Chapter 16
Lecture and Animation Outline

To run the animations you must be in Slideshow View. Use the buttons on the animation to play, pause, and turn audio/text on or off.

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See separate PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes and animations.
Functions

1. Take in food
2. Break down food
3. Absorb digested materials
4. Provide nutrients
5. Eliminate waste
Layers of Digestive System

- Digestive system is one large tube from mouth to anus plus the accessory organs

1. Mucosa:
   - innermost layer
   - secretes mucus

2. Submucosa:
   - above mucosa
   - contains blood vessels, nerves, small glands
3. **Muscularis:**
   - above submucosa
   - longitudinal, circular, and oblique muscles

4. **Serosa/adventitia:**
   - outermost layer
   - peritoneum is present called serosa
   - no peritoneum then called adventitia (Ex. Esophagus)
Figure 16.2 Digestive Tract Histology

The four tunics are the mucosa, the submucosa, the muscularis, and a serosa or an adventitia. Glands may exist along the digestive tract as part of the epithelium, within the submucosa, or as large glands outside the digestive tract.
Peritoneum

• Layer of smooth epithelial tissue

• **Mesenteries:**
  connective tissue of organs in abdominal cavity

• **Lesser omentum:**
  mesentery connecting lesser curvature of stomach to liver and diaphragm

• **Greater omentum:**
  mesentery connecting greater curvature of stomach to transverse colon and posterior body wall
Figure 16.3 Peritoneum and Mesenteries

The parietal peritoneum lines the abdominal cavity (blue), and the visceral peritoneum covers abdominal organs (red). Retroperitoneal organs are behind the parietal peritoneum. The mesenteries are membranes that connect abdominal organs to each other and to the body wall.
Oral Cavity

- First part of digestive system
- Contains stratified squamous epithelia
- **Salivary glands:**
  - produce saliva which contains enzymes to breakdown carbohydrates into glucose
  - cleanse mouth
  - dissolve and moisten food
• **Amylase:**
  salivary enzyme that breaks down carbohydrates

• **Lysozyme:**
  salivary enzymes that are active against bacteria

• **Tongue:**
  house taste buds and mucus
Figure 16.4 Oral Cavity
Teeth

- 32 teeth in normal adult
- Incisors, canine, premolars, molars, wisdom
- 20 primary teeth (baby teeth)
- Each tooth has crown, cusp, neck, root
- Center of tooth is pulp cavity
- Enamel is hard covering protects against abrasions
- Cavities are breakdown of enamel by acids from bacteria
Figure 16.5

Central incisor
Lateral incisor
Canine
First premolar
Second premolar
First molar
Second molar
Third molar (wisdom tooth)

Maxillary teeth

Central incisor (erupts at 6–8 months; lost at 5–7 years)
Lateral incisor (erupts at 8–11 months; lost at 6–8 years)
Canine (erupts at 16–20 months; lost at 8–11 years)
First molar (erupts at 10–16 months; lost at 9–11 years)
Second molar (erupts at 20–24 months; lost at 9–11 years)

Mandibular teeth

A B C D E F G H I J K L M N O P Q R S T
**Figure 16.6 Molar Tooth in Place in the Alveolar Bone**

A tooth consists of a crown, a neck, and a root. The root is covered with cementum, and the tooth is held in the socket by periodontal ligaments. Nerves and vessels enter and exit the tooth through a foramen in the part of the root deepest in the alveolus.
Palate

• Palate: roof of oral cavity

• Hard palate: anterior part

• Soft palate: posterior part
Salivary Glands

• Salivary Glands:
  - includes submandibular, sublingual, parotid
  - produce saliva contains enzymes to breakdown food
  - mumps is inflammation of parotid gland
Figure 16.7 Salivary Glands

The large salivary glands are the parotid glands, the submandibular glands, and the sublingual glands.
Pharynx

- Throat
- Connects mouth to esophagus
Esophagus

- Tube that connects pharynx to stomach
- Transport food to stomach
- Joins stomach at cardiac opening
- **Heartburn:**
  - occurs when gastric juices regurgitate into esophagus
  - caused by caffeine, smoking, or eating or drinking in excess
Swallowing

• **Voluntary phase:**
  bolus (mass of food) formed in mouth and pushed into oropharynx

• **Pharyngeal phase:**
  swallowing reflex initiated when bolus stimulates receptors in oropharynx

• **Esophageal phase:**
  moves food from pharynx to stomach

• **Peristalsis:**
  wave-like contractions moves food through digestive tract
During the voluntary phase, a bolus of food (yellow) is pushed by the tongue against the hard and soft palates and posteriorly toward the oropharynx (blue arrow indicates tongue movement; black arrow indicates movement of the bolus). Tan: bone; purple: cartilage; red: muscle.

