Physiology of Digestive System

By

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3rd Year/ Lecture 2

The Stomach

- Stomach—a muscular sac in upper left abdominal cavity immediately inferior to the diaphragm
  - Primarily functions as a food storage organ
    - Internal volume of about 50 mL when empty
    - 1.0 to 1.5 L after a typical meal
    - Up to 4 L when extremely full and extend nearly as far as the pelvis

The Stomach

- Mechanically breaks up food particles, liquefies the food, and begins chemical digestion of protein and fat
  - Chyme: soupy or pasty mixture of semidigested food in the stomach
- Most digestion occurs after the chyme passes on to the small intestine

Gross Anatomy

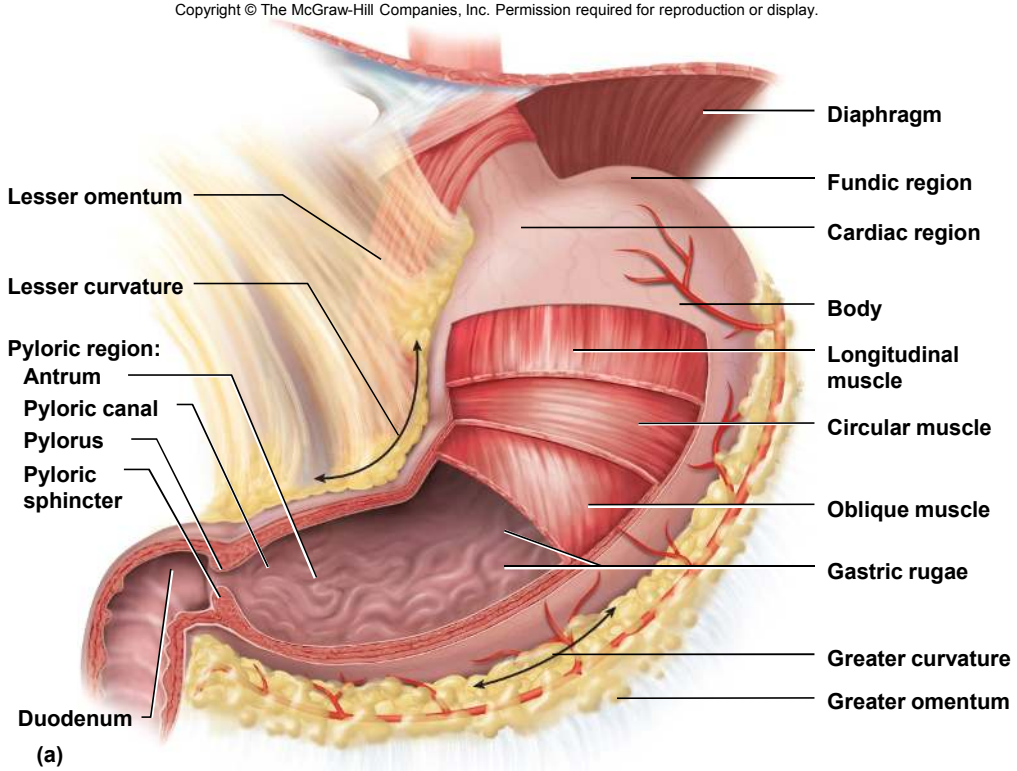


Figure 25.12a

- Note the bulge of fundus, narrowing of pyloric region, thickness of pyloric sphincter, and greater and lesser curvatures

