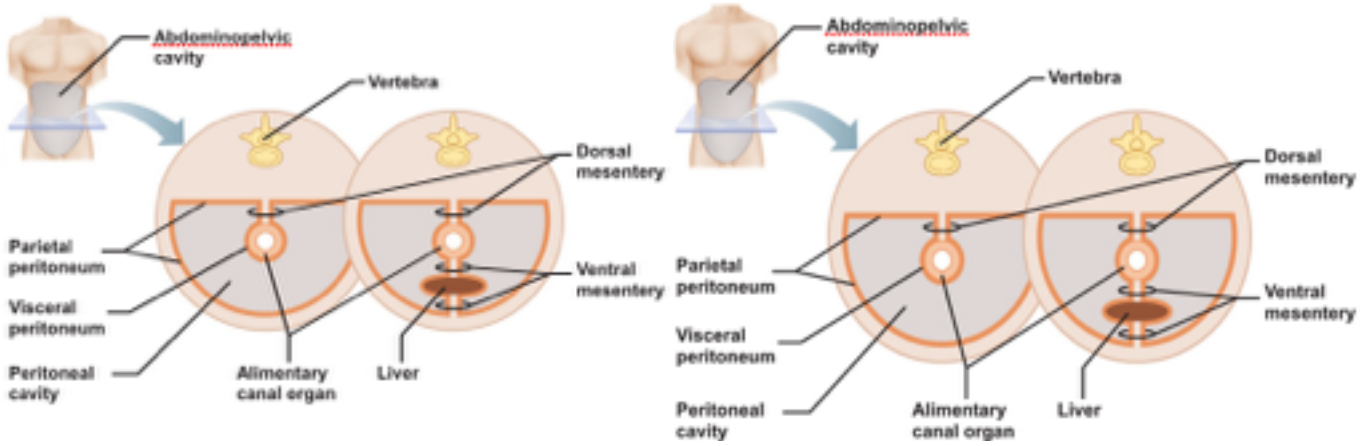
Digestive System

1. Alimentary Canal (GI Tract)
    - mouth, pharynx, esophagus, stomach, small/large intestine
    - continuous muscular tube from the mouth to anus
        - digests food—breaks down into fragments
        - absorbs digested fragments through living into bloodstream
        - excretes end products of digestion
2. Accessory Digestive Organs
    - teeth, tongue, gallbladder, liver, pancreas
        - teeth tongue in mouth, digestive glands and gallbladder connected to GI tract by ducts
        - most accessory organs secrete products such as saliva, bile, enzymes to aid in the digestion of food
- food in lumen of GI tract is technically outside bod because both ends are open

Relationship of the Digestive Organs to the Peritoneum
- most organs of the digestive system reside in the abdominopelvic cavity (lined with slick friction reducing serious membranes)
    - peritoneum most extensive of these serious membranes
    - **Visceral peritoneum**: covers external surfaces of digestive organs and is continuous with
    - **Parietal peritoneum**: lines walls of abdonminopelvic cavity
    - **Peritoneal cavity**: slitlike space between visceral and parental peritoneal—contains fluid secreted by the serous membrane
        - allows for mobile digestive organs to glide across on another (lubricates)
    - **Mesentery**: fused double layer of parietal peritoneum. Carries blood/lymphatic vessels and nerves to GI tract organs
        - also stores fat
    - most digestive organs keep a mesentery and remain in the peritoneal cavity (peritoneal organs)
        - Others, like pancreas, lose mesentery during development and come to lie posterior to the peritoneal cavity these organs are called **retroperitoneal.**



Peritonitis
- inflammation of the peritoneum
- can arise from
    - piercing/abdominal wound
    - perforating ulcer that leaks stomach juice into peritoneal cavity
    - poor sterile technique from abdominal surgery

- most common from burst appendix, bacteria containing feces sprayed over peritoneum

Blood Supply: The Splanchnic Circulation
- **Splanchnic Circulation**: includes arteries that branch off abdominal aorta to serve digestive organs and the hepatic portal circulation

Hepatic	Liver
Gastric	Stomach
Splenic	Spleen
Superior/inferior Mesentric	Small/large Intestine

- venous return from much of the abdonminopelvic region is via inferior vena cava. Venous return from digestive viscera is indirect via hepatic portal circulation
  - blood containing toxins must stop at liver
  - Hepatic Portal is a waste station (processes carbs, amino acids)

GI Tract Wall
Mucosa (innermost)
- Secretes: mucus, digestive enzymes, hormones
- Absorption: end products of digestion
- Protection: against infection
- Mucosa consista of 3 layers
  1. **Surface epithelium**: columnar epithelial goblet cells (abundant in stomach), also cells that secrete enzymes and hormones in the stomach/small intestine
     - protects digestive organs from digestive enzymes
     - eases food passage
  2. **Lamina propria**: loose CT w/ capillaries that absorb and nourish
     - isolated lymph nodes that help defend against pathogens; large collections in tonsils/ appendix
  3. **Muscularis mucosae**: small layer of smooth muscle cells—responsible for local movement of mucosa

Submucosa
- moderately dense CT with blood and lymphatic vessels, lymph nodules, never fibres
- abundant elastic fibres—allow stomach to regain normal shape after meal

Muscularis Externa
- mixing, propulsive movements
- inner circular layer+outer longitudinal layer thickens to form sphincters at organ to organ junctions
- sphincters act as valves, control food passage, prevent backflow

Serosa
- outermost protective layer = visceral peritoneum
- loose of CT covered by single layer of squamous epithelial cells

- esophagus (thoracic rather than abdominal cavity), surrounded by advent instead of serosa
  - adventia—fibrous connective tissue that binds the esophagus to the surrounding tissue

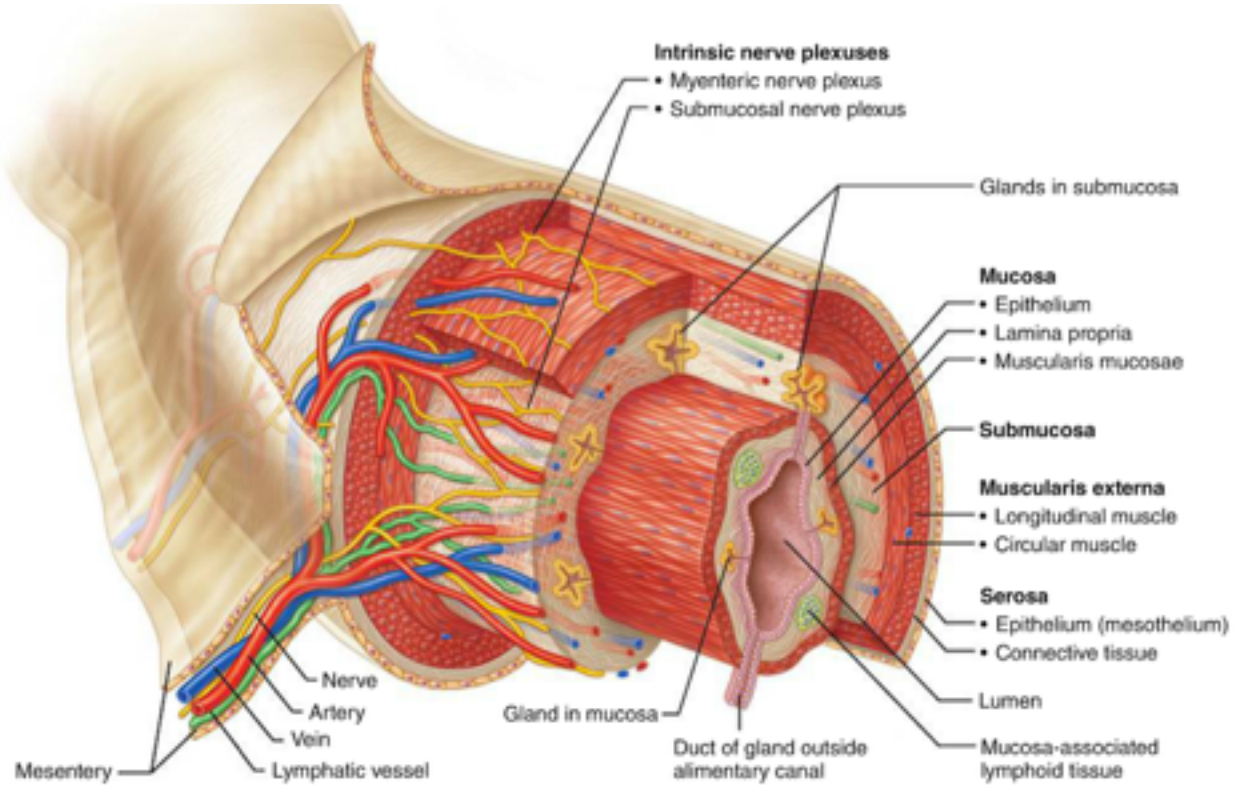
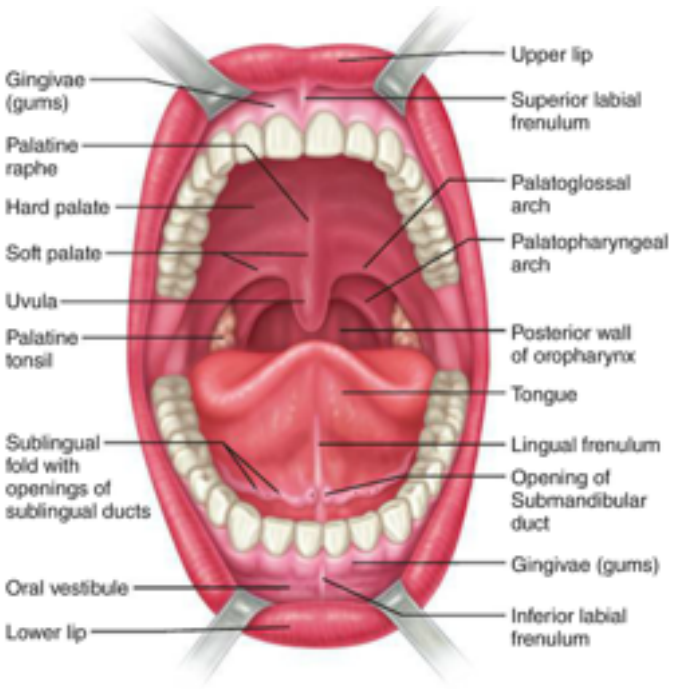


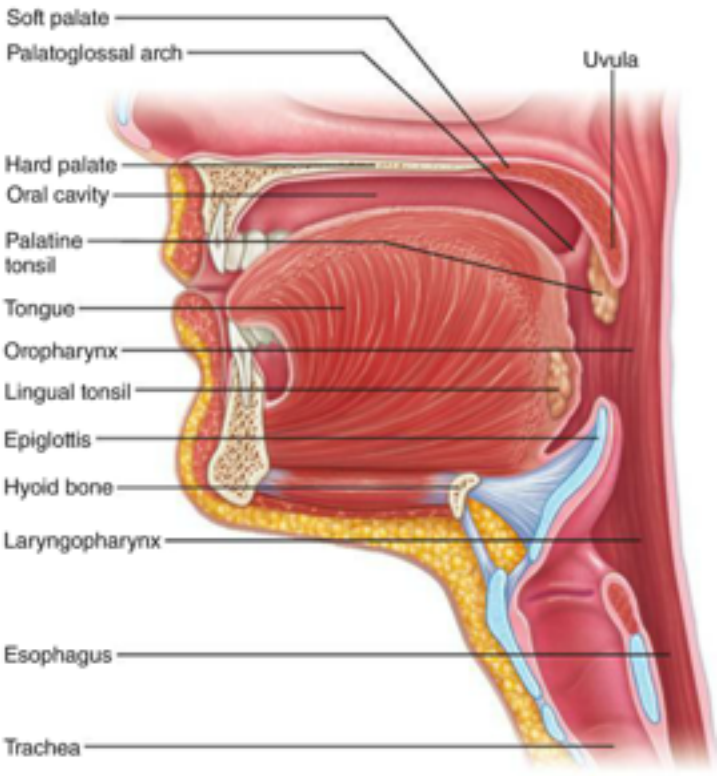
Figure 23.6 Basic structure of the alimentary canal. Its four basic layers are the mucosa, submucosa, muscularis externa, and serosa.

