Digestive System

Alimentary Tract and Accessory Organs

Function of Digestive System

1. Take in food and water – ingestion or intake
2. Break food down into nutrient molecules
3. Absorb molecules into the bloodstream
4. Eliminate any indigestible remains – elimination or defecation
5. Dispose of some metabolic wastes

Overview of Digestive System

- Alimentary canal (gastrointestinal or GI tract or gut)
  - Continuous muscular tube that runs from the mouth to anus
    - Breaks down food into smaller fragments
      - Mechanical movement
      - Chemical enzymes
    - Absorbs nutrient molecules through lining into blood
  - Organs: mouth, pharynx, esophagus, stomach, small intestine, large intestine, anus
- Accessory digestive organs
  - Oral cavity:
    - Teeth
    - Tongue
    - Salivary glands: lubrication
  - Liver
    - Gallbladder
  - Pancreas
  - Digestive glands: produce secretions that help break down foodstuffs
Digestive Processes

Processing of food involves six essential activities:

1. Ingestion
2. Propulsion
   - Peristalsis
   - Swallowing
3. Mechanical breakdown
   - Chewing
   - Churning, mixing
   - Segmentation: Local constriction of intestine that mixes food with digestive juices
4. Chemical Breakdown
   - Series of catabolic steps supported by groups of enzymes
5. Absorption
   - Blood or lymph
6. Defecation - Elimination
   - Indigestible substances
   - Bile includes wastes produced as liver processes blood

Histology of the Alimentary Canal

1. Mucosa
   - Functions
   - Secretes mucus, digestive enzymes, and hormones
   - Absorbs end products of digestion
   - Protects against infectious disease
   - Capillaries, lymphoid follicles, localized movement, glands
   - Made up of three sublayers
   - Epithelium - stratified squamous or simple columnar, mucus producing
   - Lamina propria - ample space for follicles, capillaries, and mucosal glands
   - Muscular mucosae

2. Submucosa
   - Consists of areolar connective tissue
   - Abundant amount of elastic tissue
   - Blood and lymphatic vessels
   - Lymphoid follicles
   - Submucosal nerve plexus

3. Muscularis externa
   - Circular and longitudinal muscle layer responsible for segmentation, peristalsis, and sphincters

4. Serosa (adventitia in some areas)
   - Aka the visceral peritoneum
Figure 23.5 Basic structure of the alimentary canal.

Nerve and Blood Supply to Walls

**Blood Supply:**
- Splanchnic circulation includes
  - Arteries that branch off aorta to serve digestive organs
  - Hepatic, splenic, and left gastric arteries
- Hepatic portal circulation
  - Drains nutrient-rich blood from digestive organs
  - Delivers blood to liver for processing

**Enteric Nervous System**
- Submucosal nerve plexus
- Myenteric nerve plexus
- Semiautonomous
  - Controls patterns of segmentation and peristalsis
  - Linked to CNS: visceral sensory fibers (afferent), autonomic motor fibers synapse with internal plexi (called long reflex arcs)
  - 100 million neurons in plexi

Neural reflex pathways initiated by stimuli inside or outside the gastrointestinal tract.
Path of Alimentary Tract Begins at Oral Cavity and Pharynx

- Ingestion
- Propulsion
- Saliva
- Oral mucosa

- Lubricants
- Antimicrobial proteins
- Early enzyme introduction
- Particle size reduction
- Mechanical mixing

  o Taste cell activation
  o Olfactory membrane involvement

The salivary glands and tongue papillae

- Intrinsic glands
- Extrinsic glands
- Continuous production and secretion upon activation
- Average of 1500 ml/day
- Mostly under parasympathetic control

Deglutition (swallowing)

- Relaxed muscles
- Circular muscles contract
- Longitudinal muscles relax
- Bones of palate contract
- Esophageal sphincter opens

- All tunics present
- All smooth muscle here
- Intrinsic muscle fibers
- Smooth muscle fibers
- Intramural ganglia
- Connective tissue connective

- Extrinsic muscle fibers
- Intramural ganglia
- Connective tissue connective
- Smooth muscle fibers
- Intramural ganglia
- Connective tissue connective
Stomach Organization

- Storage
- Expands from 50 ml to 4 l
- Gastric juice
- Food becomes chyme
- Region of the pylorus squishes chyme and allows ("filters") small amount of chyme to pass to duodenum; remainder pushed back into fundus – prepares food for SI
- Enteric pacemaker cells – 3 peristaltic waves per minute
- Lesser and greater omentum
- Stretch receptors
- Environment best for protein digestion

Peristaltic waves in the stomach.