Gross Anatomy

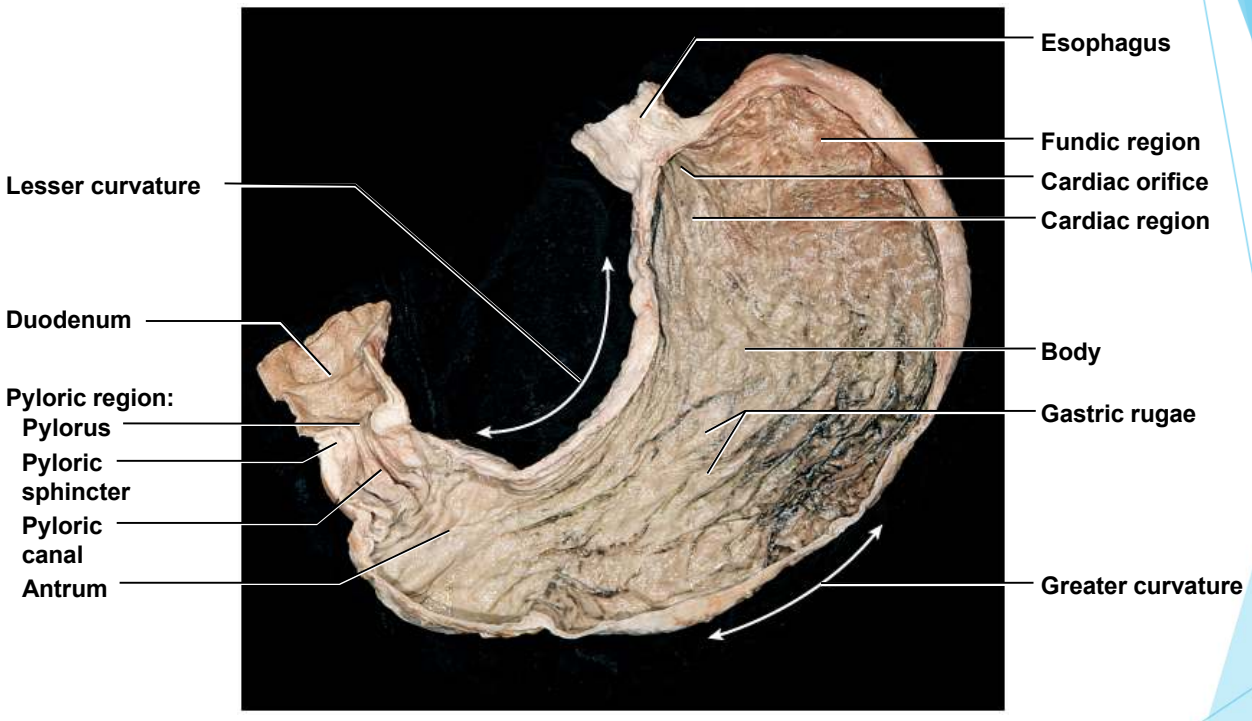


Figure 25.12b

- Longitudinal wrinkles called **rugae** can be seen in empty stomach wall

Innervation and Circulation

- Stomach receives:
  - Parasympathetic fibers from vagus
  - Sympathetic fibers from celiac ganglia
- Supplied with blood by branches of the celiac trunk
- All blood drained from stomach and intestines enters hepatic portal circulation and is filtered through liver before returning to heart

Microscopic Anatomy

- Simple columnar epithelium covers mucosa
  - Apical regions of its surface cells are filled with mucin
  - Swells with water and becomes mucus after it is secreted
- Mucosa and submucosa flat when stomach is full, but form longitudinal wrinkles called gastric rugae when empty
- Muscularis externa has three layers instead of two
  - Outer longitudinal, middle circular, and inner oblique layers

