CHAPTER 16

The Digestive System
Chapter 16 Learning Outcomes

• 16-1
  • Identify the organs of the digestive system, list their major functions, and describe the four layers of the wall of the digestive tract.

• 16-2
  • Discuss the anatomy of the oral cavity, and list the functions of its major structures.

• 16-3
  • Describe the structures and functions of the pharynx and esophagus, and the key events of the swallowing process.

• 16-4
  • Describe the anatomy of the stomach, including its histological features, and discuss its roles in digestion and absorption.
Chapter 16 Learning Outcomes

- 16-5
  - Describe the anatomy of the small intestine, including its histological features, and explain the functions and regulation of intestinal secretions.

- 16-6
  - Describe the structure and functions of the pancreas, liver, and gallbladder, and explain how their activities are regulated.

- 16-7
  - Describe the structure of the large intestine, including its regional specializations, and list its absorptive functions.

- 16-8
  - List the nutrients required by the body, describe the chemical digestion of organic nutrients, and discuss the absorption of organic and inorganic nutrients.
Chapter 16 Learning Outcomes

- 16-9
  - Describe the effects of aging on the digestive system.
- 16-10
  - Give examples of interactions between the digestive system and each of the other organ systems.
Digestive System Basics (16-1)

- **Digestive tract**, or *gastrointestinal (GI) tract*
  - Mouth, pharynx, esophagus, stomach, small and large intestines, rectum, anus

- **Accessory organs** contribute to digestion
  - Teeth, tongue, salivary glands, gallbladder, liver, and pancreas
Six Functions of the Digestive System (16-1)

1. Ingestion
   - Food enters mouth

2. Mechanical processing
   - Physical manipulation that enhances movement
   - Increases surface area for enzymes to work

3. Digestion
   - Chemical breakdown of food to absorbable size
Six Functions of Digestive System (16-1)

4. Secretion
   • Release of water, acids, enzymes, and buffers into lumen

5. Absorption
   • Movement of nutrient molecules across digestive epithelium and into interstitial fluid of body

6. Excretion
   • Elimination of waste products
<table>
<thead>
<tr>
<th>Major Subdivisions of the Digestive Tract</th>
<th>Accessory Organs of the Digestive System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oral Cavity, Teeth, Tongue</strong></td>
<td><strong>Salivary glands</strong></td>
</tr>
<tr>
<td>Mechanical processing, moistening, mixing with salivary secretions</td>
<td>Secretion of lubricating fluid containing enzymes that break down carbohydrates</td>
</tr>
<tr>
<td><strong>Pharynx</strong></td>
<td><strong>Liver</strong></td>
</tr>
<tr>
<td>Muscular propulsion of materials into the esophagus</td>
<td>Secretion of bile (important for lipid digestion), storage of nutrients, many other vital functions</td>
</tr>
<tr>
<td><strong>Esophagus</strong></td>
<td><strong>Gallbladder</strong></td>
</tr>
<tr>
<td>Transport of materials to the stomach</td>
<td>Storage and concentration of bile</td>
</tr>
<tr>
<td><strong>Stomach</strong></td>
<td><strong>Pancreas</strong></td>
</tr>
<tr>
<td>Chemical breakdown of materials by acid and enzymes; mechanical processing through muscular contractions</td>
<td>Exocrine cells secrete buffers and digestive enzymes; endocrine cells secrete hormones</td>
</tr>
<tr>
<td><strong>Small Intestine</strong></td>
<td></td>
</tr>
<tr>
<td>Enzymatic digestion and absorption of water, organic substrates, vitamins, and ions</td>
<td></td>
</tr>
<tr>
<td><strong>Large Intestine</strong></td>
<td></td>
</tr>
<tr>
<td>Dehydration and compaction of indigestible materials in preparation for elimination</td>
<td></td>
</tr>
</tbody>
</table>
Four Histological Layers of the GI Tract (16-1)

1. Mucosa
2. Submucosa
3. Muscularis externa
4. Serosa
Mucosa (16-1)

- Inner lining of lumen of GI tract
- Layered epithelium, *lamina propria*
  - Stratified squamous in high physical stress organs
  - Rest is simple columnar with surface modifications
  - Ducts of secretory glands open to surface of epithelium
  - *Villi* and microvilli increase surface area
  - *Muscularis mucosae* moves mucosal folds and villi
Submucosa (16-1)

- Dense irregular connective tissue
- Binds mucosa to muscularis externa
- Contains blood vessels and lymphatics
- Submucosal plexus on outer border
  - A neural network that can function without CNS
  - Regulates secretions and motility
  - Also has parasympathetic neurons and sensory neurons
Muscularis Externa (16-1)

- Inner circular and outer longitudinal layer of smooth muscle
  - Function to mix and propel materials
- Myenteric plexus between layers of muscle
  - Contains parasympathetic ganglia, sensory neurons, interneurons, and sympathetic postganglionic fibers
  - Parasympathetic is excitatory, increases activity
  - Sympathetic is inhibitory, decreases activity
Serosa (16-1)

- Serous membrane is the peritoneum

- **Mesenteries**
  - Specialized peritoneum helps to organize and stabilize GI tract, lymphatics, blood vessels, and nerves

- **Adventitia**
  - Name of outer layer of oral cavity, pharynx, esophagus, and rectum
Figure 16-2  The Structure of the Digestive Tract.