- peritoneal structure have both: a serosa on the side facing the peritoneal cavity and an advent on the side against the dorsal body wall

The Mouth
- vestibule and oral cavity proper
- oral or buccal cavity; bonded by lips, cheeks tongue and palate
- toungue covered by a squamous epithelium,



(b) Anterior view



(a) Sagittal section of the oral cavity and pharynx

epithelium on guns, hard palate/back of tongue
  - back of toungue is also modestly keratinized
    - keratinized for extra protection against hard foods and abrasion

Lips and Cheeks
- core of skeletal muscle
- **Obicularis orbis**: lips
- **Buccinators**: cheeks
- hold food in place during chewing, has a role in speech
- **Red margin**: part of lips where skin is too thin and hypokeratinized, there are no sebaceous or sweat glands (red from blood)

Palate
- hard palate anteriorly, soft palate posteriorly
  - **Hard palate**: underlain by palate bones and palatine process of maxillae, forming rigid surface
    - tongue pushes against rigid surface during chewing
  - **Soft palate**: mostly skeletal muscle
    - rises reflexively to close nasopharynx when we swallow
    - why we cant breathe and swallow at the same time
  - Palatoglossal/Palatopharyngeal arches: joins soft palate to tongue and oropharynx (anchors tongue)

Tongue
- interlacing skeletal muscle fibers and taste buds + some mucus and serous glands
- important for chewing, mixing of food with saliva; forms bolus for swallowing
- important during speech
  - Intrinsic muscles—skeletal
    - muscles within tongue, not attached to bone
    - 3 planes allow for tongue to change shape (thicker, longer, shorter as needed for speech and swallowing)
  - Extrinsic muscles
    - attatched to bones of skull and soft palate of tongue
    - alter tongues position (protrude, retract, move it from side to side)
    - has median septum of connective tissue divides tongue into 2 separate halves
- 3 Types of papillae
  1. **Filiform papillae**
     - conical, contain keratin (stiffens), numerous aligned in parallel rows
     - helps with licking semisolid food, friction lets manipulation of food
  2. **Fungiform papillae**
     - scattered widely over tongue surface, each has vascular core with a reddish hue
     - contain taste buds
  3. **Vallate papillae**
     - V-shaped row at back of tongue
     - like fungiform with additional surrounding furrow

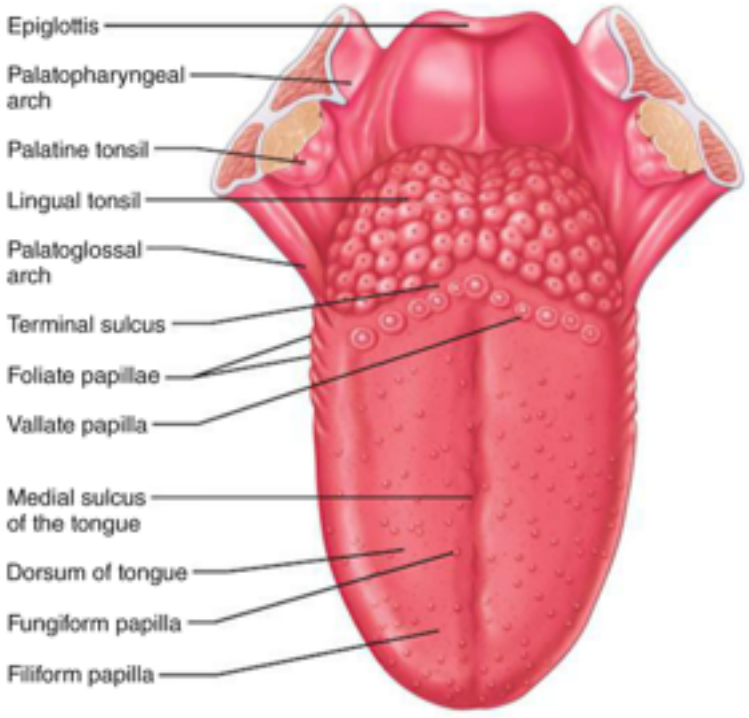
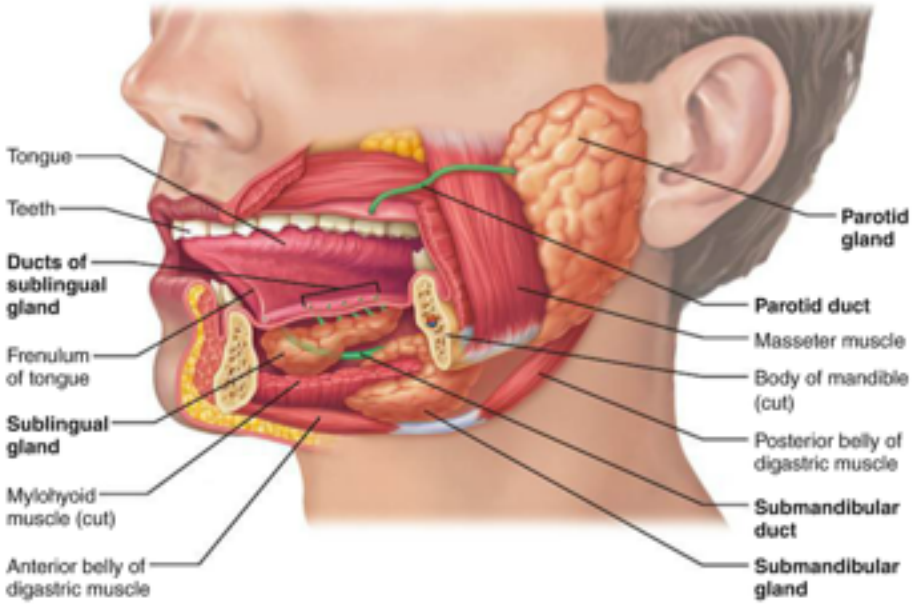


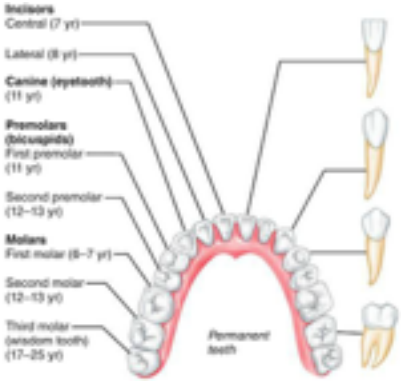
Figure 23.8 Dorsal surface of the tongue, and the tonsils.

- contains taste buds

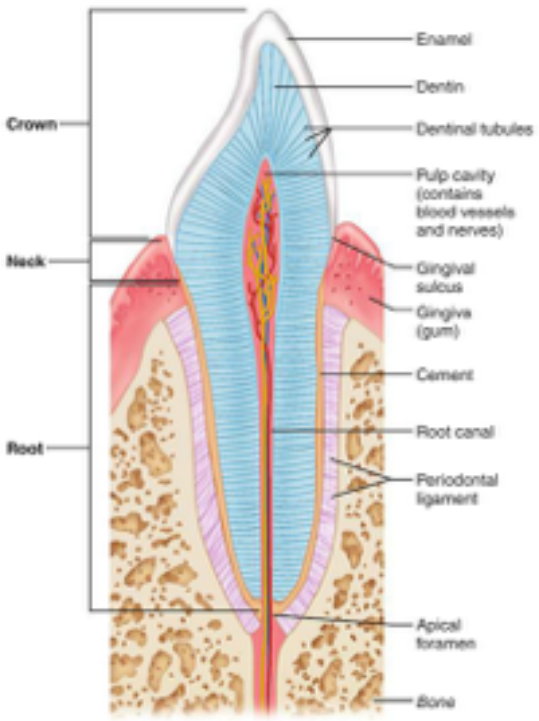
Salivary Glands
- Saliva
- 3 pairs of extrinsic (glads that lie outside the oral cavity) salivary glands
  1. **Parotid glands**
     - anterior between master muscle/skin
     - paratoid duct enters vestibule next to 2nd molar, upper jaw
     - 25% of saliva produced
  2. **Submandiluar glands**
     - medial aspect of mandible
     - runs below mucosa cavity floor, opens at base of lingual freleum
     - 70% of alive produced
  3. **Sublingual glands**
     - under tongue
     - anterior to submandiluar glands
     - opens via many ducts into floor of mouth
     - 5% of saliva
- **Buccal glands**: serous/mucous cells, present in cheek (intrinsic) help keep mouth moist
  - 2 types of security cells in salivary glads
    1. **Serous cells**: produce water secretions producing enzymes, ions, mucin
    2. **Mucous cells**: produce mucous—stringy solution
  - paratoid/submandiluar glands contain mostly serous
  - buccal contain half half
  - sublingual glands contain mostly mucous



Teeth
- in sockets (aveoli) in gum covered margins of mandible/maxilla
- Primary dentition: decidous; milk' baby teeth (20 baby teeth)
- Permanent teeth: larger, deeper roots—all but 3rd molars appear by adolescence
  - 3rd molars appear at age 17-35 (32 teeth)
- specialized tasks



- **Incisors**: chisel shaped for cutting
- **Canines**: conical for tearing and peircing
- **Premolars** (biscupids) and **molars** (4-5 cusps) for crushing
- **Dental formula**: Permanent dentition for 1 half of the mouth
  - 2I, 1C, 2PM, 3M can be upper/lower, left/right



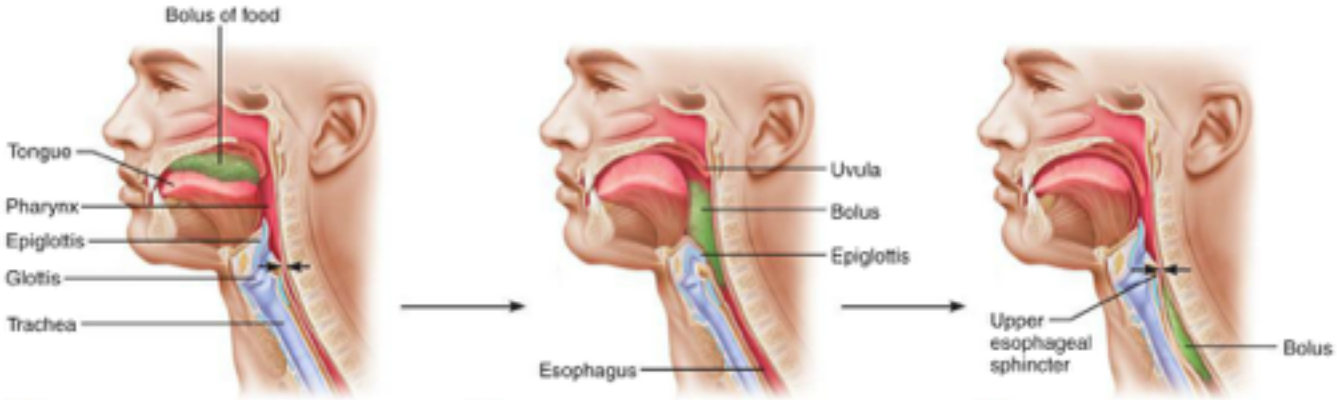
Tooth structure

A. Crown
- aboev gingiva, covered by enamel
  - Enamel is heavily mineralized with Ca++ salts and densely packed hydroxyapatite mineral
  - Enamel cells degenerate when teeth emerge
    - cracked/delayed areas wont heal

B. Root
- embedded in jawbone
  - 1 root for canines and premolars (first upper PMs have 2) Molars have 2-3 roots
  - outer surface of root is covered by calcified connective tissue called Cement—attaching root to periodontal ligament
  - gingiva adhere to enamel; with age recede to sensitive cement
    - tooth will seen longer
  - cell bodies of odontoblasts line the pulp cavity (contains CT, blood vessels, nerve fibres)
    - puple cavity extends into root canal.
  - enamel, dentin, cement is all calcified and resemble bone but avascular
    - cement and dentin (not enamel) also contain collagen

Tooth and Gum Disease
- **Dental Cavities**: bacteria demineralizes enamel/underlying dentin
- **Dental plaque**: flim of sugar, bacteria, and other mouth debris latches onto the teeth and dissolves calcium salt of the teeth
- **Periodontal Disease**: when calculus is not removed—gingivitis—pockets of infection destroys periodontal ligament/activating osteoclasts that dissolve bone

Pharynx
- food passes posteriorly into the oropharynx then into laryngopharynx
- friction resistant stratified epithelium
- skeletal muscle = pharyngeal muscle



- **Deglutition (swallowing)**: consists of voluntary (buccal) and involuntary (pharyngeal-esophageal) phases

Esophagus
- 25cm muscular tube, collapsed when it is empty
- straight down **mediastinum** of thorax; pierces through diaphragm at **esophageal hiatus** and joins stomach at the **cardiac orifice** (gastroesophageal/**cardiac sphincter**) diaphragm also supports sphincter.
- mucous cells on both sides protect the esophagus from reflux stomach acid
- 4 layers
  - Mucosa: non-keratinized stratified squamous cells mucosa and submucosa throws into folds when esophagus is empty; folds flatten during food transit
  - Submucosa: contains mucus secreting esophageal glads
  - Muscularis externa: skeletal muscle in upper 1/3 the smooth muscle in lower 2/3
  - Fibrous Adventia instead of slippery serosa

