

The Digestive System

I. Overview

A. Organs of the digestive system.

1. Alimentary canal (GI Tract):

- continuous muscular tube, open at both ends.
- digests food, absorbs digested fragments.

2. Accessory digestive organs:

- teeth, tongue, gall bladder, and glands (salivary glands, liver, pancreas).

B. Digestive processes.

1. Ingestion: process of taking food into the GI tract via the mouth.

2. Propulsion: process that moves food through the GI tract (peristalsis).

3. Mechanical digestion: physically prepares the food for chemical digestion (chewing, mixing food with saliva, churning food in stomach, segmentation).

4. Chemical digestion: series of catabolic steps in which large food molecules are broken down to monomers that can be absorbed.

5. Absorption: movement of digested products from lumen across cellular lining of the GI tract to blood/lymph.

6. Defecation: elimination of indigestible substances from the body.

C. Basic functional concepts: the GI tract intrinsically regulates itself.

1. Major stimuli for digestive activities: mechanical and chemical stimuli

- stretch and chemoreceptors on walls of the GI tract organs monitor the stretch of organ wall, pH, osmolarity, presence of substrates or products of digestion.

- reflexes initiated by receptor activation/deactivation, influences secretion of digestive juices, and motility of the GI tract.

2. Controls of digestive activity are predominantly intrinsic; however, some extrinsic regulation occurs.

- two nerve plexuses found in the GI tract walls; most regulation of digestive activity (secretion, motility) involves local reflexes within these plexuses; hormonal regulation also occurs -- intrinsic.

- some regulation is extrinsic - CNS involvement.

D. Geography / general histology.

1. Peritoneum: a double layered serous membrane that surrounds the digestive organs in abdominopelvic cavity; visceral peritoneum covers external surfaces of digestive organs; parietal peritoneum lines the walls of the abdominopelvic cavity.

- some organs are within the peritoneum; it folds around them and forms a mesentery (dorsal or ventral)

- some organs lose mesentery, lie posterior to peritoneum, retroperitoneal, usually adhere to dorsal abdominal wall.

2. Blood supply: splanchnic circulation serves digestive organs; celiac trunk has various branches; superior and inferior mesenteric arteries; hepatic portal circulation -- to liver

3. Histology: wall of the GI tract is made up of 4 basic layers (modifications depending on function).

a. Mucosa: moist epithelial membrane that lines the lumen of the alimentary canal

(i) Surface epithelium: the type varies on location, in most places it is simple columnar with goblet cells (mucus secreting cells); some cells specialized for enzyme or hormone secretion

(ii) Lamina propria: loose areolar connective tissue below the epithelium; extensive capillaries nourish the epithelium and absorb digestive nutrients; lymphatic capillaries also present.

(iii) Muscularis mucosae: thin layers of smooth muscle, involved in local movements of mucosa.

- function of mucosa: secretions of mucous, enzymes, hormones; absorption of nutrients, protection against infectious disease.

b. Submucosa: moderately dense connective tissue; blood, lymphatic vessels, lymph nodules, nerves.

c. Muscularis externa: thick double layer of smooth muscle, inner circular and outer longitudinal layers; function in segmentation and peristalsis.

4. Enteric nervous system: recall that the GI tract has the ability for intrinsic regulation; it has its own, local nerve supply formed by 2 intrinsic nerve plexuses in its wall.

a. Submucosal nerve plexus: located in the submucosa, regulates the activity of glands.

b. Myenteric nerve plexus: between the circular and longitudinal layers of muscularis externa. - it is the major nerve supply to the GI tract wall; controls GI tract motility.

- note that the enteric nervous system is linked to the central nervous system by afferent fibers; ANS motor fibers also enter the GI tract wall and synapse with neurons in both plexuses; parasympathetic inputs are associated with increased secretory activity and motility; sympathetic inputs inhibit digestive activities.