- **Mesenteric artery and vein**
- **Mesentery**
- **Circular fold**
- **Mucosa**
- **Submucosa**
- **Muscularis externa**
- **Serosa (visceral peritoneum)**
- **Circular fold**
- **Mucosal epithelium**
- **Lamina propria**
- **Villi**
- **Mucosal glands**
- **Submucosal gland**
- **Muscularis mucosae**
- **Lymphatic vessel**
- **Artery and vein**
- **Submucosal plexus**
- **Circular muscle layer**
- **Myenteric plexus**
- **Longitudinal muscle layer**
Movement of Digestive Materials (16-1)

- **Pacesetter cells** in smooth muscle trigger contraction

- **Peristalsis**
  - Waves of contraction initiated by circular layer, followed by longitudinal layer
  - Propels material down tract

- **Segmentation**
  - A mixing action with no propulsion
Figure 16-3 Peristalsis.

1. **Contraction of circular muscles behind bolus**
   - **Initial State**
     - Circular muscle
     - Longitudinal muscle
   - From mouth to anus
   - Contraction

2. **Contraction of longitudinal muscles ahead of bolus**
   - Contraction
   - Contraction

3. **Contraction in circular muscle layer forces bolus forward**
   - Contraction in circular muscle layer
   - Forces bolus forward
1. Identify the organs of the digestive system.

2. List and define the six primary functions of the digestive system.

3. Describe the functions of the mesenteries.

4. Name the layers of the digestive tract from superficial to deep.

5. Which is more efficient in propelling intestinal contents from one place to another—peristalsis or segmentation?
The Oral Cavity (16-2)

• Also called the **buccal cavity**

• Receiver of food lined with oral mucosa
  • Senses material before swallowing
  • Mechanically processes material
  • Lubricates material with saliva and mucus
  • Begins enzymatic digestion of carbohydrates and lipids

• **Gingivae**
  • The gums that surround base of teeth
The Oral Cavity (16-2)

• Boundaries
  • Cheeks form lateral walls
  • Labia or lips are continuous with cheeks
  • Hard and soft palates form roof of cavity
  • Tongue forms the floor
    • Free edge of tongue is attached to floor with lingual frenulum
  • Oropharynx starts at base of tongue and uvula
An anterior view of the oral cavity, as seen through the open mouth

Sagittal section of the oral cavity
The Tongue (16-2)

- Manipulates food within oral cavity
  - Mechanically compresses, abrades, distorts material
  - Assists in chewing and forming a bolus to swallow
  - Sensory analysis of taste, touch, temperature
- **Lingual tonsils**
  - Paired lymphoid nodules at base of tongue
The Salivary Glands (16-2)

- **Parotid**
  - On each side of oral cavity between mandible and skin
  - **Parotid duct** empties at level of second upper molar

- **Sublingual**
  - Under mucous membrane on floor of mouth

- **Submandibular**
  - Lateral sides of floor of mouth
Figure 16-5  The Salivary Glands.
Saliva (16-2)

• About 1–1.5 liters produced each day
  • While eating, pH rises from 6.7 to 7.5

• Contents and functions
  • 99.4 percent water and mucins, lubricate and reduce friction
  • Ions and buffers, change pH
  • Enzyme salivary amylase begin chemical digestion of starches
The Teeth (16-2)

• Perform chewing or mastication
  • Neck is boundary between root and crown
  • Enamel covers crown, requires $\text{Ca}^{2+}$, phosphates, and vitamin $D_3$
  • Dentin makes up most of tooth
  • Pulp cavity has blood vessels and nerves through root canal
  • Periodontal ligament, with cementum, binds to bone
Types of Teeth (16-2)

- **Incisors**
  - At front, blade-shaped for cutting

- **Cuspids**
  - Or canines, for tearing or slashing

- **Bicuspids or premolars and molars**
  - Have flattened crowns with ridges
  - For crushing, mashing, and grinding
Dental Succession (16-2)

• **Deciduous**
  - *Primary, baby or milk teeth*, usually 20 in number
  - Periodontal ligaments and roots erode during *eruption* of adult teeth

• **Secondary dentition**
  - Permanent teeth 32 in number
  - *Third molars* or *wisdom teeth* are last to come in
Figure 16-6a Teeth: Structural Components and Dental Succession.

Diagrammatic section through a typical adult tooth:

- Crown
- Neck
- Root

- Pulp cavity
- Enamel
- Dentin
- Gingiva
- Cementum
- Periodontal ligament
- Root canal
- Bone of alveolus
- Branches of blood vessels and nerve
Primary teeth, with the age at eruption given in months

**UPPER JAW**
- Central incisors (7.5 mo)
- Lateral incisor (9 mo)
- Cuspid (18 mo)
- Primary 1st molar (14 mo)
- Primary 2nd molar (24 mo)
- Primary 2nd molar (20 mo)
- Primary 1st molar (12 mo)
- Cuspid (16 mo)
- Lateral incisor (7 mo)

**LOWER JAW**
- Central incisors (6 mo)

Figure 16-6b  Teeth: Structural Components and Dental Succession.
Central incisors (7–8 yr)

Lateral incisor (8–9 yr)

Cuspid (11–12 yr)

1st Premolar (10–11 yr)

2nd Premolar (10–12 yr)

1st Molar (6–7 yr)

2nd Molar (12–13 yr)

3rd Molar (17–21 yr)

Upper dental arch

Hard palate

Lower dental arch

3rd Molar (17–21 yr)

2nd Molar (11–13 yr)

1st Molar (6–7 yr)

2nd Premolar (11–12 yr)

1st Premolar (10–12 yr)

Cuspid (9–10 yr)

Lateral incisor (7–8 yr)

Central incisors (6–7 yr)

Adult teeth, with the age of eruption given in years
6. Name the structures associated with the oral cavity.

