

- I. 2 Main divisions of the digestive system
  - a. **Alimentary canal organs** and **accessory digestive organs**.
- II. Alimentary canal organs = Organs through which food and food waste will actually pass.
  - a. **Mouth, pharynx, esophagus, stomach, small intestine, and large intestine**.
- III. Accessory digestive organs = Contribute to the processes of digestion and absorption; but no food or food waste actually passes thru them.
  - a. **Teeth, tongue, salivary glands, liver, gallbladder, and pancreas**.
- IV. Basic processes performed by the digestive system:
  - a. **Ingestion** → food is enclosed within the alimentary canal.
  - b. **Motility** → process of moving food thru the alimentary canal. **Peristalsis** is the primary means by which food is propelled thru the GI tract. It involves waves of alternating contraction and relaxation of the smooth muscle in the organ walls.
  - c. **Secretion** → release of fluid products (enzymes, acids, bile, mucus, etc.) into the tract.
  - d. **Mechanical digestion** → initial breakdown that physically prepares food for further chemical digestion. Includes chewing, mixing of food and saliva by the tongue as well as churning of food in the stomach.
  - e. **Chemical digestion** → **hydrolytic breakdown** of food molecules into their chemical building blocks by **enzymes** secreted into the alimentary canal. Small amounts occur in the mouth and stomach. Majority occurs in the s. intestine.
  - f. **Absorption** → passage of nutrients (& vitamins, minerals, and water) from the lumen of the tract across the mucosa and into either blood or lymph. Primarily occurs in the s. intestine.
  - g. **Defecation** → elimination of indigestibles from the body via the **anus** in the form of **feces**.
- V. Oral Cavity
  - a. Oral orifice to oropharynx
  - b. Site of ingestion, mechanical digestion, chemical digestion, propulsion
- VI. Intrinsic salivary glands
  - a. Embedded w/i mucosal lining of oral cavity.
  - b. Keep the oral cavity moist
- VII. Extrinsic salivary glands
  - a. 3 pairs: parotid, submandibular, and sublingual.
  - b. Produce “digestive” saliva
- VIII. Production and function of saliva
  - a. Salivary glands produce 1-1.5 L of **saliva** per day.
    - i. Moistens and cleanses the mouth.
    - ii. Dissolves food particles. Allows them to stimulate taste buds.
    - iii. Moistens food facilitating its compaction into a bolus.
    - iv. Mucus lubricates the bolus facilitating swallowing.
    - v. Contains enzymes that begin chemical digestion of starch.
  - b. Saliva is 97-99% water. It also contains:
    - i. Electrolytes
    - ii. **Salivary amylase** – an enzyme that chemically digests starch.
    - iii. **Secretory IgA** and **lysozyme** – which provide immune defense.
    - iv. **Mucin** – protein that, when dissolved in water, forms mucus.
  - c. Saliva production is caused by activation of salivary nuclei in the pons and medulla by the presence of food in the oral cavity as well as from the thought, sight, or smell of food. Activation of the salivary nuclei causes parasympathetic outflow to the salivary glands and saliva production.
  - d. Activation of the sympathetic nervous system causes a decrease in saliva production.
- IX. **Mastication** = The mechanical smashing of food by the teeth and tongue.
  - a. Coordinated by the **mastication center** within the brainstem.
  - b. Increases the surface area of food which facilitates enzymatic digestion.
  - c. Helps to compact food and saliva into a **bolus**.
- X. Other digestive processes that occur within the mouth:

- a. Food activates the salivatory nuclei of the pons and medulla and salivation results.
  - b. Teeth and tongue mechanically digest food ↑ surface area available for digestive enzymes.
  - c. Food is mixed with saliva and compacted into a bolus.
  - d. Tongue pushes the bolus into the oropharynx as swallowing is voluntarily initiated.
- XI. Swallowing = Food passes from the oral cavity into the **oropharynx** and then the **laryngopharynx** and onward to and thru the esophagus.