E. Movements of digestive tract

1. peristalsis: wave of contractions of muscularis externa that moves food along GI tract; inner circular muscle layer preceding bolus contracts, followed by contraction of longitudinal muscle layer ahead of food mass

- contraction of adjacent segments of tract

2. segmentation

- mixing movements -- non-adjacent segments of intestine contract and relax; food moved back and forth, mixed

II. Functional anatomy of digestive system.

A. Mouth, pharynx and esophagus.

1. Mouth; mucosa-lined cavity, stratified squamous epithelium

a. Lips/cheeks: keep food between teeth as chewing occurs.

b. Palate: roof of mouth.

(i) Hard palate: palatine processes of maxillary bone, palatine bones.

(ii) Soft palate: skeletal muscle.

c. Tongue: mass of interlacing skeletal muscle fibers, mucosa lined (mucous, serous glands on surface, papillae).

d. teeth: mastication or chewing

e. Salivary glands: produce saliva; both inside (intrinsic) and outside oral cavity.

(i) Functions of saliva: cleanses mouth, dissolves food chemicals so tasting can occur, moistens food, contains enzymes.

(ii) Three pairs of extrinsic salivary glands: parotid, submandibular, sublingual glands.

- composed of two major types of secretory cells, serous cells (watery secretion containing enzymes, ions), and mucous cells (secrete mucin, a protein that when mixed with water produces mucus).

(iii) Composition of saliva: water, electrolytes, proteins (salivary amylase, mucin, lysozyme, IgA, growth factors); pH 6.75 - 7.00.

(iv) Control of salivation: intrinsic glands secrete saliva continuously, keep mouth moist; however, extrinsic glands associated with bulk of salivation associated with eating.

- ingestion of food results in activation of pressoreceptors and chemoreceptors in mouth that initiate a reflex involving brainstem nuclei -
- reflex stimulation of salivary glands.

- parasympathetic stimulation results in production of large amounts of watery, enzyme-rich saliva; sympathetic stimulation results in production of small amounts of mucus-rich saliva.

2. Pharynx: mucosa-lined, epithelium is stratified squamous, muscularis externa is skeletal muscle.

3. Esophagus: muscular tube, 25 cm long.

a. General: extends from upper esophageal sphincter to gastroesophageal or cardiac sphincter (a physiological sphincter).

b. Histology: has all four basic tunics.

(i) mucosa: epithelium is stratified squamous; lamina propria and muscularis mucosae present.

(ii) submucosa: contains mucus-secreting esophageal glands that when squeezed by passing bolus release mucus onto mucosa surface.

(iii) muscularis externa is a mixture of skeletal and smooth muscle depending on level of esophagus in question; upper third is all skeletal, middle third a mix of skeletal and smooth, lower third all smooth muscle.

(iv) instead of serosa there is an adventitia.

4. Digestive processes occurring in mouth, pharynx and esophagus:

a. Mouth: mastication, moistening, lubrication of food, initiation of starch digestion.

b. Mouth, pharynx, esophagus: deglutition or swallowing; starts as a voluntary movement, turns into involuntary reflex.

(i) voluntary phase (buccal phase): tip of tongue against hard palate, contract tongue, force bolus into oropharynx; tactile receptors stimulated, reflex triggered.

(ii) soft palate contracts to close off nasopharynx, larynx rises up against epiglottis; upper esophageal sphincter relaxes.

(iii) pharynx constrictor muscles contract, food forced into esophagus; upper esophageal sphincter contracts once entry occurs.

(iv) peristalsis down to stomach, gastroesophageal sphincter relaxes as bolus approaches.

B. Stomach

- bolus converted to chyme in stomach

- digestive processes occurring in stomach

- initiation of protein digestion
- vitamin B12 absorption
- water absorption

1. Regions of stomach: cardia, fundus, body, pylorus.

2. Microscopic anatomy

a. Mucosa.

(i) surface epithelium is simple columnar, mostly mucus-secreting goblet cells (protection).

(ii) epithelium projects into invaginations into underlying lamina propria, gastric pits, that lead to gastric glands; a number of secretory cells found in gastric glands;

- mucous neck cells: upper part of gland, secrete mucus, function unknown.

- parietal cells: secrete HCl and intrinsic factor.

- chief cells: secrete pepsinogen.

- enteroendocrine cells: release a variety of hormones into vasculature of lamina propria (gastrin, histamine, etc.)

(iii) lamina propria; areolar CT, contains rich capillary networks.