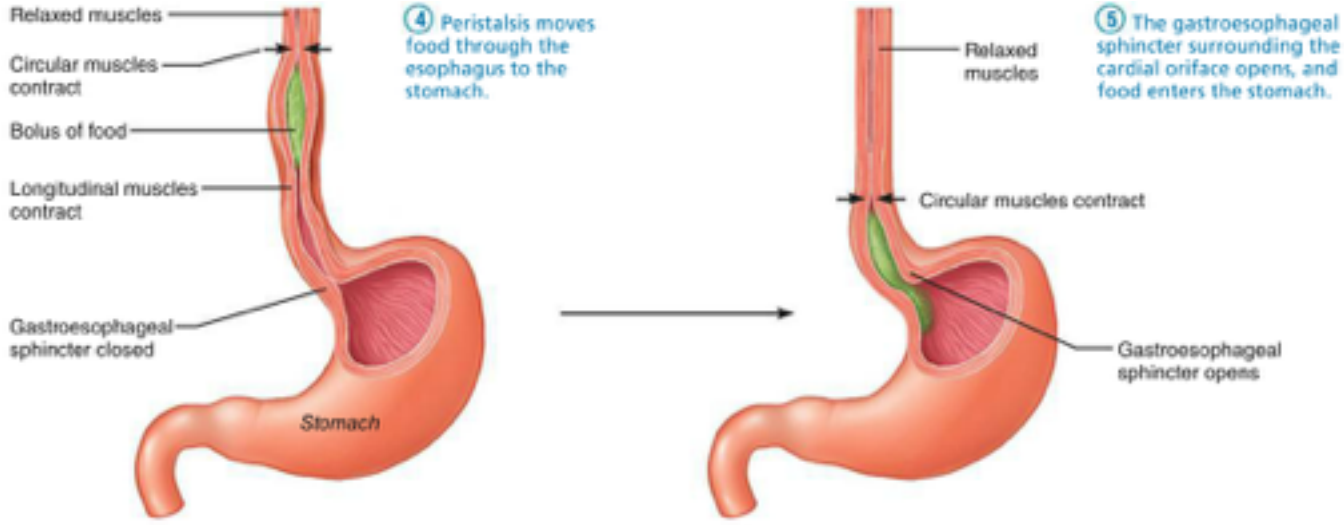


Figure 23.13 Deglutition (swallowing). The process of swallowing consists of a voluntary (buccal) phase (step 1) and an involuntary (pharyngeal-esophageal) phase (steps 2–5).

Stomach
- acts as a temporary storage tank initiates protein digestion and converts content into chyme
- fixed at esophagus/small intestine but is movable in-between
- upper left quadrant of peritoneal cavity by liver/diaphragm
  - horizonntal in short people, vertical in tall people

Gross Anatomy
- 25cm long with 50ml-4L capacity
- regions: Cardia; Fundus; body; Pyloric region (antrum to pyloric canal to pyloric sphincter)
- **Rugae**: when empty, stomach collapses—the large longitudinal folds
- Muscularis externa: help with movement, physically smashing into semisolid kind
- stomach is innervated by th autonomic nervous system
  1. Sympathtic (Flight/fight) fibres from thoracic splanchnic nerve
  2. Parasympathetic (resting/digesting) fibres from vagus nerve

Microscopic Anatomy
- muscularis externa has incomplete innermost layer of smooth muscle fibrils that run obliquely (helps break down food)
- surface epithelium (mostly goblet cells) produce mucous with bicarbonate rich layer beneath

- smooth lining dotted with millions of gastric pits leading to gastric glands which produce gastric juice
- composition varies on region of stomach (some areas secrete more mucous/hormones)

Types of Gland Cells

A. Mucous neck cells
   - at neck of glands
   - produce a different type of main (acidic) for unknown reason

B. Pareital cells
   - secretes HCl/intrinsic factor
   - activation of pepsin—denatures protein, breaks down cells walls of plant food, and kills bacteria
   - intrinsic factor is glycoprotein required for vitamin B12 absorption in small intestine

C. Chief cells
   - secrete pepsinogen (precursor of pepsin)
   - pepsin catalyzes conversion of pepsinogen to pepsin, breaks down protein
   - also secrete lipases—fat digesting enzyme

D. Enteroendocrine cells
   - secrete hormones including gastrin, histamine, serotonin, somatostatin

Functional Anatomy

- lumen of stomach is a harsh environment with high concentrations of protease (in for of pepsinogen) and HCl
- stomach protects itself with
  - Mucosal Barrier
    A. bicarbonate-rich mucus builds up on stomach wall (alkaline protects from gastric juice)
    B. epithelial cells joined by tight junctions prevent gastric juice from leaking into tissue
    C. epithelial calls replaced bt stem cells that reside in gastric pit/gastric glad junction
       - renewed every 3-6 days
  - damage to mucosal barrier can cause inflammation of stomach wall—gastritis
  - persistent damage can promote gastric and peptic ulcers (erosions of stomach wall)

• Heliobacter pylori
  - create niche by neutralizing the HCL
  - secretes cytotoxins—damages mucosa
  - disrupts cellular adhesion
  - causes inflammation/further tissue damage
  - there events lease mucosa vulnerable to the HCl in stomach
    - ulcers
  - treatment H2 (histamine) blockers eaten to inhibit HCl secretion + eat antibiotics

Small Intestine

- major digestive organ responsible for almost all nutrients and water
- extends from **pyloric sphincter** (stomach-duodenum) to the **ileocecal valve**
- because of muscle tone, the small intestine is only 2-4 metres during life and 6-7 metres in a cadaver
- 3 sections

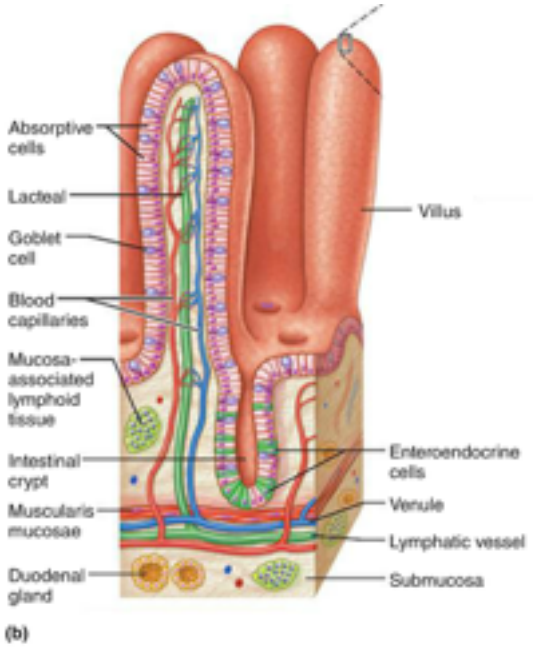
1. Duodenum
   - 25 cm long and mostly retroperitoneal, shortest intestinal subdivision
   - contains **Hepatopancreatic ampulla**: pancreatic juice from he pancreas—bulblike point on the wall of duodenum
   - **Hepatopancreatic sphincter**: smooth muscle valve that controls the entry of bile and pancreatic juice
2. Jejunum
   - 2.5m long, intraperitoneal
3. Ileum

- 3.6m long, joins the large intestine at the ileocecal valve
- intraperitoneal

- Jejunum and Ileum are suspended from the posterior abdominal wall by fan shaped mesentery and are framed by the large intestine
  - innervation:
    - sympathetic—thoracic splanchnic nerves
    - parasympathetic—parasympathetic nerve

Microscopic Anatomy of Small Intestine

- most absorption occurs in proximal part of small intestine
- 600 fold increase in surface area
  A. **Circular fold** (plicae circulares): deep, permanent folds of the mucosa and submucosa. 1cm tall, folds force chyme to spiral through lumen, slowing movement and allowing for full nutrient absorption
  B. **Villi**: fingerlike projections of the mucosa over 1mm high, longest in the duodenum and shorten along length of intestine
  C. Microvilli: long densely packed absorptive cells give fuzzy appearance called "**brush border**"
    - harbours **Brush border enzymes**: complete the digestion of carbohydrates and proteins in the small intestine

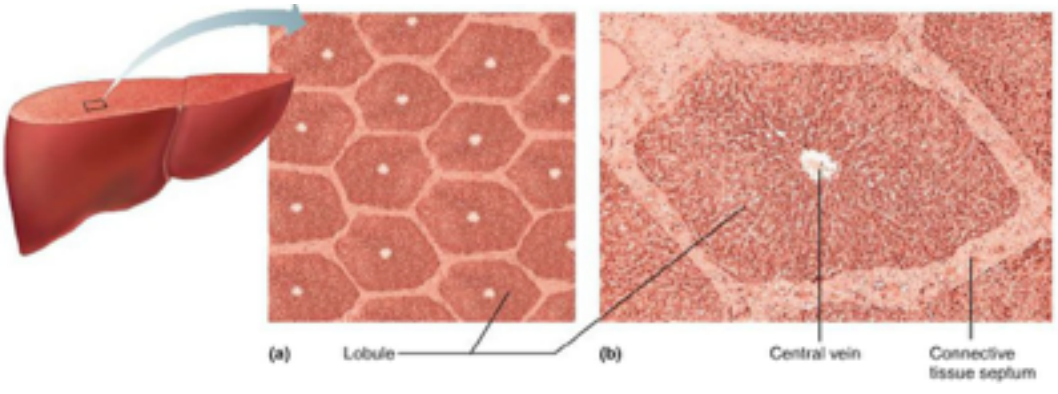


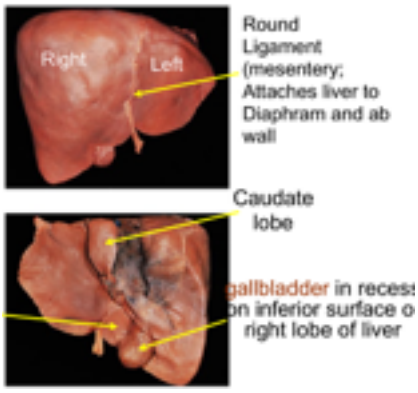
Histology of Small Intestine

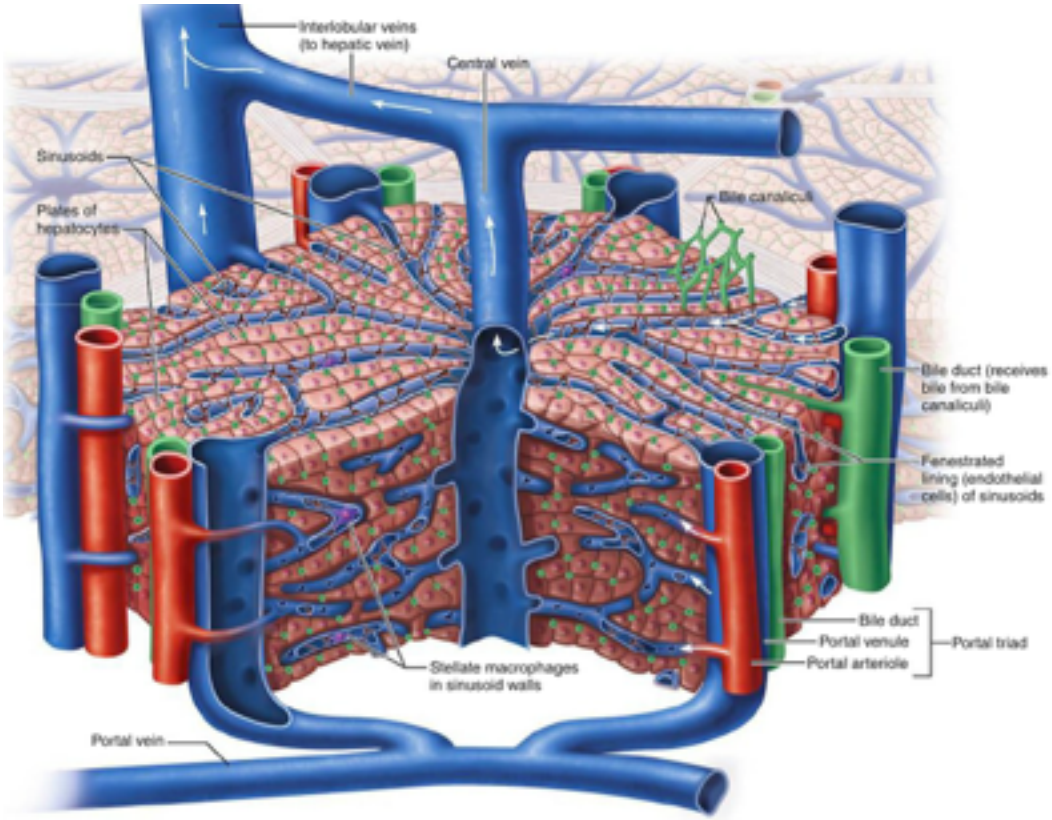
- **Intestinal crypts** (crypts of Lieberkuhn) are located between villi. Crypt cells secrete intestinal juice serving as a carrier fluid for digesting chyme (mostly water/mucous, slightly alkaline – Little in the way of enzymes)
- Crypts also contain **Paneth** cells fortify the small intestine defences by secreting defensins and lysozyme.
  - decreases along the length of the small intestine—goblet cells become more abundant
- The epithelium of the villus "sheds" into the intestinal lumen and is completely turned over (renewed) every 4-6 days by "stem" cells which reside at the base of the crypts (Paneth cells renew about every ~20 days)
- radiation therapy/chemo therapy target rapidly dividing cells, destroying the rapidly dividing GI tract epithelium

