SECTION 24-1
The digestive system, consisting of the digestive tract and accessory organs, has overlapping food utilization functions.
## Functions

<table>
<thead>
<tr>
<th>1. Ingestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Mechanical processing</td>
</tr>
<tr>
<td>• E.g. teeth, stomach</td>
</tr>
<tr>
<td>• Increase surface area for attack by enzymes</td>
</tr>
<tr>
<td>• Smaller pieces easier to move</td>
</tr>
<tr>
<td>3. Digestion</td>
</tr>
<tr>
<td>• Proteins $\rightarrow$ amino acids</td>
</tr>
<tr>
<td>• Triglycerides $\rightarrow$ glycerol + fatty acids</td>
</tr>
<tr>
<td>• Polysaccharides $\rightarrow$ monosaccharides</td>
</tr>
</tbody>
</table>

## Functions – 2

| 4. Absorption |
| 5. Secretion |
| 6. Excretion |
| • Absorb across digestive tract epithelium, eventually into blood |
| • Water, acids, enzymes, buffers, ions |
| • Removal of wastes - defecation |
### Peritoneum

A serous membrane

- Produces peritoneal fluid - lubrication
- About 7 l/day produced and absorbed (only about 35 ml present at any one time)

1. Parietal peritoneum - lines abdominopelvic cavity wall
2. Peritoneal cavity - contains serous fluid
3. Visceral peritoneum - covers organs

Retroperitoneal organs - lie posterior to peritoneum

- E.g. kidneys, pancreas

### Folds of Peritoneum

Anchor organs, but allow some movement

Mesentery

- Binds small intestine to posterior body

Mesocolon

- Binds large intestine to posterior body wall

Falciform ligament

- Binds liver to anterior wall and diaphragm

Omenta (“aprons” attached to stomach)

- Greater omentum - on greater curvature and duodenum, covers transverse colon, sm. intestine
- Lesser omentum - on lesser curvature and duodenum, attaches to liver
Mesenteries

Figure 24-2c

Mesenteries

Figure 24-2d

Discussed in lab or later in notes
General Histology of G.I. Tract REFER TO SLIDE 15

Four layers modified from a general plan to carry out function(s) of a particular region

1. Mucosa - a mucous membrane – most **superficial** layer (in contact with “outside world”)
   a) Epithelium (in contact with food)
      • Type varies with location
        ✓ Oral cavity - stratified squamous EPI
        ✓ Small intestine - simple columnar
          Secretion, absorption
          Tight junctions prevent leakage

General Histology – 2

a) Mucosa (cont.)
   • Often contains enteroendocrine cells
     Secrete hormones
     Coordinate GI Tract and glandular activity
   • Epithelial stem cells replace lost cells
b) Lamina propria ("first layer" of CT)
   • Loose CT
   • N.A.V.a.L
   • Mucous glands
   • MALT - becomes more prominent nearer rectum
### General Histology – 3

c) Muscularis mucosae

- Two layers of smooth muscle
  - Inner circular
  - Outer longitudinal
- Produces and regulates folds of mucosa

### General Histology – 4

2. Submucosa

- Dense irregular CT
- Binds mucosa to muscularis (externa)
  a) N.A.V.a.L.
  b) Submucosal (Meissner’s) plexus
    - Part of enteric (autonomic) N.S. - “Brain” of gut
      - Innervates mucosa and submucosa
      - Sensory and motor neurons
      - Para- and sympathetic ganglia
      - Controls movements of mucosa, vasoconstriction, secretion
  c) Exocrine glands
General Histology – 5

3. Muscularis (externa)
   a) Skeletal muscle
      • Mouth, pharynx, upper part of esophagus
   b) Smooth muscle - general
      • Inner circular, outer longitudinal
      • Mixing and propulsion
   c) Contains myenteric (Auerbach’s) plexus

4. Serosa (or adventitia)

The Structure of the Digestive Tract  Figure 24-3

[Diagram of the digestive tract showing layers and structures]
Movement of Digestive Materials