(iv) muscularis mucosa: thin smooth muscle layer.

b. Submucosa: CT, blood vessels and the submucosal plexus.

c. Muscularis externa: three layers in stomach, inner oblique, middle circular, outer longitudinal.

d. Serosa: the visceral peritoneum.

3. Stomach protections against autodigestion: mucus, tight junctions of epithelial cells, constant renewing of surface epithelium by division of undifferentiated stem cells in gastric glands.

4. Regulation of gastric secretion and motility

a. thought, smell, taste of food initiates release of gastric juices and increased motility -- cephalic phase

- vagal reflexes to ENS

b. presence of food in stomach -- gastric phase

- distention of stomach
 - stretch receptors activated
 - local reflexes cause increased gastric juice production and increased motility -- influences on submucosal and myenteric plexuses (ACh release by these neurons)
 - neural regulation
- presence of proteins and peptides in stomach
 - causes G-cells to release gastrin into blood
 - gastrin stimulates increased gastric juice production, predominantly HCl secretion -- influences on mucosa
 - gastrin stimulates increased motility -- influences on muscularis externa
 - hormonal regulation

- thus digestion of proteins initiated

- increased motility

- peristaltic waves in stomach start at cardia and extend to pylorus, each wave squirts about 2-3 ml of chyme through a closed pyloric sphincter; bulk of chyme "slams against sphincter and refluxes back, in a mixing motion

c. presence of chyme in small intestine -- intestinal phase

- inhibitory loop (enterogastric reflex):

- presence of acidic chyme in the duodenum stimulates enteroendocrine cells of duodenal mucosa to release hormone secretin
 - secretin inhibits gastric gland secretion and gastric motility
- presence of fatty/carbohydrate containing chyme in duodenum stimulates enteroendocrine cells of duodenal mucosa to release of gastric inhibitory peptide (GIP)
 - GIP causes inhibition of gastric gland secretion and inhibition of gastric motility
- hormonal mechanism

- physical presence of food in the duodenum stimulates stretch receptors in mucosal wall that lead to neural reflex pathways inhibiting gastric motility and gastric gland secretions

- neural mechanism

- results:

- slow down gastric digestion and emptying to meet the pace of duodenal digestion

C. Small intestine and associated structures.

1. Small intestine: body's major digestive organ where digestion is completed and most absorption occurs.

a. Divisions of SI.

(i) duodenum: shortest division, where most digestion occurs and absorption begins.

(ii) jejunum: site of absorption, all of it conducted by end of jejunum.

(iii) ileum: absorption limited to water and bile salts.

b. Microscopic anatomy: involve adaptations for nutrient absorption, adaptations to greatly increase surface area of mucosa: plica circulares (deep permanent folds of mucosa and submucosa), villi, microvilli (see below).

(i) Mucosa: has finger-like projections (1 mm) called villi.

- epithelium lining villi is simple columnar; absorptive; individual cells have invaginated plasma membranes that both increase surface area available for absorption and area available for insertion of brush border enzymes (membrane proteins); many goblet cells and enteroendocrine cells also present.

- lamina propria has capillary bed and lacteal; digested materials absorbed through epithelial cells into either capillaries or lacteal.

- between villi the mucosa is studded with pits that lead to tubular intestinal glands, intestinal crypts; intestinal cells lining these pits secrete intestinal juice, a watery HCO_3^- rich juice that neutralizes acidic stomach chyme and provides a medium for absorption; stimulus for its release is distention, presence of acidic chyme.

- epithelial cells on villi "wear off" and replaced by cells that arise from constant division of stem cells at base of crypts.

(ii) submucosa: areolar CT; lymphoid nodules (Peyer's patches); duodenal glands, alkaline mucus-secreting glands.

(iii) muscularis externa.

2. Liver and gall bladder.

- accessory digestive organs associated with SI.

- liver has many functions, many metabolic in nature; the digestive function of the liver is to produce, secrete bile, and deliver it to SI.

- the digestive function of gall bladder is to store, concentrate bile, deliver it to SI.

a. General anatomy of liver.

- four lobes comprised of lobules.