Liver

- largest gland in body at 1.4 kg, situated under diaphragm and protected by rib cage
- 4 lobes: right, left caudate, quadrate
- The functional units of the liver are composed of liver lobules composed of hexagonal lobules. Within each lobule, hepatocytes radiate from a central vein



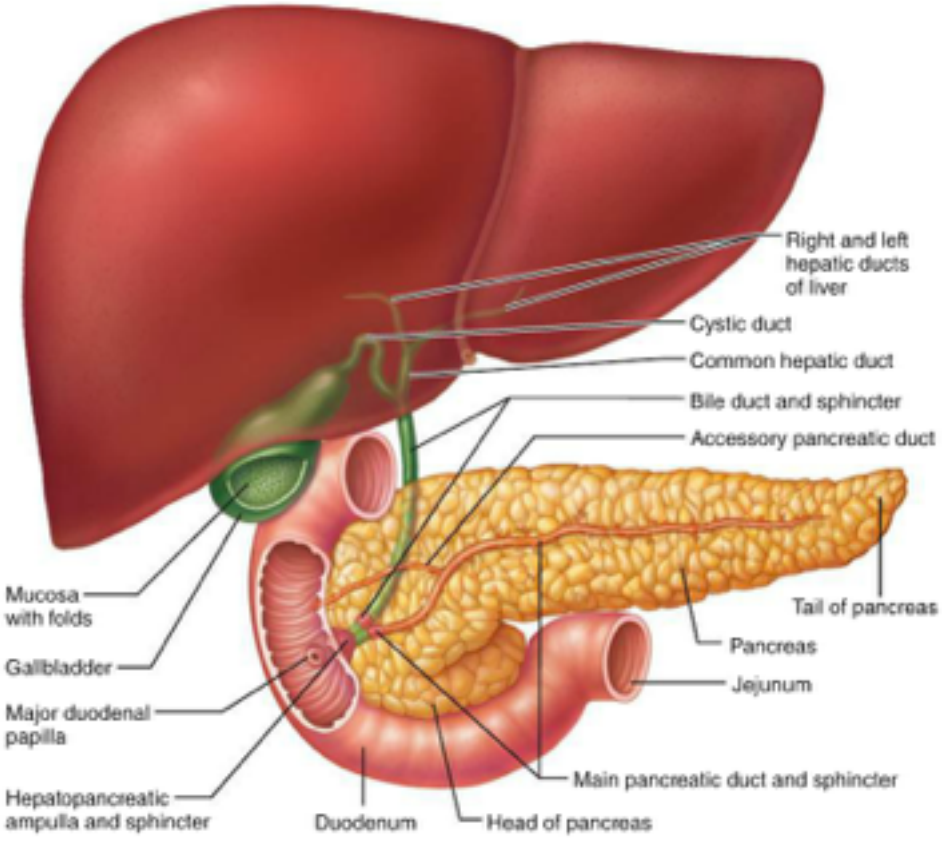




-At each of the 6 corners of the hepatic lobule is a **portal triad**, composed of a portal **arteriole**, a portal **venule** and a **bile duct**.
-Venous (portal) and arterial blood bathe the hepatocytes through a "leaky" capillary system, the liver **sinusoids**; blood is collected by the central vein, then hepatic veins which empty into the vena cava.

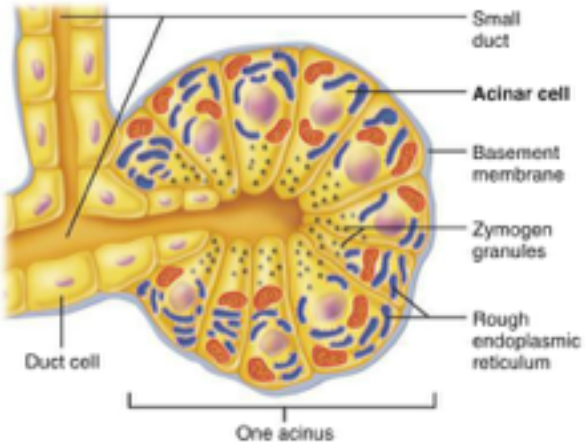
- Bile, produced by the hepatocytes, drains via cannuculi opposite to the blood flow, and is collected by the bile duct

- Bile produced from the liver exits via multiple bile ducts that fuse to form the **common hepatic duct**. This then fuses with the **cystic duct** (which drains the gallbladder) to form the **bile duct** which subsequently joins the main pancreatic duct at the hepatopancreatic ampulla, which enters the duodenum.
- As well as producing bile, hepatocytes also
  1. process nutrients, store glycogen, synthesize plasma proteins
  2. store fat-soluble vitamins
  3. detoxify blood



Gallbladder
- Thin-walled, green muscular sac ~10 cm in length
- Stores & concentrates bile for later (concentrates it by absorbing some of its water and ions) secretion into the duodenum from the cystic duct into the bile duct
- Bile: Alkali substances containing bile salts/pigments, cholesterol, triglycerides, phospholipids and electrolytes.
    - too much few bile salts and phospholipids will cause cholesterol to crystallize, forming gallstones, obstructing the flow of bile from the gallbladder
    - when the duct contracts, crystallized cholesterol will cause pain in the right thoracic region
        - blockage of bile ducts will also cause yellow bile pigments to seep into the blood and skin will eventually turn yellow

Pancreas
- Tadpole-shaped, largely retroperitoneal, gland extending across the abdomen from its tail (adjacent to spleen) to its head (encircled by duodenum).
- Produces pancreatic juice (drained from the pancreatic duct)
    - contains a wide range of digestive enzymes and bicarbonate helping neutralize chyme entering the duodenum providing optimal environments for intestinal and pancreatic enzymes
    - secreted via the pancreatic duct to the bile duct/ hepatopancreatic ampulla, emptying into the duodenum
    - accessory pancreatic duct also empties into the duodenum.
- **Zymogen granules:** in pancreatic **acinar cells** (exocrine pancreas—relsease) contain inactive digestive enzymes.
    - acinar produces enzyme rich component of the pancreatic juice has a lot of rough endoplasmic reticulum to make enzymes
- **Pancreatic islets** (islets of Langerhans – endocrine pancreas) secrete insulin and glucagon – important for metabolic regulation of blood sugar levels

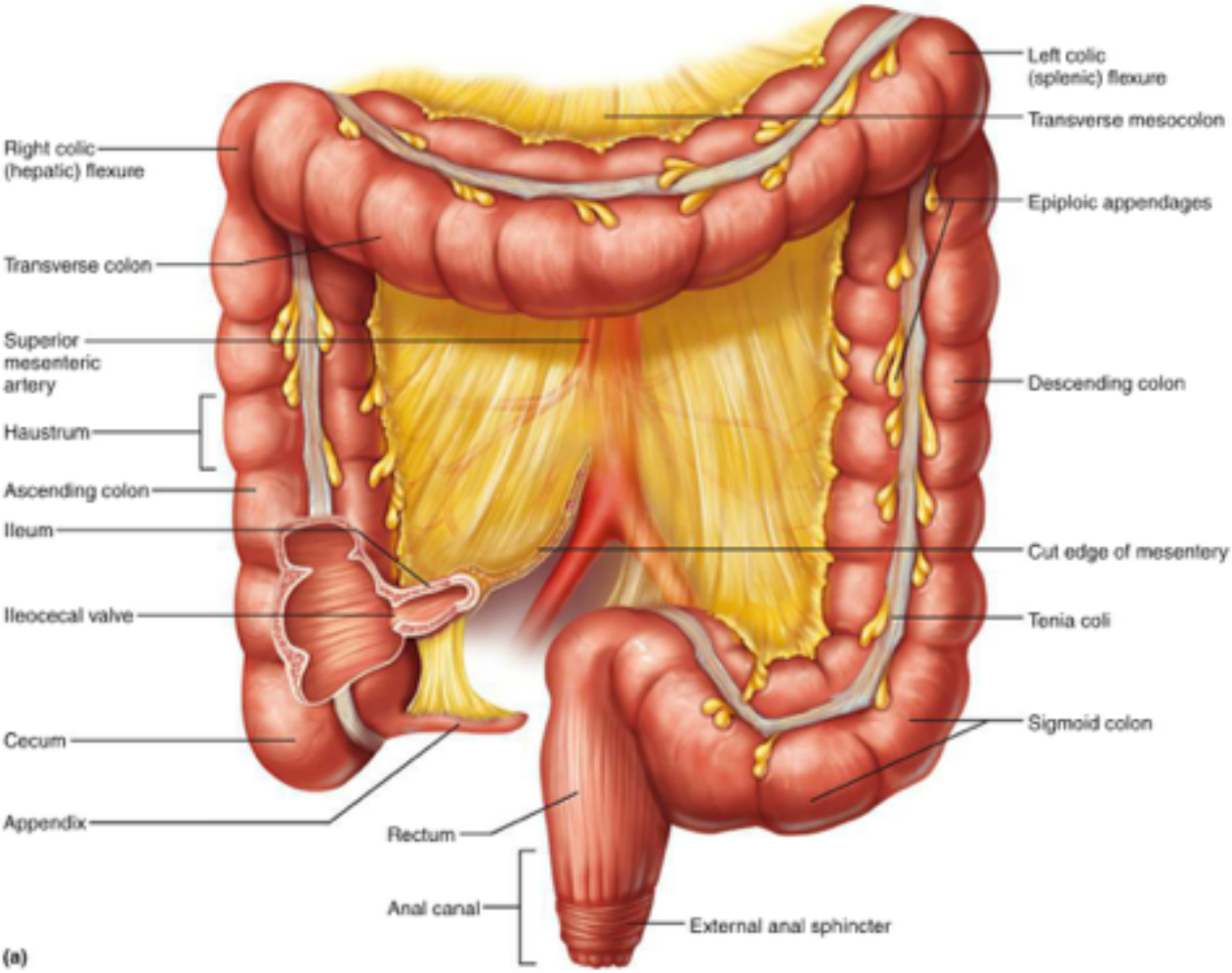


Large Intestine
- extends from ileocecal valve to anus = 1.5m, 7cm diameter
- absorbs water from indigestible food residues; eliminates rest as feces
- frames the small intestine on three sides (ileocecal valve to anus)

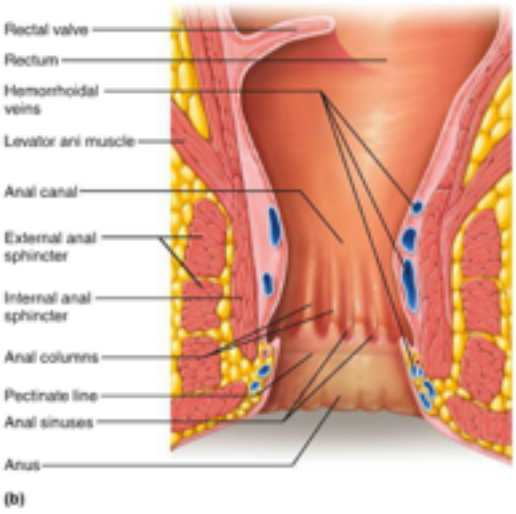
Gross Anatomy of Large Intestine
- longitudinal later of muscular is reduced to three bands of smooth muscle called **teniae coli**. Their tone pickers wall of large intestine into **haustra** (pocket like sacks of large intestine)
- **Epiploic appendages**: small fat filled pushes of visceral peritoneum—hang from surface of large intestine
    - significance isn't known
- large instestines has following subdivisions
    - **Cecum**: blind pouch, lies below ileocecal valve, first part of large intestine
        - attached to posteromedial surface of cecum is the wormlike **appendix**: contains masses go lymphoid tissue and apart of MALT. Also recolonizes the gut by serving as a bacteria storehouse—twisted structure provides perfect location for bacteria to accumulate and multiply
    - **Colon**—distinct regions
        1. Ascending colon
        2. Right colic (hepatic) fixture

3. Transverse colon (intraperitoneal)
4. Left colic (splenic) fixture
5. Descending colon
6. Sigmoid colon (intraperitoneal)

- **Rectum**
  - in the pelvis at 3rd level of sacral vetebra (straight)
  - sigmoid colon joins retum



- **Anal canal**
  - last segment 3cm long lies in perineum, external to the abdominopelvic cavity
  - 2 sphincters
    1. Involuntary anal sphincter: made of smooth muscle
    2. External anal sphincter: composed to skeletal muscle
       - sphincters open and close the anus that with normally closed
  - 2 superficial venous plexuses associated with anal canal - when inflamed, leads to *haemorrhoids*
    - no haustra in rectum or anal canal
    - muscular layers complete & well- developed so can expel feces – regulated by internal (smooth muscle)



and external (skeletal muscle) anal sphincters.

