Veins:
      * Structure:
        + Very low pressure system
        + Thinner wall than arteries:

Less smooth muscle and elastin (collapsible)

* + - * + Larger lumen than arteries:

Blood reservoir

65% of total body blood

* + - * + Have valves to prevent backflow of blood
      * Types of veins:
        + Venules (small veins):

Receive blood from capillaries

* + - * + Veins (other than venules):

Receive blood from venules

Portal veins: deliver blood from capillary bed to capillary bed

Ex: hepatic portal vein

* + - * Mechanisms of enhancing venous return:
        + Return of blood to heart is slow because of low pressure -> need way to enhance blood return to heart

Ex: skeletal muscular pump

Pressure changes (and valves) dive blood back to heart

* **Lymphatic and Immune Systems**
* Lymphatic system
  + Function:
    - A system of vessels and nodes that returns excess tissue fluid to the blood
    - Needed because plasma tends to leak out of blood capillaries
    - NOTE: Most cells get oxygen and nutrients directly from interstitial fluid (tissue fluid)
    - Filters pathogens to be targeted by immune system
  + Pathway of flow:
    - Throughout most of body, tissue fluid (interstitial fluid) enters lymphatic capillaries
      * The fluid is now called lymph
    - Moves through lymph vessels and lymph nodes
      * Blood plasma -> tissue fluid -> lymph
    - Returned to the blood at veins at the base of the neck
  + Structures:
    - Very low pressure system:
      * Uses valves to maintain flow direction
    - Lymphatic capillaries:
      * Wall: endothelium (simple squamous epithelium)
      * Minivalves:
        + Formed by loose edges of cells
    - Large lymph vessels:
      * Has valves (similar to those of veins)
    - Lymph nodes:
      * Contains reticular CT (with reticular fibers)
      * Lymph flows through
      * Pathogens are filtered out by immune cells
  + Pathology:
    - Lymphedema: accumulation of interstitial fluid due to poor lymphatic drainage
      * Ex: elephantiasis (extreme)
        + Caused by parasitic worm
* Immune system
  + Function:
    - A system of cells, tissues, and organs that is dispersed widely throughout the body to defend against pathogens
  + Cells:
    - Leukocytes: white “blood” cells
      * Examples:
        + Macrophages:

Engulf foreign material/debris

NOT specific to one type of antigen

Presents antigen on cell surface

* + - * + Lymphocytes:

Recognizes and attacks one specific type of antigen

Must be activated first

Ex: by macrophage

* + Tissues and organs:
    - Lymphoid tissue: reticular CT with lots of lymphocytes
      * Common in places where pathogens may enter
      * Ex: MALT (mucosa associated lymphoid tissue)
    - Lymphoid organs: mostly lymphoid tissue
      * Primary lymphoid organs:
        + Where lymphocytes are made
        + Thymus and red bone marrow
      * Secondary lymphoid organs:
        + Contain mature lymphocytes
        + Lymph nodes
        + Spleen
        + Tonsils
        + Appendix
        + Peyer’s patches
* **Nervous System**
* Function
  + Receive sensory input: monitor changes inside and outside the body
  + Integration (most complex): processes and interprets sensory input
  + Motor output: causes a response by activating effector organs (muscle or gland)
  + Properties:
    - All cells are naturally charged
    - Nervous tissue: uses electrical charge for rapid communication
* Organization
  + Central nervous system (CNS):
    - Brain
    - Spinal cord
  + Peripheral nervous system (PNS): nerves and ganglia
    - Regional divisions:
      * Spinal nerves: nerves that transmit signals to and from spinal cord
      * Crania nerves: nerves that transmit signals to and from brain
    - Functional divisions: they are all connected!
      * Afferent (sensory): carries impulses to CNS
        + Somatic sensory: monitors external environment, skin, body wall, limbs
        + Visceral sensory: monitors visceral organs
      * Efferent (motor): carries impulses to effector organs
        + Somatic motor (usually voluntary):

To skeletal muscle

* + - * + Visceral motor (involuntary): autonomic nervous system

To cardiac and smooth muscle, glands

Sympathetic: “fight or flight”

Parasympathetic: “rest and digest”

* Histology of nervous system
  + Neurons: nerve cells – but NOT always found in nerves
    - Properties:
      * Function: rapid transmission and integration of signals
      * Specialized for conducting electrical impulses
      * Cannot divide after birth: BUT new neurons can be generated from stem cells
    - Anatomy of a typical (multipolar) neuron:
      * Cell body (soma):
        + Contains nucleus
      * Dendrites:
        + Receive signals from other cells
        + Send signals to cell body
      * Axon:
        + Receives signals from axon hillock of cell body
        + Axon terminals: transmit signal to other neurons
        + Myelin sheath:

Made of glial cells

Insulates axons from each other

Speeds up signal

* + - * + Nodes of Ranvier: gaps in myelin
      * Synapse: site of neuron-neuron communication
        + Most are chemical, using neurotransmitter that diffuses across synaptic cleft
        + Some are electrical, using gap junctions
    - Pathology:
      * Multiple sclerosis: an autoimmune disease of the CNS
        + Results in damage to both myelin and axons
    - Types of neurons
      * Functional classification:
        + Sensory (afferent) neurons:

Carry signals to CNS

Make up the sensory division of PNS

NOTE: axon terminal is (typically) in CNS

* + - * + Motor (efferent) neurons:

Carry signal from CNS to effector

Make up the motor division of PNS

NOTE: cell body is (typically) in CNS

* + - * + Interneurons: between sensory and motor neurons

Found entirely within CNS

* + - * Structural classification:
        + Multipolar (many things to cut):

Many processes

Most neurons (typical)

* + - * + Bipolar (two things to cut):

One axon, one fused dendrite

Found in some sensory organs

* + - * + Unipolar/pseudounipolar (one thing to cut):

Typical sensory neurons

Receptive endings, no dendrites

Axon with peripheral and central processes

* + Neuroglia/glia: support cells
    - Properties:
      * Don’t send nervous signals
      * Outnumber neurons
      * Continue dividing through out life
        + Most brain cancers are gliomas: tumors of glial cells
    - Types:
      * Found in CNS only:
        + Oligodendrocytes: forms myelin sheath
        + Astrocytes: most abundant, controls environment around neurons
        + Microglia: immune cells
        + Ependymal cells: lines fluid-filled cavities, propels fluid
      * Found in PNS only:
        + Schwann cells: forms myelin sheath
        + Satellite cells: controls environment around neuron cell bodies
  + Histology of gross anatomy:
    - Nerve: group of axons traveling together in the PNS
      * Nerve anatomy (deep to superficial):
        + Endoneurium: surrounds axon
        + Perineurium: surrounds each subgroup of axons
        + Epineurium: wraps around outside of nerve
        + Fascicle: subgroup of axons
      * Nerves vs. neurons:
        + Each nerve contains the axons of many neurons
        + Axons are also called nerve fibers
        + Axons carry signals toward the axon terminals
        + Most nerves carry signals in both directions because contain neurons oriented in both directions

Only exceptions are some cranial nerves

* + - Ganglion: collection of neuron cell bodies in PNS
    - Grey and white matter: general types of nervous tissue in CNS
      * White matter: myelinated axons
      * Gray matter: everything else = unmyelinated axons, dendrites, cell bodies
    - Tract: collection of axons traveling together inside the CNS
      * White matter
    - Nucleus: collection of neuron cell bodies inside the CNS
      * Gray matter
* Brain
  + Complexity:
    - 100 billion neurons
    - Many synapses per neuron
  + Development:
    - Neural tube: fluid filled
    - Primary brain vesicles:
      * Prosencephalon: forebrain
      * Mesencephalon: midbrain
      * Rhombencephalon: hindbrain
    - Secondary brain vesicles:
      * Forebrain:
        + Telencephalon
        + Diencephalon
      * Midbrain:
        + Mesencephalon
      * Hindbrain:
        + Metencephalon
        + Myelencephalon
    - Adult brain structures (rostral to caudal):
      * Telencephalon: cerebrum
      * Diencephalon: diencephalon
      * \*Mesencephalon: midbrain
      * \*Metencephalon (they “met”):
        + Pons
        + Cerebellum
      * \*Myelencephalon: medulla oblongata
      * \* = brain stem
    - Ventricles: fluid-filled cavities
      * Lateral ventricles in cerebrum
      * Third ventricle in diencephalon
      * Cerebral aqueduct in midbrain
      * Fourth ventricle between pons, cerebellum, medulla oblonglata
  + Cerebrospinal fluid:
    - CSF: fluid that fills ventricles
      * Cushions brain
      * Transports nutrients, wastes, other chemicals
    - Choroid plexus:
      * Found in all 4 ventricles
      * Produces the CSF
      * Contains:
        + Capillaries: produce CSF by filtration
        + Ependymal cells: modify CSF
    - Circulation of CSF: propelled by cilia of ependymal cells
      * Produced in later ventricles
      * 3rd ventricle (also makes CSF)
      * Cerebral aqueduct
      * 4th ventricle (also makes CSF)
        + Central canal of spinal cord (some CSF)
      * Apertures
      * Subarachnoid space
      * Arachnoid villi
      * Dural sinuses (combines with blood from veins)
      * Internal jugular veins
      * Back to heart
  + Meninges: 3 layers of CT surrounding the CNS
    - Protect the CNS
    - Contains a portion of the CSF
    - Dura mater: outer layer (“tough mother”)
      * Periosteal layer (outer): periosteum
      * Meningeal layer (inner)
      * Dural sinus: space between these layers that carries blood
        + Functions as a vein
    - Arachnoid mater: middle layer (“spidery mother”)
      * Subarachnoid space: contains CSF and large blood vessels
    - Pia mater: inner layer (“gentle mother”)
      * Carries small blood vessels to nervous tissue
  + Pathologies:
    - Spina bifida:
      * Neural tube fails to close completely
      * Can result in partial paralysis and risk of infection
    - Hydrocephalus
      * Buildup of excess CSF in the brain