• Acquires nutrients from environment

• Anabolism
  – Uses raw materials to synthesize essential compounds

• Catabolism
  – Decomposes substances to provide energy cells need to function
16-1 The digestive system — the digestive tract plus accessory organs — performs various food-processing functions
• **Digestive tract** also called gastrointestinal (GI) tract or alimentary canal
  – Is a muscular tube
  – Extends from oral cavity to anus:
    • Passes through pharynx, esophagus, stomach, and small and large intestines
Accessory Organs

**ORAL CAVITY, TEETH, TONGUE**
Mechanical processing, moistening, mixing with salivary secretions

**SALIVARY GLANDS**
Secretion of lubricating fluid containing enzymes that break down carbohydrates

**LIVER**
Secretion of bile (important for lipid digestion), storage of nutrients, and many other vital functions

**PHARYNX**
Muscular propulsion of materials into the esophagus

**ESOPHAGUS**
Transport of materials to the stomach

Figure 16-1
Digestive Tract

GALLBLADDER
Storage and concentration of bile

PANCREAS
Exocrine cells secrete buffers and digestive enzymes; endocrine cells secrete hormones

LARGE INTESTINE
Dehydration and compaction of indigestible materials in preparation for elimination

STOMACH
Chemical breakdown of materials by acid and enzymes; mechanical processing through muscular contractions

SMALL INTESTINE
Enzymatic digestion and absorption of water, organic substrates, vitamins, and ions

Figure 16-1
Functions of the Digestive System

1. **Ingestion**
   - Occurs when materials enter digestive tract via the mouth

2. **Mechanical processing**
   - Crushing and shearing
   - Makes materials easier to propel along digestive tract

3. **Digestion**
   - The chemical breakdown of food into small organic fragments for absorption by digestive epithelium
Functions of the Digestive System

4. **Secretion**
   - Is the release of water, acids, enzymes, buffers, and salts
   - By epithelium of digestive tract
   - By glandular organs

5. **Absorption**
   - Movement of organic substrates, electrolytes, vitamins, and water
   - Across digestive epithelium
   - Into interstitial fluid of digestive tract

6. **Excretion**
   - Removal of waste products from body fluids
Digestive Tract

• Lining of the digestive tract protects surrounding tissues against
  – Corrosive effects of digestive acids and enzymes
  – Mechanical stresses, such as abrasion
  – Bacteria either ingested with food or that reside in digestive tract
Histological Organization of the Digestive Tract

• Major layers of the digestive tract
  – Mucosa
  – Submucosa
  – Muscularis externa
  – Serosa
The Structure of the Digestive Tract

Figure 16-2
Histological Organization of the Digestive Tract

• The Mucosa
  – Is the inner lining of the digestive tract
  – Is a mucous membrane consisting of:
    • Epithelium, moistened by glandular secretions
    • Lamina propria of areolar tissue
Histological Organization of the Digestive Tract

• The Digestive Epithelium
  – Mucosal epithelium is simple or stratified:
    • Depending on location, function, and stresses:
      – oral cavity, pharynx, and esophagus:
        » mechanical stresses
        » lined by stratified squamous epithelium
      – stomach, small intestine, and most of large intestine:
        » absorption
        » simple columnar epithelium with mucous (goblet) cells
Histological Organization of the Digestive Tract

• The Submucosa
  – Is a layer of dense, irregular connective tissue
  – Surrounds muscularis mucosae
  – Has large blood vessels and lymphatic vessels
  – May contain exocrine glands:
    • Secrete buffers and enzymes into digestive tract
Submucosal Plexus

- Innervates the mucosa and submucosa
- Contains:
  - Sensory neurons
  - Parasympathetic ganglionic neurons
  - Sympathetic postganglionic fibers
The Muscularis Externa

- Is dominated by smooth muscle cells
- Are arranged in:
  - Inner circular layer
  - Outer longitudinal layer
- Are involved in:
  - Mechanical processing
  - Movement of materials along digestive tract
Digestive Tract

• The Serosa
  – Serous membrane covering muscularis externa
  – Visceral peritoneum over some CT:
    • Continuous with parietal peritoneum that lines cavity
  – Except in oral cavity, pharynx, esophagus, and rectum:
    • Where adventitia, a dense sheath of collagen fibers, firmly attaches the digestive tract to adjacent structures
The Movement of Digestive Materials

• By muscular layers of digestive tract
  – Consist of visceral smooth muscle tissue
  – Along digestive tract:
    • Has rhythmic cycles of activity
    • Controlled by pacesetter cells
  – Cells undergo spontaneous depolarization:
    • Triggering wave of contraction through entire muscular sheet
The Movement of Digestive Materials