Microscopic Anatomy

- mucosa is **simple columnar epithelium** except in anal canal which is lined by **stratified squamous epithelium**
  - abundant crypts with many goblet cells
    - eases fecal passage and protects intestinal wall from irritating acids and gases released by resident bacteria

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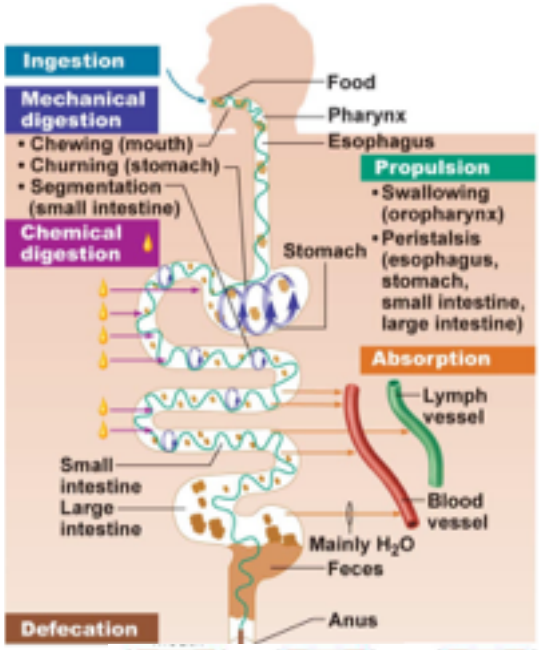
Digestive Processes



6 essential processes

I. Ingestion
II. Propulsion
III. Mechanical Digestion
IV. Chemical Digestion
V. Absorption
VI. Defecation

Ingestion

- taking in of food to the digestive tract via the mouth

Propulsion

- Mechanical process of moving food through alimentary canal: starts with swallowing (voluntary)
- Food is subsequently moved through the digestive tract via peristalsis, an involuntary process involving smooth muscle.
- while peristalsis involves *directional* movement of food, it also contributes *some* mixing due to alternate waves of contraction & relaxation of smooth muscles in the organ walls

Mechanical Digestion

- Physical process - prepares food for subsequent chemical and/or enzymatic digestion.
- increases the surface area of ingested food, starting with chewing
- **Segmentation**: mixes food with digestive juices—increases absorption by repeatedly moving different parts of food mass over intestinal mucosa.

Chemical Digestion

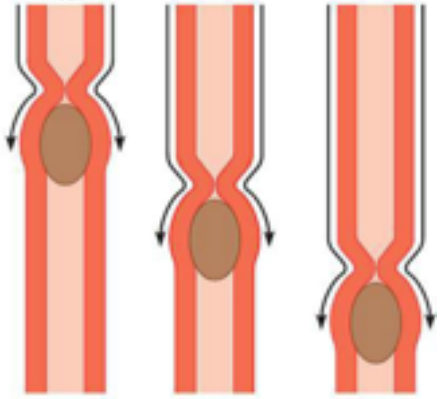
- series of **catabolic** steps used to break down complex food molecules into their basic “building blocks”
- necessary for absorption
- process relies on enzymes which are secreted into the lumen of the alimentary canal
- beings with amylase in the mouth

Apsorption

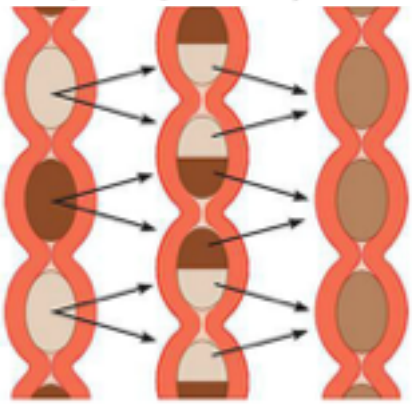
- process whereby the passage of digested end products, vitamins, minerals and water from the lumen of the GI tract through the mucosal lining
  - via active or passive transport into blood or lymph
- Most absorption takes place in the small intestine.

Defication

- eliminates indigestible substances from body via anus in form of feces



(a) Peristalsis: Adjacent segments of alimentary tract organs alternately contract and relax, moving food along the tract distally.



(b) Segmentation: Nonadjacent segments of alimentary tract organs alternately contract and relax, moving food forward then backward. Food mixing and slow food propulsion occur.

Basic Functional Concepts

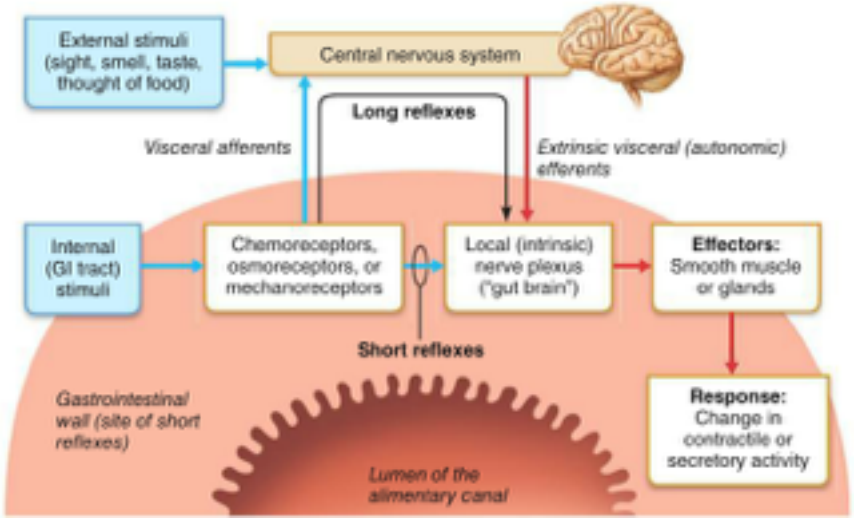
- Regulatory mechanisms act to create optimal conditions in the GI lumen for both digestion and absorption of the products of digestion

Regulatory Stimuli can be Mechanical or Chemical

- mechano-, osmo- & chemoreceptors located in walls of GI tract organs to detect such stimuli
- key signals
    A. stretch of organ wall due to filling
    B. osmolarity & pH of contents, which change during food processing
    C. substrates & end-products of digestion
    D. stimuli activate receptors that result in reflexes leading to

• Stimuli active receptors that result in reflexes leading to:

- Altered secretion (increase or decrease) of digestive juices/enzymes into the GI lumen or of hormones into the blood stream
- Change in the mixing & propulsion of the contents of GI tract



Regulation and be intrinsic or extrinsic

I. **Short reflexes**: mediated by local (enteric) plexuses in response to GI tract stimuli (*intrinsic*)

II. **Long reflexes**:triggered by extrinsic ***or*** intrinsic stimuli

- involve CNS centres & *extrinsic* autonomic nerves
- Reflexes typically converge on

• **Submucosal plexus**: occupies the submucosal plexus

• **Myenteric plexus**: lies between circular and longitudinal muscle laters or muscular externa

- neurons of these plexuses provide nerve supply to the GI tract wall and control the motility (motion) Pg. 855

- Generally: Smooth muscle is excited by nerves secreting Acetylcholine or Substance P
    - inhibited by nerves secreting Vasoactive Intestinal Peptide (VIP) or nitric oxide (NO)
- stomach & small intestine also contain **hormone-producing cells** that respond to local chemical factors, signals from nerve fibres or to stretch.
- hormones may act locally or travel via blood to adjacent organs to influence secretory or contractile activity

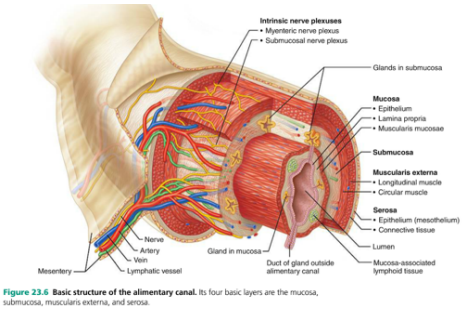


Figure 23.6 **Basic structure of the alimentary canal.** Its four basic layers are the mucosa, submucosa, muscularis externa, and serosa.

Oral Cavity Regulation

- is the only part of GI tract for ingestion
- Digestive functions of mouth carried out by: teeth, tongue, salivary glands (mechanical, chemical)
- Mouth also begins propulsive act of swallowing food traverses **pharynx** & enters **esophagus**

Digestive Processes in mouth

- Mechanical = chewing (mastication)
- partly voluntary & partly reflexive, results in mechanical breakdown & mixing of food.
- Chemical = Enzymes secreted by products of the salivary glands.
    - Typically no absorption in mouth (some notable exceptions such as nitroglycerine)

Saliva

A. Cleanses mouth
B. Dissolves food chemicals so they can be tasted
C. moistens and compacts food bolus
D. contains salivary amylase—beings digestion of starchy food

- composition
  - 97-99.5% water (therefore hypo-osmotic); pH 6.75-7
  - osmolarity depends on stimulus for salivation and precise glands that are active
  - saliva contains: electrolytes (Na, K, Cl, PO& HCO), amylase (initiates starch digestion) mucin (lubricates), urea & uric acid (metabolic waste products)
  - Intrinsic salivary (buccal) glands secrete lingual lipase
  - Additional secretions include:
    - IgA antibodies
    - lysozyme: bactericidal enzyme that inhibits bacterial growth in mouth and may help prevent tooth decay
    - defensins: acts as local antibiotic and function as cytokines to call defensive cells
  - in addition, bacteria that live at back of tongue promote conversion of food derived nitrates in saliva to nitric oxide
    - happens around gums, where acid-producing bacteria cluster

Control of Salivation

- Average output = 1000-1500 ml/day
- **Intrinsic** salavary glands (0.1 ml/min continuous secretion) keep mouth moist
  - Intake of food and/or other stimuli are required to activate extrinsic glands (up to 4 ml/min)
- Regulated primarily by parasympathetic division of autonomic nervous system:
- Chemoreceptors & mechanoreceptors in mouth signal to the **salivatory nuclei** in brain stem (pons and medulla)
  - results in increased parasympathetic activity via (**facial** & **glossopharyngeal** nerves [VII & IX]) to watery serous secretions, enzyme rich saliva
- Chemoreceptors activated most strongly by acids, while mechanoreceptors activated by **any** mechanical stimulus in mouth
- Sympathetic stimulation causes increase in mucous secretion
  - Strong stimulation constricts blood vessels serving saliva glands – dry mouth (**xerostomia**)
    - dehydration can also inhibit salivation because low blood volume reduces filtration pressure at capillary beds
- Salivation can also be triggered by sight, smell, or even the thought of food and by irritation
  - (e.g. bacteria, spicy food, hyperacidity) in the lower GI tract—saliva neutralizes the acid coming up from stomach

Voluntary/involuntary Regulation of Deglutition

- swallowing
  - coordinated activity of tongue, soft palate, pharynx, esophagus involving >22 separate muscle groups
  - 2 phases: buccal & pharyngeal-esophageal
    1. Buccal
       - Phaseoccurs in mouth; **voluntary**
       - Tip of tongue forced against hard palate.
       - Tongue is then contracted to force bolus of food into oropharynx
       - In pharynx, food stimulates tactile receptors resulting in involuntary reflex activity
    2. Pharyngeal-esophagealInvoluntary
       - controlled by **swallowing centre** in medulla & lower pons through cranial nerves (including vagus)

- All routes except to stomach blocked off & food squeezed into esophagus by peristaltic contractions

Heartburn
- burning, radiating substernal pain due to regurgitation of gastric juice into esophagus
- causes: gastric reflux - due to eating/drinking to excess, obesity or pregnancy, running; hiatal hernia. [GERD gastroesophageal reflux disease]
- **Hiatal Hernia**: structural abnormality due to abnormal relaxation or weakening of the gastroesophageal sphincter—juice in stomach may enter esophagus
- Barretts Esophagus: intestinal lining develops at the esophagus (may be related to GERD)

Stomach
- temporary storgae tank
- beginning of chemical break down of proteins; food converted to chyme

Digestive Processes Occurring in the stomach
- Mechanical digestion via churning action of stomach and propulsion
- Protein digestion essentially only type of significant enzymatic digestion—primarily via action of **pepsin** (precursor being pepsinogen and activated by HCl)
  - In children, stomach glands also secrete **rennin** which acts to digest casein (milk).
- lipid-soluble drugs such as ..... & ..... are easily absorbed by the stomach mucosa; what can happen if there is considerable or regular movement of these drugs across the stomach lining?
- only stomach function essential to life is production of **intrinsic factor** – required to absorb vitamin b12 which is needed to produce erythrocytes
- secretion of HCl facilitates reduction of food particles into chyme denatures proteins & nucleic acids
  - transforms inactive pepsinogen into pepsin and destroys bacteria

Regulation of Gastric Secretion
- gastric mucosa secretes up to 2-3 L of gastric juice each day
- controlled by both neural & hormonal mechanisms

(i) **Neural**: long (vagus nerve-mediated) & short (local enteric) nerve reflexes

(ii) **Hormonal**: GASTRIN (secreted by G cells of stomach and duodenum): stimulates secretion of pepsinogen & HCl
- Stimuli acting at three distinct sites: the head, the stomach and the small intestine, impact on gastric secretory activity. Accordingly, there are three phases of gastric secretion:

A. Cephalic phase: occurs before food enters the stomach, short lived phase (a few minutes long)
   - **olfactory/taste bud inputs:** hypothalamus vagal nuclei of medulla oblongata – leads to stimulation of secretion of gastric juice
   - **visual/conscious thought inputs *conditioned*** reflex based on prior experience (this reflex significantly reduced if depressed/no appetite)
     - triggered by the smell, taste, sight or even simply the thought of food.