Microscopic Anatomy

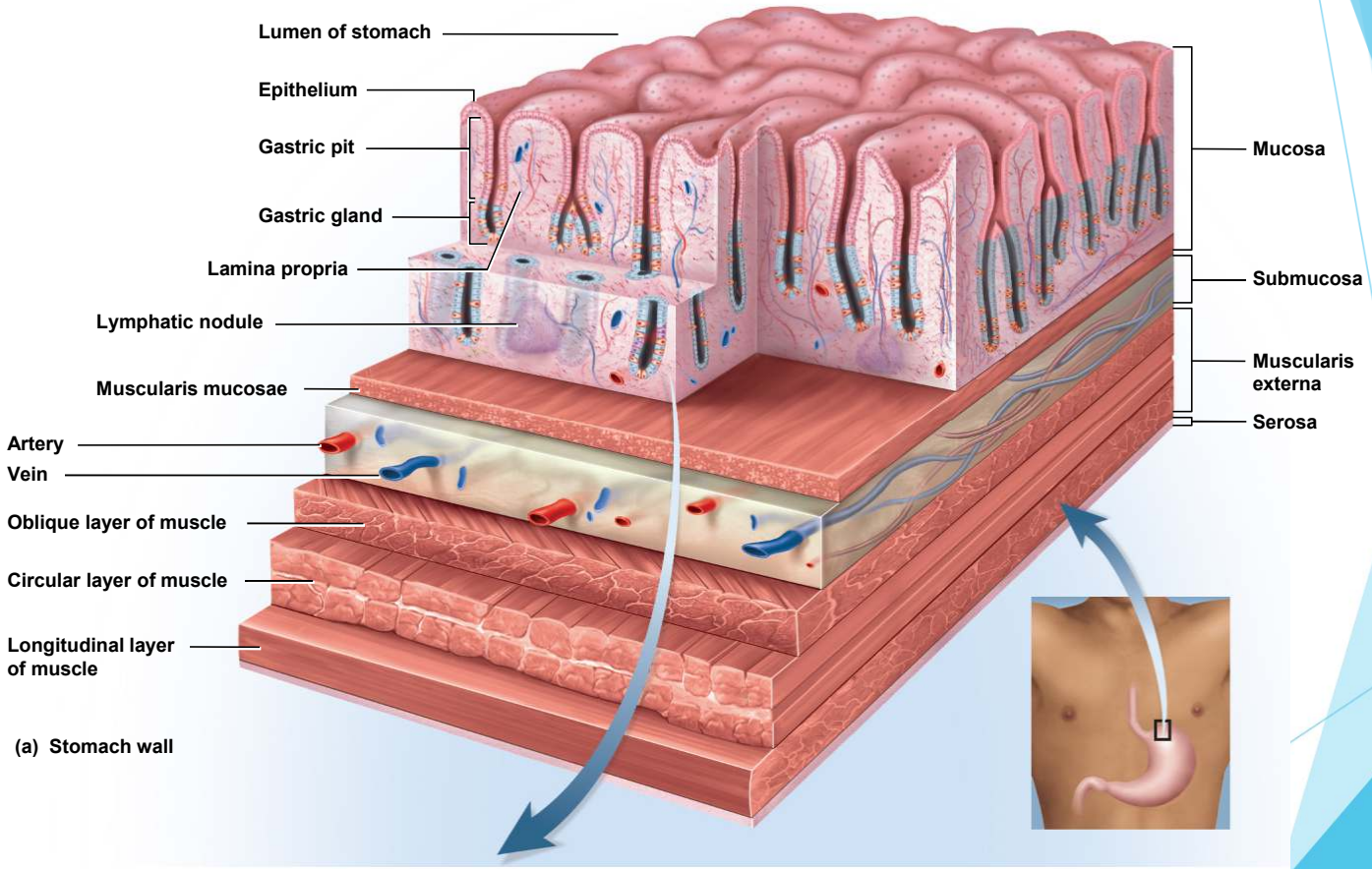


Figure 25.13a

Microscopic Anatomy

- Gastric pits—depressions in gastric mucosa
  - Lined with simple columnar epithelium
  - Two or three tubular glands open into the bottom of each gastric pit
    - Cardiac glands in cardiac region
    - Pyloric glands in pyloric regions
    - Gastric glands in the rest of the stomach

Microscopic Anatomy

- Mucous cells—secrete mucus
  - Predominate in cardiac and pyloric glands
  - In gastric glands, called mucous neck cells since they are concentrated at the neck of the gland
- Regenerative (stem) cells—found in the base of the pit and in the neck of the gland
  - Divide rapidly and produce a continual supply of new cells to replace cells that die
- Parietal cells—found mostly in the upper half of the gland
  - Secrete hydrochloric acid (HCl), intrinsic factor, and a hunger hormone called ghrelin

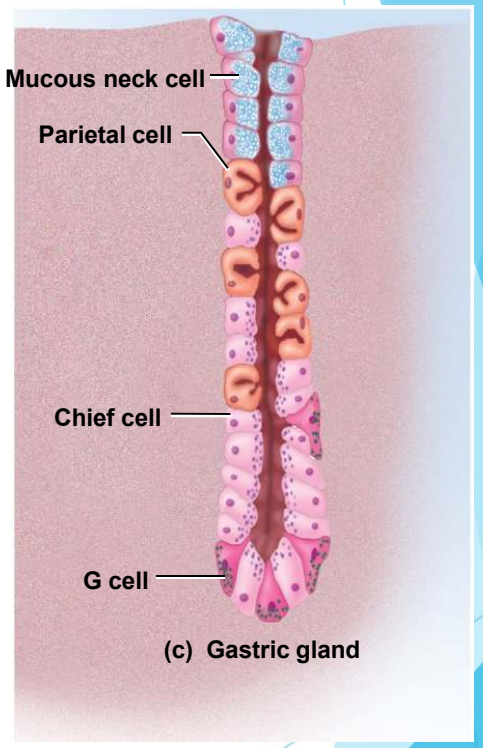


Figure 25.13c

Microscopic Anatomy

- Chief cells—most numerous
  - Secrete gastric lipase and pepsinogen
  - Dominate lower half of gastric glands
  - Absent in pyloric and cardiac glands
- Enteroendocrine cells—concentrated in lower end of gland
  - Secrete hormones and paracrine messengers that regulate digestion

