Introduction to the Digestive System

- Acquires nutrients from environment
- Anabolism
  - Uses raw materials to synthesize essential compounds
- Catabolism
  - Decomposes substances to provide energy cells need to function
Catabolic Reactions

Require two essential ingredients:

1. Oxygen

2. Organic molecules broken down by intracellular enzymes:
   - e.g., carbohydrates, fats, and proteins
• **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
Figure 24–1 The Components of the Digestive System.
Figure 24–1 The Components of the Digestive System.
Digestive Tract

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
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
The Digestive Organs and the Peritoneum

- Lined with serous membrane consisting of
  - Superficial mesothelium covering a layer of areolar tissue
  - Serosa, or visceral peritoneum:
    - covers organs within peritoneal cavity
  - Parietal peritoneum:
    - lines inner surfaces of body wall
Digestive Tract

- Peritoneal Fluid
  - Is produced by serous membrane lining
  - Provides essential lubrication
  - Separates parietal and visceral surfaces
  - Allows sliding without friction or irritation
Mesenteries
- Are double sheets of peritoneal membrane
- Suspend portions of digestive tract within peritoneal cavity by sheets of serous membrane
  - That connect parietal peritoneum
  - With visceral peritoneum
Digestive Tract

- Mesenteries
  - Areolar tissue between mesothelial surfaces
    - Provides an access route to and from the digestive tract
    - For passage of blood vessels, nerves, and lymphatic vessels
  - Stabilize positions of attached organs
  - Prevent intestines from becoming entangled
Digestive Tract

- **Mesentery Development**
  - **During embryonic development**
    - Digestive tract and accessory organs are suspended in peritoneal cavity by:
      - dorsal mesentery
      - ventral mesentery
    » later disappears along most of digestive tract except at the *lesser omentum* and at the *falciform ligament*
Figure 24–2 Mesenteries.
Digestive Tract

- The Lesser Omentum
  - Stabilizes position of stomach
  - Provides access route for blood vessels and other structures entering or leaving liver

- The Falciform Ligament
  - Helps stabilize position of liver
    - Relative to diaphragm and abdominal wall
The Dorsal Mesentery

- Enlarges to form an enormous pouch, called the **greater omentum**
  - Extends inferiorly between:
    - the body wall and the anterior surface of small intestine
  - Hangs like an apron:
    - from lateral and inferior borders of stomach
- Adipose tissue in greater omentum:
  - conforms to shapes of surrounding organs
  - pads and protects surfaces of abdomen
  - provides insulation to reduce heat loss
  - stores lipid energy reserves
The Mesentery Proper

- Is a thick mesenterial sheet
- Provides stability
- Permits some independent movement
- Suspends all but first 25 cm (10 in.) of small intestine
- Is associated with initial portion of small intestine (duodenum) and pancreas
- Fuses with posterior abdominal wall, locking structures in position
The **Mesocolon**

- A mesentery associated with a portion of the large intestine
  - **Transverse mesocolon** supports transverse colon
  - **Sigmoid mesocolon** supports sigmoid colon
- During development, mesocolon of ascending colon, descending colon, and the rectum
  - Fuse to dorsal body wall
  - Lock regions in place
Figure 24–2b Organization of Mesenteries in an Adult.
Figure 24–2c Mesenteries: Anterior View of the Empty Peritoneal Cavity.
Figure 24–2d Sagittal Section Showing the Mesenteries of an Adult.
Digestive Tract

- Histological Organization of the Digestive Tract
  - Major layers of the digestive tract
    - Mucosa
    - Submucosa
    - Muscularis externa
    - Serosa
Figure 24–3 The Structure of the Digestive Tract
The Mucosa

- Is the inner lining of digestive tract
- Is a mucous membrane consisting of
  - Epithelium, moistened by glandular secretions
  - Lamina propria of areolar tissue
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
The Digestive Epithelium

- **Enteroendocrine cells**
  - Are scattered among columnar cells of digestive epithelium
  - Secrete hormones that:
    - coordinate activities of the digestive tract and accessory glands
Lining of Digestive Tract

Folding increases surface area for absorption:

1. Longitudinal folds, disappear as digestive tract fills

2. Permanent transverse folds (*plicae circulares*)
Digestive Tract

- The Mucosa
  - Lamina Propria
    - Consists of a layer of areolar tissue that contains:
      - blood vessels
      - sensory nerve endings
      - lymphatic vessels
      - smooth muscle cells
      - scattered areas of lymphoid tissue
The Lamina Propria

- **Muscularis mucosae**
  - Narrow band of smooth muscle and elastic fibers in lamina propria
  - Smooth muscle cells arranged in two concentric layers:
    - inner layer encircles lumen (circular muscle)
    - outer layer contains muscle cells parallel to tract (longitudinal layer)
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

- Also called plexus of Meissner
- Innervates the mucosa and submucosa
- Contains
  - Sensory neurons
  - Parasympathetic ganglionic neurons
  - Sympathetic postganglionic fibers
Digestive Tract