- a. The initial push of the bolus out of the oral cavity is voluntary.
  - b. The bolus is then move thru the pharynx by the **pharyngeal constrictor muscles**.
  - c. Meanwhile, the epiglottis closes the larynx preventing entry into the respiratory tract and inspiration is inhibited to reduce the likelihood of aspiration of the food.
  - d. The superior esophagus is forced open and peristalsis moves the bolus to the stomach.
  - e. The esophageal phase of swallowing concludes upon the opening of the cardiac sphincter and the entry of the bolus into the stomach.
- XII. **Esophagus** = Muscular 10" tube that propels food from the laryngopharynx to the stomach.
- a. No digestive processes are initiated w/i the esophagus.
  - b. It's collapsed when not propelling food.
  - c. The submucosa contains mucus-secreting glands for lubrication.
- XIII. **Stomach** = An enlarged segment of the tract that functions mainly in storing food and mixing it with **gastric juice** (creating a paste called **chyme**).
- a. Other functions of stomach include:
    - i. Chemical digestion of proteins
    - ii. Secretion of **intrinsic factor** – a chemical that is necessary for **vitamin B<sub>12</sub>** absorption. B<sub>12</sub> is necessary for RBC synthesis
    - iii. Destruction of ingested bacteria via secreted **hydrochloric acid**.
  - b. Stomach's diameter and volume vary with its contents. The empty stomach's mucosa is thrown into visible folds called **rugae**. They allow the stomach to expand.
  - c. Epithelium and the muscularis externa are adapted for the functions of the stomach.
  - d. The gastric mucosa is a simple columnar epithelium with millions of **gastric pits**.
  - e. Surface epithelia are known as **surface mucous cells** b/c they secrete a basic mucus.
  - f. The gastric pits lead into **gastric glands**, which secrete the gastric juice (2-3 L/ day).
  - g. Cells comprising the gastric glands vary depending on the particular region of the stomach. The basic cell types are:
    - i. **Mucous neck cells** – found in the upper portion of the gland. Secrete acidic mucus and function as stem cells for surface mucous cells.
    - ii. **Chief cells** – primary function is secretion of **pepsinogen**, an inactive form the protease, **pepsin**. Pepsinogen is activated by HCl and by pepsin itself.
    - iii. **Parietal cells** – found in the middle of the glands. Secrete **hydrochloric acid** (which gives the stomach a low pH (1-3)) as well as **intrinsic factor**.
    - iv. **Enteroendocrine cells** – secrete multiple hormones into the plasma,
      1. **Gastrin** - hormone that is released in response to stomach stretch or vagal activity. It stimulates an increase in stomach motility and secretory activity.
      2. Ghrelin - hormone released by the empty stomach. It acts on the hypothalamus to cause hunger.
  - h. Why is the stomach not digested by itself? The answer is manifold:
    - i. A thick coating of **bicarbonate-containing mucus** lines the wall.
    - ii. Damaged cells are quickly shed and replaced.
    - iii. Epithelial cells are joined by **tight junctions**, which prevent the juice from leaking.
  - i. Gastric muscularis externa has 3 layers rather than the normal 2. Deep to the circular layer of muscle is the **oblique layer**, which allows the stomach to churn, mix, and pummel food.
  - j. Note that nutrients are not absorbed in the stomach. (Alcohol and some drugs are.)
  - k. Muscular activity in the stomach has 2 primary aims:
    - i. **Gastric mixing** is the mechanical smashing of the bolus and commingling of it with gastric juice to form **chyme**.

- ii. **Gastric emptying** refers to the peristaltic wave that forces small volumes of chyme through the pyloric sphincter and into the duodenum.
- XIV. Gastric activity (muscle contractions and the secretion of gastric juice) is stimulated:
- a. By the sight/smell/taste/thought of food. This is the **cephalic phase**. Visual, taste, & olfactory receptors send info to the hypothalamus, which initiates parasympathetic signals to the stomach via CN X. ACh released by the vagus nerve stimulates gastric activity.