During the pharyngeal phase, the soft palate is elevated, closing off the nasopharynx. The pharynx and larynx are elevated (blue arrows indicate muscle movement).

Successive constriction of the pharyngeal constrictors from superior to inferior (blue arrows) forces the bolus through the pharynx and into the esophagus. As this occurs, the vestibular and vocal folds expand medially to close the passage of the larynx. The epiglottis is bent down over the opening of the larynx largely by the force of the bolus pressing against it.

As the inferior pharyngeal constrictor contracts, the upper esophageal sphincter relaxes (outwardly directed blue arrows), allowing the bolus to enter the esophagus.

During the esophageal phase, the bolus is moved by peristaltic contractions of the esophagus toward the stomach (inwardly directed blue arrows).

**PROCESS Figure 16.8 Events During the Three Phases of Swallowing**
1. A wave of smooth muscle relaxation moves ahead of the bolus, allowing the digestive tract to expand.

2. A wave of contraction of the smooth muscle behind the bolus propels it through the digestive tract.

PROCESS Figure 16.9 Peristalsis
Stomach

- Located in abdomen
- Storage tank for food
- Can hold up to 2 liters of food
- Produces mucus, hydrochloric acid, protein digesting enzymes
- Contains a thick mucus layer that lubricates and protects epithelial cells on stomach wall form acidic pH (3)
• 3 muscular layers:
  outer longitudinal, middle circular, and inner oblique to produce churning action

• Rugae:
  large folds that allow stomach to stretch

• Chyme:
  paste-like substance that forms when food begins to be broken down
• Pyloric opening:
  opening between stomach and small intestine

• Pyloric sphincter:
  thick, ring of smooth muscle around pyloric opening

• Hunger pangs:
  stomach is stimulated to contract by low blood glucose levels usually 12-24 hours after a meal
Figure 16.10 Anatomy and Histology of the Stomach
(a) Cutaway section reveals muscular layers and internal anatomy. (b) A section of the stomach wall illustrates its histology, including several gastric pits and glands. (c) Photomicrograph of gastric glands.
Regulation of Stomach Secretions

- Parasympathetic stimulation, gastrin, histamine increase stomach secretions
- Cephalic phase:
  - 1st phase
  - stomach secretions are initiated by sight, smell, taste, or food thought
• **Gastric phase:**
  - 2\textsuperscript{nd} phase
  - partially digested proteins and distention of stomach promote secretion

• **Intestinal phase:**
  - 3\textsuperscript{rd} phase
  - acidic chyme stimulates neuronal reflexes and secretions of hormones that inhibit gastric secretions by negative feedback loops
**Cephalic Phase**

1. The taste, smell, or thought of food or tactile sensations in the mouth stimulate the medulla oblongata (green arrow).
2. Vagus nerves carry parasympathetic action potentials to the stomach (pink arrow), where enteric plexus neurons are activated.
3. Postganglionic neurons stimulate secretion by parietal and chief cells and stimulate gastrin and histamine secretion by endocrine cells.
4. Gastrin is carried through the circulation back to the stomach (purple arrow), where, along with histamine, it stimulates secretion.

**Gastric Phase**

1. Distention of the stomach stimulates mechanoreceptors (stretch receptors) and activates a parasympathetic reflex. Action potentials generated by the mechanoreceptors are carried by the vagus nerves to the medulla oblongata (green arrow).
2. The medulla oblongata increases action potentials in the vagus nerves that stimulate secretions by parietal and chief cells and stimulate gastrin and histamine secretion by endocrine cells (pink arrow).
3. Distention of the stomach also activates local reflexes that increase stomach secretions (orange arrow).
4. Gastrin is carried through the circulation back to the stomach (purple arrow), where, along with histamine, it stimulates secretion.

**Intestinal Phase**

1. Chyme in the duodenum with a pH less than 2 or containing fat digestion products (lipids) inhibits gastric secretions by three mechanisms (2-4).
2. Chemoreceptors in the duodenum are stimulated by $H^+$ (low pH) or lipids. Action potentials generated by the chemoreceptors are carried by the vagus nerves to the medulla oblongata (green arrow), where they inhibit parasympathetic action potentials (pink arrow), thereby decreasing gastric secretions.
3. Local reflexes activated by $H^+$ or lipids also inhibit gastric secretion (orange arrows).
4. Secretin and cholecystokinin produced by the duodenum (brown arrows) decrease gastric secretions in the stomach.

**PROCESS Figure 16.11 Regulation of Stomach Secretions**

(a) Cephalic phase. (b) Gastric phase. (c) Intestinal phase.
Movement in Stomach

• **Mixing waves:**
  - weak contraction
  - thoroughly mix food to form chyme

• **Peristaltic waves:**
  - stronger contraction
  - force chyme toward and through pyloric sphincter

• **Hormonal and neural mechanisms stimulate stomach secretions**

• **Stomach empties every 4 hours after regular meal, and 6-8 hours after high fatty meal**
1. A mixing wave initiated in the body of the stomach progresses toward the pyloric sphincter (pink arrows directed inward).