7. The oral cavity is lined by which type of epithelium?

8. The digestion of which nutrient would be affected by damage to the parotid salivary glands?

9. Which type of tooth is most useful for chopping off bits of raw vegetables?
The Pharynx (16-3)

- Food passes through oropharynx and laryngopharynx to esophagus
- Mucosa is stratified squamous epithelium
- Lamina propria contains mucous glands and tonsils
- Muscles cooperate with oral cavity and esophageal muscles for swallowing
The Esophagus (16-3)

• Muscular tube acts as passageway from pharynx to stomach
  • Posterior to trachea
  • Enters abdominal cavity through esophageal hiatus in diaphragm
  • Lined with stratified squamous epithelium
  • Circular muscles at either end form upper and lower esophageal sphincters
Swallowing (16-3)

- Also called **deglutition**
  - Initiated voluntarily, proceeds automatically
  - Tongue forms **bolus** or small mass
- Three phases
  1. Buccal phase
     - Voluntary
  2. Pharyngeal phase
  3. Esophageal phase
     - Pharyngeal and esophageal phases are involuntary due to swallowing reflex triggered by pharyngeal stretch
Figure 16-7 The Swallowing Process.

1. **Buccal Phase**
   - Soft palate
   - Bolus
   - Epiglottis
   - Esophagus
   - Trachea

2. **Pharyngeal Phase**
   - Tongue
   - Bolus

3. **Esophageal Phase**
   - Peristalsis
   - Trachea

4. **Bolus Enters Stomach**
   - Lower esophageal sphincter
   - Stomach
   - Thoracic cavity
10. Describe the function of the pharynx.

11. Name the structure connecting the pharynx to the stomach.

12. What process is occurring when the soft palate and larynx elevate and the glottis closes?
The Stomach (16-4)

- Four functions
  1. Temporary storage of ingested food
  2. Mechanical breakdown of ingested food
  3. Chemical digestion by acids and enzymes
  4. Production of \textit{intrinsic factor} needed for vitamin B_{12} absorption

- **Chyme** is mixture of food and gastric secretions
The Stomach (16-4)

• Four regions

1. Cardia
   • Where the esophagus connects

2. Fundus
   • Bulge of superior stomach

3. Body
   • Largest area between fundus and pylorus

4. Pylorus
   • Most distal, connects stomach to small intestine
   • Pyloric sphincter regulates flow of chyme into small intestine
The Stomach (16-4)

- Can expand to accommodate up to 1.5 liters
  - **Rugae** are folds of mucosa when stomach is empty
- **Muscularis externa**
  - Has circular, longitudinal, and third oblique layer
- **Greater omentum**
  - Peritoneal pouch extends from stomach down over viscera
- **Lesser omentum**
  - Extends from stomach to liver
The Gastric Wall (16-4)

- Lined with simple columnar epithelium with numerous mucous cells
  - Secretes alkaline mucus that protects epithelium
- **Gastric pits**
  - Shallow depressions that open to surface
    - Neck cells undergo active mitosis, replacing mucosal cells
- **Gastric glands**
  - In fundus, body, and pylorus, secrete through gastric pits
  - Cells produce 1.5 liters/day of *gastric juice*
The Gastric Gland Cells (16-4)

- **Parietal cells** secrete:
  - Intrinsic factor for vitamin $B_{12}$ absorption
  - Hydrochloric acid (HCl)
    - Lowers pH of gastric juice to 1.5–2.0
    - Kills microorganisms and activates enzymes

- **Chief cells** secrete:
  - **Pepsinogen**, activated by HCl into proteolytic enzyme, **pepsin**
This anterior view of the stomach shows important superficial landmarks.
The stomach is surrounded by the peritoneal cavity. Its position is maintained by the greater and lesser omenta.
### Layers of the Stomach Wall

<table>
<thead>
<tr>
<th><strong>Mucosa</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric pit (opening to gastric gland)</td>
</tr>
<tr>
<td>Mucous epithelium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Submucosa</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamina propria</td>
</tr>
<tr>
<td>Muscularis mucosae</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Muscularis externa</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Oblique muscle</td>
</tr>
<tr>
<td>Circular muscle</td>
</tr>
<tr>
<td>Longitudinal muscle</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Serosa</strong></th>
</tr>
</thead>
</table>

This diagrammatic section shows the organization of the stomach wall.
This diagram of a gastric gland shows the sites of parietal cells and chief cells.
Three Phases of Regulation of Gastric Activity (16-4)

1. Cephalic phase
2. Gastric phase
3. Intestinal phase
Cephalic Phase (16-4)

- Triggered by sight, smell, taste, thought of food
- Prepares stomach to receive food
- Parasympathetic stimulation of gastric cells increases production of gastric juice
Gastric Phase (16-4)

- Begins when food enters stomach
- Stretch reflexes increase myenteric stimulation of mixing waves
- Submucosal plexus
  - Stimulates parietal and chief cells
  - Stimulates **G cells** to produce **gastrin**
  - Results in rapid increase in gastric juice production
Intestinal Phase (16-4)

- Begins when chyme enters small intestine
- Mostly inhibitory slowing gastric emptying
  - Enterogastric reflex inhibits gastrin production
  - Intestinal hormones *secretin*, *cholecystokinin* (*CCK*), and *gastric inhibitory peptide* (*GIP*) reduce gastric activity
- Ensures efficient intestinal functions
  - Secretion, digestion, and absorption
**Cephalic Phase**

Sight, smell, taste, or thoughts of food

- **Central nervous system**
- **Vagus nerve (N X)**

**Submucosal plexus**

**Gastrin**

- **Mucous cells** → Mucus
- **Chief cells** → Pepsinogen
- **Parietal cells** → HCl

**KEY**

- **Stimulation**
Figure 16-9 The Phases of Gastric Secretion.