1. Propulsion: Peristaltic waves move from the fundus toward the pylorus.
2. Grinding: The most vigorous peristalsis and mixing action occur close to the pylorus. The pyloric end of the stomach acts as a pump that delivers small amounts of chyme into the duodenum.
3. Retropulsion: The peristaltic wave closes the pyloric valve, forcing most of the contents of the pylorus backward into the stomach.

Microscopic anatomy of the stomach.

Gastric juice:
- Mucus producing cells
- Parietal cells: HCl + intrinsic factor (for SI absorption of B12 & RBC production)
- Chief cells: pepsinogen, lipase
- Enteroendocrine cells: paracrine and endocrine substances influencing blood flow and stomach secretions
- Up to 3 l/day

Mucosal barrier:
- Tissue regeneration
- Tight junctions join epithelial cells
- Bicarbonate-rich, thick mucus

Stomach acid:
- Kills many bacteria
- Chemically degrades food
- Activates enzymes supplementing chemical breakdown
Neural and hormonal mechanisms that regulate release of gastric juice.

**Stimulatory events**
- **Cephalic phase**
- **Gastric phase**
- **Intestinal phase**

**Inhibitory events**
- **Para-Vagus nerve**
- **Hypothalamus and medulla oblongata**
- **Taste and smell receptors**

**Gastric phase**
- **Distension** activates stretch receptors
- **Long reflexes** (via medulla and vagus nerve) release to blood
- **G cells**
  - **Short reflexes** (especially peptides and caffeine) and rising pH activate chemoreceptors
  - **Gastrin release** to blood

**Sympathetic nervous system activation** (overrides parasympathetic controls)

**Intestinal phase**
- **Partially digested foods in duodenum** or distension of the duodenum when stomach begins to empty
- **Intestinal (enteric) gastrin release** to blood

**Enterogastric reflex** (involves both short and long reflexes)
- **Brief effect** of duodenum; presence of fatty, hypertonic, acidic chyme
- **Release of enterogastrones** (secretin, cholecystokinin)
  - **Stimulate** appetite, depression
  - **Inhibit** sympathetic activity

**Food chemicals**
- **Acidity** (pH < 2)
- **Loss of food chemicals**
- **Emotional stress**

**Gastrin**
- **Distension**
  - Presence of sight and thought

**Controlling stomach emptying via receptors at duodenum**
- **Liquids move quickly**
- **Solids must liquify**
- **Carbs get to duodenum first**
- **Fats remain in stomach longest**
- **Maybe >6 hrs.**

**The Small Intestine**

**Gross Anatomy**
- **Small intestine** is the major organ of digestion and absorption
- 2–4 m long (7–13 ft) from pyloric sphincter to ileocecal valve, point at which it joins large intestine
- **Small diameter** of 2.5–4 cm (1.0–1.6 inches)
- **Subdivisions**
  - **Duodenum**: mostly retroperitoneal; ~25.0 cm (10.0 in) long; curves around head of pancreas
  - **Jejunum**: ~2.5 m (8 ft) long
  - **Ileum**: ~3.6 m (12 ft) long
- **Blood supply**
  - Superior mesenteric artery brings blood supply
  - Veins (carrying nutrient-rich blood) drain into superior mesenteric veins, then into hepatic portal vein, and finally into liver
- **Nerve supply**
  - Parasympathetic innervation via vagus nerve, and sympathetic innervation from thoracic splanchnic nerves
Mesenteries of the abdominal digestive organs.

Greater omentum
Transverse mesocolon
Transverse colon
Descending colon
Jejunum
Mesentery
Sigmoid mesocolon
Sigmoid colon
Ileum

Microscopic Anatomy

- Modifications of small intestine for absorption
  - huge surface area for nutrient absorption
    - Surface area is increased 600- to ~200 m² (size of a tennis court)
- Modifications include:
  - Length
  - Circular folds
    - Permanent folds (~1 cm deep)
  - Villi
    - Fingerlike projections of mucosa (~1 mm high)
    - dense capillary bed
    - Lacteals
    - Absorptive enterocytes
  - Microvilli
    - brush border
    - brush border enzymes, used for final carbohydrate and protein digestion

Vein carrying blood to hepatic portal vessel

Muscle layers
Circular folds
Villi

Loss of cells here and regeneration from crypt base

Enterocytes (absorptive cells)
Lacteal
Goblet cell
Blood capillaries
Mucosa-associated lymphoid tissue
Intestinal crypt
Muscularis mucosae
Duodenal gland

(b) Alkaline mucus

1-2 L intestinal juice/day
- Water
- Mucus
- Lipase & defensins – paneth cells
- Hormones – enteroendocrine cells
Gross anatomy of the human liver – anterior view

Lobes are artificial designations not structural or functional designations.