• Pacesetter Cells
  – Located in muscularis mucosae and muscularis externa:
    • Surrounding lumen of digestive tract

• Peristalsis
  – Consists of waves of muscular contractions
  – Moves a bolus along the length of the digestive tract
Peristaltic Motion

1. Circular muscles contract behind bolus:
   - While circular muscles ahead of bolus relax

2. Longitudinal muscles ahead of bolus contract:
   - Shortening adjacent segments

3. Wave of contraction in circular muscles:
   - Forces bolus forward
The Movement of Digestive Materials

- **Segmentation**
  - Cycles of contraction:
    - Churn and fragment the bolus
    - Mix contents with intestinal secretions
  - Does not follow a set pattern:
    - Does not push materials in any one direction
Peristalsis

Figure 16-3
Peristalsis

**Figure 16-3**

**STEP 2**

Contraction of longitudinal muscles ahead of bolus

**STEP 3**

Contraction in circular muscle layer forces bolus forward
16-2 The oral cavity contains the tongue, salivary glands, and teeth, each with specific functions
Functions of Oral Cavity

• Sensory analysis
  – Of material before swallowing

• Mechanical processing
  – Through actions of teeth, tongue, and palatal surfaces

• Lubrication
  – Mixing with mucus and salivary gland secretions

• Limited digestion
  – Of carbohydrates and lipids
Oral Cavity

Figure 16-4a
Oral Cavity

Figure 16-4b
The Tongue

• Manipulates materials inside mouth

• Functions of the tongue
  – **Mechanical processing** by compression, abrasion, and distortion
  – **Manipulation** to assist in chewing and to prepare material for swallowing
  – **Sensory analysis** by touch, temperature, and taste receptors
  – **Secretion** of mucins and the enzyme *lingual lipase*
Salivary Glands

• Three pairs secrete into oral cavity
  – Each pair has distinctive cellular organization:
    • And produces saliva with different properties
• **Parotid Salivary Glands**
  – Inferior to zygomatic arch
  – Produce serous secretion:
    • Enzyme *salivary amylase* (breaks down starches)
  – Drained by *parotid duct* (Stensen duct):
    • Which empties into vestibule at second molar
• **Sublingual Salivary Glands**
  – Covered by mucous membrane of floor of mouth
  – Produce mucous secretion:
    • Acts as a buffer and lubricant
  – **Sublingual ducts** (Rivinus ducts):
    • Either side of lingual frenulum
Oral Cavity

• **Submandibular Salivary Glands**
  – In floor of mouth
  – Within mandibular groove
  – Secrete buffers, glycoproteins (mucins), and salivary amylase

  – **Submandibular ducts** *(Wharton ducts)*:
    • Open immediately posterior to teeth
    • Either side of lingual frenulum
Oral Cavity

- **Salivary Glands**
  - Produce 1.0 to 1.5 liters of saliva each day:
    - 70% by submandibular glands
    - 25% by parotids
    - 5% by sublingual glands
The Salivary Glands

Figure 16-5

- Parotid salivary gland
- Parotid duct
- Openings of sublingual ducts
- Lingual frenulum
- Opening of left submandibular duct
- Sublingual salivary gland
- Submandibular salivary gland
- Submandibular duct
Oral Cavity

• Saliva
  – 99.4% water
  – 0.6% includes:
    • Electrolytes (Na⁺, Cl⁻, and HCO₃⁻)
    • Buffers
    • Glycoproteins (mucins)
    • Antibodies
    • Enzymes
    • Waste products
The Teeth

• Tongue movements pass food across occlusal surfaces of teeth
• Chew (masticate) food
• Tooth structure
  – Dentin:
    • A mineralized matrix similar to that of bone
    • Does not contain cells
  – Pulp cavity:
    • Receives blood vessels and nerves through the root canal
The Teeth

• Tooth Structure
  – Root:
    • Of each tooth sits in a bony socket (alveolus)
    • A layer of cementum covers dentin of the root:
      – providing protection and anchoring periodontal ligament
  – Crown:
    • Exposed portion of tooth
    • Projects beyond soft tissue of gingiva
    • Dentin covered by layer of enamel
The Teeth

• Alveolar Processes
  – Of the maxillae:
    • Form maxillary arcade (upper dental arch)
  – Of the mandible:
    • Form mandibular arcade (lower dental arch)
The Teeth

Figure 16-6a
Types of Teeth

• Dental Arcades (Arches)
  – Contain four types of teeth:
    1. Incisors
    2. Cuspids (canines)
    3. Bicuspids (premolars)
    4. Molars
Dental Succession

