Chapter 22: Digestive System

Converts food into raw materials necessary for cell maintenance and growth

Chapters 22: Digestive System

Digestive System:
Main Divisions of Digestive System:
1) **Alimentary Canal** (gastrointestinal tract)
   - Continuous, muscular tube (lumen “outside” body)
   - Digests / absorbs food
2) **Accessory Organs**
   - Glands; line / located outside GI tract
   - Produce digestive secretions

Main Divisions of Digestive System:

Functions of Digestive System:
1) **Ingestion**
   - Taking food in (mouth)
2) **Propulsion**
   - Food movement through GI tract
     - Swallowing (voluntary)
     - Peristalsis (involuntary)
3) **Mechanical Digestion**
   - Physical breakdown / mixing of food
     - Chewing (oral cavity) / Mixing (stomach)
     - Segmentation
4) **Chemical Digestion**
   - Enzymatic breakdown of food → monomers
5) **Absorption**
   - Movement of monomers into blood / lymph
     - Organics / vitamins / minerals / water
6) **Defecation**
   - Elimination of indigestible material (via anus)
Sphincters (smooth muscle rings) regulate passage of materials through system:

1) Lips (guard entrance - voluntary)
2) Cardiac Sphincter (entrance to stomach)
3) Pyloric Sphincter (exit to stomach)
4) Iliocecal Valve (small intestine → large intestine)
5) Internal Anal Sphincter (involuntary)
6) External Anal Sphincter (voluntary)

Histology of GI Tract:

Four Layers:

1) **Mucosa** (mucous membrane)
   - 3 layers:
     - **Epithelium** (simple / stratified)
     - **Lamina propria** (areolar tissue)
     - **Muscularis mucosae** (smooth muscle)
   - Functions:
     - Secretes mucus
     - Absorbs monomers
     - Protects from infection

2) **Submucosa**
   - Dense irregular connective tissue
   - Nerves / vessels / lymphoid tissue / glands
   - **Plexus of Meissner** (submucosal plexus)
     - Regulates glands / muscle in mucosa

3) **Muscularis externa**
   - Smooth muscle
   - 2 layers – circular / longitudinal
   - Mixes / propels food (e.g., peristalsis)
   - **Plexus of Auerbach** (myenteric plexus)
     - Controls GI tract mobility

4) **Serosa / Adventitia**
   - Serosa = serous membrane
   - Adventitia = no serosa; fibrous sheath

Cellular Lifespan:
- 3 – 6 days
Digestive System – Oral (Buccal) Cavity:

Function:
1) Sensory Analysis
2) Mechanical Processing
3) Lubrication
4) Chemical Digestion (limited…)

1) Tongue:
• Mechanical processing [compression / abrasion / distortion]
• Assist chewing / prepare for swallowing
• Sensory analysis
• Chemical digestion – Lingual lipase (fats)

• Contains extrinsic (gross control) and intrinsic (fine control) muscles
• Contains papillae
  - Filiform (rough - friction)
  - Fungiform (taste buds)
  - Circumvallate (taste buds)

~ 3000
Lifespan: 10 days

2) Salivary Glands:
• Produce and secrete saliva [1 – 1.5 L / day]

Lubricate mouth: Water (~ 99.5%)
Protect body: Antibodies
Chemical digestion:
  - Salivary amylase (carbs)

Mumps: Viral infection of Parotid gland

A) Intrinsic Glands (Buccal glands)
• Inside oral cavity

B) Extrinsic Glands
• Outside oral cavity: connected via ducts
  - Parotid / Submandibular / Sublingual
    • Serous cells (parotid / ½ submandibular)
    • Water / ions / enzymes
    • Mucous cells (sublingual / ½ submandibular)
    • Mucus (mucin / glycoproteins)
Duct
Mucous
cells
Serous
cells

Thinking...
Smelling...
Tasting...