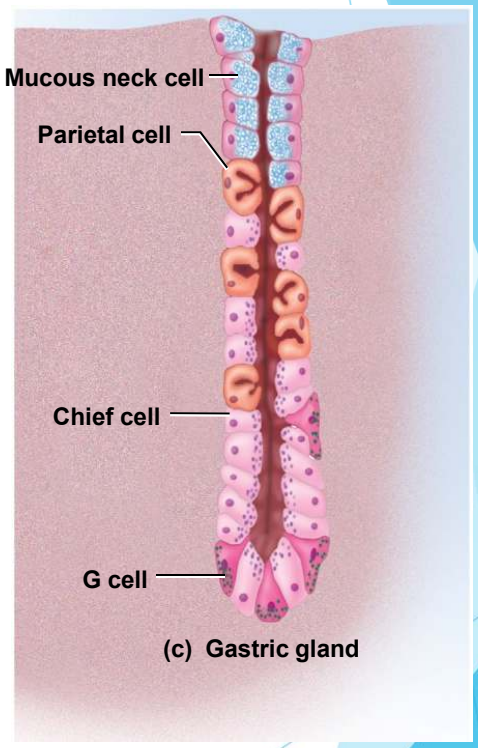


Figure 25.13c

Pyloric and Gastric Glands

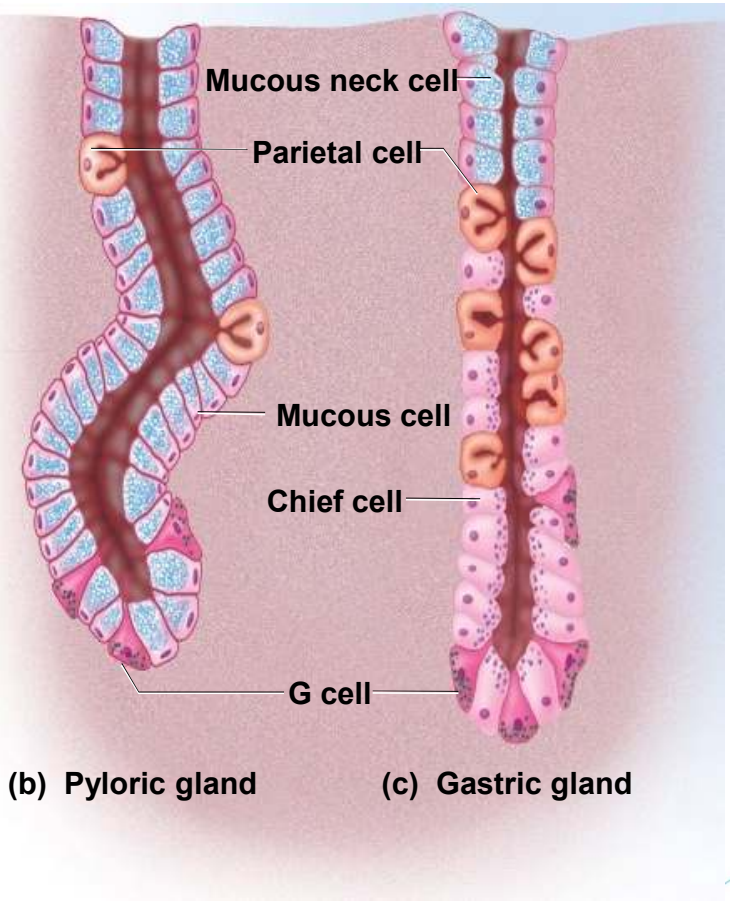


Figure 25.13b,c

Gastric Secretions

- Gastric juice—2 to 3 L per day produced by the gastric glands
- Mainly a mixture of water, hydrochloric acid, and pepsin

Hydrochloric Acid

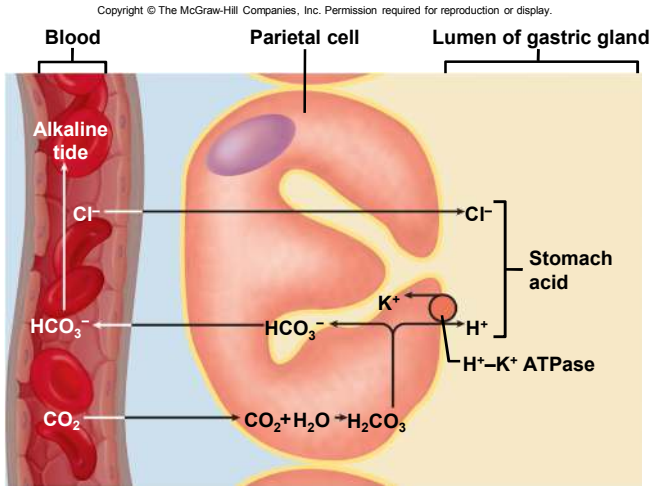


Figure 25.14

- Gastric juice has a high concentration of hydrochloric acid
  - pH as low as 0.8

Hydrochloric Acid

- Parietal cells produce HCl and contain carbonic anhydrase (CAH)
  - $CO_2 + H_2O \xrightarrow{CAH} H_2CO_3 \rightarrow HCO_3^- + H^+$
  - H^+ is pumped into gastric gland lumen by H^+-K^+ ATPase pump
    - Antiporter uses ATP to pump H^+ out and K^+ in
  - HCO_3^- exchanged for Cl^- (chloride shift) from blood plasma
    - Cl^- (chloride ion) pumped into the lumen of gastric gland to join H^+ forming HCl
    - Elevated HCO_3^- (bicarbonate ion) in blood causes alkaline tide increasing blood pH

Hydrochloric Acid

- Activates pepsin and lingual lipase
- Breaks up connective tissues and plant cell walls
  - Helps liquefy food to form chyme
- Converts ingested ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+})
  - Fe^{2+} absorbed and used for hemoglobin synthesis
- Contributes to nonspecific disease resistance by destroying most ingested pathogens

Pepsin

- Zymogens—digestive enzymes secreted as inactive proteins
  - Converted to active enzymes by removing some of their amino acids
- Pepsinogen—zymogen secreted by the chief cells
  - Hydrochloric acid removes some of its amino acids and forms pepsin that digests proteins
  - Autocatalytic effect—as some pepsin is formed, it converts more pepsinogen into more pepsin
- Pepsin digests dietary proteins into shorter peptide chains
  - Protein digestion is completed in the small intestine