• During embryonic development, two sets of teeth form
  – Primary dentition, or deciduous teeth
  – Secondary dentition, or permanent dentition
Dental Succession

• Primary Teeth
  – Also called deciduous teeth, milk teeth, or baby teeth
  – 20 temporary teeth of primary dentition
  – Five on each side of upper and lower jaws:
    • 2 incisors
    • 1 cuspid
    • 2 deciduous molars
• Secondary Dentition
  – Also called permanent dentition
  – Replaces deciduous teeth
  – 32 permanent teeth
  – Eight on each side, upper and lower:
    • 2 incisors
    • 1 cuspid
    • 5 molars
Secondary Teeth

Figure 16-6c
16-3 The pharynx is a passageway between the oral cavity and the esophagus, which conducts solids and liquids on to the stomach.
The Pharynx

• A common passageway for solid food, liquids, and air

• Regions of the pharynx
  – Nasopharynx
  – Oropharynx
  – Laryngopharynx
The Esophagus

• A hollow muscular tube
• About 25 cm (10 in.) long and 2 cm (0.80 in.) wide
• Conveys solid food and liquids to the stomach
• Begins posterior to cricoid cartilage
• Is innervated by fibers from the esophageal plexus
The Esophagus

- Resting Muscle Tone
  - In the circular muscle layer in the superior 3 cm (1.2 in.) of esophagus, prevents air from entering
Swallowing

- Also called deglutition
  - Can be initiated voluntarily
  - Proceeds automatically
  - Is divided into three phases:
    - Buccal phase
    - Pharyngeal phase
    - Esophageal phase
The Swallowing Process

**STEP 1**
**BUCCAL PHASE**

- Soft palate
- Bolus
- Epiglottis
- Esophagus
- Trachea

**STEP 2**
**PHARYNGEAL PHASE**

- Tongue
- Bolus

Figure 16-7

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The Swallowing Process

**STEP 3**  
ESOPHAGEAL PHASE

- Peristalsis
- Trachea

**STEP 4**  
BOLUS ENTERS STOMACH

- Thoracic cavity
- Lower esophageal sphincter
- Diaphragm
- Stomach

Figure 16-7
16-4 The J-shaped stomach receives the bolus from the esophagus and aids in chemical and mechanical digestion
The Stomach

• Major Functions of the Stomach
  – Storage of ingested food
  – Mechanical breakdown of ingested food
  – Disruption of chemical bonds in food material by acid and enzymes
  – Production of intrinsic factor, a glycoprotein required for absorption of vitamin B$_{12}$ in small intestine
The Stomach

• Regions of the Stomach
  – Cardia
  – Fundus
  – Body
  – Pylorus
The Stomach

• Anatomy of the Stomach
  – The stomach is shaped like an expanded J:
    • Short lesser curvature forms medial surface
    • Long greater curvature forms lateral surface
  – Anterior and posterior surfaces are smoothly rounded
  – Shape and size vary from individual to individual and from one meal to the next
  – Stomach typically extends between levels of vertebrae T7 and L3
Anatomy of the Stomach

Figure 16-8a
Anatomy of the Stomach

Figure 16-8b
The Gastric Wall

• Histology of the Stomach
  – Simple columnar epithelium lines all portions of stomach
  – Epithelium is a secretory sheet:
    • Produces mucus that covers interior surface of stomach
    • **Gastric pits**: shallow depressions that open onto the gastric surface
    • Mucous cells, at the base, or neck, of each gastric pit, actively divide, replacing superficial cells
The Gastric Wall

• **Gastric Glands**
  – In fundus and body of stomach:
    • Extend deep into underlying lamina propria
  – Each gastric pit communicates with several gastric glands:
    • Parietal cells
    • Chief cells
The Gastric Wall

Figure 16-8c
The Gastric Wall

- Parietal Cells
  - Secrete intrinsic factor and hydrochloric acid (HCl)
- Chief Cells
  - Are most abundant near base of gastric gland:
    - Secrete pepsinogen (inactive proenzyme):
      - is converted by HCl in the gastric lumen:
        » to pepsin (active proteolytic enzyme)
The Gastric Wall

Figure 16-8d

Gastric pit

Mucous cells

Neck

Parietal cells

Smooth muscle cell

Chief cells

Endocrine cell

(d)
Regulation of Gastric Activity

- Production of acid and enzymes by the gastric mucosa can be
  - Controlled by the CNS
  - Regulated by short reflexes of ENS
  - Regulated by hormones of digestive tract

- Three phases: cephalic phase, gastric phase, and intestinal phase
The Phases of Gastric Secretion