B. Gastric
   - 3-4 hours long
   - provides ~2/3 gastric secretions
   - initiated by distension of stomach, peptides, low acidity
     - **distension**: stretch receptors local & long (vagal reflexes release of Ach and increases output of gastric juices)
     - **peptides & low acidity**: more important trigger
       - leads to secretion of gastrin (by “G” cells of stomach antrum), and histamine (by enterochromaffin-like (ECL) cells & mast cells)
       - neural reflexes also ac
       - Gastrin increases gastric juice secretion, especially HCL by parietal cells.

- caffeine also ⇑ gastrin secretion
proteins are buffers
- gastrin secretion inhibited when gastric pH<2 (feedback) & by emotional upsets (via sympathetic ns) Pg.870

- Process of HCl secretion
- H+ actively pumped (against steep concentration gradient) into stomach lumen in response to Gastrin + Ach + Histamine
- H+ derived from carbonic acid
- Cl- follows H+ to maintain electrical balance
- H+ , K+ and ATPase product

• Alkaline tide: HCO3 ejected into capillary blood—blood drawing from stomach more alkaline than blood serving it.

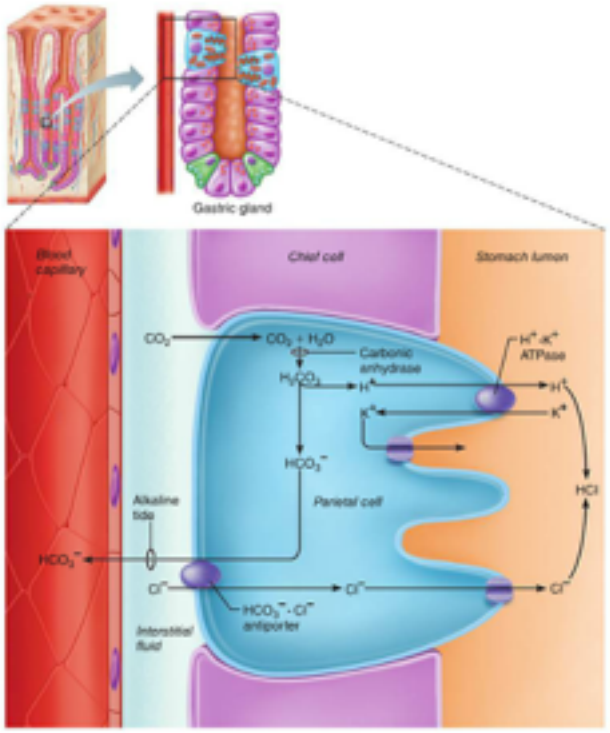
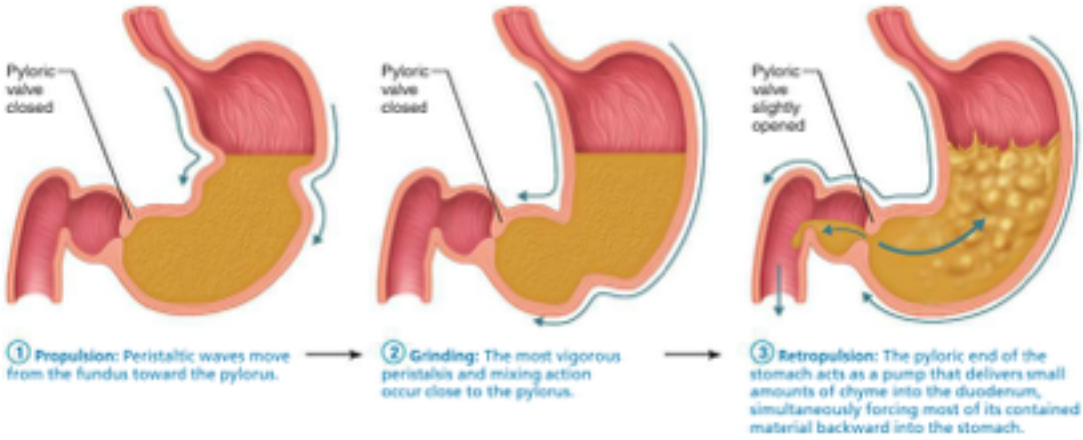


Figure 23.18 Mechanism of HCl secretion by parietal cells. H^+ and HCO_3^- (bicarbonate ions) are generated from the dissociation of carbonic acid (H_2CO_3) within the parietal cell. As H^+-K^+ ATPase pumps H^+ into the lumen, K^+ enters the cell. Meanwhile, the HCO_3^--Cl^- antiporter transports HCO_3^- into the interstitial space in exchange for chloride ions (Cl^-), establishing the alkaline tide. Cl^- and K^+ then diffuse into the lumen through membrane channels.

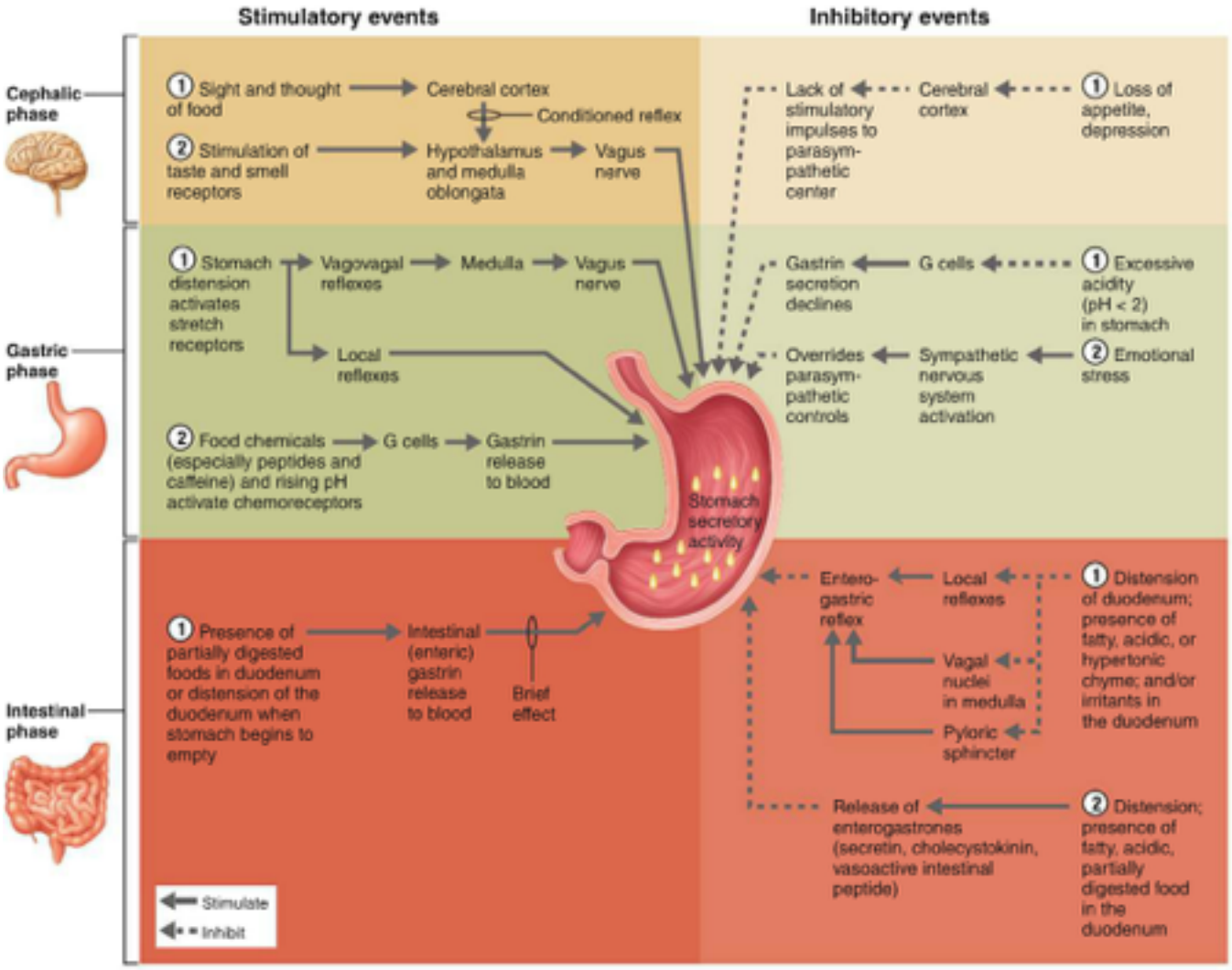
• Ulcer: excess acid secretion by stomach overcomes protective mucus barrier & damages organ lining (esophagus, stomach or duodenum)
- more common in esophagus or duodenum –
- risk factors: smoking, habitual use of NSAIDs, alcohol, certain chronic diseases, infection with Helicobacter pylori
- treatment- cimetidine (Tagamet) - inhibits histamine-H2 receptor interaction
- Other principle drug target is the gastric proton pump. Inhibitors such as omeprazole block the pump decreasing luminal acidity

C. Intestinal
- **excitatory** component followed by an **inhibitory** component
  a) **excitatory** mediated by **intestinal gastrin** from **intestinal mucosal cells** triggered by low pH and foodstuffs as chyme first enters duodenum.
  b) **inhibitory enterogastric reflex** occurs as duodenum continues to fill with H+, proteins, fats, etc: Result:
     1. vagal nuclei in medulla inhibited
     2. local reflexes inhibited
     3. sympathetic fibers activated - pyloric sphincter tightens
- Secretion of enterogastrones; secretin, cholecystokinin, vasoactive intestinal peptide (VIP), gastric inhibitory peptide.
- result: gastric secretion decreases and gastric emptying slows
- Beneficial effects:
  (i) small intestine protected from excess acidity
  (ii) entry of chyme correlated with intestinal processing ability



- **Gastric Motility and Emptying**: Receptive relaxation of smooth muscle (fundus and body) – allows stomach to stretch without increasing tension

- **Regulation of Gastric Emptying**
  Stomach usually empties completely within 4 hr after a meal, depending on volume of meal and contents. Carbohydrate meal moves through quickly; fats slow movement by coating top of chyme & being digested slowly in duodenum – delays stomach emptying to up to 6 hours; rate of stomach emptying is largely dependent on signalling from the *duodenum*



- Vomiting (Emesis):
  - excessive stretching of stomach/intestine or presence of irritants
    - eg: bacterial toxins, excessive alcohol, spicy foods, some drugs
    - emetic centre in medulla is stimulated & motor responses elicited:
      A. skeletal muscles of abdominal wall & diaphragm contract
      B. cardiac sphincter relaxes
      C. soft palate rises to close off nasal passages

Composition of Bile
- yellow-green, alkaline
- hepatocytes produce 500-1000ml bile/day

- contains bile salts, bile pigments, cholesterol, neutral fats, phospholipids & electrolytes
- In bile salts, cholic acid & chenodeoxycholic acid: cholesterol derivatives that emulsify fats—breaks into smaller pieces
    - bile salts amphipathic (hydrophobic/hydrophillic parts)
        - hydrophobic (nonpolar) parts cling onto the fat, the hydrophilic (polar) part helps them repel each other and interact with water
- main bile pigment is bilirubin (waste product of hemoglobin); intestinal bacteria convert bilirubin to stercobilin ➔ turns feces brown
- ONLY digestive function of liver: produce bile, a cholesterol derivative
    - gallbladder: a storage organ for bile – contracts upon stimulus to release bile
    - bile is a fat emulsifier: larger surface area when droplets are smaller, easier for fat digesting enzymes
        - Bile production and flow into the duodenum