- The Muscularis Externa
  - Is dominated by smooth muscle cells
  - Are arranged in
    - Inner circular layer
    - Outer longitudinal layer
• The Muscularis Externa
  • Involved in
    • Mechanical processing
    • Movement of materials along digestive tract
  • Movements coordinated by enteric nervous system (ENS)
    • Sensory neurons
    • Interneurons
    • Motor neurons
The Muscularis Externa

- ENS
  - Innervated primarily by parasympathetic division of ANS:
    - sympathetic postganglionic fibers:
      » the mucosa
      » the myenteric plexus (plexus of Auerbach)
The Serosa

- Serous membrane covering muscularis externa
  - 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
Digestive Tract

- 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
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
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
Figure 24–4 Peristalsis.
Figure 24–4 Peristalsis.

STEP 2
Contraction of longitudinal muscles ahead of bolus

STEP 3
Contraction in circular muscle layer forces bolus forward
Control of Digestive Function

- Neural mechanisms
  - Control:
    - movement of materials along digestive tract
    - secretory functions
  - Motor neurons:
    - control smooth muscle contraction and glandular secretion
    - located in myenteric plexus
Neural Mechanisms

- Short reflexes
  - Are responsible for local reflexes
  - Control small segments of digestive tract
  - Operate entirely outside of CNS control:
    - sensory neurons
    - motor neurons
    - interneurons
Digestive Tract

- Neural Mechanisms
  - Long reflexes
    - Higher level control of digestive and glandular activities
    - Control large-scale peristaltic waves
    - Involve interneurons and motor neurons in CNS
    - May involve parasympathetic motor fibers that synapse in the myenteric plexus:
      - glossopharyngeal, vagus, or pelvic nerves
Hormonal Mechanisms

- At least 18 peptide hormones that affect
  - Most aspects of digestive function
  - Activities of other systems
- Are produced by enteroendocrine cells in digestive tract
- Reach target organs after distribution in bloodstream
Digestive Tract

- Local Mechanisms
  - Prostaglandins, histamine, and other chemicals released into interstitial fluid, may affect adjacent cells within small segment of digestive tract
  - Coordinating response to changing conditions
    - *For example*, variations in local pH, chemical, or physical stimuli
  - Affect only a portion of tract
Figure 24–5 The Regulation of Digestive Activities.
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

- Oral Mucosa
  - Lining of oral cavity
  - Has stratified squamous epithelium
  - Of cheeks, lips, and inferior surface of tongue
    - Is relatively thin, nonkeratinized, and delicate
  - Inferior to tongue is thin and vascular enough to rapidly absorb lipid-soluble drugs
  - Cheeks are supported by pads of fat and the buccinator muscles
Oral Cavity

- **Labia**
  - Also called lips
  - Anteriorly, the mucosa of each cheek is continuous with that of the lips

- **Vestibule**
  - Space between the cheeks (or lips) and the teeth
Oral Cavity

- **Gingivae** (Gums)
  - Ridges of oral mucosa
  - Surround base of each tooth on alveolar processes of maxillary bones and mandible
Oral Cavity

(a) Oral cavity, sagittal section

Figure 24–6a The Oral Cavity.
Figure 24–6b The Oral Cavity.
Oral Cavity

- 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*
Oral Cavity

- Salivary Glands
  - Three pairs secrete into oral cavity
  - Each pair has distinctive cellular organization
    - And produces saliva with different properties
Oral Cavity

- **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
Oral Cavity

- **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
**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 1.0–1.5 liters of saliva each day
    - 70% by submandibular glands
    - 25% by parotids
    - 5% by sublingual glands
Figure 24–7 The Salivary Glands.
Oral Cavity

- **Saliva**
  - 99.4% water
  - 0.6% includes
    - Electrolytes ($\text{Na}^+$, $\text{Cl}^-$, and $\text{HCO}_3^-$)
    - Buffers
    - Glycoproteins (mucins)
    - Antibodies
    - Enzymes
    - Waste products
Oral Cavity

- Functions of Saliva
  - Lubricating the mouth
  - Moistening and lubricating materials in the mouth
  - Dissolving chemicals that stimulate taste buds and provide sensory information
  - Initiating digestion of complex carbohydrates by the enzyme *salivary amylase* (ptyalin or alpha-amylase)
Control of Salivary Secretions

By autonomic nervous system

- Parasympathetic and sympathetic innervation:
  - parasympathetic accelerates secretion by all salivary glands

Salivatory nuclei of medulla oblongata influenced by

- Other brain stem nuclei
- Activities of higher centers
Oral Cavity

- The Teeth
  - Tongue movements pass food across occlusal surfaces of teeth
  - Chew (masticate) food
Oral Cavity