2. The more fluid part of the chyme is pushed toward the pyloric sphincter (blue arrows), whereas the more solid center of the chyme squeezes past the peristaltic constriction back toward the body of the stomach (orange arrow).

3. Peristaltic waves (purple arrows) move in the same direction and in the same way as the mixing waves but are stronger.

4. Again, the more fluid part of the chyme is pushed toward the pyloric region (blue arrows), whereas the more solid center of the chyme squeezes past the peristaltic constriction back toward the body of the stomach (orange arrow).

5. Peristaltic contractions force a few milliliters of the most fluid chyme through the pyloric opening into the duodenum (small red arrows). Most of the chyme, including the more solid portion, is forced back toward the body of the stomach for further mixing (yellow arrow).
Small Intestine

- Measures 6 meters in length
- Major **absorptive** organ
- Chyme takes 3-5 hours to pass through
- Contains enzymes to further breakdown food
- Contains secretions for protection against chyme’s acidity
Parts of Small Intestine

- **Duodenum:**
  - 25 cm long
  - contains absorptive cells, goblet cells, granular cells, endocrine cells
  - contains microvilli and many folds
  - contains bile and pancreatic ducts

- **Jejunum:**
  2.5 meters long and absorbs nutrients

- **Ileum:**
  3.5 meters long
Figure 16.13  Small Intestine
Figure 16.14 Anatomy and Histology of the Duodenum
(a) Wall of the duodenum, showing the circular folds. (b) Villi on a circular fold. (c) A single villus, showing the lacteal and capillary network. (d) Transmission electron micrograph of microvilli on the surface of a villus.
Large intestine

- Function is to absorb water from indigestible food
- Contains cecum, colon, rectum, anal canal
- **Cecum:**
  - joins small intestine at *ileocecal junction*
  - has appendix attached
- **Appendix:**
  9 cm structure that is often removed
• Colon:
  - 1.5 meters long
  - contains ascending, transverse, descending, sigmoid regions

• Rectum:
  straight tube that begins at sigmoid and ends at anal canal
• **Anal canal:**
  last 2-3 cm of dig. tract

• **Food takes 18-24 hours to pass through**

• **Feces is product of water, indigestible food, and microbes**

• **Microbes synthesize vitamin K**
Figure 16.21 Large Intestine
(a) The large intestine consists of the cecum, colon, rectum, and anal canal. The teniae coli are bands of smooth muscle along the length of the colon. (b) Radiograph of the large intestine following a barium enema.
Liver Anatomy

• Weighs about 3 lbs.
• In right upper quadrant of abdomen under diaphragm
• Right, left, caudate, quadrate lobes
• **Porta:**
  gate where blood vessels, ducts, nerves enter and exit
• Receives blood from hepatic artery
Figure 16.16 Liver
(a) Anterior view. (b) Inferior view. (c) Histology.
• **Lobules:**
divisions of liver with portal triads at corners

• **Portal triad:**
contain hepatic artery, hepatic portal vein, hepatic duct

• **Hepatic cords:**
  - between center margins of each lobule
  - separated by hepatic sinusoids
• **Hepatic sinusoids:**
  contain phagocytic cells that remove foreign particles from blood

• **Central vein:**
  - center of each lobule
  - where mixed blood flows towards
  - forms hepatic veins
Liver Ducts

• Hepatic duct:
  transport bile out of liver

• Common hepatic duct:
  formed from left and right hepatic duct

• Cystic duct:
  - joins common hepatic duct
  - from gallbladder

• Common bile duct:
  formed from common hepatic duct and cystic duct
The hepatic ducts from the liver lobes combine to form the common hepatic duct.

The common hepatic duct combines with the cystic duct from the gallbladder to form the common bile duct.

The common bile duct joins the pancreatic duct.

The combined duct empties into the duodenum at the duodenal papilla.

Pancreatic secretions may also enter the duodenum through an accessory pancreatic duct, which also empties into the duodenum.

**PROCESS Figure 16.17  Flow of Bile and Pancreatic Secretions Through the Duct System of the Liver, Gallbladder, and Pancreas**
Gallbladder

- Small sac on inferior surface of liver
- Stores and concentrates bile
Functions of Liver

- Digestive and excretory functions
- Stores and processes nutrients
- Detoxifies harmful chemicals
- Synthesizes new molecules
- Secretes 700ml of bile each day

**Bile:**
- dilutes and neutralizes stomach acid and breaks down fats
1. Vagus nerve stimulation (red arrow) causes the gallbladder to contract, thereby releasing bile into the duodenum.

2. Secretin, produced by the duodenum (purple arrows) and carried through the circulation to the liver, stimulates bile secretion by the liver (green arrows inside the liver).