Gastric Phase

- Distension
- Elevated pH
- Stretch receptors
- Chemoreceptors

Submucosal and myenteric plexuses

by bloodstream

Gastrin

Mucous cells
Chief cells
Parietal cells
G cells

Mucus
Pepsinogen
HCl
Partly digested peptides

Mixing waves
Figure 16-9 The Phases of Gastric Secretion.

Intestinal Phase

- Enterogastric reflex
- Myenteric plexus
- Chief cells
- Parietal cells
- Peristalsis

**KEY**
- Decreased pH
- Presence of lipids and carbohydrates
- Secretin
- GIP
- CCK

- By bloodstream
- Inhibition
Digestion in the Stomach (16-4)

- Pepsin initiates protein digestion to small peptides
- Salivary amylase will digest carbohydrates until pH <4.5
- No nutrients are absorbed in the stomach
  - Mucosa covered in alkaline mucous
  - Epithelial cells lack transport mechanisms
  - Gastric lining is impermeable to water
  - Digestion is incomplete, nutrients are still complex
13. Name the four main regions of the stomach.

14. Discuss the significance of the low pH in the stomach.

15. When a person suffers from chronic gastric ulcers, the branches of the vagus nerves that serve the stomach are sometimes cut in an attempt to provide relief. Why might this be an effective treatment?
Three Segments of the Small Intestine (16-5)

• Major site of digestion and absorption

1. Duodenum
2. Jejunum
3. Ileum
The Duodenum (16-5)

- Closest to the stomach
- C-shape curves around pancreas
- Receives chyme from stomach, plus liver and pancreatic secretions
- Mostly *retroperitoneal*, or behind peritoneum
The Jejunum and Ileum (16-5)

- **Jejunum**
  - Most chemical digestion and absorption here
  - Supported by mesentery and within peritoneum

- **Ileum**
  - The longest segment
  - Ends at *ileocecal valve* that controls flow into large intestine
Figure 16-10 The Segments of the Small Intestine.

Regions of the Small Intestine

- Duodenum
- Jejunum
- Ileum

The positions of the duodenum, jejunum, and ileum in the abdominopelvic cavity

Circular folds

b A representative view of the jejunum
The Intestinal Wall (16-5)

- Has three levels of increased surface area
  1. **Circular folds** or *plicae circulares*
     - Transverse ridges
  2. **Villi**
     - Fingerlike projections of mucosa covered with simple columnar epithelium
  3. **Microvilli**
     - Modified apical surface of columnar cells
       - Also called the *brush border*
The Villus (16-5)

• Each villus has:
  • *Intestinal glands*
    • Secrete mucous and *intestinal juice*
  • Capillary bed
    • Transports gases
    • Transports absorbed nutrients to hepatic portal system
  • **Lacteal** or lymphatic capillary
    • Transports fatty acids, packaged into chylomicrons
Figure 16-11 The Intestinal Wall.

- A single circular fold and multiple villi
- Capillaries
- Mucous cells
- Lacteal
- Brush border
- Tip of villus (LM x 250)
- A villus in sectional view

Layers of the Small Intestine:
- Mucosa
- Submucosa
- Muscularis externa
- Serosa

The organization of the intestinal wall

Internal structures in a single villus, showing the capillary network and lacteal
A single circular fold and multiple villi
Figure 16-11b The Intestinal Wall.

- Villi
- Intestinal gland
- Lymphoid nodule
- Lacteal

Layers of the Small Intestine:
- Mucosa
- Submucosa
- Muscularis externa
- Serosa

Submucosal artery and vein
Muscularis mucosae
Lymphatic vessel
Submucosal plexus
Circular layer of smooth muscle
Myenteric plexus
Longitudinal layer of smooth muscle

The organization of the intestinal wall
Internal structures in a single villus, showing the capillary network and lacteal.
Figure 16-11d The Intestinal Wall.

- Capillaries
- Mucous cells
- Lacteal
- Brush border
- Tip of villus

LM x 250

A villus in sectional view
Intestinal Movements (16-5)

- Weak peristaltic contractions
  - Initiated locally by neural network independent of CNS

- **Gastroenteric reflex**
  - Initiated by distention of stomach
  - Increased peristaltic contractions empty duodenum

- **Gastroileal reflex**
  - Triggered by gastrin, relaxes ileocecal valve
Intestinal Secretions (16-5)

• **Intestinal juice** is about 1.8 liters/day
  • Mostly water from mucosa by osmosis
  • Rest is secreted by intestinal glands
    • Activated during cephalic phase of gastric secretions
    • Buffers to raise pH of acidic chyme
    • Activation of enzymes for digestion
Intestinal Hormones (16-5)

