Chapter 20 The Gastrointestinal System

- Overview of GI Processes
- Functional Anatomy
- Digestion and Absorption
- General Principle of GI Regulation
- GI Secretion and Regulation
- GI Motility and its Regulation

20.1. Overview of Gastrointestinal System Processes

- Consumed nutrients too large to enter directly into bloodstream
- Undergo digestion before absorption
- Motility and secretion aid digestion and absorption
- Four Basic Digestive Processes (Figure 20.1)
  - **Gastric Motility** is movement of food through GI tract by means of:
    - Ingestion--taking food into mouth
    - Mastication--chewing food & mixing it with saliva
    - Deglutition--swallowing food
    - Peristalsis--rhythmic wave-like contractions that move food through GI tract
    - Functions: Mix chyme and regulate gastric emptying
    - Mechanism: Peristalsis is coordinated by enteric nervous system
  - **Secretion** is the transport of contents to the lumen of GI tract
    - Exocrine secretions include: HCl, H₂O, HCO₃⁻, bile, lipase, pepsin, amylase, trypsin, & histamine
    - Endocrine secretions includes hormones secreted into stomach and small intestine to help regulate GI system
  - **Digestion** is the breakdown of food molecules by enzymes into their smaller subunits.
    - Digestion is helped by mechanical forces such as chewing.
  - **Absorption** is passage of digested end products into blood or lymph. Absorption and digestion are the primary functions of the digestive system

20.2 Functional Anatomy of the Gastrointestinal System

- **Gastrointestinal Tract (Figure 20.2):** Hollow tube15 feet long, Food →mouth → pharynx → esophagus → stomach → small intestine → colon → rectum → anus
- **Wall of GI Tract (Figure 20.3):** Mucosa lines lumen; submucosa: connective tissue; muscularis externa: smooth muscle; serosa: Connective tissue
  - **Mouth/oral cavity** is the entrance of digestive system
    - Motility: Ingestion, mastication (chewing) breaks up food and mixes food with saliva and swallowing
    - Secretion
      - Salivary glands secrete saliva (bicarbonate amylase, lipase, mucus and lysozyme)
      - Mucus=lubricant
      - Lysozyme = Kill bacteria
    - Digestion
      - Salivary amylase catalyzes partial digestion of starch
      - Lingual lipase breaks down a small amount of lipids
    - Absorption: Food molecules are not absorbed. Some medications, for example nitroglycerin are absorbed.
Pharynx and Esophagus

- **Motility**
  - Deglutition (swallowing) begins as voluntary activity in oral cavity (Figure 20.31). Pharyngeal and esophageal phases are involuntary and cannot be stopped. To swallow, larynx is raised so that epiglottis covers entrance to respiratory tract. A swallowing center in medulla orchestrates complex pattern of contractions required for swallowing
  - Peristalsis
  - Secretion: Mucus lubricates food passage and protect the esophageal wall from damage by enzymes and acids.
  - No digestion and absorption occur in pharynx and esophagus

Stomach

- Enclosed by lower esophageal sphincter on top & pyloric sphincter on bottom. It is the most distensible part of GI tract
- Functions: Storage of food (main); initial digestion of proteins; continue digestion of lipids (small amount); killing bacteria with high acidity; moving soupy food mixture (chyme) slowly into intestine

Gastric Motility Function

- Mixing chime: Waves of peristalsis functions in mixing of chyme with HCl and pepsin
- Regulation of gastric emptying
- Receptive relaxation: Filling, receive food from esophagus is accomplished by receptive relaxation
- Food storage: Holds chyme until digestion proceeds and intestines ready to receive it
- Gastric emptying: Stronger contractions cause pyloric sphincter to open. Emptying rate increases in proportion to volume of chyme in stomach and strength of gastric peristalsis

Gastric emptying

- Stronger contractions cause pyloric sphincter to open. Emptying rate increases in proportion to volume of chyme in stomach and strength of gastric peristalsis

Secretion

- Gastric pits Located in stomach lining and lead to gastric glands
- Gastric mucosal barrier is a protective layer of mucus and bicarbonate that are secreted from neck cells and goblet cells. Mucus protects stomach
- Intrinsic factor secreted by parietal cells is necessary for absorption of vitamin B₁₂
- Endocrine/Paracrine cells: Enterochromaffin-like cells secrete histamine & serotonin. G cells secrete gastrin. D cells secrete somatostatin
- Hydrogen ions secreted by parietal cells. The stomach pH = 2. This acid environment is necessary for activating pepsinogen to pepsin; denaturing proteins and killing bacteria

Digestion

- Proteins partially digested by pepsin; no carbohydrate digestion (salivary amylase is soon inactivated by acidity); lipid digestion continues.