The Production and Action of Pepsin

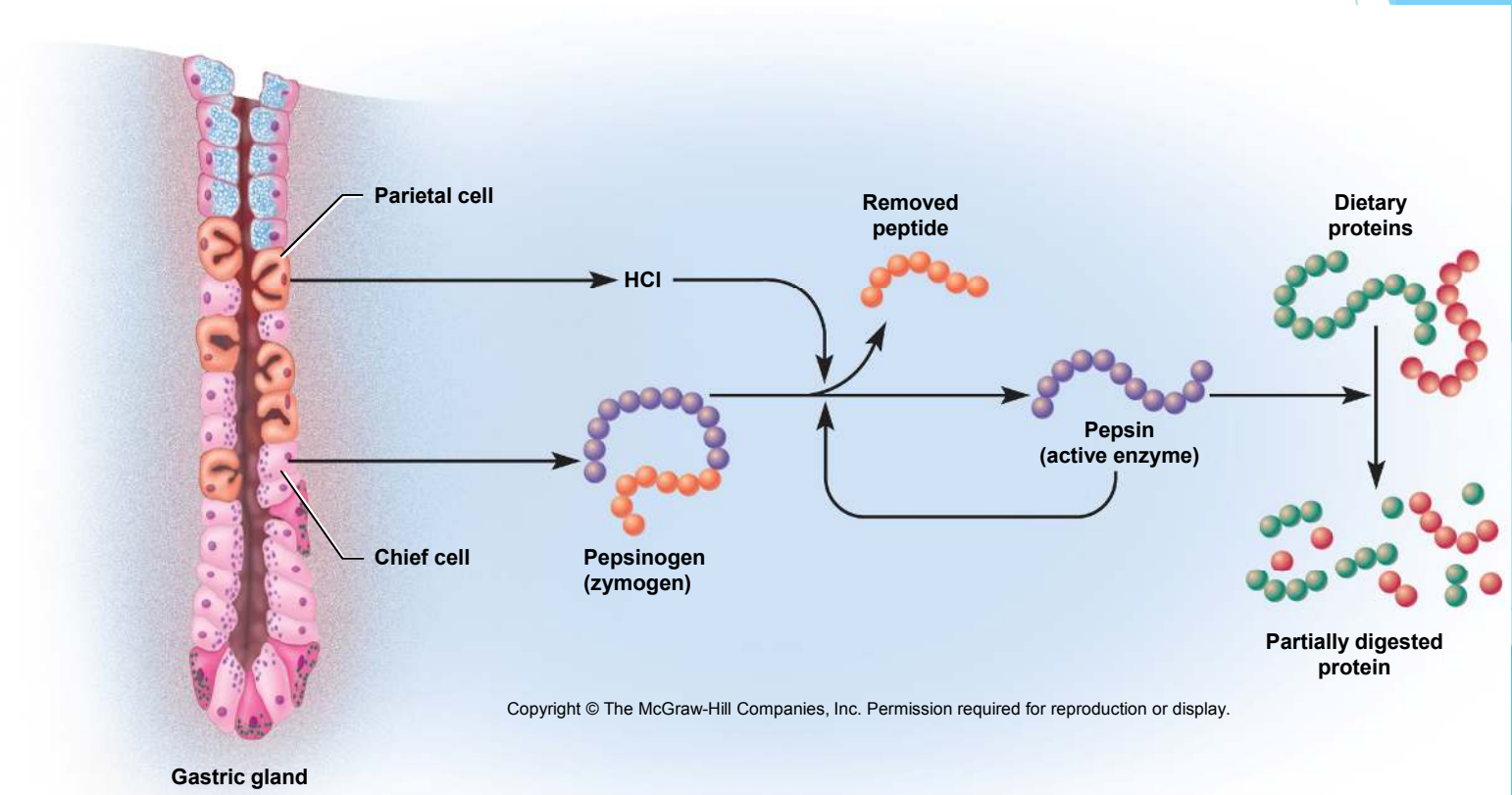


Figure 25.15

Gastric Lipase

- Gastric lipase—produced by chief cells
- Gastric lipase and lingual lipase play a minor role in digesting dietary fats
  - Digests 10% to 15% of dietary fats in the stomach
  - Rest digested in the small intestine

Intrinsic Factor

- Intrinsic factor—a glycoprotein secreted by parietal cells
- Essential to absorption of vitamin B_{12} by the small intestine
  - Binds vitamin B_{12} and then intestinal cells absorb this complex by receptor-mediated endocytosis

Intrinsic Factor

- Vitamin B_{12} is needed to synthesize hemoglobin
  - Prevents pernicious anemia
- Secretion of intrinsic factor is the only indispensable function of the stomach
  - Digestion can continue if stomach is removed (gastrectomy), but B_{12} supplements will be needed

Chemical Messengers

- Gastric and pyloric glands have various kinds of enteroendocrine cells that produce as many as 20 chemical messengers
  - Some are hormones that enter blood and stimulate distant cells
  - Others are paracrine secretions that stimulate neighboring cells

Chemical Messengers

Cont.