- 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
Oral Cavity

- **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*
Oral Cavity

- Alveolar Processes
  - Of the maxillae
    - Form maxillary arcade (upper dental arch)
  - Of the mandible
    - Form mandibular arcade (lower dental arch)
Figure 24–8a Teeth.
Figure 24–8b Teeth.
Oral Cavity

- Dental Arcades (Arches)
  - Contain four types of teeth:
    1. Incisors
    2. Cuspids (canines)
    3. Bicuspids (premolars)
    4. Molars
Oral Cavity

- Incisors
  - Blade-shaped teeth
  - Located at front of mouth
  - Used for clipping or cutting
  - Have a single root
Oral Cavity

- Cuspids (Canines)
  - Conical
  - Sharp ridgeline
  - Pointed tip
  - Used for tearing or slashing
  - Have a single root
Oral Cavity

- **Bicuspids (Premolars)**
  - Flat crowned
  - Prominent ridges
  - Used for crushing, mashing, and grinding
  - Have one or two roots
Oral Cavity

- Molars
  - Very large, flat crowns
  - With prominent ridges
  - Used for crushing and grinding
  - Have three or more roots
Oral Cavity

- **Dental Succession**
  - During embryonic development, two sets of teeth form
    - **Primary dentition**, or deciduous teeth
    - **Secondary dentition**, or permanent dentition
Deciduous Teeth

- Also called primary 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
Oral Cavity

Figure 24–9a Primary and Secondary Dentitions.
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
Oral Cavity

Figure 24–9b Primary and Secondary Dentitions.
Oral Cavity

Figure 24–9c Primary and Secondary Dentitions.
Oral Cavity

- Mastication
  - Also called chewing
  - Food is forced from oral cavity to vestibule and back
  - Crossing and recrossing occlusal surfaces
Oral Cavity

- Muscles of Mastication
  - Close the jaws
  - Slide or rock lower jaw from side to side
  - Chewing involves mandibular
    - Elevation and depression
    - Protraction and retraction
    - Medial and lateral movement
The Pharynx

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

- Regions of the pharynx
  - Nasopharynx
  - Oropharynx
  - Laryngopharynx

- Food passes through oropharynx and laryngopharynx to esophagus
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
The Esophagus

- Histology of the Esophagus
  - Wall of esophagus has three layers
    - Mucosal
    - Submucosal
    - Muscularis
The Esophagus

1. Mucosa contains:
   - Nonkeratinized and stratified squamous epithelium

2. Mucosa and submucosa:
   - Form large folds that extend the length of the esophagus

3. Muscularis mucosae:
   - Consists of irregular layer of smooth muscle
The Esophagus

4. Submucosa contains esophageal glands:
   - Which produce mucous secretion
   - Reduces friction between bolus and esophageal lining

5. Muscularis externa:
   - Has usual inner circular and outer longitudinal layers
Figure 24–10 The Esophagus.

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The Esophagus

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

Figure 24–11 The Swallowing Process.
The Esophagus

Figure 24–11 The Swallowing Process.

STEP 2 PHARYNGEAL PHASE

Tongue

Bolus
The Esophagus

Figure 24–11 The Swallowing Process.
The Esophagus

Figure 24–11 The Swallowing Process.
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

- 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
The Stomach

- Regions of the Stomach
  - Cardia
  - Fundus
  - Body
  - Pylorus
Figure 24–12a The Stomach.
The Stomach

Figure 24–12b The Structure of the Stomach Wall.
The Stomach

- **Smooth Muscle**
  - **Muscularis mucosae and muscularis externa**
    - Contain extra layers of smooth muscle cells
    - In addition to circular and longitudinal layers
The Stomach

- **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 Stomach

- **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 Stomach

Figure 24–13a The Stomach Lining.
The Stomach

Figure 24–13b The Stomach Lining.
The Stomach

- **Parietal Cells**
  - Secrete intrinsic factor and hydrochloric acid (HCl)

- **Chief Cells**
  - Secrete hydrochloric acid (HCl)
  - Are most abundant near base of gastric gland
    - Secrete **pepsinogen** (inactive proenzyme)
The Stomach

Figure 24–14 The Secretion of Hydrochloric Acid.
The Stomach

- Pepsinogen
  - Is converted by HCl in the gastric lumen
    - To **pepsin** (active proteolytic enzyme)
The Stomach

- Pyloric Glands
  - Located in the pylorus
  - Produce mucous secretion
    - Scattered with enteroendocrine cells
      - G cells produce gastrin
      - D cells release somatostatin, a hormone that inhibits release of gastrin
The Stomach

- 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
Figure 24–15 The Phases of Gastric Secretion.
Figure 24–15 The Phases of Gastric Secretion.
The Stomach