Figure 16-9

STEP 1  CEPHALIC PHASE

Sight, smell, taste, or thoughts of food

Central nervous system

Vagus nerve (N X)

Submucosal plexus

Mucous cells
Chief cells
Parietal cells

Mucus
Pepsinogen
HCl

G cells

Gastrin

KEY
- Stimulation
- Inhibition
The Phases of Gastric Secretion

Figure 16-9
The Phases of Gastric Secretion

Figure 16-9
Digestion in the Stomach

• Stomach performs preliminary digestion of proteins by pepsin
  – Some digestion of carbohydrates (by salivary amylase)
  – Lipids (by lingual lipase)

• Stomach contents
  – Become more fluid
  – pH approaches 2.0
  – Pepsin activity increases
  – Protein disassembly begins

• Although digestion occurs in the stomach, nutrients are not absorbed there
16-5 The small intestine digests and absorbs nutrients
The Small Intestine

- Plays key role in digestion and absorption of nutrients
- 90% of nutrient absorption occurs in the small intestine
The Small Intestine

• The Duodenum
  – The segment of small intestine closest to the stomach
  – 25 cm (10 in.) long
  – “Mixing bowl” that receives chyme from stomach and digestive secretions from pancreas and liver
  – Functions of the duodenum:
    • To receive chyme from stomach
    • To neutralize acids before they can damage the absorptive surfaces of the small intestine
The Small Intestine

• The Jejunum
  – Is the middle segment of the small intestine
  – 2.5 meters (8.2 ft) long
  – Is the location of most:
    • Chemical digestion
    • Nutrient absorption
  – Has few plicae circulares
  – Small villi
The Small Intestine

• The Ileum
  – The final segment of the small intestine
  – 3.5 meters (11.48 ft) long
  – Ends at the ileocecal valve, a sphincter that controls flow of material from the ileum into the large intestine
Segments of the Intestine

Duodenum

Jejunum

Large intestine

Ileum

Rectum

Figure 16-10
The Intestinal Wall

- **Histology of the Small Intestine**
  - **Plicae circulares:**
    - Transverse folds in intestinal lining
    - Are permanent features:
      - do not disappear when small intestine fills
  - **Intestinal villi:**
    - A series of fingerlike projections:
      - in mucosa of small intestine
    - Covered by simple columnar epithelium:
      - covered with microvilli
The Intestinal Wall

• Histology of the Small Intestine
  – Intestinal glands:
    • Mucous cells between columnar epithelial cells
    • Eject mucins onto intestinal surfaces
The Intestinal Wall

Plicae circulares

Small intestine

Plica circulares

Villi

Figure 16-11a
The Intestinal Wall

Figure 16-11b
The Intestinal Wall

Epithelium with microvilli
Mucous cell
Lacteal
Capillary network
Nerve
Lamina propria
Arteriole
Venule
Lymphatic vessel

Figure 16-11c
The Small Intestine

• **Duodenal Glands**
  – Also called submucosal glands or Brunner glands
  – Produce copious quantities of mucus:
    • When chyme arrives from stomach
Intestinal Movements

• Chyme arrives in duodenum
  – Weak peristaltic contractions move it slowly toward jejunum:
    • Myenteric reflexes
    • Not under CNS control
    • Parasympathetic stimulation accelerates local peristalsis and segmentation
Intestinal Movements

• The Gastroenteric Reflex
  – Stimulates motility and secretion:
    • Along entire small intestine

• The Gastroileal Reflex
  – Triggers relaxation of ileocecal valve
  – Allows materials to pass from small intestine into large intestine
Intestinal Secretions

• Watery intestinal juice
  – 1.8 liters per day enter intestinal lumen
  – Moisten chyme
  – Assist in buffering acids
  – Keep digestive enzymes and products of digestion in solution
<table>
<thead>
<tr>
<th>HORMONE</th>
<th>STIMULUS</th>
<th>ORIGIN</th>
<th>TARGET</th>
<th>EFFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrin</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>As above</td>
</tr>
<tr>
<td>Secretin</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>Cholecystokinin (CCK)</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>Gastric inhibitory peptide (GIP)</td>
<td>Arrival of chyme containing large quantities of fats and glucose</td>
<td>Duodenum</td>
<td>Pancreas</td>
<td>Stimulates release of insulin by pancreatic islets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stomach</td>
<td>Inhibits gastric secretion and motility</td>
</tr>
</tbody>
</table>
Activities of Major Digestive Tract Hormones

Figure 16-12
16-6 The pancreas, liver, and gallbladder are accessory glands that assist with the digestive process in the small intestine
The Pancreas