  - b. Indirectly in response to stretch or the presence of amino acids w/i the stomach. Both activate reflexes that stimulate gastric activity as well as gastrin release. This is **gastric phase** and is responsible for the greatest volume of gastric juice secretion.
- XV. Gastric activity is inhibited:
- a. By chyme accumulating w/i the duodenum. In response to stretch, duodenal endocrine cells begin to release **cholecystokinin** and **secretin**. Both these hormones inhibit gastric activity.
  - b. By stress, anxiety, and fear (via increased sympathetic activity).
- XVI. Small intestine
- a. Site of most digestion and almost all nutrient absorption.
  - b. Divided into 3 unequal sections: the **duodenum**, **jejunum**, and the **ileum**.
  - c. The duodenum receives the **common bile duct** (delivering bile from the liver and gallbladder) and the **main pancreatic duct** (delivering pancreatic juice). These unite in the duodenal wall to form the **hepatopancreatic ampulla**. The **hepatopancreatic sphincter** controls entry of bile and pancreatic juice into the intestinal lumen.
  - d. The jejunum is the primary site of digestion and absorption.
  - e. The ileum is primarily involved in absorption of water, electrolytes and vitamins.
  - f. There are several structures that maximize small intestine surface area.
  - g. **Circular folds (plicae circulares)** – deep, circular, permanent folds of the mucosa and submucosa. They increase surface area and slow the movement of chyme. This provides more time for absorption and digestion to occur.
  - h. **Villi** – fingerlike extensions of the mucosa. Absorptive epithelial cells line the surface. Within the core of each villus is the lamina propria, which contains blood capillaries (for absorption of amino acids and monosaccharides) and a **lacteal** (for absorption of fatty acids).
  - i. **Microvilli** – tiny projections of the plasma membrane of each absorptive epithelial cell. They give the cell's luminal surface a fuzzy appearance known as the **brush border**. Membrane bound enzymes are embedded in the brush border and function in nutrient breakdown.
  - j. Epithelial invaginations known as **intestinal glands (crypts of Lieberkuhn)** secrete over 2 L/day of **intestinal juice**, which consists primarily of mucus, electrolytes, and water. The intestinal glands also contain enteroendocrine cells, which secrete hormones (such as intestinal gastrin, secretin, and cholecystokinin) into the plasma.
  - k. **Alkaline mucous glands** in the duodenal submucosa help neutralize acidic chyme.
  - l. Recall that the terminal ileal submucosa contains **Peyer's patches**.
  - m. Small intestine is the primary site of a mixing activity known as **segmentation** – alternating contractions and relaxations that mix intestinal contents rather than propel it forward.
  - n. Motility and secretory activity of the small intestine is enhanced by parasympathetic stimulation and inhibited by sympathetic activity.
- XVII. The **liver** is an accessory digestive organ
- a. It has multiple functions including:
    - i. Carbohydrate metabolism – storage and release of glucose
    - ii. Removal of drugs, toxins, and foreign chemicals from the plasma
    - iii. Storage of vitamins (A, D, E, and K) and minerals (iron and copper)
    - iv. Protein and lipid metabolism
    - v. Synthesis of plasma proteins (e.g., albumin, fibrin, etc.)
    - vi. Phagocytosis of old RBCs and of pathogens.
    - vii. Production of **bile** (0.5-1 L/day).
  - b. A CT capsule and visceral peritoneum almost completely surround the liver.

- c. The CT capsule sends septa w/i the liver to provide structural support and divide the liver interior into hexagonal shaped **liver lobules**.
  - d. The center of each lobule contains a **central vein**.
  - e. Extending out from the central vein are the **hepatic cords** (composed of **hepatocytes**).