- Several are peptides produced in both the digestive tract and the central nervous system: gut–brain peptides
  - Substance P, vasoactive intestinal peptide (VIP), secretin, gastric inhibitory peptide (GIP), cholecystokinin, and neuropeptide Y (NPY)

Gastric Motility

Cont.

- Antrum holds about 30 mL of chyme
- As a parastaltic wave passes down the antrum, it squirts about 3 mL of chyme into the duodenum at a time
- Allowing only a small amount into the duodenum enables the duodenum to:
  - Neutralize the stomach acid
  - Digest nutrients little by little
- If duodenum is overfilled it inhibits gastric motility
- Typical meal emptied from stomach in 4 hours
  - Less time if the meal is more liquid
  - As long as 6 hours for a high-fat meal

Vomiting

- Vomiting—the forceful ejection of stomach and intestinal contents (chyme) from the mouth
- Emetic center in the medulla oblongata integrates multiple muscle actions
- Vomiting induced by:
  - Overstretching of the stomach or duodenum
  - Chemical irritants such as alcohol and bacterial toxins
  - Visceral trauma
  - Intense pain or psychological and sensory stimuli

Vomiting

- Vomiting is usually preceded by nausea and retching
- Retching—thoracic expansion and abdominal contraction creates a pressure difference that dilates the esophagus
  - Lower esophageal sphincter relaxes while the stomach and duodenum contract spasmodically
  - Chyme enters esophagus but then drops back to the stomach as the stomach relaxes
  - Does not get past the upper esophageal sphincter
  - Usually accompanied by tachycardia, profuse salivation, and sweating

Vomiting

- Vomiting—occurs when abdominal contractions and rising thoracic pressure force the upper esophageal sphincter to open
  - Esophagus and body of the stomach relax
  - Chyme is driven out of the stomach and mouth by strong abdominal contractions combined with reverse peristalsis of gastric antrum and duodenum
- Projectile vomiting—sudden vomiting with no prior nausea or retching
  - Common in infants after feeding

Digestion and Absorption

- Salivary and gastric enzymes partially digest protein and lesser amounts of starch and fat in the stomach
- Most digestion and nearly all absorption occur after the chyme has passed into the small intestine

Digestion and Absorption

- Stomach does not absorb any significant amount of nutrients
  - Aspirin
  - Some lipid-soluble drugs
- Alcohol is absorbed mainly by small intestine
  - Intoxicating effects depend partly on how rapidly the stomach is emptied

Protection of the Stomach

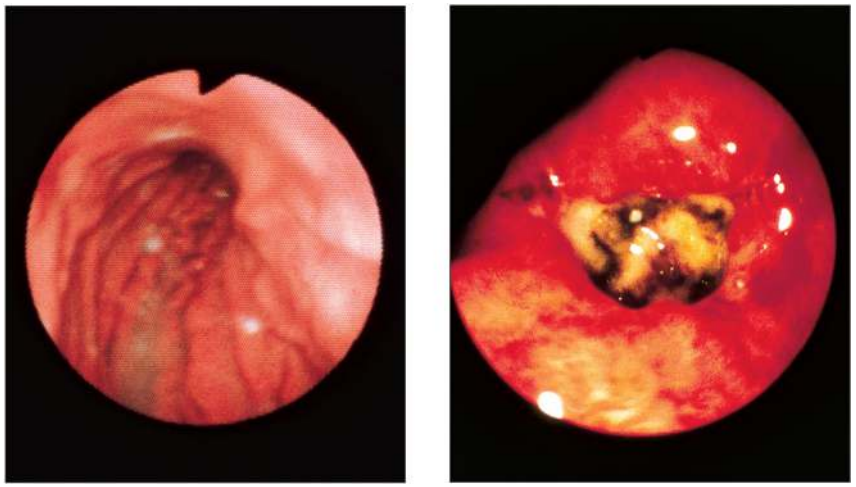
- Living stomach is protected in three ways from the harsh acidic and enzymatic environment it creates
  - Mucous coat: thick, highly alkaline mucus resists action of acid and enzymes
  - Tight junctions: between epithelial cells prevent gastric juice from seeping between them and digesting the connective tissue of the lamina propria and beyond

Protection of the Stomach

Cont.

- Epithelial cell replacement: stomach epithelial cells live only 3 to 6 days
  - Sloughed off into the chyme and digested with the food
  - Replaced rapidly by cell division in the gastric pits
- Breakdown of these protective measures can result in inflammation and peptic ulcer

Peptic Ulcer



(a) Normal **(b) Peptic ulcer**

CNR/SPL/Photo Researchers, Inc.