- **Gastrin** in response to high-protein chyme
  - Stimulates production of acid and enzymes
- **Secretin** in response to low-pH chyme
  - Increases buffers and bile secretions
- **Cholecystokinin (CCK)** in response to high-fat chyme
  - In pancreas, increases enzyme production
  - In gallbladder, causes the ejection of bile
- **Gastric inhibitory peptide (GIP)** in response to high-fat and high-glucose chyme
<table>
<thead>
<tr>
<th>Hormone</th>
<th>Stimulus</th>
<th>Origin</th>
<th>Target</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gastrin</strong></td>
<td>Vagus nerve stimulation or arrival of food in the stomach</td>
<td>Stomach</td>
<td>Stomach</td>
<td>Stimulates production of acids and enzymes, increases motility</td>
</tr>
<tr>
<td></td>
<td>Arrival of chyme containing large quantities of undigested proteins</td>
<td>Duodenum</td>
<td>Stomach</td>
<td>Stimulates production of acids and enzymes, increases motility</td>
</tr>
<tr>
<td><strong>Secretin</strong></td>
<td>Arrival of chyme in the duodenum</td>
<td>Duodenum</td>
<td>Pancreas</td>
<td>Stimulates production of alkaline buffers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stomach</td>
<td>Inhibits gastric secretion and motility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Liver</td>
<td>Increases rate of bile secretion</td>
</tr>
<tr>
<td><strong>Cholecystokinin (CCK)</strong></td>
<td>Arrival of chyme containing lipids and partially digested proteins</td>
<td>Duodenum</td>
<td>Pancreas</td>
<td>Stimulates production of pancreatic enzymes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Gallbladder</td>
<td>Stimulates contraction of gallbladder</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Duodenum</td>
<td>Causes relaxation of sphincter at base of bile duct</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stomach</td>
<td>Inhibits gastric secretion and motility</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CNS</td>
<td>May reduce hunger</td>
</tr>
<tr>
<td><strong>Gastric inhibitory peptide (GIP)</strong></td>
<td>Arrival of chyme containing large quantities of fats and glucose</td>
<td>Duodenum</td>
<td>Stomach</td>
<td>Stimulates release of insulin by pancreatic islets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Inhibits gastric secretion and motility</td>
</tr>
</tbody>
</table>
Figure 16-12 The Activities of Major Digestive Tract Hormones.
Digestion in the Small Intestine (16-5)

- Most important digestive processes are completed in small intestine
- Most is done by enzymes and buffers from pancreas and liver
- Small intestine enzymes reside on brush border
16. Which ring of muscle regulates the flow of chyme from the stomach to the small intestine?

17. Name the three segments of the small intestine from proximal to distal.

18. How is the small intestine adapted for the absorption of nutrients?
The Pancreas (16-6)

• Lies behind stomach, extends from duodenum toward spleen, and is retroperitoneal

• Major tissues and functions
  • **Pancreatic islets** are endocrine cells that secrete insulin and glucagon
  • **Pancreatic acinar cells** are exocrine and produce digestive enzymes and buffers
  • Secrete **pancreatic juice**
• Acinar cells are organized into pouches called pancreatic acini

• Duct networks converge into pancreatic duct
  • Empties into duodenum

• Pancreatic enzymes are in four classes
  • Carbohydrases, lipases, nucleases, and proteases
The gross anatomy of the pancreas. The head of the pancreas is tucked into a C-shaped curve of the duodenum that begins at the pylorus of the stomach.
Control of Pancreatic Secretions (16-6)

- High-acid chyme triggers secretin release
  - Acts to increase sodium bicarbonate to buffer chyme
- CCK
  - Stimulates production and release of enzymes
    - Pancreatic amylase breaks down carbohydrates
    - Pancreatic lipase breaks down fats
    - Pancreatic proteases
      - Trypsin, chymotrypsin, carboxypeptidase
Anatomy of the Liver (16-6)

• Found in right hypochondriac and epigastric abdominopelvic regions
  • Encapsulated and covered by visceral peritoneum
  • Four lobes
    • Large left and right
    • Smaller caudate and quadrate
  • Anterior has *falciform ligament*, posterior has *round ligament*
Figure 16-14 The Surface Anatomy of the Liver.

- **Coronary ligament**
- **Falciform ligament**
- **Round ligament**
- **Gallbladder**
- **Anterior surface of the liver**
- **Right lobe**
- **Left lobe**
- **Left hepatic vein**
- **Coronary ligament**
- **Inferior vena cava**
- **Caudate lobe**
- **Common bile duct**
- **Hepatic portal vein**
- **Hepatic artery proper**
- **Quadrate lobe**
- **Gallbladder**
- **Posterior surface of the liver**

© 2013 Pearson Education, Inc.
Histology of the Liver (16-6)

• Lobes divided into about 100,000 liver lobules
  • Functional unit of liver
  • Hepatocytes covered in microvilli, arranged in plates
  • Sinusoids, specialized capillaries, empty into central vein
• Portal triad found at each of six corners of lobule
  • Branch of hepatic portal vein
  • Branch of hepatic artery
  • Bile duct
Blood Flow through the Liver (16-6)

- Blood comes from hepatic artery and hepatic portal vein
- As it flows through sinusoids, hepatocytes:
  - Absorb nutrient molecules
  - Secrete plasma proteins
- Blood leaves sinusoid into **central canal**
  - Merge to form hepatic veins
  - Drains into IVC
Histology of the Bile Production in the Liver
(16-6)

- **Hepatocytes** secrete bile into **bile canaliculi**
  - Between adjacent liver cells
  - Empty into bile duct in triad

- Bile flows into **common hepatic duct**
  - Into **common bile duct** into duodenum if hepatopancreatic sphincter is open
  - Or will back up into **cystic duct** and into gallbladder
Figure 16-15 Liver Histology.

A diagrammatic view of liver structure, showing relationships among lobules

Interlobular septum  Bile duct  Branch of hepatic portal vein  Portal area  Bile ductules

A sectional view showing the vessels and ducts within a portal area

Sinusoid  Hepatocytes  Bile canaliculi

Bile duct  Branch of hepatic artery proper

Portal area  LM x 350

A single liver lobule and its cellular components
A diagrammatic view of liver structure, showing relationships among lobules.