Salivary Control:
Stimulation of chemoreceptors and mechanoreceptors
Increased salivation (watery saliva)
Activation of parasympathetic motor neurons

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Salivary Control:
Release of mucus-rich saliva ("dry mouth")
Constriction of blood vessels to salivary glands
Stimulation of the sympathetic motor neurons
3) Teeth:

Mastication = Chewing (complicated process)

- Break down connective tissue (meat) and fibers (plants)
- Saturate food with salivary secretions / enzymes

2 Sets of Teeth

1) Deciduous (milk)
   - 20 total (10 top / 10 bottom)
   - In by 2 yrs. of age

2) Permanent
   - 32 total (16 top / 16 bottom)
   - Incisors (cutting)
   - Canines (tearing)
   - Premolars (crushing)
   - Molars (grinding)

Digestive System – Oral (Buccal) Cavity:

3) Teeth:

1a) Enamel (crown)
   - Acellular; highly mineralized

1b) Cementum (root)
   - Bone-like material (acellular)

2) Dentin
   - Peridontal ligament

3) Pulp Cavity
   - Blood vessels, / nerves
   - Root canal

Dental Plaque
- Hardest biologically manufactured substance
- $\text{Ca}_4\text{P}_2\text{O}_{10}$

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Take Home Message…
Digestive System – Esophagus:
• Conveys food / liquids to stomach (dorsal to trachea / heart)
• Contains all four histological layers
1) **Mucosa**: Stratified squamous epithelium (non-keratinized)
   • Irregular muscularis mucosae layer
2) **Submucosa**: Esophageal glands (mucus-secreting)
3) **Muscularis externa** (2 layers – circular / longitudinal)
   • Superior = skeletal muscle
   • Middle = ½ skeletal / ½ smooth muscle
   • Inferior = smooth muscle
4) Primarily adventitia (anchors esophagus)

Digestive Processes of Mouth → Esophagus:
1) Ingestion
2) Mechanical Digestion (e.g., mastication)
3) Chemical Digestion
   • Salivary amylase (Carbs → polysacc.) / Lingual Lipase (Lipids → fatty acids)
4) Propulsion
   • Deglutination (swallowing)
     • Buccal phase (voluntary)
     • Pharyngeal-esophageal phase (swallowing reflex – involuntary)

Time from Mouth → Stomach = 1 – 8 seconds
Food = bolus
Digestive System – Stomach:

- Esophagus
- • Storage tank (distensible)
  • Max = 1 - 1.5 L
  • Location of chemical digestion
  • Bolus → chyme

- Cardiac Sphincter
- • Diaphragm
- • Heartburn
- • Fundus
- • Body
- • Heartburn

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1) Mucosa: Simple columnar epithelium
   • Goblet cells = mucus (protection from acids / enzymes)
   • Rugae: Prominent folds → allow for distention
   - Gastric Pits (produce gastric juices = 1.5 L / day)
     - Mucous Neck Cells
       • Secrete mucus
     - Parietal Cells
       • Secrete hydrochloric acid (pH 1.5 - 3.5)

- Greater Curvature
- • Lesser Curvature
- • Cardiac Sphincter
- • Pyloric Sphincter

Stomach – Acid Production:
- HCl not produced directly in cytoplasm (too corrosive)
  Functions:
  • Kill microorganisms
  • Denature proteins
  • Break down cell walls / CTs
  • Active digestive enzymes

- Alkaline Tide: pH increase in gastric blood return due to HCO₃⁻ entry

- Carbonic anhydrase
- • CO₂ + H₂O → H₂CO₃
  • H₂CO₃ → H⁺ + HCO₃⁻

- Chloride: Cl⁻

- Alkaline tide by bloodstream

KEY
- Out of interstitial fluid or cytosol: diffusion
- Into interstitial fluid or cytosol: Carrier-mediated transport
- Active transport
- Countertransport
Digestive System – Stomach:

1) **Mucosa**: Simple columnar epithelium
   - Goblet cells = mucus (protection from acids / enzymes)
   - Rugae: Prominent folds – allow for distention
   - Gastric Pits (produce gastric juices – 1.5 L / day)
     A) Mucous Neck Cells
        • Secrete mucus
     B) Parietal Cells
        • Secrete hydrochloric acid (pH 1.5 - 3.5)
        • Secrete intrinsic factor (vitamin B₁₂)
     C) Chief Cells
        • Secrete Pepsin (protein breakdown)
        • Secrete Rennin / Gastric Lipase (infants)
     D) Enteroendocrine Cells
        • Secrete hormones (e.g., G cells = gastrin)

   → **Gastric Juices (1.5 L / day)**

2) Submucosa
3) **Muscularis externa** (3 layers – oblique / circular / longitudinal)
4) Serosa – Connective tissues / mesothelium (visceral peritoneum)

**Gastric Ulcer**
Breach in mucosal barrier

Helicobacter pylori
Stomach - Regulation of Gastric Secretion (3 phases):

1) **Cephalic Phase**
   - Occurs before food ingested (sensing of food...)
   - CNS triggers gastric juice secretion (stomach preparation)

2) **Gastric Phase**
   - Gastric secretion triggered by distension, peptides, \( \uparrow \) pH (food in stomach)
     - A) Neural Response = ACh release (short reflex arc - stretch receptors)
     - B) Hormonal Response = **Gastrin** release (chemoreceptors)

3) **Intestinal Phase**
   - Gastric secretion regulated by chyme entering small intestine
     - A) **Enterogastric Reflex**: Inhibits gastric secretions / motility
     - B) Hormone Release
       - **Cholecystokinin (CCK) / Gastric Inhibitory Peptide (GIP)**
         - Triggered by lipids / carbs
       - Secretin
         - Triggered by \( \downarrow \) pH in SI

**Inhibit gastric secretions**

**Carbs / liquids** = fast digestive rate
**Fats / proteins** = slow digestive rate
Digestive Processes of Stomach:
1) Mechanical Digestion (Churning of stomach)
2) Chemical Digestion
   • Pepsin (Proteins → small peptides)
   • Rennin (milk proteins) / Gastric Lipase (fats)
3) Propulsion (Peristalsis)
4) Absorption
   • Lipid-soluble substances (e.g., alcohol / drugs)

Digestive System – Small Intestine:
1) Duodenum (~ 10”):
   • Receives chyme from stomach and exocrine secretions from liver / pancreas
2) Jejunum (~ 8”):
   • Chemical digestion / nutrient absorption
3) Ileum (~ 12”):
   • Joins large intestine at ileocecal valve

Modifications for Absorption:
1) Plicae circulares (circular folds)
   • Permanent folds (mucosa) / submucosa; mix chyme
2) Villi
   • Finger-like projections of mucosa; ↑ surface area
   • Lacteal: Modified lymphatic capillaries; absorb lipids
3) Microvilli
   • Finger-like projections of plasma membrane; ↑ surface area
   • Contain digestive enzymes (brush border enzymes)

Surface Area:
Without Modifications = ~ 3.5 sq. ft.
With Modifications = ~ 2200 sq. ft.
Digestive System – Small Intestine:
Contains all four histological layers:

1) Mucosa: Simple columnar epithelium (microvilliated)
   - Many goblet cells; scattered enteroendocrine cells
   - Intestinal crypts (Crypts of Lieberkuhn)
   - Secrete intestinal juices / generation of epithelial cells

2) Submucosa:
   - Brunner’s Glands: Secrete alkaline mucus (neutralize chyme)
   - Peyer’s Patches: lymphoid nodules

3) Muscularis externa (2 layers – circular / longitudinal)
   - Myogenic Reflexes: Weak peristaltic contractions (limited distance)
   - Gastroenteric Reflex: Stimulates motility along SI
   - Gastrocolic Reflex: Triggers relaxation of ileocecal valve