GI tract wall contains visceral (single-unit) smooth muscle

- Cells have *gap junctions*
- Pacesetter cells $\rightarrow$ spontaneous depolarization $\rightarrow$ spontaneous rhythmic contractions = *peristalsis*

Initial stimulus may be:

- Pacesetter cells - or -
- Motor innervation
Peristalsis and Segmentation

Peristalsis
Waves of muscular contraction
Moves bolus from mouth toward anus
1. Circular muscle contracts behind bolus, relaxes in front of bolus
2. Longitudinal muscle contracts in front of bolus
3. Circular muscle contracts, pushes bolus

Segmentation
- Churn back and forth
- Mix contents of tube
Control of Digestive Function

1. Neural mechanisms

   **Myenteric plexus in muscularis externa**

   Muscle contraction and glandular secretion
   
   - Parasympathetic ganglia
   - Sensory neurons
   - Motor neurons
   - Interneurons
1. Neural Mechanisms (cont.)

<table>
<thead>
<tr>
<th>A. Short reflexes (a.k.a. myenteric reflexes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Do not involve CNS</strong></td>
</tr>
<tr>
<td>• Control a local region of the tract</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Enteric nervous system</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Overall coordination of short reflexes in different regions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C. Long reflexes</th>
</tr>
</thead>
<tbody>
<tr>
<td>• <strong>Involve CNS</strong> (e.g. via IX, X and pelvic nerves)</td>
</tr>
<tr>
<td>• Control large-scale peristaltic waves</td>
</tr>
<tr>
<td>• Move material from region to region</td>
</tr>
</tbody>
</table>

**Hormonal and Local Mechanisms**

<table>
<thead>
<tr>
<th>2. Hormonal mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Smooth muscle and glands respond to hormones</td>
</tr>
<tr>
<td>• GI tract produces at least 18 hormones</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3. Local mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Local chemical (e.g. prostaglandins, histamine)</td>
</tr>
<tr>
<td>• Changes in pH, stretch</td>
</tr>
</tbody>
</table>
SECTION 24-2
The oral cavity contains the tongue, salivary glands, and teeth, each with specific functions.
Oral Cavity

Lined with stratified squamous epithelium

Note on Figure 24-6:
- Cheeks
- Vestibule
- Labial frenulum
- Fauces
- Hard and soft palate
- Pharyngeal arches

Tongue

Manipulates food for chewing, swallowing, speech
Sensory (taste, touch, temperature)
Secretes mucins and lingual lipase (below)

*Lingual glands* in lamina propria
- Secrete lingual lipase
  - Initiates digestion of fats to fatty acids and monoglycerides
  - Works over wide pH range ($\approx 3.0–6.0$)
    
    May continue to work in stomach for a while
Tongue – 2

Muscles

*Extrinsic*
- Originates outside of tongue
- Inserts on CT of tongue
- Chewing, swallowing
- Moves tongue in and out, side to side

*Intrinsic*
- Originates and inserts within tongue
- Changes shape of tongue for speech, swallowing

The Salivary Glands

- Parotid, submandibular (submaxillary) and sublingual salivary glands
- Small amount of saliva also from buccal, labial and palatal glands
Salivary Glands – 1

1. Parotid salivary glands (25% of saliva)
   - Anterior to ears
   - Secretes via parotid ducts near second molar
   - Serous secretion contains salivary amylase
     ✓ Begins digestion of starches
     ✓ Secretion is all serous (cells stain darkly)
     Why? What organelle is present that takes up the stain?