  - f. At each of the 6 corners of a lobule is a **portal triad** – a **branch** of the **hepatic artery** (a **portal arteriole**), a **branch** of the **hepatic portal vein** (a **portal venule**), and a **bile duct**.
  - g. The portal venules and the portal arterioles are linked to the central vein by capillaries known as **liver sinusoids**, which run btwn the hepatic cords.
  - h. Blood flows into a liver lobule at any of its 6 corners. Blood from the portal venule and portal arteriole mingles in the sinusoids and flows towards the central vein. As blood flows thru the sinusoids:
    - i. Gases are exchanged btwn the blood and the hepatocytes
    - ii. Nutrients (absorbed in SI) are taken up from the plasma by hepatocytes.
    - iii. Toxins and poisons are removed from the plasma by hepatocytes.
    - iv. Pathogens and old RBCs are engulfed by macrophages.
  - i. Blood will reach the central vein and central veins will combine into larger veins that eventually coalesce to form the hepatic veins.
  - j. Running alongside the liver sinusoids are the **bile canaliculi**. Hepatocytes secrete bile into bile canaliculi which empty into bile ducts at the portal triads. The triad bile ducts eventually combine to yield the left and right hepatic ducts that exit the liver.
  - k. Note that blood flows inward from the portal triads to the central vein, while bile flows outward towards the portal triads.
- XVIII. Bile secretion is the primary digestive function of the liver.
- a. Bile is a mixture of bile salts, bile pigments (e.g., **bilirubin**) and other chemicals.
  - b. It's synthesized by the liver, stored and concentrated by the gallbladder, and secreted into the duodenum.
  - c. Bile salts **emulsify** fats. Because of their hydrophobic nature, fats tend to clump together in the watery environs of the GI tract. Clumped fat reduces the surface area exposed to fat-digesting enzymes. Emulsification is the act of separating the large fat globules into tiny separate fatty droplets. This increases the available surface area for lipases to work upon.
  - d. Note that bile salts are reabsorbed in the ileum and travel back to the liver (via the hepatic portal circulation) where they are reused.
- XIX. The **gallbladder** is a thin-walled muscular sac found on the ventral surface of the liver.
- a. It functions primarily in the storage and concentration of bile.
  - b. Its wall has 3 layers: an inner mucosa lined by simple columnar epithelium and folded into rugae; a smooth muscle muscularis that contracts to expel bile into the duodenum when required; and an outer serosa.
  - c. The liver continuously produces bile. However the hepatopancreatic sphincter is normally closed. This results in bile backing up into the common bile duct, cystic duct, and ultimately into the gallbladder.
  - d. When fatty chyme arrives in the small intestine, intestinal glands secrete the hormone cholecystokinin.
    - i. CCK causes gallbladder contraction and relaxation of the hepatopancreatic sphincter, letting bile flow into the duodenum.
- XX. The **pancreas**
- a. Mostly retroperitoneal and deep to the greater curvature of the stomach.
  - b. **Head** of the pancreas sits next to the duodenum as it loops away from the pylorus. The **body** extends behind the stomach and its **tail** ends at the spleen.
  - c. The pancreas primarily consists of **acini** – small clusters of enzyme secreting cells. These acinar cells empty their secretion into small ducts. Small ducts coalesce into larger ducts that empty into the **main pancreatic duct**, which runs centrally along the long axis of the pancreas
  - d. The function of the acinar and duct cells is the secretion of **pancreatic juice** (1.5 L/day).
  - e. Acinar cells contribute digestive enzymes to the pancreatic juice including:

- i. Protein-digesting enzymes (a.k.a. **proteases**).
    - ii. Fat-digesting enzymes such as **pancreatic lipase**.
    - iii. Carbohydrate-digesting enzymes such as **pancreatic amylase**.
  - f. Duct cells contribute a **watery bicarbonate-rich solution** which has a slightly alkaline pH that helps neutralize the acidity of the chyme.