4) Serosa (jejunum / ileum); Adventitia (duodenum)
Digestive System – Liver / Gallbladder:
1) Liver:
   • Largest gland in body (~ 3 lbs)
   • 4 lobes (right (largest); left; caudate; quadrate)
   • Produces bile and filters / processes blood

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Function unit = Liver lobe
(~ 100,000 / liver)
**Digestive System – Liver / Gallbladder:**

1) **Liver:**

- **Sinusoids lack basal lamina**

**Hepatic Triad**

**Liver sinusoids**

- **Central Vein**

**Hepatocytes (Hepatic cord)**

- Produce bile (emulsification)
- Processes nutrients
  - glucose → glycogen
  - amino acids → proteins
- Store fat-soluble vitamins
- Store iron (ferritin)
- Ammonia → urea
- Drug inactivation
- Toxin / antibody removal

**Kupffer Cells:**

- Phagocytes (pathogens / debris)
- Store iron, lipids, heavy metals
Hepatocytes (Hepatic cord)

- Produce bile (emulsification)
- Processes nutrients
  - glucose → glycogen
  - amino acids → proteins
- Store fat-soluble vitamins
- Store iron (ferritin)
- Ammonia → urea
- Drug inactivation
- Toxin / antibody removal

Kupffer Cells:
- Phagocytes (pathogens / debris)
- Store iron, lipids, heavy metals

Hepatitis: Phagocytes

Hepatitis

Cirrhosis

Liver / Gallbladder:

1) Liver:

- Hepatocytes (Hepatic cord)
- Bile canaliculus

Composition of Bile:

1) Bile Salts
   - Acids derived from cholesterol (e.g., cholic acid)
   - Emulsify fats
   - Recycled (Enterohepatic circulation of bile)

2) Bilirubin
   - Waste product of hemoglobin (Hb)
   - Metabolized in gut to form urobiligen
   - Makes feces brown

3) Cholesterol / neutral fats / phospholipids

Bile DOES NOT contain enzymes that digest fats...

Bilirubin is produced by the liver from the breakdown of old red blood cells. It is then conjugated with glucuronic acid in the liver and excreted in the bile. If the liver is unable to conjugate bilirubin, it accumulates in the bloodstream, leading to jaundice.

Bile is a greenish-yellow fluid produced by the liver and stored in the gallbladder. It aids in the digestion of fats by emulsifying them into smaller droplets, which allows the digestive enzymes in the small intestine to access and break them down.
Digestive System – Liver / Gallbladder:

1) Liver:
   • Largest gland in body (~ 3 lbs)
   • 4 lobes (right (largest); left; caudate; quadrate)
   • Produces bile and filters / processes blood

2) Gallbladder:
   • Sack-like structure; stores / concentrates bile

Digestive System – Pancreas:

• Mixed endocrine / exocrine gland (exocrine = digestion)
**Digestive System – Pancreas:**

- **Mixed endocrine / exocrine gland** (exocrine = digestion)
- **Exocrine cell types:** (produce pancreatic juice; ~ 1 L/day)

1. **Acinar Cells**
   - Produce digestive enzymes:
     - Trypsin, Carboxypeptidase, Chymotrypsin (proteins)
     - Pancreatic Amylase (carbohydrates)
     - Pancreatic Lipase (lipids)
     - Nucleases (nucleic acids)

2. **Duct Cells**
   - Produce bicarbonate-rich fluid (pH ~ 8)

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**Regulation of Pancreatic Juice and Bile Secretion:**

- **Acidic, fatty chyme in duodenum**
- **Acinar cells**
  - Enzymes released
  - Simulation of enteroendocrine cells
  - Cholecystokinin
  - Secretin
  - Gastric secretion

- **Bile released to duodenum**
- **Bile salts absorbed (returned to liver)**
- **Bile production**

- **Gallbladder contractions**
- **Duodenal papilla relaxed**
- **Bicarbonate released from pancreatic and bile ducts**