Salivary Glands - 2

2. Submandibular (submaxillary) salivary gland
   - 70% of saliva
   - Located under mandible
   - Secretion contains buffers, salivary amylase and mucus
     I.e. both serous and mucous secretion
     Stains both dark and light
   - Empties into mouth under tongue ("gleek" gland)
Salivary Glands - 3

3. Sublingual salivary gland - 5% of saliva
   - Located under tongue
   - Secretion contains thin mucus, buffers, very little salivary amylase
   - Secretion almost entirely mucus
     ✓ Stains lightly

Composition of Saliva

99.4% water, rest is solutes
   - Ions - e.g. chloride (activates salivary amylase)
   - Salivary amylase (begin CH$_2$O digestion)
   - Bicarbonate and phosphate buffers
   - Urea and uric acid (waste products from protein metabolism)
   - Mucus (lubricates food)
   - Immunoglobulin A and lysozyme (antimicrobial)
Secretion of Saliva

1 to 1.2 liters/day!!
- Parasympathetic stimulation → salivation
- Sympathetic stimulation → dry mouth

Secretion increased by:
1. Food in mouth, taste of food, chewing (even without food in mouth)
2. Smell, sight, sound of food
   - Memory → cortex → salivary nuclei
3. Stomach or small intestine irritation

Teeth

Discussed in lab or later in notes
## Teeth (a.k.a. Dentes)

**Periodontal ligament**
- Dense CT
- With cementum, anchors tooth in alveolar process

**Tooth composition**
1. **Dentin** = bulk of tooth
   - Calcified CT
   - Harder than bone (higher \([\text{Ca}^{2+}]\))

## Teeth – 2

2. **Pulp cavity within crown**
   - Contains pulp (N.A.V.a.L.)
   - Root canal and apical foramen
3. **Enamel** - hardest biological substance
   - Covers dentin, crown
   - Crystalline calcium phosphate

**Deciduous teeth** = 20; appear about 20 months.
- 2 incisors, 1 **cuspid**, 2 molars (per quadrant)

**Permanent teeth** = 32; appear at 6 - 12 yrs.
- 2 incisors, 1 **cuspid** (canine), 2 bicuspid (premolars), 3 molars
Primary and Secondary Teeth

Adult dental formula
2:1:2:3

Mechanical and Chemical Digestion in Mouth

Mastication = chewing
Food mixed with saliva = bolus

Enzymes in saliva
- Salivary amylase - begins breaking CH₂Os → disaccharides and trisaccharides
  Starch → maltose, maltotriose, α-dextrins
  Inactivated by stomach acid
- Lingual lipase
  Begins triglycerides → fatty acids + monoglycerides
  Remains active in stomach (for a while)
SECTION 24-3
The pharynx is a passageway between the oral cavity and esophagus

Pronounced: far-inks

Swallowing (Deglutition)

1. Buccal (voluntary) phase
   • Tongue moves bolus from oral cavity to oropharynx

2. Pharyngeal phase
   • *Involuntary* movement into esophagus
   • Bolus stimulates receptors in posterior oropharynx which signal:
     - *Deglutition center* in medulla and pons
       • Soft palate, uvula move up
       • Larynx moves up
       • Epiglottis closes
       • Vocal folds close
       • Breathing ceases (1–2 sec)
### SECTION 24-4
The esophagus is a muscular tube that transports solids and liquids from the pharynx to the stomach

#### Esophagus
Passes through diaphragm at esophageal hiatus, connects to stomach

**Histology**

1. **Mucosa**
   a) Stratified squamous EPI (nonkeratinized)
   b) Lamina propria
      - Mucosal glands near stomach
   c) Muscularis mucosae
Esophagus - 2

2. Submucosa
   • Areolar CT with N.A.V.a.L.
   • Mucous glands - lubrication
     Mucosa and submucosa are folded
     • Allows expansion during swallowing

3. Muscularis (externa)
   • Skeletal muscle fibers in upper 1/3
   • Skeletal and smooth in middle 1/3
   • Smooth in lower 1/3

4. Adventitia (not serosa)

Esophageal “Sphincters”

Upper and lower (cardiac) “sphincters”
   • Are physiological sphincters, not anatomical sphincters like pyloric or ileocolic sphincters
   • Muscle tone in circular muscle keeps ends closed
SECTION 24-5
The stomach is a J-shaped organ that receives the bolus from the esophagus and aids in chemical and mechanical digestion.
Stomach Anatomy