- Interlobular septum
- Bile duct
- Branch of hepatic portal vein
- Portal area
- Bile ductules
Figure 16-15b  Liver Histology.

- Sinusoid
- Central vein
- Kupffer cells
- Bile canaliculi
- Branch of hepatic artery proper
- Branch of hepatic portal vein
- Bile duct
- Hepatocytes

A single liver lobule and its cellular components
Figure 16-15c  Liver Histology.

- Branch of hepatic artery proper
- Branch of hepatic portal vein (containing blood)
- Hepatocytes
- Sinusoids
- Bile duct

Portal area  LM x 350

A sectional view showing the vessels and ducts within a portal area
Metabolic Regulation by the Liver (16-6)

• Hepatocytes
  • Extract nutrients and toxins from blood
    • Store and synthesize nutrient molecules
    • Fat-soluble vitamins A, D, E, and K are stored
  • Monitor and adjust circulating nutrients
    • High blood glucose triggers synthesis of glycogen
    • Low blood glucose triggers breakdown of glycogen and release of glucose
Hematological Regulation by the Liver (16-6)

- Phagocytic Kupffer cells remove old or damaged RBCs, debris, and pathogens from blood
- Hepatocytes synthesize plasma proteins
  - Determine osmotic pressure of plasma
  - Function as nutrient transporters
  - Key elements of clotting and complement cascades
Production and Role of Bile (16-6)

• Bile contains:
  • Water and ions that dilute and buffer
  • Bilirubin from destroyed RBCs
  • Cholesterol and **bile salts**
    • **Emulsification** by bile salts
      • Breaks apart large fat globules into smaller ones
      • Increases surface area of lipids for enzymatic action
<table>
<thead>
<tr>
<th>Major Functions of the Liver</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIGESTIVE AND METABOLIC FUNCTIONS</strong></td>
</tr>
<tr>
<td>Synthesis and secretion of bile</td>
</tr>
<tr>
<td>Storage of glycogen and lipid reserves</td>
</tr>
<tr>
<td>Maintenance of normal blood levels of glucose, amino acids, and fatty acids</td>
</tr>
<tr>
<td>Synthesis and interconversion of nutrient types (e.g., transamination of amino acids or conversion of carbohydrates to lipids)</td>
</tr>
<tr>
<td>Synthesis and release of cholesterol bound to transport proteins</td>
</tr>
<tr>
<td>Inactivation of toxins</td>
</tr>
<tr>
<td>Storage of iron reserves</td>
</tr>
<tr>
<td>Storage of fat-soluble vitamins</td>
</tr>
<tr>
<td><strong>OTHER MAJOR FUNCTIONS</strong></td>
</tr>
<tr>
<td>Synthesis of plasma proteins</td>
</tr>
<tr>
<td>Synthesis of clotting factors</td>
</tr>
<tr>
<td>Synthesis of the inactive hormone angiotensinogen</td>
</tr>
<tr>
<td>Phagocytosis of damaged red blood cells (by Kupffer cells)</td>
</tr>
<tr>
<td>Blood storage (major contributor to venous reserve)</td>
</tr>
<tr>
<td>Absorption and breakdown of circulating hormones (insulin, epinephrine) and immunoglobulins</td>
</tr>
<tr>
<td>Absorption and inactivation of lipid-soluble drugs</td>
</tr>
</tbody>
</table>
The Gallbladder (16-6)

- Hollow, pear-shaped organ tucked up under liver
- Stores and concentrates bile
- CCK triggers contractions of gallbladder and relaxation of hepatopancreatic sphincter
- Concentration of bile allows for efficient storage
  - Too concentrated bile can form gallstones
This interior view of the duodenum shows the opening at the duodenal papilla and the location of the hepatopancreatic sphincter.

A view of the inferior surface of the liver reveals the position of the gallbladder and the ducts that transport bile from the liver to the gallbladder and duodenum.
19. Does a high-fat meal raise or lower the level of cholecystokinin (CCK) in the blood?

20. The digestion of which nutrient would be most impaired by damage to the exocrine pancreas?

21. What effect would a decrease in the amount of bile salts in bile have on the digestion and absorption of fats?
The Large Intestine (16-7)

- Begins at **ileocecal valve**, ends at anus
- Horseshoe-shaped, frames the small intestine
- Functions
  - Reabsorb water, compacting chyme into feces
  - Absorption of vitamins freed by bacterial action
  - Storage of feces prior to defecation
The Cecum (16-7)

• An expanded pouch
  • Chyme enters through **ileocecal valve**
  • Functions to initiate compaction

• **Appendix** on posteromedial surface
  • Functions
    • Contains lymphoid nodules for immune function
    • Inflammation is called **appendicitis**
The Colon (16-7)

- Large diameter, lacks villi, and has abundant mucous cells

- Externally has:
  - **Haustra**: pouches that distend and elongate
  - **Taeniae coli**: three longitudinal bands of smooth muscle

- Segments
  - Ascending colon, transverse colon, descending colon, sigmoid colon
The Rectum (16-7)

- Expandable organ for storing feces
- **Anal canal** is last portion
  - Contains longitudinal anal columns
- **Anus** is the exit of the anal canal
  - **Internal anal sphincter** made of smooth muscle of muscularis externa, under ANS control
  - **External anal sphincter** is voluntary, skeletal muscle
The gross anatomy and regions of the large intestine.