- Lies posterior to the stomach
  - From duodenum toward spleen
- Is bound to posterior wall of abdominal cavity
- Is wrapped in thin, connective tissue capsule
The Pancreas

• Histological Organization
  – Lobules of the pancreas:
    • Are separated by connective tissue partitions (septa)
    • Contain blood vessels and tributaries of pancreatic ducts
    • In each lobule:
      – ducts branch repeatedly
      – end in blind pockets (pancreatic acini)
The Pancreas

• Pancreatic Acini
  – Blind pockets
  – Are lined with simple cuboidal epithelium
  – Contain scattered pancreatic islets

• Pancreatic Islets
  – Endocrine tissues of pancreas
  – Scattered (1% of pancreatic cells)
Figure 16-13a

The Pancreas

- Common bile duct
- Accessory pancreatic duct
- Pancreatic duct
- Lobules
- Tail of pancreas

Duodenum

Head of pancreas

Body of pancreas

Duodenal papilla

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The Pancreas

Figure 16-13b

Duct

Pancreatic acini (exocrine)

Pancreatic islet (endocrine)

(b) LM × 75

Figure 16-13b
The Pancreas

• Pancreatic Secretions
  – 1000 mL (1 qt) pancreatic juice per day
  – Controlled by hormones from duodenum
  – Contain pancreatic enzymes
The Pancreas

• Pancreatic Enzymes

  – Pancreatic alpha-amylase:
    • A carbohydrase
    • Breaks down starches
    • Similar to salivary amylase

  – Pancreatic lipase:
    • Breaks down complex lipids
    • Releases products (e.g., fatty acids) that are easily absorbed
The Pancreas

• Pancreatic Enzymes
  – Nucleases:
    • Break down nucleic acids
  – Proteolytic enzymes:
    • Break certain proteins apart
    • Proteases break large protein complexes
    • Peptidases break small peptides into amino acids
    • 70% of all pancreatic enzyme production
    • Secreted as inactive proenzymes
    • Activated after reaching small intestine
The Liver

- Is the largest visceral organ (1.5 kg; 3.3 lb)
- Lies in right hypochondriac and epigastric regions
The Liver

• Anatomy of the Liver
  – Is wrapped in tough fibrous capsule
  – Is covered by visceral peritoneum
  – Is divided into lobes
The Surface Anatomy of the Liver

Figure 16-14a
The Surface Anatomy of the Liver

**Figure 16-14b**

- **Left hepatic vein**
- **Coronary ligament**
- **Inferior vena cava**
- **Caudate lobe**
- **Common bile duct**
- **Hepatic portal vein**
- **Hepatic artery**
- **Quadrant lobe**
- **Gallbladder**

*(b) Posterior surface*
The Liver

• Hepatic Blood Supply
  – One-third of blood supply:
    • Arterial blood from hepatic artery proper
  – Two-thirds venous blood from hepatic portal vein, originating at:
    • Esophagus
    • Stomach
    • Small intestine
    • Most of large intestine
The Liver

• Histological Organization of the Liver
  – Liver lobules:
    • The basic functional units of the liver
    • Each lobe is divided:
      – by connective tissue
      – into about 100,000 liver lobules
      – about 1 mm diameter each
    • Is hexagonal in cross section
    • With six portal areas (hepatic triads):
      – one at each corner of lobule
The Liver

• A Portal Area
  – Contains three structures:
    • Branch of hepatic portal vein
    • Branch of hepatic artery proper
    • Small branch of bile duct
Figure 16-15a

(a) Bile duct  Branch of hepatic portal vein  Portal area
Liver Histology

Figure 16-15b

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

Figure 16-15c

(c) LM × 35

- Sinusoid
- Hepatocytes
- Branch of hepatic portal vein (containing blood)
- Branch of hepatic artery
- Bile duct
The Liver

• **Hepatocytes**
  – Are liver cells
  – Adjust circulating levels of nutrients:
    • Through selective absorption and secretion
  – In a liver lobule form a series of irregular plates arranged like wheel spokes
  – Many **Kupffer cells** (stellate reticuloendothelial cells) are located in sinusoidal lining
  – As blood flows through sinusoids:
    • Hepatocytes absorb solutes from plasma
    • And secrete materials such as plasma proteins
Bile Ducts

Figure 16-16b

- Hepatopancreatic sphincter
- Duodenal papilla
- Intestinal lumen
- Common bile duct
- Pancreatic duct
- Pancreas

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The Liver

The Physiology of the Liver

1. Metabolic regulation
2. Hematological regulation
3. Bile production
<table>
<thead>
<tr>
<th>TABLE 16-2  Major Functions of the Liver</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIGESTIVE AND METABOLIC FUNCTIONS</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>
</tbody>
</table>
### Table 16-2  Major Functions of the Liver