Figure 24–15 The Phases of Gastric Secretion.
# The Stomach

<table>
<thead>
<tr>
<th>Phase</th>
<th>Functions</th>
<th>Duration</th>
<th>Mechanism</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cephalic phase</strong></td>
<td>Prepares stomach for arrival of food</td>
<td>Short (minutes)</td>
<td>Neural: preganglionic fibers in vagus nerves and synapses in submucosal plexus</td>
<td>Primary: stimulation of mucus, enzyme, and acid production, leading to increased volume of gastric juice</td>
</tr>
<tr>
<td><strong>Gastric phase</strong></td>
<td>Enhances secretion started in cephalic stage; homogenizes and acidifies chyme; initiates digestion of proteins by pepsin</td>
<td>Long (3–4 hr)</td>
<td>Neural: short reflexes triggered by stretch receptors and chemoreceptors&lt;br&gt;Hormonal: stimulation of gastrin release by G cells&lt;br&gt;Local: release of histamine by mast cells as stomach fills</td>
<td>Increased acid and pepsinogen production; increased motility and initiation of mixing waves</td>
</tr>
<tr>
<td><strong>Intestinal phase</strong></td>
<td>Controls rate of chyme entry into duodenum</td>
<td>Long (hours)</td>
<td>Neural: short reflexes triggered by distension of duodenum&lt;br&gt;Hormonal: Primary—stimulation of CCK, GIP, and secretin by acids, carbohydrates, and lipids&lt;br&gt;Secondary—release of gastrin in response to presence of undigested proteins</td>
<td>Feedback inhibition of gastric acid and pepsinogen production; reduction in gastric motility</td>
</tr>
</tbody>
</table>
The Stomach

- Digestion and Absorption 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
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 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 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 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
Figure 24–16 Segments of the Intestine.

The Small Intestine

Duodenum

Jejunum

Large intestine

Ileum

Rectum

Plicae circulares

(b) Jejunum

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The Small Intestine

- **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 Small Intestine

- **Histology of the Small Intestine**
  - Intestinal glands
    - Mucous cells between columnar epithelial cells
    - Eject mucins onto intestinal surfaces
  - Crypts of Lieberkühn
    - Openings from intestinal glands:
      - to intestinal lumen
      - at bases of villi
    - Entrances for brush border enzymes
Figure 24-17 The Intestinal Wall.
The Small Intestine

Figure 24–17 The Intestinal Wall.
Figure 24–17 The Intestinal Wall.
The Small Intestine

Figure 24–17 The Intestinal Wall.
The Small Intestine

- **Brush Border Enzymes**
  - Integral membrane proteins
  - On surfaces of intestinal microvilli
  - Break down materials in contact with brush border
The Small Intestine

- Intestinal Glands
  - Enteropeptidase
    - A brush border enzyme
    - Activates pancreatic proenzyme trypsinogen
  - Enteroendocrine cells
    - Produce intestinal hormones such as gastrin, cholecystokinin, and secretin
The Small Intestine

- **Duodenal Glands**
  - Also called submucosal glands or Brunner glands
  - Produce copious quantities of mucus
    - When chyme arrives from stomach
The Small 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
The Small Intestine

- 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
The Small Intestine

- 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
The Pancreas

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

- Regions of the Pancreas
  - Head
    - Broad
    - In loop of duodenum
  - Body
    - Slender
    - Extends toward spleen
  - Tail
    - Short and rounded
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)
The Pancreas

Figure 24–18a The Gross Anatomy of the Pancreas.
Figure 24–18b-c The Cellular Organization of the Pancreas.
The Pancreas

Functions of the Pancreas

1. Endocrine cells of the pancreatic islets:
   - Secrete insulin and glucagon into bloodstream

2. Exocrine cells:
   - Acinar cells and epithelial cells of duct system secrete pancreatic juice
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
- Extends to left hypochondriac and umbilical regions
- Performs essential metabolic and synthetic functions
Anatomy of the Liver

- Is wrapped in tough fibrous capsule
- Is covered by visceral peritoneum
- Is divided into lobes
Figure 24–19a The Anatomy of the Liver.
The Liver

Figure 24–19b, c The Anatomy of the Liver.
The Liver

Figure 24–19b, c The Anatomy of the Liver.
Hepatic Blood Supply

1/3 of blood supply
- Arterial blood from hepatic artery proper

2/3 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
The Liver

Figure 24–20 Liver Histology.
Figure 24–20 Liver Histology.
Figure 24–20 Liver Histology.
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
The Liver

- The Bile Duct System
  - Liver secretes **bile** fluid
    - Into a network of narrow channels (**bile canaliculi**)
    - Between opposing membranes of adjacent liver cells
The Liver

- **Right and Left Hepatic Ducts**
  - Collect bile from all bile ducts of liver lobes
  - Unite to form **common hepatic duct** that leaves the liver

- **Bile Flow**
  - From common hepatic duct to either
    - The common bile duct, which empties into duodenal ampulla
    - The **cystic duct**, which leads to gallbladder
The Liver