- **ASCENDING COLON**
  - Ileocecal valve
  - Cecum
  - Vermiform appendix

- **TRANSVERSE COLON**

- **DESCENDING COLON**
  - Inferior mesenteric vein
  - Inferior mesenteric artery
  - Haustra

- **SIGMOID COLON**
  - Greater omentum (cut)
  - Taenia coli

- **RECTUM**
  - Anal canal
  - Anal columns
  - Internal anal sphincter
  - External anal sphincter
  - Anus

**Figure 16-17** The Large Intestine.
The gross anatomy and regions of the large intestine

- Aorta
- Hepatic portal vein
- Superior mesenteric vein
- Inferior vena cava
- Splenic vein
- Superior mesenteric artery
- Inferior mesenteric vein
- Greater omentum (cut)
- Descending colon
- Inferior mesenteric artery
- Taenia coli
- Haustra
- Ileocecal valve
- Cecum
- Vermiform appendix
- Ileum
- Cecum
- Taenia coli
- Sigmoid colon
- Rectum

© 2013 Pearson Education, Inc.
Anatomical details of the rectum and anus

- Anal canal
- Anal columns
- Internal anal sphincter
- External anal sphincter
- Anus
Absorption in the Large Intestine (16-7)

- Reabsorbs water
  - Of 1500 mL of chyme that enters cecum/day, 1300 mL are reabsorbed
- Reabsorbs bile salts
  - Enters hepatic portal circulation to return to liver
Absorption of Vitamins (16-7)

• Bacteria in colon make three key vitamins

1. Vitamin K
   • Needed for production of clotting factors

2. Biotin
   • Essential for glucose metabolism

3. Vitamin B₅
   • Required for synthesis of neurotransmitters and steroid hormones
Absorption of Organic Wastes (16-7)

• Bacteria convert bilirubin into:
  • Absorbable forms
    • Are then eliminated in urine, giving yellow color
  • Non-absorbable forms
    • Remain in feces, giving brown color
Absorption of Organic Wastes (16-7)

- Bacterial action breaks down peptides
  - Ammonia, nitrogenous compounds, hydrogen sulfide
- Ammonia and other toxins absorbed
  - Liver converts them into harmless forms eliminated by kidneys
- Indigestible carbohydrates
  - Provide nutrient source for bacteria, forming *flatus*, gas
Movements of the Large Intestine (16-7)

• Transit time very slow
  • Allowing for water reabsorption

• Mass movements
  • Powerful peristaltic contractions
  • Occur 3–4 times/day
  • Triggered by distention of stomach, "gastrocolic reflex"
Defecation Reflex (16-7)

- Involves two feedback loops
  1. Short loop
     - Stretch receptors in rectal walls stimulate local peristalsis
     - Moves feces toward anus, distends rectum
  2. Long loop
     - Stimulates parasympathetic reflex
       - Triggers involuntary relaxation of internal sphincter
       - Conscious relaxation of external sphincter
22. Identify the four segments of the colon.

23. What are some structural differences between the large intestine and the small intestine?

24. A narrowing of the ileocecal valve would hamper movement of chyme between what two organs?
• Diets include:
  • Carbohydrates, proteins, lipids, large organic molecules
    • Broken down into absorbable forms by enzymes
      • Hydrolysis reactions
    • Taken up by cells to produce ATP or synthesize other molecules
  • Fats, water, electrolytes, and vitamins
    • No processing, but require special transport mechanisms
Carbohydrate Digestion and Absorption (16-8)

- Begins in mouth, mastication, and salivary amylase
  - Carbohydrates broken into di- or trisaccharides
- Pancreatic amylase continues process
- Brush border enzymes complete process into:
  - Monosaccharides
    - Absorbed through facilitated diffusion or cotransport
Lipid Digestion and Absorption (16-8)

- Triglycerides enter duodenum in large fat droplets
  - Bile salts emulsify, pancreatic lipase hydrolyzes into:
    - Fatty acids and monoglycerides
      - Combine with bile salts to form **micelles**
      - Diffuse into epithelial cells, converted into triglycerides
      - Coated with proteins to form **chylomicrons**
      - Absorbed into lacteals
Protein Digestion and Absorption (16-8)

- Initiated by mastication and exposure to HCl
  - Pepsin breaks proteins into large peptides
  - Pancreatic proteases break them down into short peptide chains
- Peptidases on brush border
  - Complete process by cleaving off individual amino acids
- Amino acids absorbed by carrier proteins
<table>
<thead>
<tr>
<th>Enzyme</th>
<th>Source</th>
<th>Target</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARBOHYDRASES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amylase</td>
<td>Salivary glands, pancreas</td>
<td>Complex carbohydrates</td>
<td>Disaccharides and trisaccharides</td>
</tr>
<tr>
<td>Maltase, sucrase, lactase</td>
<td>Small intestine</td>
<td>Maltose, sucrose, lactose</td>
<td>Monosaccharides</td>
</tr>
<tr>
<td><strong>LIPASES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancreatic lipase</td>
<td>Pancreas</td>
<td>Triglycerides</td>
<td>Fatty acids and monoglycerides</td>
</tr>
<tr>
<td><strong>PROTEASES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pepsin</td>
<td>Stomach</td>
<td>Proteins, polypeptides</td>
<td>Short polypeptides</td>
</tr>
<tr>
<td>Trypsin, chymotrypsin, carboxypeptidase</td>
<td>Pancreas</td>
<td>Proteins, polypeptides</td>
<td>Short peptide chains</td>
</tr>
<tr>
<td>Peptidases</td>
<td>Small intestine</td>
<td>Dipeptides, tripeptides</td>
<td>Amino acids</td>
</tr>
<tr>
<td><strong>NUCLEASES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pancreas</td>
<td>Nucleic acids</td>
<td>Nitrogenous bases and simple sugars</td>
</tr>
</tbody>
</table>
## Figure 16-18 Chemical Events in Digestion