**Other Major Functions**

- Synthesis of plasma proteins
- Synthesis of clotting factors
- Synthesis of the inactive hormone angiotensinogen
- Phagocytosis of damaged red blood cells (by Kupffer cells)
- Blood storage (major contributor to venous reserve)
- Absorption and breakdown of circulating hormones (insulin, epinephrine) and immunoglobulins
- Absorption and inactivation of lipid-soluble drugs
The Gallbladder

• Is a pear-shaped, muscular sac
• Stores and concentrates bile prior to excretion into small intestine
• Is located in the fossa on the posterior surface of the liver’s right lobe
The Gallbladder

- Functions of the Gallbladder
  - Stores bile
  - Releases bile into duodenum, but only under stimulation of hormone cholecystokinin (CCK)
  - CCK:
    - Hepatopancreatic sphincter remains closed
    - Bile exiting liver in common hepatic duct cannot flow through common bile duct into duodenum
    - Bile enters cystic duct and is stored in gallbladder
The Gallbladder

• Physiology of the Gallbladder
  – Full gallbladder contains 40–70 mL bile
  – Bile composition gradually changes in gallbladder:
    • Water is absorbed
    • Bile salts and solutes become concentrated
16-7 The large intestine is divided into three parts with regional specialization
The Large Intestine

- Is horseshoe shaped
- Extends from end of ileum to anus
- Lies inferior to stomach and liver
- Frames the small intestine
- Also called large bowel
- Is about 1.5 meters (4.9 ft) long and 7.5 cm (3 in.) wide
The Large Intestine

• Functions of the Large Intestine
  – Reabsorption of water
  – Compaction of intestinal contents into feces
  – Absorption of important vitamins produced by bacteria
  – Storage of fecal material prior to defecation
The Large Intestine

Parts of the Large Intestine

1. Cecum:
   - The pouchlike first portion

2. Colon:
   - The largest portion

3. Rectum:
   - The last 15 cm (6 in.) of digestive tract
The Large Intestine

• The Cecum
  – Is an expanded pouch
  – Receives material arriving from the ileum
  – Stores materials and begins compaction
The Large Intestine

• **Appendix**
  – Also called vermiform appendix
  – Is a slender, hollow appendage about 9 cm (3.6 in.) long
  – Is dominated by lymphoid nodules (a lymphoid organ)
  – Is attached to posteromedial surface of cecum:
    • **Mesoappendix** connects appendix to ileum and cecum
The Large Intestine

• The Colon
  – Has a larger diameter and thinner wall than small intestine
  – The wall of the colon:
    • Forms a series of pouches (haustra)
  – Haustra permit expansion and elongation of colon
The Large Intestine

• Colon Muscles
  – Three longitudinal bands of smooth muscle (taeniae coli):
    • Run along outer surfaces of colon
    • Deep to the serosa
    • Similar to outer layer of muscularis externa
  – Muscle tone in taeniae coli creates the haustra
The Large Intestine

• **Ascending Colon**
  – Begins at superior border of cecum
  – Ascends along right lateral and posterior wall of peritoneal cavity to inferior surface of the liver and bends at **right colic flexure** (hepatic flexure)

• **Transverse Colon**
  – Crosses abdomen from right to left; turns at **left colic flexure** (splenic flexure)
  – Is supported by transverse mesocolon
  – Is separated from anterior abdominal wall by greater omentum
The Large Intestine

• The Descending Colon
  – Proceeds inferiorly along left side to the iliac fossa (inner surface of left ilium)
  – Is retroperitoneal, firmly attached to abdominal wall

• The Sigmoid Colon
  – Is an S-shaped segment, about 15 cm (6 in.) long
  – Starts at sigmoid flexure
  – Lies posterior to urinary bladder
  – Is suspended from sigmoid mesocolon
  – Empties into rectum
The Large Intestine

• The Rectum
  – Forms last 15 cm (6 in.) of digestive tract
  – Is an expandable organ for temporary storage of feces
  – Movement of fecal material into rectum triggers urge to defecate

• The **anal canal** is the last portion of the rectum
  – Contains small longitudinal folds called **anal columns**
The Large Intestine

- **Anus**
  - Also called anal orifice
  - Is exit of the anal canal
  - Has keratinized epidermis like skin
The Large Intestine

• Anal Sphincters
  – **Internal anal sphincter:**
    • Circular muscle layer of muscularis externa
    • Has smooth muscle cells, not under voluntary control
  – **External anal sphincter:**
    • Encircles distal portion of anal canal
    • A ring of skeletal muscle fibers, under voluntary control
Figure 16-17a
The Large Intestine