- right/left hepatic duct + cystic duct (from GB) ---> common bile duct; common bile duct + pancreatic duct forms hepatopancreatic ampulla that opens to duodenum at a hepatopancreatic sphincter.

b. Microscopic anatomy of liver.

- hexagonal lobules around a central vein; plates of hepatocytes irradiating from central vein separated by sinusoids (large capillaries).

- at each corner of lobule is portal triad: branch of hepatic artery, branch of hepatic vein, bile duct.

c. Bile: yellow-green, neutral pigment.

- bile salts, bile pigments, cholesterol, neutral fats, phospholipids, electrolytes.

- role is to emulsify fats, the function of bile salts and phospholipids.

- bile salts conserved by enterohepatic circulation, reabsorbed to blood at distal ileum, returned to liver by portal blood.

3. Pancreas: accessory digestive organ; secretes pancreatic juice.

a. Microscopic anatomy.

- acinar cells (exocrine), islets (endocrine)

b. Composition of pancreatic juice.

- water
- enzymes in inactive form: trypsinogen, chymotrypsinogen, procarboxypeptidase.
- enzymes in active form: amylase, lipases, nucleases.
- electrolytes : HCO_3^-

4. Digestive processes occurring in SI.

- when digestion occurring, hepatopancreatic sphincter constricted, basal liver bile production backing into GB.

a. Liver involvement:

(i) acid chyme in duodenum, enteroendocrine cells release secretin; stimulates hepatocytes to increase bile production.

(ii) fatty chyme in duodenum, enteroendocrine cells secrete cholecystokinin; stimulates GB contraction, relaxes hepatopancreatic sphincter, potentiates action of secretin on liver.

b. Pancreas involvement:

(i) acid chyme in duodenum, enteroendocrine cells release secretin; stimulates secretion of HCO_3^- rich pancreatic juice; duct cells targeted.

(ii) fatty chyme in duodenum, enteroendocrine cells secrete cholecystokinin; stimulates secretion of enzyme-rich pancreatic juice.

c. Activation of pancreatic proteases: initiated by epithelium-bound enterokinase.

d. Motility of SI.

- during digestion most motility is segmentation, distention major stimulus.
- towards end of digestion most motility becomes peristaltic (propulsive) in nature; distention is stimulus.
- opening of ileocecal sphincter stimulated by increased ileal motility and gastrin release by stomach.

D. Large intestine.

- ileocecal valve --> anus; thicker than the small intestine, but shorter.
- absorbs water from indigestible food residues and eliminates them from the body.

1. Gross anatomy:

- note teniae coli, remnants of longitudinal muscle layer of muscularis; tone of tenae coli causes walls of the large intestine to pucker forming haustra.

- Cecum is a "bag" below the ileocecal valve; note vermiform appendix.
- Colon: ascending, transverse, descending, and sigmoid; note flexures.
- Rectum: rectal valve, internal anal sphincter, external anal sphincter, anus and anal canal.

2. Microscopic anatomy:

- Colon: mucosa is simple columnar epithelium with many goblet cells (for lubrication) and numerous crypts; there are no plicae, no villi, no cells with digestive enzymes on brush border.
- Anal canal: mucosa is stratified squamous; it is organized into anal columns and sinuses; note the two superficial venous plexuses, one associated with anal canal and the other with the anus itself; these plexuses are culprits in hemorrhoids.

3. Bacterial flora: bacteria that enter rectum from the small intestine and spread and remain in the lumen of the large intestine; ferment some indigestible carbohydrates (cellulose); synthesize B complex vitamins, vitamin K.

4. Digestive process occurring in the large intestine.

- absorption of water; propulsive activities that force fecal material toward the anus and eliminates it by defecation.

a. Motility of the large intestine.

- presence of food residues in ileum increases ileal motility and relaxes ileocecal sphincter (food residues enter LI).
- presence of food in stomach causes gastrin release which enhances ileal motility and, as described above, causes opening of ileocecal sphincter (gastroileal reflex).

i. Haustral contractions: haustra fill with residue, distention, reflex contraction moves contents to the next haustra.

ii. Mass movements (mass peristalsis): long, slow moving, powerful contractile waves that move over large areas of the colon and force contents toward the rectum; occurring during and after eating; presence of food in stomach causes mass movements in LI, both via action of gastrin and enteric NS reflex (gastrocolic reflex).

b. Defecation reflex: spinal cord mediated, PS reflex; ultimately walls of the sigmoid colon and rectum contract and sphincters relax, feces forced to exterior.