<table>
<thead>
<tr>
<th>REGION</th>
<th>CARBOHYDRATES</th>
<th>LIPIDS</th>
<th>PROTEINS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORAL CAVITY</td>
<td>Salivary amylase</td>
<td>Lingual lipase</td>
<td>Pepsin</td>
</tr>
<tr>
<td>ESOPHAGUS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STOMACH</td>
<td>Disaccharides, Trisaccharides</td>
<td>Monoglycerides, Fatty acids in micelles</td>
<td>Bile salts and pancreatic lipase</td>
</tr>
<tr>
<td>SMALL INTESTINE</td>
<td>Pancreatic alpha-amylase</td>
<td>Chylomicrons</td>
<td>Trypsin, Chymotrypsin, Elastase, Carboxypeptidase</td>
</tr>
<tr>
<td>INTESTINAL MUCOSA</td>
<td>Lactase, Maltase, Sucrase</td>
<td>FACILITATED DIFFUSION</td>
<td>FACILITATED DIFFUSION</td>
</tr>
<tr>
<td></td>
<td>FACILITATED DIFFUSION AND COTRANSPORT</td>
<td>FACILITATED DIFFUSION AND COTRANSPORT</td>
<td>FACILITATED DIFFUSION AND COTRANSPORT</td>
</tr>
<tr>
<td>ROUTE TO BLOODSTREAM</td>
<td>Monosaccharides</td>
<td>Monoglycerides, Fatty acids</td>
<td>Amino acids</td>
</tr>
<tr>
<td></td>
<td>FACILITATED DIFFUSION</td>
<td>Triglycerides</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chylomicrons</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>EXOCYTOSIS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capillary</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Monosaccharides</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Water and Electrolyte Absorption (16-8)

- Intestinal epithelial cells absorb dissolved nutrients and ions
  - Water "follows" through osmosis
  - Na\(^+\) and Cl\(^-\) key in promoting water reabsorption
  - Other ions include K\(^+\), Mg\(^{2+}\), I\(^-\), HCO\(^-\), Fe\(^{2+}\), and Ca\(^{2+}\)
  - Ca\(^{2+}\) absorption under control of parathyroid hormone and calcitriol
Absorption of Vitamins (16-8)

- **Fat-soluble vitamins**: A, D, E, and K
  - Absorbed in micelles along with lipids
  - Vitamin K also produced in colon by bacteria

- **Water-soluble vitamins**: B vitamins and C
  - All but B$_{12}$ are easily absorbed by digestive epithelium
  - B$_{12}$ requires intrinsic factor
  - Bacteria in gut are also source of water-soluble vitamins
25. An increase in which component of a meal would increase the number of chylomicrons in the lacteals?

26. Removal of the stomach would impair the absorption of which vitamin?

27. Why is diarrhea potentially life threatening but constipation is not?
Age-Related Changes in the GI Tract (16-9)

- Division rate of epithelium declines
  - Peptic ulcers more likely
- Smooth muscle tone decreases
  - Slows rate of peristalsis, leads to constipation
  - Straining leads to hemorrhoids
- Cumulative damage becomes apparent
  - Tooth loss, liver disease
Age-Related Changes in the GI Tract (16-9)

- Increase in cancer rate
  - Colon and stomach cancers

- Dehydration
  - Osmoreceptor sensitivity declines

- Aging of other systems affects digestive tract
  - Bone loss can lead to tooth loss
  - Loss of taste and olfactory sensations change diets
28. Identify general digestive system changes that occur with aging.
Digestive System Integration with Other Systems (16-10)

- Functionally connected to all other systems
- Anatomically connected to nervous, cardiovascular, endocrine, and lymphatic systems
Provides vitamin D_3_ needed for the absorption of calcium and phosphorus

Skull, ribs, vertebrae, and pelvic girdle support and protect parts of digestive tract; teeth are important in mechanical processing of food

Protects and supports digestive organs in abdominal cavity; controls entrances and exits of digestive tract

ANS regulates movement and secretion; reflexes coordinate passage of materials along tract; control over skeletal muscles regulates ingestion and defecation; hypothalamic centers control hunger, satiation, and feeding

Epinephrine and norepinephrine stimulate constriction of sphincters and depress digestive activity; hormones coordinate activity along digestive tract

Distributes hormones of the digestive tract; carries nutrients, water, and ions from sites of absorption; delivers nutrients and toxins to liver

Tonsils and other lymphoid nodules defend against infection and toxins absorbed from the digestive tract; lymphatic vessels carry absorbed lipids to venous system

Increased thoracic and abdominal pressure through contraction of respiratory muscles can assist in defecation

Provides substrates essential for neurotransmitter synthesis

Provides nutrients and substrates to endocrine cells; endocrine cells of pancreas secrete insulin and glucagon; liver produces angiotensinogen

Absorbs fluid to maintain normal blood volume; absorbs vitamin K; liver excretes heme (as bilirubin), synthesizes coagulation proteins

Secretions of digestive tract (acids and enzymes) provide innate (nonspecific) defense against pathogens

Pressure of digestive organs against the diaphragm can assist in exhalation and limit inhalation

For all systems, the digestive system absorbs organic substrates, vitamins, ions, and water required by all cells.
29. Identify the functional relationships between the digestive system and other body systems.

30. List the digestive system functions that are related to the cardiovascular system.