Gross anatomy of the human liver – posterior view

Microscopic anatomy of the liver.

Liver Lobules:
• Hepatocytes lining sinusoidal capillaries
• Stellate macrophages
• Central vein
• Bile ducts

Portal triads ‘at the corners’
Microscopic anatomy of the liver – marvel of natural selection

Interlobular veins (to hepatic vein)
Central vein
Sinusoids
Plates of hepatocytes
Bile canaliculi
Bile duct (receives bile from bile canaliculi)
Fenestrated lining (endothelial cells) of sinusoids
Stellate macrophages in sinusoid walls
Portal vein
Bile duct
Portal venules
Portal arterioles
Portal triad
Hepatocytes

Hepatocyte Function

• Hepatocytes have increased rough and smooth ER, Golgi apparatus, peroxisomes, and mitochondria
• Produce ~900 ml bile per day
• Process bloodborne nutrients
  • Example: store glucose as glycogen and make plasma proteins
• Store fat-soluble vitamins
• Perform detoxification
  • Example: converting ammonia to urea
• Regenerate readily – complete regeneration in 6-12 months after 80% loss

Bile

• Yellow-green, alkaline solution containing:
  • Bile salts: cholesterol derivatives that function in fat emulsification and absorption
  • Bilirubin: pigment formed from heme
  • Bacteria break down in intestine to stercobilin that gives brown color of feces
  • Cholesterol, triglycerides, phospholipids, and electrolytes
• Enterohepatic circulation
  • Recycling mechanism that conserves bile salts
  • Bile salts are:
    1. Reabsorbed into blood by acorn (the last part of small intestine)
    2. Returned to liver via hepatic portal blood
    3. Rescreted in newly formed bile
• About 95% of secreted bile salts are recycled, so only 5% is newly synthesized each time
The Gallbladder

- Gallbladder is a thin-walled muscular sac on ventral surface of liver
- Functions to store and concentrate bile by absorbing water and ions
- Contains many honeycomb folds that allow it to expand as it fills
- Muscular contractions release bile via cystic duct, which flows into bile duct

The Pancreas

- Location: mostly retroperitoneal, deep to greater curvature of stomach
- Exocrine function: produce **pancreatic juice**
  - **Acini**: zymogen granules containing proenzymes
  - **Ducts**: secrete to duodenum via main pancreatic duct; smaller duct cells produce water and bicarbonate
  - 1200-1500 ml/day watery, alkaline solution (pH 8)
    - Electrolytes, primarily HCO$_3^-$
    - Digestive enzymes
      - Proteases (for proteins); secreted in inactive form to prevent self-digestion – activated by intestinal enzymes
      - Amylase (for carbohydrates)
      - Lipases (for lipids)
      - Nucleases (for nucleic acids)
- Endocrine function: secretion of insulin and glucagon by pancreatic islet cells – one control over blood sugar concentration

Structure of the enzyme-producing tissue of the pancreas.

- Small duct
- Acinar cell (secretes enzymes)
- Zymogen granules
- Rough endoplasmic reticulum
- Duct cell (secretes HCO$_3^-$ and H$_2$O)
- One acinus
- Basement membrane
Activation of pancreatic proteases in the small intestine.

What Are Enzymes?

- Enzyme: “A protein molecule produced by living organisms able to catalyze, or facilitate, a specific chemical reaction involving other substances without itself being destroyed or changed in any way.”
- “…speeding the rate at which a biochemical reaction proceeds but not altering the direction or nature of the reaction.”