Gallbladder

- Liver produces bile constantly. When digestion not occurring, hepatopancreatic sphincter is closed, bile "backs up" through the cystic duct; stored & concentrated in gallbladder.
- Release of bile into duodenum occurs when muscular wall of gallbladder contracts, bile expelled into cystic duct ➔ bile duct
- when digestion not occurring, hepatopancreatic sphincter closed
    - major stimulus for gallbladder contraction is cholecystokinin (CCK; (cholecysto = gallbladder and kinin = movement): secreted by small intestine in response to secretin, proteins, fat and chyme Secretin also increases bile synthesis by liver.
- **CCK:** (i) stimulates gallbladder contraction (ii) stimulates secretion of pancreatic juice (iii) relaxes hepatopancreatic sphincter
- bile salts are conserved by recycling (90-95%) through the enterohepatic circulation: Ileum (bile transporter) to blood to liver (via hepatic portal vein) to new bile.
- Bile salts in portal circulation is the most important stimulus for bile secretion
- **Gallstones**: too much cholesterol, too little bile salts allows the cholesterol to crystallize—obstruct flow of bile
- obstructive jaundice: jaundice cause by blocked ducts
    - also caused by liver disease
    - ***Gallstone treatments:*** dissolve with drugs, pulverize with usound, vaporize with lasers, surgical removal of gallbladder.
        - after removal bile duct enlarges to assume bile storing role

Pancreas

- acini: groups of secretory acinar cells clustered around ducts. Mediate the **exocrine** function of the pancreas
- Produces a range of enzymes that digest ***all*** categories of food

Composition of Pancreatic Juice (exocrine)

- ~1200-1500 ml/day: water + electrolytes (***bicarbonate***; pH~8) + enzymes
- alkalinity allows it to:
    - (i) neutralize acidic chyme
    - (ii) create optimal pH for intestinal & pancreatic enzymes
- proteolytic enzymes are produced & released in **inactive**, **precursor** form - activated once in duodenum to prevent the pancreas from digesting itself
- amylase, lipases & nucleases secreted in active form but typically require ions or bile for optimum activity
- Pancreas secretes bicarbonate to neutralize HCl in chyme. A result of this bicarb secretion is extrusion of H into the bloodstream by the pancreas.
    - This counters the bicarb secreted by the stomach, resulting in neutral pH of venous flow returning to the heart

Regulation of Pancreatic Secretion

- Hormonal (2 intestinal hormones):
  (i) Secretin: exposure of fatty chyme, HCl triggers secretion, stimulates pancreatic duct cells to secrete watery, bicarbonate-rich juice
  (ii) CCK: stimulates pancreatic acinar cells to secrete enzyme-rich juice
    - Presence of *both* hormones results in substantial increase in pancreatic secretions.

E. Parasympathetic nervous system:

- vagal stimulation of secretory activity
- primarily during cephalic & gastric phases of gastric secretion

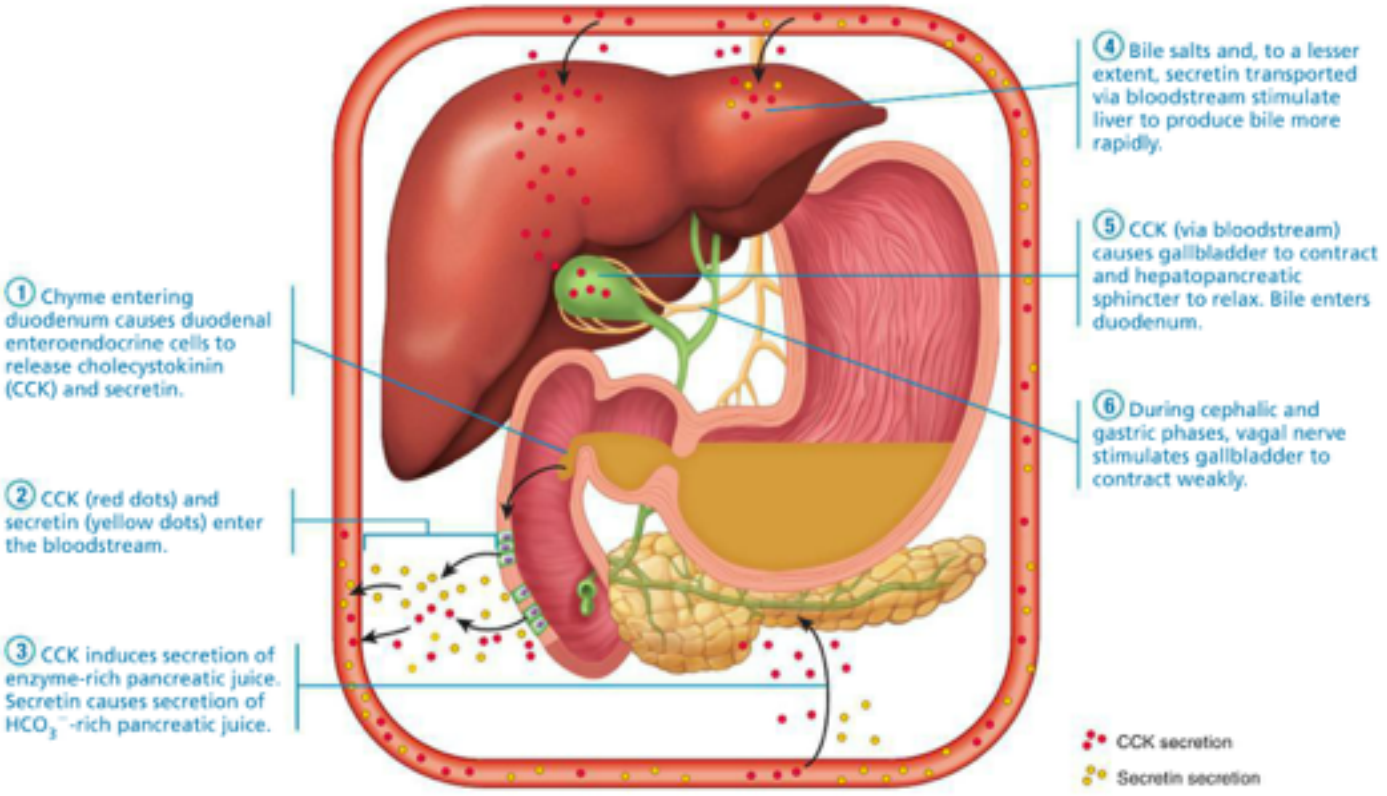


Figure 23.28 Mechanisms promoting secretion and release of bile and pancreatic juice. When digestion is not occurring, bile is stored and concentrated in the gallbladder. Acidic fatty chyme entering the small intestine initiates several mechanisms that accelerate the output of pancreatic juice and bile, and cause the gallbladder to contract and the hepatopancreatic sphincter to relax. This allows bile and pancreatic juice to enter the small intestine. The single most important stimulus for bile secretion is an increased level of bile salts in the enterohepatic circulation.

Small intestine regulation

- Body 's major digestive organ; completes digestion and virtually all absorption (by absorptive cells through apical microvilli)
- Intestinal glands secrete 1-2 L intestinal juice/day: major stimulus is distension or irritation of intestinal mucosa by hypertonic/acidic chyme
- There are very few enzymes in intestinal juice; most enzymes manufactured by the intestine are **brush border enzymes**, which are physically affixed to the cell membrane Intestinal juice is mainly water + mucus
  - Luminal enzymes, bile, and bicarbonate are supplied by liver and pancreas.
- Requirements for Optimal Intestinal Digestive Activity
  A. optimal liver & pancreatic function
  B. slow, measured delivery of chyme from stomach.

- Serves 2 major roles: (i) neutralize stomach HCl; (ii) contents of stomach are hypertonic

Small Intestine Motility

- segmentation most common motility pattern
- initiated by intrinsic pacemaker cells in longitudinal muscle layer; operate at different frequencies: duodenum 12-14/min, ileum, 8-9/minute
- intensity of segmentation altered by long & short reflexes & by hormones
- once absorption almost finished, segmentation wanes, **motilin** is then released by duodenum
- initiates peristalsis starting in the proximal duodenum and running 50-70 cm.
    - **Migrating mobility(motor) complex**: true peristalsis occurs late in digestive phase when most nutrient absorbed, each wave occurs more distally
        - takes MMC 2 hours from duodenum to ileum
    - process then repeats itself sweeping last parts of bacteria, meal, debris
    - once chyme has passed through the small intestine, back pressure from cecum closes valve
- Ileal motility increases, and Ileocecal sphincter relaxes, in response to:
    (i) gastroileal reflex (initiated by stomach; is this a long or a short reflex?)
    (ii) gastrin

Chemical Digestion of Nurtrients

- Chemical digestion = catabolism
- Typically results in the breakdown of food into subunits (often monomers) which can be adsorbed
- Chemical reaction for digestion of complex molecules involves hydrolysis

Carbohydrates

- (200-600 g/day)
- Monomers = **monosaccharides** - absorbed directly in the small intestine
- Major dietary monosaccharides: **glucose, fructose, galactose**
- Glucose, fructose and galactose have the same chemical composition ($C_6H_{12}O_6$) and therefore they are called monosaccharide
- Most digestible dietary carbohydrates in form of starch (complex carbohydrate).
- Some common dietary disaccharides: **sucrose** (table sugar-glucose/fructose) **lactose** (milk-Galactose/Glucose) **maltose** (grains-Glucose/Glucose)
- glycogen & starch = **polysaccharides** (branched glucose polymers)
- glycogen – common “storage” form for carbohydrates in muscle and liver
- starch is the common carbohydrate storage form in plants.
- Cellulose: plant polysaccharide (glucose polymer) that cannot be digested
    - important as it provides fibre - help move food bulk along the GI tract

Summary

I. begins in mouth (salivary amylase) reduces to oligosaccharides (~3-8 monomers) optimal at pH=6.75-7 Salivary amylase inactivated by acidity in stomach; digested by pepsin
II. small intestine - pancreatic amylase reduces most starch to maltose (10 min)
III. intestinal brush border enzymes (dextrinase, glucoamylase, maltase, sucrase, lactase) completes digestion to monosaccharides for adsorption

- **lactose intolerance**: undigested disaccharides produce crate osmotic gradients that prevent water absorption—diarrhea

Proteins

- dietary proteins (~125 g/day) + enzyme proteins (15-25 g/day) + protein from sloughed & disintegrating mucosal cells (15-25 g/day)
- Digested to small peptides and amino acids

Digestion of Proteins

A. begins in stomach with pepsin secreted by chief cells; (pH 1.5-3.5); cleaves bonds with tyrosine & phenylalanine
B. Hydrolyzes 10-15% ingested protein, inactivated by high pH of small intestine
C. Generates polypeptides and a few amino acids many proteolytic enzymes present in small intestine:
    - trypsin & chymotrypsin secreted by pancreas
    - carboxypeptidase - brush border and pancreatic
    - aminopeptidase & dipeptidase - Brush border
        - although amino peptidase and carboxypeptidase can break down a protein byitself, teamwork between enzymes speed up the process of breaking down proteins

- Sum total of proteolysis –free amino acids and some di and tripeptides; di and tripeptides are hydrolyzed in enterocytes to amino acids

Lipids

- (30 -150+ gm)
- Primarily neutral fats (Triglycerides)
- small intestine only significant site of fat digestion (**pancreatic lipases**)
- fats need to be emulsified with bile salts resulting in droplets of ~1 µm – suspended in aqueous environment
    - emulsification doesn't break chemical bonds, just reduces attraction between fat molecules
- lipases cleave triglycerides to fatty acids + glycerol/2-monoglycerides

Nucleic acids

- DNA/RNA
- represents a relatively small component of food
    1. **Pancreatic nucleases** RNAase and DNAase, reduces RNA and DNA to constituent nucleotides
    2. intestinal brush border **nucleosidases** & **phosphatases**; reduce nucleotides to free bases, pentose sugars and phosphate ions. Enter villi via carriers, then to blood.