The Common Bile Duct

- Is formed by union of
  - Cystic duct
  - Common hepatic duct
- Passes within the lesser omentum toward stomach
- Penetrates wall of duodenum
- Meets pancreatic duct at duodenal ampulla
Figure 24–21 The Gallbladder and Bile Ducts.
Figure 24–21 The Gallbladder and Bile Ducts.
The Liver

The Physiology of the Liver

1. Metabolic regulation
2. Hematological regulation
3. Bile production
The Liver

- Metabolic Regulation

  The liver regulates:

  1. Composition of circulating blood
  2. Nutrient metabolism
  3. Waste product removal
  4. Nutrient storage
  5. Drug inactivation
The Liver

- Composition of Circulating Blood
  - All blood leaving absorptive surfaces of digestive tract
    - Enters hepatic portal system
    - Flows into the liver
  - Liver cells extract nutrients or toxins from blood
    - Before they reach systemic circulation through hepatic veins
  - Liver removes and stores excess nutrients
    - Corrects nutrient deficiencies by mobilizing stored reserves or performing synthetic activities
The Liver

- Metabolic Activities of the Liver
  - Carbohydrate metabolism
  - Lipid metabolism
  - Amino acid metabolism
  - Waste product removal
  - Vitamin storage
  - Mineral storage
  - Drug inactivation
The Liver

- Hematological Regulation
  - Largest blood reservoir in the body
  - Receives 25% of cardiac output
The Liver

- Functions of Hematological Regulation
  1. Phagocytosis and antigen presentation
  2. Synthesis of plasma proteins
  3. Removal of circulating hormones
  4. Removal of antibodies
  5. Removal or storage of toxins
  6. Synthesis and secretion of bile
The Liver

The Functions of Bile

- Dietary lipids are not water soluble
- Mechanical processing in stomach creates large drops containing lipids
- Pancreatic lipase is not lipid soluble
  - Interacts only at surface of lipid droplet
- Bile salts break droplets apart (emulsification)
  - Increases surface area exposed to enzymatic attack
  - Creates tiny emulsion droplets coated with bile salts
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

- Regions of the Gallbladder
  - Fundus
  - Body
  - Neck
The Gallbladder

- The Cystic Duct
  - Extends from gallbladder
  - Union with common hepatic duct forms common bile duct
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
Coordination of Secretion and Absorption

- Neural and hormonal mechanisms coordinate activities of digestive glands
- Regulatory mechanisms center around duodenum
  - Where acids are neutralized and enzymes added
Coordination of Secretion and Absorption

- Neural Mechanisms of the CNS
  - Prepare digestive tract for activity (parasympathetic innervation)
  - Inhibit gastrointestinal activity (sympathetic innervation)
  - Coordinate movement of materials along digestive tract (the enterogastric, gastroenteric, and gastroileal reflexes)
  - Motor neuron synapses in digestive tract release neurotransmitters
Coordination of Secretion and Absorption

- Intestinal Hormones
  - Intestinal tract secretes peptide hormones with multiple effects
    - In several regions of digestive tract
    - In accessory glandular organs
Coordination of Secretion and Absorption

- Hormones of Duodenal Enteroendocrine Cells
  - Coordinate digestive functions
    - Secretin
    - Cholecystokinin (CCK)
    - Gastric inhibitory peptide (GIP)
    - Vasoactive intestinal peptide (VIP)
    - Gastrin
    - Enterocrinin
Coordination of Secretion and Absorption

- **Secretin**
  - Is released when chyme arrives in duodenum
  - Increases secretion of bile and buffers by liver and pancreas

- **Cholecystokinin (CCK)**
  - Is secreted in duodenum
    - When chyme contains lipids and partially digested proteins
  - Accelerates pancreatic production and secretion of digestive enzymes
  - Relaxes hepatopancreatic sphincter and gallbladder
    - Ejecting bile and pancreatic juice into duodenum
Coordination of Secretion and Absorption

- **Gastric Inhibitory Peptide (GIP)**
  - Is secreted when fats and carbohydrates enter small intestine

- **Vasoactive Intestinal Peptide (VIP)**
  - Stimulates secretion of intestinal glands
  - Dilates regional capillaries
  - Inhibits acid production in stomach
Coordination of Secretion and Absorption

- **Gastrin**
  - Is secreted by G cells in duodenum
    - When exposed to incompletely digested proteins
  - Promotes increased stomach motility
  - Stimulates acids and enzyme production

- **Enterocrinin**
  - Is released when chyme enters small intestine
  - Stimulates mucin production by submucosal glands of duodenum
Coordination of Secretion and Absorption

Figure 24–22 The Activities of Major Digestive Tract Hormones.
## Coordination of Secretion and Absorption