Relationship of the Accessory organs (liver, gallbladder and pancreas) to the duodenum.
Bile and Pancreatic Secretion into the Small Intestine

- Bile duct and pancreatic duct unite in wall of duodenum
  - Fuse together in bulblike structure called **hepatopancreatic ampulla**
  - **Ampulla opens into duodenum via volcano-shaped major duodenal papilla**
- **Hepatopancreatic sphincter** controls entry of bile and pancreatic juice into duodenum
- **Accessory pancreatic duct**: smaller duct that empties directly into duodenum

**Regulation of bile and pancreatic secretions**

- Bile and pancreatic juice secretions are both stimulated by neural and hormonal controls
  - **Hormonal controls include**:
    - Cholecystokinin (CCK)
    - Secretin
  - **Bile secretion is increased when**:
    - Enterohepatic circulation returns large amounts of bile salts
    - Secretin, from intestinal cells exposed to HCl and fatty chyme, stimulates gallbladder to release bile
  - Hepatopancreatic sphincter is closed, unless digestion is active
- **Bile is stored in gallbladder and released to small intestine only with contraction**

**Mechanisms promoting secretion and release of bile and pancreatic juice.**

1. **CCK and secretin are secreted by duodenal enteroendocrine cells**.

2. **Cholecystokinin (CCK)**
   - Release is stimulated by proteins and fats in chyme.

3. **Secretin**
   - Release is stimulated by acidic chyme.

4. CCK and secretin enter the circulation and cause the following four events:

   - **Bile secretion by liver**:
     - Bile salts returning from enterohepatic circulation are the most powerful stimulus for bile secretion.
     - Secretin is a minor stimulus.
     - CCK causes gallbladder contraction.
     - Vagus nerve stimulates weak gallbladder contraction during cephalic and gastric phases.

   - **Pancreatic secretion**:
     - CCK induces secretion by acinar cells of enzyme-rich pancreatic juice.
     - Secretin causes secretion by duct cells of HCO$_3^-$-rich pancreatic juice.
     - Vagus nerve weakly stimulates during cephalic and gastric phases.

5. **Sphincter relaxation**:
   - CCK causes hepatopancreatic sphincter to relax. Bile and pancreatic juice enter duodenum.

Gross anatomy of the large intestine.
Large Intestine

Subdivisions of large intestine
1. Cecum: first part of large intestine
2. Appendix: masses of lymphoid tissue
   • Part of MALT
   • Bacterial storehouse capable of recolonizing gut when necessary
3. Colon: has several regions, most of which are retroperitoneal (except transverse and sigmoid)
   • Ascending colon ends at right colic (hepatic) flexure
   • Transverse colon ends left colic (splenic) flexure
   • Descending colon
   • Sigmoid colon: S-shaped portion that travels through pelvis
4. Rectum: three rectal valves
5. Anal canal: last segment of large intestine
   • Has two sphincters
     • Internal anal sphincter: smooth muscle
     • External anal sphincter: skeletal muscle

Reflexes and the Colon and Rectum

Defecation reflex.

- Presence of food in the stomach
- Presence of gas in the intestines

Voluntary motor nerves to external anal sphincter
- Stimulation of parasympathetic (vagus) fibers to and from rectum
- Rectum expands, and the internal anal sphincter relaxes

Sensory nerve fibers from stretch receptors in wall
- A spinal reflex is initiated
- Feces move into rectum

If it is convenient to defecate, voluntary motor neurons to external anal sphincter in brain send nerve impulses to skeletal muscles
- Rectum and sigmoid colon contract
- Feces move into rectum
- External anal sphincter relaxes
- Feces pass
Carbohydrate digestion and absorption in the small intestine.

Pancreatic amylase breaks down starch and glycogen into oligosaccharides and disaccharides. Disaccharides break oligosaccharides and disaccharides into monosaccharides.

Brush border enzymes can transport sugars across the apical membrane. Na+ and K+ ATPase in the basolateral membrane generate a concentration gradient that drives the transport of sugars.

Protein digestion and absorption in the small intestine.

Pancreatic proteases break down proteins and protein fragments into smaller pieces and some individual amino acids. Brush border enzymes break protein fragments into amino acids.

Amino acids are cotransported across the apical membrane of the absorptive epithelial cell. This active transport uses the Na+ concentration gradient established by the Na+-K+ ATPase in the basolateral membrane.

Emulsification, digestion, and absorption of fats.

Bile salts in the duodenum break large fat globules into smaller fat droplets, increasing the surface area available to lipase enzymes. Pancreatic lipases hydrolyze triglycerides, yielding monoglycerides and free fatty acids.

Micelles (consisting of fatty acids, monoglycerides, and bile salts) ferry their contents to epithelial cells. Monoglycerides diffuse from micelles into epithelial cells.