- process: feces are forced into the rectum and rectal pressure increases; impulses are sent along involuntary motor nerve to internal anal sphincter (relaxes), to sigmoid colon and rectum walls (contract); also mass movements are stimulated in other colon segments

- if external anal sphincter relaxes (voluntarily controlled), defecation occurs.

- if external and sphincter contracts (voluntarily controlled), defecation is delayed, sigmoid and rectal walls relax; eventually pressure goes backup in rectum, reflex is reinitiated, will keep being reinitiated until rectum is emptied.

III. Physiology of chemical digestion and absorption.

A. Digestion.

- accomplished by enzymes secreted by both intrinsic and accessory glands into the lumen of the alimentary canal.

- enzymatic break down of any type of food molecule called hydrolysis.

1. Carbohydrate digestion.

- CH₂O in diet are mostly starches (polysaccharides); some disaccharides (sucrose, lactose, maltose) and relatively few monosaccharides (glucose, fructose, galactose).

- starch digestion begins in the mouth by salivary amylase and continues in the stomach until salivary amylase destroyed by the hydrochloric acid; it is then continued by pancreatic amylase; at this point starch has been reduced to small oligosaccharides.

- small oligosaccharides acted upon by intestinal brush border enzymes [dextrinase, glucoamylase (act on oligosaccharides >3 simple sugars) and disaccharidases act on disaccharides]; by the end of the process you are left with monosaccharides which are readily absorbed.

2. Protein digestion.

- digestion begins in the stomach with pepsin (proteins broken into large polypeptides); polypeptides enter the small intestine where trypsin, chymotrypsin, and carboxypeptidase break them down into smaller polypeptides; brush border enzymes act on small peptides.

- Brush border enzymes:

- a. carboxypeptidase: strip 1 aa at a time from carboxy end of polypeptide.
- b. aminopeptidase: strip 1 aa at a time from amino terminus of polypeptide.
- c. dipeptidase: breaks down final dipeptide produced by action of i and ii above.

3. Lipid digestion.

- digestion begins in the small intestine (the sole site of lipid digestion); lipids are emulsified by bile salts and acted on only by pancreatic lipase.

4. Nucleic acid digestion.

- DNA/RNA present in small amounts hydrolyzed to their nucleotide monomers by pancreatic nucleases; nucleotides are torn apart (into free nitrogenous bases, pentose sugars, phosphate ions) by intestinal brush border enzymes.

B. Absorption.

- occurs mostly in the duodenum and jejunum; only events occurring in the ileum are water absorption and bile salt absorption; absorption involves transepithelial transport rather than movement between cells (due to tight junctions); most nutrients absorbed through epithelium of villi by active transport mechanisms driven directly or indirectly by ATP hydrolysis.

1. CH₂O.

- monosaccharides such as glucose and galactose are transported by common protein carriers located in luminal membrane of epithelial cells of SI - a form of secondary active transport coupled to sodium; fructose absorption is not ATP dependent and occurs through facilitated diffusion.

2. Proteins.

- several types of carriers transport different classes of amino acids; coupled to active transport of sodium.

C. Lipids.

- (fatty acids + MG) + bile salts + bile phospholipids --> micelles; fatty acids, MG leave micelles -> epithelial cells --> resynthesized to TG --> combined with protein to form chylomicrons--> extruded --> into lacteal.

D. Nucleic acids.

- sugars, nitrogenous bases, and phosphates: absorbed by specialized carriers.

E. Vitamins.

- fat soluble (A, D, E, K) are incorporated into the micelles and move across the epithelium by passive diffusion; water soluble also pass by simple diffusion except B-12.

F. Electrolytes.

- sodium aids in transport of many substances; potassium moves into the cell with downward gradient and simple diffusion; HCO_3^- is actively secreted into lumen in exchange for chloride ions.

G. Water.

- is transported through osmosis wherever a concentration gradient is established; water often follows sodium.