### TABLE 24–2 Major Digestive Hormones and Their Primary Effects

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Stimulus</th>
<th>Origin</th>
<th>Target</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<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 hepatopancreatic sphincter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Stomach</td>
<td>Inhibits gastric secretion and motion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CNS</td>
<td>May reduce hunger</td>
</tr>
<tr>
<td>Enterocinin</td>
<td>Arrival of chyme in duodenum</td>
<td>Duodenum</td>
<td>Duodenum</td>
<td>Stimulates mucin production</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>
<tr>
<td></td>
<td></td>
<td></td>
<td>Adipose tissue</td>
<td>Stimulates lipid synthesis</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Skeletal muscle</td>
<td>Stimulates glucose use</td>
</tr>
</tbody>
</table>
Coordination of Secretion and Absorption

<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>Vasoactive intestinal</td>
<td>Arrival of chyme in the duodenum</td>
<td>Duodenum</td>
<td>Duodenal glands, stomach</td>
<td>Stimulates buffer secretion; inhibits acid production; dilates intestinal capillaries</td>
</tr>
<tr>
<td>peptide (VIP)</td>
<td></td>
<td></td>
<td>stomach</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 24–2  Major Digestive Hormones and Their Primary Effects
Coordination of Secretion and Absorption

- Intestinal Absorption
  - It takes about 5 hours for materials to pass from duodenum to end of ileum
  - Movements of the mucosa increases absorptive effectiveness
    - Stir and mix intestinal contents
    - Constantly change environment around epithelial cells
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

- Serosa of the Colon
  - Contains numerous teardrop-shaped sacs of fat
    - Fatty appendices or epiplioic appendages
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

- **Blood Supply of the Large Intestine**
  - Receives blood from tributaries of
    - Superior mesenteric and inferior mesenteric arteries
  - Venous blood is collected from
    - Superior mesenteric and inferior mesenteric veins
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
The Large Intestine

Figure 24–23a The Gross Anatomy and Regions of the Large Intestine.
Figure 24–23b, c The Large Intestine.
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 Large Intestine

- Histology of the Large Intestine
  - Does not produce enzymes
  - Provides lubrication for fecal material
  - Large lymphoid nodules are scattered throughout the lamina propria and submucosa
  - The longitudinal layer of the muscularis externa is reduced to the muscular bands of taeniae coli
Figure 24–24 The Mucosa and Glands of the Colon.
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 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 Large Intestine

- **Vitamins**
  - Are organic molecules
  - Important as cofactors or coenzymes in metabolism
  - Normal bacteria in colon make three vitamins that supplement diet
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 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 Large Intestine

- **Organic Wastes**
  - 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 Large Intestine

- Organic Wastes
  - Bacteria feed on indigestible carbohydrates (complex polysaccharides)
    - Produce **flatus**, or intestinal gas, in large intestine
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 (haustral churning) mix contents of adjacent haustra
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 Large Intestine

Two Positive Feedback Loops

1. Short reflex:
   - Triggers peristaltic contractions in rectum

2. Long reflex:
   - Coordinated by sacral parasympathetic system
   - Stimulates mass movements
The Large Intestine

- Rectal stretch receptors also trigger two reflexes important to voluntary control of defecation
  - **A long reflex**
    - Mediated by parasympathetic innervation in pelvic nerves
    - Causes relaxation of internal anal sphincter
  - **A somatic reflex**
    - Motor commands carried by pudendal nerves
    - Stimulates contraction of external anal sphincter (skeletal muscle)
Figure 24–25 The Defecation Reflex.
The Large Intestine

- Elimination of Feces
  - Requires relaxation of internal and external anal sphincters
  - Reflexes open internal sphincter, close external sphincter
  - Opening external sphincter requires conscious effort
Digestion

- Essential Nutrients
  - A typical meal contains
    - Carbohydrates
    - Proteins
    - Lipids
    - Water
    - Electrolytes
    - Vitamins
Digestive system handles each nutrient differently

- Large organic molecules
  - Must be digested before absorption can occur
- Water, electrolytes, and vitamins
  - Can be absorbed without processing
  - May require special transport
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
Digestion

- 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
Digestion

- Digestive Enzymes
  - Brush border enzymes break nucleotides into
    - Sugars
    - Phosphates
    - Nitrogenous bases
### SUMMARY TABLE 24–3  Digestive Enzymes and Their Functions