Fatty acids and monoglycerides are recombined and packaged with other fatty substances and proteins to form chylomicrons. Chylomicrons are extruded from the epithelial cells by exocytosis, enter lacteals, and are carried away from the intestine in lymph.
Nucleic Acid Digestion

<table>
<thead>
<tr>
<th>Footwall</th>
<th>Enzyme(s) and source</th>
<th>Site of action</th>
<th>Path of absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nucleic acids</td>
<td>2. Enzyme(s) and source</td>
<td>3. Site of action</td>
<td>4. Path of absorption</td>
</tr>
</tbody>
</table>

- Nucleic acid digestion
  - Vitamins
    - Nucleic acids
      - Enzyme(s) and source
      - Site of action
      - Path of absorption
      - Units enter intestinal cells by active transport via membrane carriers.
      - Units are absorbed into capillary blood in the villi and transported to the liver via the hepatic portal vein.

Absorption of Vitamins, Electrolytes, and Water

- Vitamin absorption
  - In small intestine
    - Fat-soluble vitamins (A, D, E, K) are carried by micelles; diffuse into absorptive cells.
    - Fat-soluble vitamins (A, D, E, K) are carried by micelles; diffuse into absorptive cells.
    - Vitamins K and B vitamins from bacterial metabolism are absorbed.
  - In large intestine: vitamin K and B vitamins from bacterial metabolism are absorbed.

- Absorption of electrolytes
  - Most ions are transported actively along length of small intestine.
  - Iron and calcium are absorbed in duodenum.
  - Na+ absorption is coupled with active absorption of glucose and amino acids.
  - K+ is transported actively.
  - K+ diffuses in response to osmotic gradients; lost if water absorption is poor.
  - Usually amount in intestinal lumen is amount absorbed.
  - Water is absorbed more actively than electrolytes.
  - Ca2+ absorption is regulated by vitamin D.

- Absorption of water
  - 9 L water, most from GI tract secretions, enter small intestine.
  - 95% is absorbed in the small intestine by osmosis.
  - Most of rest absorbed in large intestine.
  - Water uptake is coupled with solute uptake.
  - Net osmosis occurs if concentration gradient is established by active transport of solutes.
  - Na+ absorption is coupled with active absorption of glucose and amino acids.
  - Cl− is transported actively.
  - K+ diffuses in response to osmotic gradients; lost if water absorption is poor.
  - Usually amount in intestinal lumen is amount absorbed.
  - Ionic iron is stored in mucosal cells with ferritin.
  - When needed, transported in blood by transferrin.
  - Ca2+ absorption is regulated by vitamin D.
Table 23.2 - Overview of the Functions of the Gastrointestinal Organs (continued)

<table>
<thead>
<tr>
<th>Region</th>
<th>Major Functions</th>
<th>Additional Functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth (oral cavity)</td>
<td>Mechanical breakdown and digestion facilitated by smooth muscle of the tongue and muscles of the pharynx and esophagus</td>
<td>Includes mastication, swallowing, and taste sensations.</td>
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<tr>
<td>Tongue*</td>
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<tr>
<td>Parotid gland</td>
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<td>Sublingual gland</td>
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<td>Submandibular</td>
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<td>Salivary glands*</td>
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<tr>
<td>Esophagus</td>
<td>Mechanical transport of food from the mouth to the stomach</td>
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<td>Pharynx</td>
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<tr>
<td>Stomach</td>
<td>Storage and mechanical breakdown of food</td>
<td></td>
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<tr>
<td>Pancreas*</td>
<td>Secretion of enzymes and bicarbonate</td>
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<tr>
<td>(Spleen)</td>
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<tr>
<td>Liver*</td>
<td>Secretion of bile, detoxification, and synthesis</td>
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<tr>
<td>Gallbladder*</td>
<td>Storage and concentration of bile, regulation of bile flow in response to hormonal signals</td>
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<tr>
<td>Transverse colon</td>
<td>Absorption of water, electrolytes, and minerals</td>
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<tr>
<td>Jejunum</td>
<td>Highly modified for digestion and absorption (small intestine)</td>
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<tr>
<td>Ileum</td>
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<td>Descending colon</td>
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<td>Cecum</td>
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<td>Sigmoid colon</td>
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<td>Rectum</td>
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<tr>
<td>Appendix</td>
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<tr>
<td>Large intestine</td>
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<td>Anal canal</td>
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</tbody>
</table>

*The colon/loops facilitate the functions correspond to the order of digestive functions (anatomical test order) illustrated in Figure 23.2.