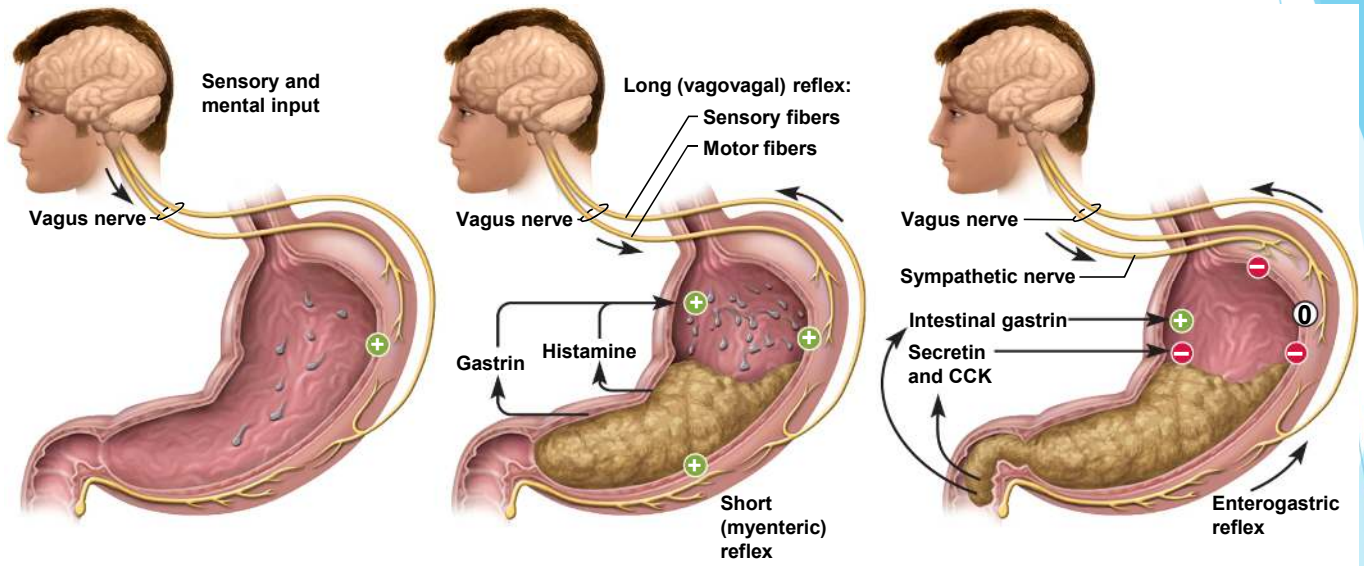
Figure 25.16a,b

- Gastritis, inflammation of the stomach, can lead to a peptic ulcer as pepsin and hydrochloric acid erode the stomach wall.
- Most ulcers are caused by acid-resistant bacteria *Helicobacter pylori*, that can be treated with antibiotics and Pepto-Bismol.

Regulation of Gastric Function

- Nervous and endocrine systems collaborate
  - Increase gastric secretion and motility when food is eaten; suppresses them when the stomach empties
- Gastric activity is divided into three phases
  - Cephalic phase: stomach being controlled by brain
  - Gastric phase: stomach controlling itself
  - Intestinal phase: stomach being controlled by small intestine
- Phases overlap and can occur simultaneously

Regulation of Gastric Function



1 Cephalic phase
Vagus nerve stimulates gastric secretion even before food is swallowed.

2 Gastric phase
Food stretches the stomach and activates myenteric and vagovagal reflexes. These reflexes stimulate gastric secretion. Histamine and gastrin also stimulate acid and enzyme secretion.

3 Intestinal phase
Intestinal gastrin briefly stimulates the stomach, but then secretin, CCK, and the enterogastric reflex inhibit gastric secretion and motility while the duodenum processes the chyme already in it. Sympathetic nerve fibers suppress gastric activity, while vagal (parasympathetic) stimulation of the stomach is now inhibited.

Key
- ⊕ Stimulation
- ⊖ Inhibition
- 0 Reduced or no effect

Figure 25.17

Regulation of Gastric Function

- Cephalic phase
  - Stomach responds to sight, smell, taste, or thought of food
  - Sensory and mental inputs converge on the hypothalamus
    - Relays signals to medulla oblongata
  - Vagus nerve fibers from medulla oblongata stimulate the enteric nervous system of stomach
    - In turn, stimulates gastric secretion

Regulation of Gastric Function

- Gastric phase
  - Period in which swallowed food and semidigested protein activate gastric activity
    - Two-thirds of gastric secretion occurs in this phase
  - Ingested food stimulates gastric activity in two ways
    - By stretching the stomach
      - Activates short reflex mediated through myenteric nerve plexus
      - Activates long reflex mediated through the vagus nerves and the brainstem
    - By increasing the pH of its contents

Regulation of Gastric Function

Cont.