<table>
<thead>
<tr>
<th>Enzyme (proenzyme)</th>
<th>Source</th>
<th>Optimal pH</th>
<th>Target</th>
<th>Products</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBOHYDRASES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maltase, sucrase, lactase</td>
<td>Brush border of small intestine</td>
<td>7–8</td>
<td>Maltose, sucrose, lactose</td>
<td>Monosaccharides</td>
<td>Found in membrane surface of microvilli</td>
</tr>
<tr>
<td>Pancreatic alpha-amylase</td>
<td>Pancreas</td>
<td>6.7–7.5</td>
<td>Complex carbohydrates</td>
<td>Disaccharides and trisaccharides</td>
<td>Breaks bonds between simple sugars</td>
</tr>
<tr>
<td>Salivary amylase</td>
<td>Salivary glands</td>
<td>6.7–7.5</td>
<td>Complex carbohydrates</td>
<td>Disaccharides and trisaccharides</td>
<td>Breaks bonds between simple sugars</td>
</tr>
<tr>
<td>Enzyme (proenzyme)</td>
<td>Source</td>
<td>Optimal pH</td>
<td>Target</td>
<td>Products</td>
<td>Remarks</td>
</tr>
<tr>
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<td>-----------------------------</td>
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<td>---------------------------</td>
<td>-----------------------------------------------------------</td>
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<tr>
<td><strong>PROTEASES</strong></td>
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<tr>
<td>Carboxypeptidase</td>
<td>Pancreas</td>
<td>7–8</td>
<td>Proteins, polypeptides, amino acids</td>
<td>Short-chain peptides</td>
<td>Activated by trypsin</td>
</tr>
<tr>
<td>Procarboxypeptidase</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Chymotrypsin</td>
<td>Pancreas</td>
<td>7–8</td>
<td>Proteins, polypeptides</td>
<td>Short-chain peptides</td>
<td>Activated by trypsin</td>
</tr>
<tr>
<td>Chymotrypsinogen</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Dipeptidases, peptidases</td>
<td>Brush border of small intestine</td>
<td>7–8</td>
<td>Dipeptides, tripeptides</td>
<td>Amino acids</td>
<td>Found in membrane surface of brush border</td>
</tr>
<tr>
<td>Elastase (proelastase)</td>
<td>Pancreas</td>
<td>7–8</td>
<td>Elastin</td>
<td>Short-chain peptides</td>
<td>Activated by trypsin</td>
</tr>
<tr>
<td>Enteropeptidase</td>
<td>Brush border and lumen of small intestine</td>
<td>7–8</td>
<td>Trypsinogen</td>
<td>Trypsin</td>
<td>Reaches lumen through disintegration of shed epithelial cells</td>
</tr>
<tr>
<td>Pepsin (pepsinogen)</td>
<td>Chief cells of stomach</td>
<td>1.5–2.0</td>
<td>Proteins, polypeptides</td>
<td>Short-chain polypeptides</td>
<td>Secreted as proenzyme pepsinogen; activated by H⁺ in stomach acid</td>
</tr>
<tr>
<td>Rennin</td>
<td>Stomach</td>
<td>3.5–4.0</td>
<td>Milk proteins</td>
<td></td>
<td>Secreted only in infants; causes protein coagulation</td>
</tr>
<tr>
<td>Trypsin (trypsinogen)</td>
<td>Pancreas</td>
<td>7–8</td>
<td>Proteins, polypeptides</td>
<td>Short-chain peptides</td>
<td>Proenzyme activated by enteropeptidase; activates other pancreatic proteases</td>
</tr>
</tbody>
</table>
## Digestion

### SUMMARY TABLE 24–3  Digestive Enzymes and Their Functions

<table>
<thead>
<tr>
<th>Enzyme (proenzyme)</th>
<th>Source</th>
<th>Optimal pH</th>
<th>Target</th>
<th>Products</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LIPASES</strong></td>
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<td></td>
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</tr>
<tr>
<td>Lingual lipase</td>
<td>Glands of tongue</td>
<td>3.0–6.0</td>
<td>Triglycerides</td>
<td>Fatty acids and monoglycerides</td>
<td>Begins lipid digestion</td>
</tr>
<tr>
<td>Pancreatic lipase</td>
<td>Pancreas</td>
<td>7–8</td>
<td>Triglycerides</td>
<td>Fatty acids and monoglycerides</td>
<td>Bile salts must be present for efficient action</td>
</tr>
<tr>
<td><strong>NUCLEASES</strong></td>
<td></td>
<td>7–8</td>
<td>Nucleic acids</td>
<td>Nitrogenous bases and simple sugars</td>
<td>Includes ribonuclease for RNA and deoxy-ribonuclease for DNA</td>
</tr>
</tbody>
</table>

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Figure 24–26 A Summary of the Chemical Events in Digestion.
Digestion

- 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
Figure 24–27 Digestive Secretion and Absorption of Water.
Ion Absorption

- Osmosis does not distinguish among solutes
  - Determined only by total concentration of solutes
- To maintain homeostasis
  - Concentrations of specific ions must be regulated
- Sodium ion absorption
  - Rate increased by aldosterone (steroid hormone from suprarenal cortex)
- Calcium ion absorption
  - Involves active transport at epithelial surface
  - Rate increased by parathyroid hormone (PTH) and calcitriol
Digestion

- Ion Absorption
  - Potassium ion concentration increases
    - As other solutes move out of lumen
  - Other ions diffuse into epithelial cells along concentration gradient
  - Cation absorption (magnesium, iron)
    - Involves specific carrier proteins
    - Cell must use ATP to transport ions to interstitial fluid
Digestion