- **Vagal input**
Digestive Processes of Small Intestine:
1) Mechanical Digestion (segmentation)
2) Chemical Digestion
   • Trypsin / Chymotrypsin / Carboxypeptidase (Proteins → small peptides)
   • Pancreatic amylase (Carbs → disaccharides)
   • Pancreatic lipase / Bile salts (Lipids → fatty acids / glycerol)
   • Nucleases (Nucleic acids → nucleotides)
3) Propulsion (Peristalsis – migrating mobility complex ~ 5-hour trip)
4) Absorption
   • Primary site of nutrient absorption

Digestive System – Large Intestine:
• Extends from ileocecal valve to anus (~ 5')
• Functions: 1) absorb water from indigestible food
   2) absorb essential vitamins
   3) store fecal material

Contains bacterial flora
Ferment indigestible carbohydrates (500 ml gas / day)
Synthesize B complex vitamins and vitamin K

Antibiotics (affect gut flora)
Diet
Promotes “good” gut flora growth

~ 1000 species (10^14 cells)
Digestive System – Large Intestine:
All four histological layers present:
1) **Mucosa**: Simple columnar / Stratified squamous (rectum)
   - No plicae circulares / villi; many goblet cells
2) **Submucosa**:
   - Superficial venous plexi (hemorrhoids)
3) **Muscularis externa** (2 layers – circular / longitudinal)
   - Longitudinal layer reduced to taeniae coli (muscular band)
4) **Serosa** (transverse / sigmoid); **Adventitia** (ascending / descending)

Digestive Processes of Large Intestine:
1) **Absorption**
   - **Feces**: 75% water / 20% indigestible waste / 5% bacteria
   - **Ions**
   - **Vitamins**
   - **Giardia** ("Beaver Fever")

2) **Propulsion**
   - **Cecum** → **Transverse Colon** (very slow...)
   - **Haustral Churning** = segmentation (miles adjacent haustra)
   - **Peristalsis**
   - **Transverse Colon** → **Rectum** (more rapid...)
   - **Mass Movements** = powerful peristaltic waves (several times / day)
   - **Triggered by food in stomach (clear system...)**

3) **Defecation**
   - **Defecation Reflex**: Distension of rectal wall triggers multiple positive feedback loops
Digestive Processes of Large Intestine:

1) Absorption
2) Propulsion
   - Cecum → Transverse Colon (very slow...)
   - Haustral Churning = segmentation (mixes adjacent haustra)
   - Peristalsis
   - Transverse Colon → Rectum (more rapid...)
   - Mass Movements = powerful peristaltic waves (several times / day)
     - Triggered by food in stomach (clear system...)
3) Defecation
   - Defecation Reflex: Distension of rectal wall triggers multiple positive feedback loops
   - Voluntary Control of Defecation
     - Valsalva’s Maneuver: Forced exhalation with glottis closed
       - If pressure > 55 mm Hg in rectum, external sphincter involuntarily relaxes

Physiology of Chemical Digestion:

- **Catabolic process (breakdown)**
  - Hydrolysis = addition of water at chemical bonds
  - Macromolecules → Monomers
    - Carbohydrates → Monosaccharides
    - Proteins → Amino acids
    - Lipids → Monoglycerides & Fatty acids
    - Nucleic acids → Bases, phosphates & ribose
### 3) Lipids

- **Physiology of Chemical Digestion:**
  - **Triglycerides, fatty acids & bile salts** → **Micelles** → **Lumen**
  - **Simple diffusion**
  - **Triglycerides & Fatty acids**
  - **Chylomicrons**
  - **Exocytosis**
  - **Lacteal of lymphatic system** → **Enters bloodstream @ il. subclavian vein**

### 4) Nucleic Acids

- **Bases, phosphates & ribose**
  - **Pancreatic nucleases**
  - **Brush border enzymes**

**Physiology of Chemical Digestion:**

- **Mouth**
- **Esophagus**
- **Stomach**
- **Small Intestine**
- **Large Intestine**