3. Cholecystokinin, produced by the duodenum (pink arrows) and carried through the circulation to the gallbladder, stimulates the gallbladder to contract, thereby releasing bile into the duodenum (green arrow outside the liver).

4. Bile salts also stimulate bile secretion. Over 90% of bile salts are reabsorbed in the ileum and returned to the liver (blue arrows), where they stimulate additional secretion of bile salts.
Pancreas

- Located posterior to stomach in inferior part of left upper quadrant
- Head near midline of body
- Tail extends to left and touches spleen
- Endocrine tissues have pancreatic islet that produce insulin and glucagon
- Exocrine tissues produce digestive enzymes
Figure 16.19 Anatomy and Histology of the Duodenum and Pancreas

(a) The head of the pancreas lies within the duodenal curvature, with the pancreatic duct emptying into the duodenum. (b) Histology of the pancreas, showing both the acini and the pancreatic duct system.
1. Parasympathetic stimulation from the vagus nerve (red arrow) causes the pancreas to release a secretion rich in digestive enzymes.

2. Secretin (purple arrows), released from the duodenum, stimulates the pancreas to release a watery secretion, rich in bicarbonate ions.

3. Cholecystokinin (pink arrows), released from the duodenum, causes the pancreas to release a secretion rich in digestive enzymes.

PROCESS Figure 16.20 Control of Pancreatic Secretion
Digestive Process

1. Digestion:
   breakdown of food occurs in stomach and mouth

2. Propulsion:
   moves food through digestive tract includes swallowing and peristalsis

3. Absorption:
   primarily in duodenum and jejunum of small intestine

4. Defecation:
   elimination of waste in the form of feces
Figure 16.22 Digestion

Food consists primarily of carbohydrates, lipids, and proteins. Carbohydrates are broken down into monosaccharides, lipids into fatty acids and monoglycerides, and proteins into amino acids.
Figure 16.23 Digestion of Carbohydrates, Lipids, and Proteins

The enzymes involved in digesting carbohydrates, lipids, and proteins are depicted in relation to the region of the digestive tract where each functions.
Carbohydrate Digestion

- Polysaccharides split into disaccharides by salivary and pancreatic amylases
- Disaccharides broken down into monosaccharides by disaccharidases on surface of intestinal epithelium
- Glucose is absorbed by cotransport with Na\(^+\) into intestinal epithelium
- Glucose is carried by hepatic portal vein to liver and enters most cells by facilitated diffusion
Monosaccharide (glucose) transport

1. Glucose is absorbed by symport with \( \text{Na}^+ \) into intestinal epithelial cells.
2. Symport is driven by a sodium gradient established by a \( \text{Na}^+ - \text{K}^+ \) pump.
3. Glucose moves out of the intestinal epithelial cells by facilitated diffusion.
4. Glucose enters the capillaries of the intestinal villi and is carried through the hepatic portal vein to the liver.

PROCESS Figure 16.24  Transport of Glucose Across the Intestinal Epithelium
Lipid Digestion

- Bile salts emulsify lipids
- Lipase breaks down lipids which form micelles
- Micelles are in contact with intestinal epi. and diffuse with cells where they are packaged and released into lacteals
- Lipids are stored in adipose tissue and liver
Lipid transport

1. Bile salts surround fatty acids and monoglycerides to form micelles.

2. Micelles attach to the cell membranes of intestinal epithelial cells, and the fatty acids and monoglycerides pass by simple diffusion into the intestinal epithelial cells.

3. Within the intestinal epithelial cell, the fatty acids and monoglycerides are converted to triglycerides; proteins coat the triglycerides to form chylomicrons, which move out of the intestinal epithelial cells by exocytosis.

4. The chylomicrons enter the lacteals of the intestinal villi and are carried through the lymphatic system to the general circulation.

PROCESS Figure 16.25 Transport of Lipids Across the Intestinal Epithelium
Proteins Digestion

• Proteins are split into polypeptides by enzymes secreted by stomach and pancreas
• Peptides and amino acids are absorbed into intestinal epi. cells
• Amino acids are actively transported into cells (help from GH and insulin)
• Amino acids used to build new proteins
Acidic and most neutral amino acids are absorbed by symport into intestinal epithelial cells.

Symport is driven by a sodium gradient established by a Na⁺–K⁺ pump.

Amino acids move out of intestinal epithelial cells.

Amino acids enter the capillaries of the intestinal villi and are carried through the hepatic portal vein to the liver.
Water and Minerals

• Water can move across intestinal wall in either direction
• Depends on osmotic conditions
• 99% of water entering intestine is absorbed
• Minerals are actively transported across wall of small intestine
Figure 16.28 Fluid Volumes in the Digestive Tract
The primary functions of the digestive system are the breakdown of food (called digestion) and absorption of nutrients.