- Ion Absorption
  - Anions (chloride, iodide, bicarbonate, and nitrate)
    - Are absorbed by diffusion or carrier-mediated transport
  - Phosphate and sulfate ions
    - Enter epithelial cells by active transport
Digestion

- Vitamins are organic compounds required in very small quantities.
- Are divided in two major groups:
  - Fat-soluble vitamins
  - Water-soluble vitamins
# Digestion

<table>
<thead>
<tr>
<th>Ion or Vitamin</th>
<th>Transport Mechanism</th>
<th>Regulatory Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na⁺</td>
<td>Channel-mediated diffusion, cotransport, or active transport</td>
<td>Increased when sodium-linked cotransport is under way; stimulated by aldosterone</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>Active transport</td>
<td>Stimulated by calcitriol and PTH</td>
</tr>
<tr>
<td>K⁺</td>
<td>Channel-mediated diffusion</td>
<td>Follows concentration gradient</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>Active transport</td>
<td></td>
</tr>
<tr>
<td>Fe²⁺</td>
<td>Active transport</td>
<td></td>
</tr>
<tr>
<td>Cl⁻</td>
<td>Channel-mediated diffusion or carrier-mediated transport</td>
<td></td>
</tr>
<tr>
<td>I⁻</td>
<td>Channel-mediated diffusion or carrier-mediated transport</td>
<td></td>
</tr>
<tr>
<td>HCO₃⁻</td>
<td>Channel-mediated diffusion or carrier-mediated transport</td>
<td></td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>Channel-mediated diffusion or carrier-mediated transport</td>
<td></td>
</tr>
<tr>
<td>PO₄³⁻</td>
<td>Active transport</td>
<td></td>
</tr>
<tr>
<td>SO₄²⁻</td>
<td>Active transport</td>
<td></td>
</tr>
<tr>
<td>Water-soluble vitamins (except B₁₂)</td>
<td>Channel-mediated diffusion</td>
<td>Follows concentration gradient</td>
</tr>
<tr>
<td>Vitamin B₁₂</td>
<td>Active transport</td>
<td>Must be bound to intrinsic factor prior to absorption</td>
</tr>
<tr>
<td>Fat-soluble vitamins</td>
<td>Diffusion</td>
<td>Absorbed from micelles along with dietary lipids</td>
</tr>
</tbody>
</table>
Effects of Aging on the Digestive System

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
Effects of Aging on the Digestive System

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. Decline in olfactory and gustatory sensitivities:
   ▪ Leads to dietary changes that affect entire body
Digestive System Integration

Figure 24–28 Functional Relationships between the Digestive System and Other Systems.

**THE DIGESTIVE SYSTEM IN PERSPECTIVE**

**Integumentary System**
- Provides vitamin D₃ needed for the absorption of calcium and phosphorus
- Provides lipids for storage by adipocytes in subcutaneous layer

**Skeletal System**
- Skull, ribs, vertebrae, and pelvic girdle support and protect parts of digestive tract; teeth important in mechanical processing of food
- Absorbs calcium and phosphate ions for incorporation into bone matrix; provides lipids for storage in yellow marrow

**Muscular System**
- Protects and supports digestive organs in abdominal cavity; controls entrances and exits to digestive tract
- Liver regulates blood glucose and fatty acid levels, metabolizes lactic acid from active muscles
Digestive System Integration

THE DIGESTIVE SYSTEM IN PERSPECTIVE

Nervous System

- 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
- Provides substrates essential for neurotransmitter synthesis

Endocrine System

- Epinephrine and norepinephrine stimulate constriction of sphincters and depress digestive activity; hormones coordinate activity along tract
- Provides nutrients and substrates to endocrine cells; endocrine cells of pancreas secrete insulin and glucagon; liver produces angiotensinogen

Cardiovascular System

- Distributes hormones of the digestive tract; carries nutrients, water, and ions from sites of absorption; delivers nutrients and toxins to liver
- Absorbs fluid to maintain normal blood volume; absorbs vitamin K; liver excretes heme (as bilirubin), synthesizes coagulation proteins

Figure 24–28 Functional Relationships between the Digestive System and Other Systems.

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THE DIGESTIVE SYSTEM IN PERSPECTIVE

**Lymphoid System**
- 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
- Secretions of digestive tract (acids and enzymes) provide nonspecific defense against pathogens

**Respiratory System**
- Increased thoracic and abdominal pressure through contraction of respiratory muscles can assist in defecation
- Pressure of digestive organs against the diaphragm can assist in exhalation and limit inhalation

**Urinary System**
- Excretes toxins absorbed by the digestive epithelium; excretes some bilirubin produced by liver
- Absorbs water needed to excrete waste products at the kidneys; absorbs ions needed to maintain normal body fluid concentrations

**Reproductive System**
- Provides additional nutrients required to support gamete production and (in pregnant women) embryonic and fetal development

Figure 24–28 Functional Relationships between the Digestive System and Other Systems.