Figure 16-17b

- Rectum
- Anal canal
- Anal columns
- Internal anal sphincter
- External anal sphincter
- Anus

(b) Rectum, sectioned
The Large Intestine

- Histology of the Large Intestine
  - Lack villi
  - Abundance of mucous cells
  - Presence of distinctive intestinal glands:
    - Are deeper than glands of small intestine
    - Are dominated by mucous cells
The Functions of the Large Intestine

• Physiology of the Large Intestine
  – Less than 10% of nutrient absorption occurs in large intestine
  – Prepares fecal material for ejection from the body
The Functions of the Large Intestine

- Absorption in the Large Intestine
  - Reabsorption of water
  - Reabsorption of bile salts:
    - In the cecum
    - Transported in blood to liver
  - Absorption of vitamins produced by bacteria
  - Absorption of organic wastes
The Functions of the Large Intestine

• Vitamins
  – Are organic molecules
  – Are important as cofactors or coenzymes in metabolism
  – Normal bacteria in colon make three vitamins that supplement diet
The Functions of the Large Intestine

Three Vitamins Produced in the Large Intestine

1. Vitamin K (fat soluble):
   • Required by liver for synthesizing four clotting factors, including prothrombin

2. Biotin (water soluble):
   • Important in glucose metabolism

3. Pantothenic acid: B₅ (water soluble):
   • Required in manufacture of steroid hormones and some neurotransmitters
The Functions of the Large Intestine

• Organic Wastes
  – Bacteria convert bilirubin to urobilinogens and stercobilinogens:
    • Urobilinogens absorbed into bloodstream are excreted in urine
    • Urobilinogens and stercobilinogens in colon convert to **urobilins** and **stercobilins** by exposure to oxygen
The Functions of the Large Intestine

• Toxins
  – Bacteria break down peptides in feces and generate:
    • Ammonia:
      – as soluble ammonium ions
    • Indole and skatole:
      – nitrogen compounds responsible for odor of feces
    • Hydrogen sulfide:
      – gas that produces “rotten egg” odor
The Functions of the Large Intestine

• Toxins
  – Bacteria feed on indigestible carbohydrates (complex polysaccharides):
    • Produce *flatus*, or intestinal gas, in large intestine
The Functions of the Large Intestine

- Movements of the Large Intestine
  - Gastroileal and gastroenteric reflexes:
    - Move materials into cecum while you eat
  - Movement from cecum to transverse colon is very slow, allowing hours for water absorption
  - Peristaltic waves move material along length of colon
  - Segmentation movements (*hastral churning*) mix contents of adjacent hastra
The Functions of the Large Intestine

- Movements of the Large Intestine
  - Movement from transverse colon through rest of large intestine results from powerful peristaltic contractions (mass movements)
  - Stimulus is distension of stomach and duodenum; relayed over intestinal nerve plexuses
  - Distension of the rectal wall triggers defecation reflex:
    - Two positive feedback loops
    - Both loops triggered by stretch receptors in rectum
The Functions of the Large Intestine

• Elimination of Feces
  – Requires relaxation of internal and external anal sphincters
  – Reflexes open internal sphincter and close external sphincter
  – Opening external sphincter requires conscious effort
16-8 Digestion is the mechanical and chemical alteration of food that allows the absorption and use of nutrients
Digestion

• Essential Nutrients

  – A typical meal contains:
    • Carbohydrates
    • Proteins
    • Lipids
    • Water
    • Electrolytes
    • Vitamins
Digestion

- The Processing and Absorption of Nutrients
  - Breaks down physical structure of food
  - Disassembles component molecules
  - Molecules released into bloodstream are:
    - Absorbed by cells
  - Broken down to provide energy for ATP synthesis:
    - Or used to synthesize carbohydrates, proteins, and lipids
Digestion