In Figure 24-12, note:
1. Cardia - around esophageal opening
   - Many mucus glands
2. Fundus
   - Dome shaped region above esophageal opening
3. Body - main central portion
4. Pylorus
   - Connects with duodenum via pyloric sphincter
5. Rugae = folds of mucosa; allow stretch
6. Lesser and greater curvatures
The Stomach Lining

Stomach Histology

1. Mucosa - folded into gastric pits with gastric glands
   Cell types:
   A. Mucous surface cells
      • Near lumen
      • Secrete alkaline mucus
   B. Mucous neck cells
      • In “neck” of gastric glands
      • Secrete alkaline mucus

Why **alkaline** mucus?
### Stomach Histology – 2

#### C. Chief (zymogenic) cells
- Secrete pepsinogen
  - **HCl and/or pepsin**
  - **Pepsinogen ---\(\rightarrow\) Pepsin**
- Begin protein digestion
- In **infants**:
  - Secrete *gastric lipase*
    - ✓ Digest fats in milk
  - Secrete *rennin*
    - ✓ Coagulates milk proteins

### Stomach Histology – 3

#### D. Parietal (oxyntic) cells
- Secrete HCl and intrinsic factor
#### E. G cells - secrete *gastrin* (a hormone)
  - Found in pyloric antrum
    - Constricts lower esophageal sphincter
    - Increases stomach motility
    - Stimulates secretion of “gastric juices”
Stomach Histology – 4

2. Submucosa
   - Similar to rest of G.I. Tract

3. Muscularis externa
   - Has *three* layers of smooth muscle
   - *Add* inner oblique to circular and longitudinal layers

4. Serosa
   - Forms greater and lesser omenta

The Stomach Lining

Mucous cells: light-staining, near lumen
Parietal cells: “pink fried eggs”
Chief cells: not “pink fried eggs”

Discussed in lab or later in notes
Parietal Cells Secrete HCl and Intrinsic Factor

A. HCl secretion
   1. H⁺ and HCO₃⁻ generated inside parietal cell
      a) CO₂ + H₂O \rightarrow \text{carbonic anhydrase} \rightarrow H₂CO₃ \rightarrow H^+ + HCO₃⁻
      b) Proton (H⁺) pumps on apical (luminal) surface
         pump H⁺ into lumen in exchange for K⁺
         (transporter = H⁺/K⁺ ATPase)
   2. Extracellular Cl⁻ exchanged for intracellular HCO₃⁻
      a) Basolateral HCO₃⁻/Cl⁻ \text{antiporter} moves
         HCO₃⁻ \text{out of and Cl⁻ into cell}
         • The small increase (from HCO₃⁻) in plasma pH = “alkaline tide”

B. Parietal Cells – 2

A. HCl secretion (cont.)
   3. Cl⁻ and K⁺ leak into stomach lumen
      • I.e., K⁺ is recycled and Cl⁻ moves through cell
   4. Water follows
      • Result is net loss of H⁺ and Cl⁻ (and water) from cell into lumen

HCl functions:
   • Kills bacteria
   • Denatures proteins, enzymes in food
   • Helps break down plant materials and CT
   • Helps activate pepsinogen to pepsin
Secretion of Hydrochloric Acid

**Figure 24-14**

![Diagram of Secretion of Hydrochloric Acid]

- **Tight junction**
- **Lumen of gastric gland**
- **Interstitial fluid**

**Note additions to this Figure.**

**KEY**
- Diffusion
- Carrier-mediated transport
- Active transport
- Countertransport

Parietal Cells - Intrinsic Factor

**B. Intrinsic Factor**
- A glycoprotein
- Facilitates Vitamin B$_{12}$ absorption by intestine (required for RBC formation)

Link to HCl synthesis animation:

[https://www.youtube.com/watch?v=3eP499dFhhA](https://www.youtube.com/watch?v=3eP499dFhhA)
# Regulation of Gastric Activity

Acid and enzyme secretion, and stomach motility controlled by:

1. CNS
2. Short reflexes (enteric N.S.)
3. Hormones

## Phases of Gastric control:

1. Cephalic
2. Gastric
3. Intestinal

*Note differences between these phases regarding stimulus, function, duration, mechanism, and actions*

## 1. Cephalic Phase of Gastric Control

**Function:**
- Prepare stomach for arrival of food

**Duration:**
- Minutes

**Stimulus/mechanism:**

A. Neural
   - Sight, smell, thinking of food
   - Preganglionic fibers (vagus) → submucosal plexus
Cephalic Phase of Gastric Secretion

Actions: Secretion
- Mucous cells: mucus
- Chief cells: pepsinogen
- Parietal cells: HCl
- G cells: gastrin release →
  - Will ↑ motility, secretion

2. Gastric Phase of Gastric Control

Stimulus: Food in stomach
- Distension of stomach
- pH increase in stomach
  (Undigested proteins, peptides in stomach act as buffers)

Functions:
- Increase secretions begun in cephalic phase
- Mix and acidify chyme (“kime”)
- Begin protein digestion (pepsin)

Duration:
- 3–4 hours
### Gastric Phase – 2

#### Mechanisms:

A. Neural: *short reflexes* involving submucosal and myenteric plexuses
   - Stretch receptors
   - Chemoreceptors (pH)
     - (Food $\rightarrow$ ↑ stomach pH)

B. Hormonal: more Gastrin release due to:
   - Parasympathetic activity (ACh)
   - Peptides and amino acids in chyme

### Gastric Phase – 3

#### Mechanisms (cont.)

C. Local effects
   - Histamine released as stomach fills
     - Histamine from mast cells and enterochromaffin-like cells
     - * Stimulates parietal cells

#### Actions:

- Increased secretion by
  - Mucous, chief and parietal cells
- Increased stomach motility (mixing movements)
Gastric Phase of Gastric Secretion

**Short reflex**

**Actions:**
- Increased secretion by mucous, chief and parietal cells
- Increased stomach motility (mixing movements)

---

Intestinal Phase

**Stimulus:** hormonal (CCK, GIP, secretin)

**Function:**
- Control rate of chyme movement into duodenum
- i.e. Don’t let stomach send duodenum more than it can handle at once!

**Duration:**
- Several hours
### Intestinal Phase – 2

**Mechanisms:**

A. **Neural:** *short reflexes* (enterogastric reflex)
   - Stretch and chemoreceptors *in duodenum* signal myenteric plexus

B. **Hormonal:** Acid, CH$_2$Os and lipids in duodenum
   - **Cholecystokinin** (CCK) secretion: Inhibits gastric emptying
   - **Gastric Inhibitory Peptide** (GIP): Inhibits gastric secretion (HCl), motility (**controversial: may be more important for causing insulin secretion**)
   - **Secretin** secretion: Inhibits gastric secretions (stimulates pancreatic secretions)

### Intestinal Phase of Gastric Secretion  
**Fig. 24-15**

**Actions:**
- ↓ acid and pepsinogen secretion
- ↓ stomach motility
Digestion in the Stomach

Digestion:
A. Proteins: Begin *limited* digestion of proteins to peptides, small polypeptides
   - Occurs when pH < 2
   - Limited digestion
     - Short duration
     - Pepsin only attacks certain peptide bonds
B. Carbohydrates and lipids
   - Salivary amylase and lingual lipase
     Work until pH < 4.5 (1 to 2 hours)

Absorption of Nutrients in the Stomach

No *nutrient absorption* because:
- No nutrient transporters present!
- Mucus lines stomach lumen
- EPI not very permeable to H₂O
- Residence time in stomach relatively short

Some absorption of:
- Alcohol (EtOH), aspirin, lipid-soluble drugs