Absorption

- ~10 L of food, drink & GI secretions enter GI tract/day - 0.5-1 L reach large intestine
    - virually all foodstuffs 80% of electrolytes and most of the water are absorbed by small intestine
- most digestion and adsorption of digestion products complete by time chyme reaches ileum
    - ileum primarily functions to recycle bile salts via portal circulation to the liver
    - at end of ileum, some water, indigestible food materials (eg: cellulose) & millions of bacteria enter the large intestine via the _____ valve
- Intestinal cells are joined at luminal surfaces by tight junctions
    - because of tight junctions substances cannot move inbetween cells and must pass through the epithelial cells into the interstitial fluid abutting the basolateral membranes to enter blood capillaries

Absorption of Carbohydrates

- have to be monosaccharides
- common protein carriers move glucose & galactose into epithelial cells; O2 active transport involving Na movement of monosaccharides into blood capillaries by diffusion
- fructose moves entirely by facilitated diffusion; no requirement for ATP

Absorption of Protein

- several carrier transport different a.a
- many coupled to active transport of sodium
- short chains are actively absorbed, digested to their amino acids within epithelial cells
- a.a enter capillary blood by diffusion

Absorption of Lipids
- micelles/vesicles aid in the absorption of lipids and well as bile salts

Nucleic Acid Absorption
- special carrier in epithelium of villi actively transport then enter blood

Absoprtion of vitamins
- absopbed by small intestine and large absorbs some of the K and B viatmins
- b12—endocytosis

Absoprtion of Electrolytes
- most ions absopbed along the small intestine
- calcium and iron largely absorbed in duodenum
- Na in small intestine couple with active absorption
- potassium moves acreoss the intestinal mucosa passively
- **Ferritin**: binds to ionic iron and actively transported into mucosal cells—mucosal iron barrier
  - also acts as iron storage
- **Transferrin**: plasma protein that transports iron into the circulation
- calcium: absorption related to blood levels of ionic calcium. Low plasma calcium triggers secretion of PTH from parathyroid gland
  - PTH triggers activation of vitamin D by kidneys, increasing uptake of calcium by the small intestine.
  - PTH also facilities calcium release form bone and enhancing the calcium absorption in kidneys

Absoption of Water
- ~9 L water, mostly GI tract secretions, enters small intestine/day • 95% absorbed in small intestine by osmosis (300-400 ml/hr)
- water can move freely in both directions - active uptake of solutes like Na directs water from chyme to enterocyte to blood.

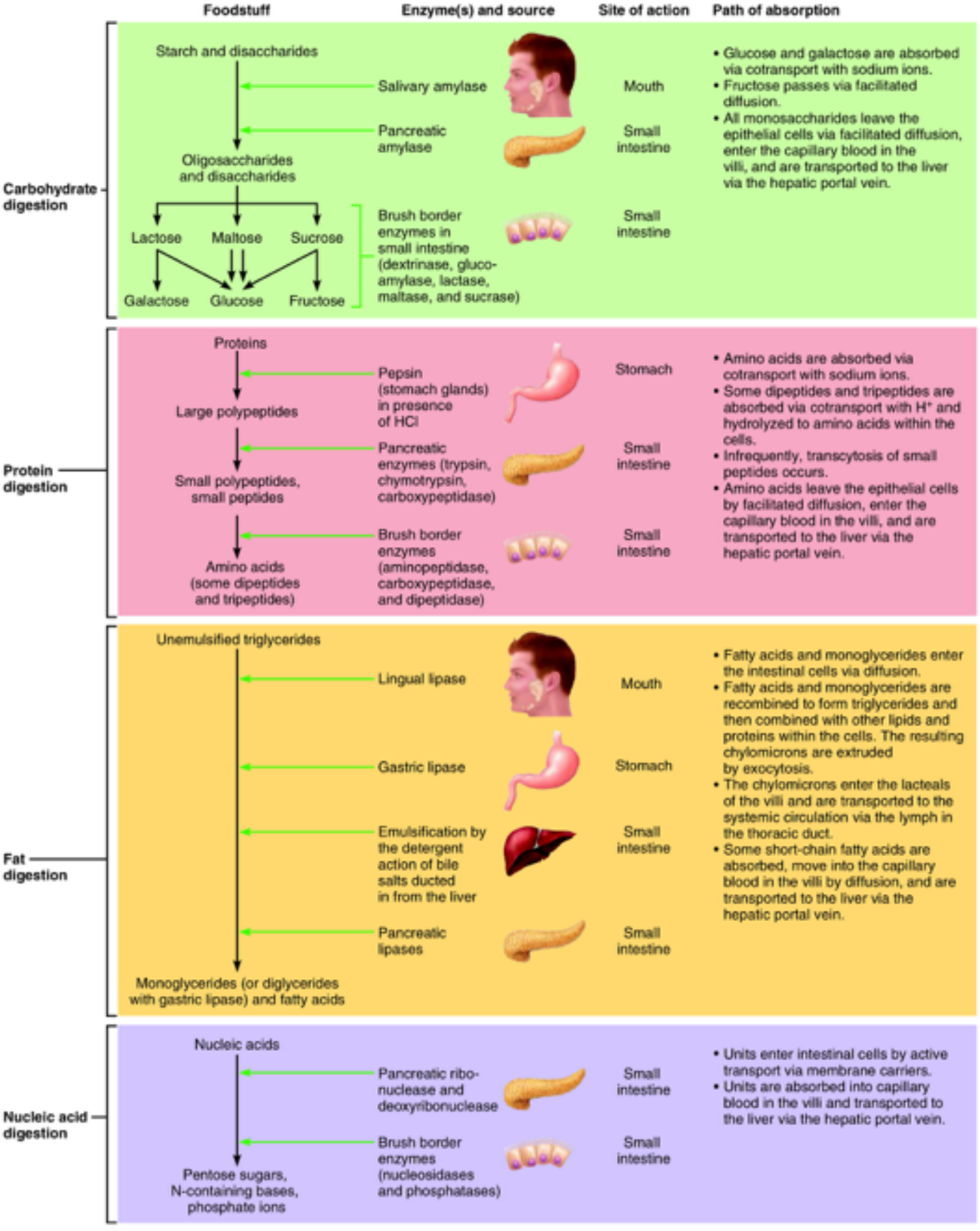


Figure 23.32 Flowchart of digestion and absorption of foodstuffs.

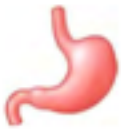
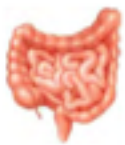
Table 23.1 Hormones and Paracrines That Act in Digestion*

HORMONE	SITE OF PRODUCTION	STIMULUS FOR PRODUCTION	TARGET ORGAN	ACTIVITY
Cholecystokinin (CCK)	Duodenal mucosa	Fatty chyme (also partially digested proteins)	Stomach	▪ Inhibits stomach's secretory activity
			Liver/pancreas	▪ Potentiates secretin's actions on these organs
			Pancreas	▪ Increases output of enzyme-rich pancreatic juice
			Gallbladder	▪ Stimulates organ to contract and expel stored bile
			Hepatopancreatic sphincter	▪ Relaxes sphincter to allow entry of bile and pancreatic juice into duodenum
Gastric inhibitory peptide (GIP) (or glucose-dependent insulinotropic peptide)	Duodenal mucosa	Fatty chyme	Stomach	▪ Inhibits HCl production (minor effect)
			Pancreas (beta cells)	▪ Stimulates insulin release
Gastrin	Stomach mucosa (G cells)	Food (particularly partially digested proteins) in stomach (chemical stimulation); acetylcholine released by nerve fibers	Stomach (parietal cells)	▪ Increases HCl secretion
				▪ Stimulates gastric emptying (minor effect)
			Small intestine	▪ Stimulates contraction of intestinal muscle
			Ileocecal valve	▪ Relaxes ileocecal valve
			Large intestine	▪ Stimulates mass movements
Histamine	Stomach mucosa	Food in stomach	Stomach	▪ Activates parietal cells to release HCl
Intestinal gastrin	Duodenal mucosa	Acidic and partially digested foods in duodenum	Stomach	▪ Stimulates gastric glands and motility
Motilin	Duodenal mucosa	Fasting; periodic release every 1½-2 hours by neural stimuli	Proximal duodenum	▪ Stimulates migrating motor complex
Secretin	Duodenal mucosa	Acidic chyme (also partially digested proteins and fats)	Stomach	▪ Inhibits gastric gland secretion and gastric motility during gastric phase of secretion
			Pancreas	▪ Increases output of pancreatic juice rich in bicarbonate ions; potentiates CCK's action
			Liver	▪ Increases bile output
Serotonin	Stomach mucosa	Food in stomach	Stomach	▪ Causes contraction of stomach muscle
Somatostatin	Stomach mucosa; duodenal mucosa	Food in stomach; stimulation by sympathetic nerve fibers	Stomach	▪ Inhibits gastric secretion of all products
			Pancreas	▪ Inhibits secretion
			Small intestine	▪ Inhibits GI blood flow; thus inhibits intestinal absorption
			Gallbladder and liver	▪ Inhibits contraction and bile release
Vasoactive intestinal peptide (VIP)	Enteric neurons	Chyme containing partially digested foods	Small intestine	▪ Stimulates buffer secretion
				▪ Dilates intestinal capillaries
				▪ Relaxes intestinal smooth muscle
			Pancreas	▪ Increases secretion
			Stomach	▪ Inhibits acid secretion

*Except for somatostatin, all of these polypeptides also stimulate the growth (particularly of the mucosa) of the organs they affect.

Table 23.2 Overview of the Functions of the Gastrointestinal Organs

ORGAN	MAJOR FUNCTIONS*	COMMENTS/ADDITIONAL FUNCTIONS
Mouth and associated accessory organs	■ Ingestion: food is voluntarily placed into oral cavity ■ Propulsion: voluntary (buccal) phase of deglutition (swallowing) initiated by tongue; propels food into pharynx ■ Mechanical breakdown: mastication (chewing) by teeth and mixing movements by tongue ■ Digestion: salivary amylase in saliva, produced by salivary glands, begins chemical breakdown of starch	Mouth serves as a receptacle; most functions performed by associated accessory organs. Mucus in saliva helps dissolve foods so they can be tasted and moistens food so that tongue can compact it into a bolus that can be swallowed. Saliva cleanses and lubricates oral cavity and teeth.
Pharynx and esophagus	■ Propulsion: peristaltic waves move food bolus to stomach, thus accomplishing involuntary (pharyngeal-esophageal) phase of deglutition	Primarily food chutes; mucus produced helps to lubricate food passageways.
Stomach	■ Mechanical breakdown and propulsion: peristaltic waves mix food with gastric juice and propel it into the duodenum ■ Digestion: pepsin begins the digestion of proteins ■ Absorption: absorbs a few fat-soluble substances (aspirin, alcohol, some drugs)	Also stores food until it can be moved into the duodenum. Hydrochloric acid produced is a bacteriostatic agent and activates protein-digesting enzymes. Mucus produced helps lubricate and protect stomach from self-digestion. Intrinsic factor produced is required for intestinal absorption of vitamin B_{12}.
Small intestine and associated accessory organs (liver, gallbladder, pancreas)	■ Mechanical breakdown and propulsion: segmentation by smooth muscle of the small intestine continually mixes contents with digestive juices and, along with short-distance peristaltic waves, moves food along tract, allowing sufficient time for digestion and absorption ■ Digestion: digestive enzymes delivered from pancreas and brush border enzymes attached to microvilli membranes complete digestion of all classes of foods ■ Absorption: breakdown products of carbohydrate, protein, fat, and nucleic acid digestion, plus vitamins, electrolytes, and water, are absorbed by active and passive mechanisms	Small intestine is highly modified for digestion and absorption (circular folds, villi, and microvilli). Alkaline mucus produced by intestinal glands and bicarbonate-rich juice ducted in from pancreas help neutralize acidic chyme and provide proper environment for enzymatic activity. Bile produced by liver emulsifies fats and enhances (1) fat digestion and (2) absorption of fatty acids, monoglycerides, cholesterol, phospholipids, and fat-soluble vitamins. Gallbladder stores and concentrates bile, releasing it to small intestine in response to hormonal signals.
Large intestine	■ Digestion: some remaining food residues are digested by enteric bacteria (which also produce vitamin K and some B vitamins) ■ Absorption: absorbs most remaining water, electrolytes (largely NaCl), and vitamins produced by bacteria ■ Propulsion: propels feces toward rectum by haustral churning and mass movements ■ Defecation: reflex triggered by rectal distension; eliminates feces from body	Temporarily stores and concentrates residues until defecation can occur. Copious mucus produced by goblet cells eases passage of feces through colon.

Gastric		↑ Gastric motility and emptying	Long neural reflexes (gastroileal reflex)	↑ Activity in ileum
			Gastrin	↑ Segmenting movements in ileum; relaxes ileocecal sphincter
Intestinal		Distension of small intestine	Long and short neural reflexes	↑ Strength of segmentation
		Reduced intestinal volume; fasting	Long and short neural reflexes; initiated by ↑ blood levels of motilin	Initiates migrating motor complex (peristalsis); repeats until next meal