• Digestive Enzymes
  – Are secreted by:
    • Salivary glands
    • Tongue
    • Stomach
    • Pancreas
• Digestive Enzymes
  – Break molecular bonds in large organic molecules:
    • Carbohydrates, proteins, lipids, and nucleic acids
    • In a process called hydrolysis
  – Are divided into classes by targets:
    • Carbohydrases break bonds between simple sugars
    • Proteases break bonds between amino acids
    • Lipases separate fatty acids from glycerides
• Digestive Enzymes
  – Brush border enzymes break nucleotides into:
    • Sugars
    • Phosphates
    • Nitrogenous bases
<table>
<thead>
<tr>
<th>ENZYME</th>
<th>SOURCE</th>
<th>OPTIMAL pH</th>
<th>TARGET</th>
<th>PRODUCTS</th>
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<tr>
<td><strong>CARBOHYDRASES</strong></td>
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<tr>
<td>Amylase</td>
<td>Salivary glands, pancreas</td>
<td>6.7–7.5</td>
<td>Complex carbohydrates</td>
<td>Disaccharides and trisaccharides</td>
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<td>Maltase, sucrase, lactase</td>
<td>Small intestine</td>
<td>7–8</td>
<td>Maltose, sucrose, lactose</td>
<td>Monosaccharides</td>
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<tr>
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<td>Pancreas</td>
<td>7–8</td>
<td>Triglycerides</td>
<td>Fatty acids and monoglycerides</td>
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<td>Stomach</td>
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<td>Proteins, polypeptides</td>
<td>Short polypeptides</td>
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<tr>
<td>Trypsin, chymotrypsin, carboxypeptidase</td>
<td>Pancreas</td>
<td>7–8</td>
<td>Proteins, polypeptides</td>
<td>Short peptide chains</td>
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<tr>
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<td>Small intestine</td>
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<td>Pancreas</td>
<td>7–8</td>
<td>Nucleic acids</td>
<td>Nitrogenous bases and simple sugars</td>
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</tbody>
</table>
Figure 16-18
Figure 16-18
Water and Electrolyte Absorption

- Water Absorption
  - Cells cannot actively absorb or secrete water
  - All movement of water across lining of digestive tract:
    - Involves passive water flow down osmotic gradients due to electrolyte movement
The Absorption of Vitamins

• Vitamins are organic compounds required in very small quantities
• Are divided into two major groups:
  – Fat-soluble vitamins
  – Water-soluble vitamins
16-9 Many age-related changes affect digestion and absorption
1. Division of epithelial stem cells declines
   – Digestive epithelium becomes more susceptible to damage by abrasion, acids, or enzymes

2. Smooth muscle tone and general motility decreases
   – Peristaltic contractions become weaker
3. Cumulative damage from toxins (alcohol, other chemicals) absorbed by digestive tract and transported to liver for processing
4. Rates of colon cancer and stomach cancer rise with age
   – Oral and pharyngeal cancers common among elderly smokers
5. Dehydration
6. Other systems changes (bone — calcium)
16-10 The digestive system is extensively integrated with other body systems
The Digestive System in Perspective

Functional Relationships Between the Digestive System and Other Systems
The Integumentary System provides vitamin D$_3$ needed for the absorption of calcium and phosphorus.

The Digestive System provides lipids for storage by adipocytes in subcutaneous layer.
The Skeletal System’s axial division and pelvic girdle support and protect parts of digestive tract; teeth important in mechanical processing of food.

The Digestive System absorbs calcium and phosphate ions for incorporation into bone matrix; provides lipids for storage in yellow marrow.
The Nervous System’s 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 behaviors.

The Digestive System provides substrates essential for neurotransmitter synthesis.
The Endocrine System’s hormones epinephrine and norepinephrine stimulate constriction of sphincters and depress digestive activity; hormones coordinate activity along tract.

The Digestive System provides nutrients and substrates to endocrine cells; endocrine cells of pancreas secrete insulin and glucagon; liver produces angiotensinogen.
The Cardiovascular System distributes the hormones of the digestive tract; carries nutrients, water, and ions from sites of absorption; delivers nutrients and toxins to liver

The Digestive System absorbs fluid to maintain normal blood volume; absorbs vitamin K; liver excretes heme (as bilirubin), synthesizes blood clotting proteins
The Lymphoid System’s tonsils and other lymphoid nodules along digestive tract defend against infection and toxins absorbed from the tract; lymphatic vessels carry absorbed lipids to venous system.

The Digestive System’s secretions (acids and enzymes) provide nonspecific defense against pathogens.
The Respiratory System can assist in defecation by increased thoracic and abdominal pressure through contraction of respiratory muscles.

The Digestive System’s organs may press against the diaphragm to assist in exhalation and limit inhalation.
The Muscular System protects and supports digestive organs in abdominal cavity; controls entrances and exits of digestive tract.

The Digestive System’s liver regulates blood glucose and fatty acid levels, metabolizes lactic acid from active muscles.
The Urinary System excretes toxins absorbed by the digestive epithelium; excretes some bilirubin produced by liver.

The Digestive System absorbs water needed to excrete waste products at the kidneys; absorbs ions needed to maintain normal body fluid concentrations.
The Digestive System provides additional nutrients required to support gamete production and (in pregnant women) embryonic and fetal development.