  - g. When acidic, fatty chyme arrives in the duodenum, its enteroendocrine cells secrete secretin and cholecystokinin (CCK).
    - i. CCK travels in the blood to the pancreas where it primarily stimulates the secretion of enzymes by the acinar cells.
    - ii. Secretin also travels to the pancreas and stimulates the duct cells to release large amounts of the bicarbonate-rich fluid.
    - iii. CCK also causes contraction of the gallbladder as well as relaxation of the hepatopancreatic sphincter.
    - iv. During the cephalic & gastric phases of gastric secretion, parasympathetic input to the pancreas via the vagus nerve also prompts pancreatic juice release.
  - h. Scattered amidst the pancreatic acini are the hormone-producing **islets of Langerhans**. Their major function is the regulation of blood glucose levels.
  - i. Islets of Langerhans consist of 2 primary cell types.
    - i. **Alpha cells** secrete the hormone **glucagon**.
    - ii. **Beta cells** secrete the hormone **insulin**.
  - j. Insulin is released in response to high plasma [glucose] and acts to lower plasma [glucose] by acting on the liver and skeletal muscles stimulating them to remove glucose from the blood and store it as glycogen.
  - k. Insulin also acts on adipocytes - increasing lipogenesis and decreasing lipolysis.
  - l. Glucagon is released in response to low plasma [glucose] and acts to ↑ plasma [glucose] by stimulating hepatic glycogenolysis and the release of glucose into the plasma.
- XXI. The **large intestine**
  - a. Functions primarily to propel indigestible food remains and then expel them as feces.
  - b. As it does it also absorbs any excess water remaining. It's about 5' in length. Its name arises from the size of its diameter. It begins at the **ileocecal valve** and terminates at the **anus**.
  - c. The colonic mucosa is simple columnar epithelium with multitudes of goblet cells. Goblet cell mucus provides fecal lubrication.
  - d. The terminal anal canal is lined by stratified squamous epithelium.
  - e. The colon has no plicae, villi, or microvilli.
  - f. The colon does have **colonic intestinal glands**. Their primary output is mucus.
  - g. The submucosa is unremarkable. The muscularis externa is unique in that the outer longitudinal layer is transformed into teniae coli.
  - h. W/i the lower sigmoid and rectum the teniae coli broaden and fuse to form a uniform longitudinal layer.
  - i. The colon contains serosa in portions and adventitia in others.
  - j. Millions of bacteria colonize the large intestine. They break down indigestible carbohydrate residues and produce many B vitamins as well as most of the body's vitamin K supply.
  - k. Typically 100 g of feces are produced per day consisting of 75% water and 25% solids. Solids include dead bacteria, fat, inorganic matter, protein, undigested plant fibers, bile pigments, and shed epithelial cells.
- XXII. Muscular movements w/i the colon include:
  - a. **Haustral contractions** – push food residue and fecal matter of haustrum to haustrum. Instigated by the stretching of a haustrum.
  - b. **Mass movements** – sweeping waves of peristalsis that move over large areas of the colon and force its contents towards the rectum. They typically occur 1-3 times/day. Mass movements are also initiated by the presence of food within the stomach. This is known as the **gastrocolic reflex**. This reflex is also stimulated by caffeine.

- c. **Defecation** – when fecal matter enters and stretches the rectum, stretch receptors measure the degree of stretch. If stretch is great, signals are sent to the spinal cord and the defecation reflex is initiated. Parasympathetic output to the rectum and anal canal results in relaxation of the internal anal sphincter and waves of contraction of the rectal muscularis. Conscious input from the cerebral cortex maintains closure of the external anal sphincter – unless rectal stretch reaches threshold level. Defecation occurs with relaxation of the external sphincter coupled with powerful contractions of the descending colon, sigmoid colon, and rectum. It's assisted by the rise in intra-abdominal pressure created by the contraction of the diaphragm and abdominal muscles. The muscles of the pelvic floor must also relax during defecation.