- Gastric secretion is stimulated by three chemicals
  - Acetylcholine (ACh)—secreted by parasympathetic nerve fibers of both reflexes
  - Histamine—a paracrine secretion from enteroendocrine cells in the gastric glands
  - Gastrin—a hormone produced by the enteroendocrine G cells in pyloric glands

Regulation of Gastric Function

- Intestinal phase
  - Stage in which the duodenum responds to arriving chyme and moderates gastric activity through hormones and nervous reflexes
  - Duodenum initially enhances gastric secretion, but soon inhibits it
    - Stretching of the duodenum accentuates vagovagal reflex that stimulates the stomach
    - Peptides and amino acids in chyme stimulate G cells of the duodenum to secrete more gastrin which further stimulates the stomach

Regulation of Gastric Function

- Enterogastric reflex—duodenum sends inhibitory signals to the stomach by way of the enteric nervous system and signals to the medulla oblongata; triggered by acid and semidigested fats in the duodenum
  - Inhibits vagal nuclei: reducing vagal stimulation of the stomach
  - Stimulate sympathetic neurons: send inhibitory signals to the stomach

Regulation of Gastric Function

- Chyme also stimulates duodenal enteroendocrine cells to release secretin and cholecystokinin
  - They stimulate the pancreas and gallbladder
  - Also suppress gastric secretion

Regulation of Gastric Function

- Pyloric sphincter contracts tightly to limit chyme entering duodenum
  - Gives duodenum time to work on chyme
- Enteroendocrine cells also secrete glucose-dependent insulinotropic peptide (GIP) originally called gastrin-inhibiting peptide
  - Stimulates insulin secretion in preparation for processing nutrients about to be absorbed by the small intestine

Feedback Control of Gastric Secretion

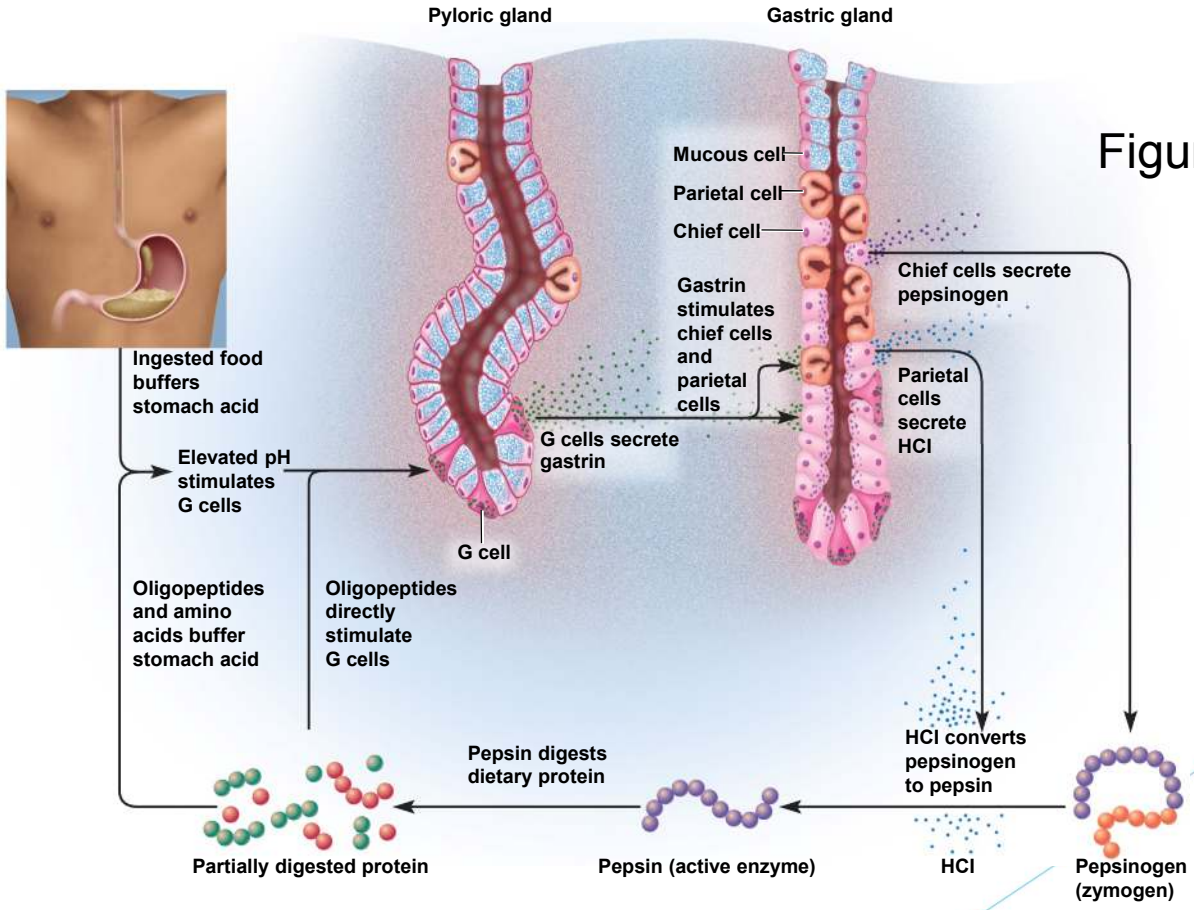


Figure 25.18