Absorption

- Food is not absorbed. Alcohol and aspirin are only commonly ingested substances absorbed

Self-Protective Mechanisms of Stomach

- The stomach lining is impermeability of parietal & chief cells to HCl. There is a layer of alkaline mucus containing HCO₃⁻ and tight junctions between adjacent epithelial cells
- Rapid rate of cell division (entire epithelium replaced in 3 days)
- Enzymes are secreted inactively
- Prostaglandins (PGs) inhibit gastric secretions
- Peptic ulcers are erosions of mucous membranes of stomach or duodenum caused by action of HCl. *Helicobacter pylori* infection is associated with ulcers

Small Intestine

- Is a coiled, hollow tube of 8–10 feet (about 3 meters) long. It has three divisions: duodenum, jejunum and ileum. It is the primary site of digestion and absorption
- Secretion of Small Intestine: Epithelial cells in crypts of Lieberkuhn (Figure 20.6) secrete bicarbonate-rich fluid in proximal small intestine. Bicarbonate is absorbed in distal small
intestine.

- **Secretions into Duodenum**
  - Pancreatic juice containing digestive enzymes and bicarbonate (neutralizes acidic chyme)
  - Bile enters duodenum from liver. Bile can be stored in gallbladder. Bile salts which aid in fat digestion

- **Absorption in Small Intestine**
  Absorption of all digested food, most electrolytes and water occurs in SI. Absorption is facilitated by long length & tremendous surface area from villi. Villi contain blood vessels and lacteal for absorption of nutrients

- **Motility of Small Intestine**
  - Segmentation: Mix content
  - Peristalsis: Propel content forward
  - Migrating motility complex occurs between meals. Its intense contractions that travel short distances to sweep clean intestines

- **Digestion in SI**: With the presence of pancreatic enzymes, and brush boarder enzymes, most of the digestion of is completed.

- **Large Intestine (LI) or Colon**
  - Chyme from small intestine → cecum → ascending colon → transverse colon → descending colon → sigmoid colon → rectum → anal canal
  - Has no digestive function
  - Reclaim water and electrolytes: Absorbs H₂O, electrolytes, B & K vitamins, & folic acid
  - LI contains large population of microflora that produce folic acid, vitamin K and ferment indigestible food to produce fatty acids
  - Secrets mucus
  - Sigmoid colon stores feces
  - Appendix stores probiotics and may have immune function

- **Motility in Large Intestine**
  - Haustral contractions slowly mix the colonic contents in proximal colon.
  - Mass movements propel feces into the distal part of LI where it is stored until defecation occurs

- **Motility Reflexes**
  - Intestino-intestinal reflex: Injury or severe stress inhibits intestinal contractions
  - Ileogastric reflex: Distension of ileum inhibits gastric motility
  - Gastroileal reflex: Presence of chyme in stomach increases motility in ileum

- **Rectum and Anus**
  - Colon empties undigested wastes into rectum, then feces excreted through anus
  - Internal anal sphincter = smooth muscle
  - External anal sphincter = skeletal muscle
  - Relaxation of both sphincters necessary to open sphincter and excrete feces = defecation

- **Accessory Glands**
  - Secreted products via ducts into the lumen of the GI tract
  - Salivary glands which secreted saliva
  - Pancreas which secretes pancreatic juice
  - Liver which secretes bile
  - No absorption, digestion and movement of food molecules
  - **Structure of an Accessory Gland (Figure 20.9)**: Acini are secretary cells that release primary secretion containing water, ions and enzymes
  - **Characteristics of Saliva (Figure 20.10)**
Saliva is produced by three pairs of salivary glands. Saliva contains bicarbonate ions, mucus and salivary amylase, lysozyme and lingual lipase.

- **The Pancreas (Figure 20.11):** Exocrine portion produces pancreatic juice that is rich in bicarbonate and pancreatic amylase and lipases, proteases and nuclease.
- **The Liver (Figure 20.12):** The largest organ in the abdominal cavity. It removes of old red blood cells; elimination of wastes and toxins; synthesis of plasma proteins; secretion and modification of hormones; and processing of nutrients; manufactures and secretes bile (related to digestive function).
  - Bile salts are synthesized in liver from cholesterol. They are secreted in bile to duodenum to emulsify fat (do not digest fat). After emulsification: much more surface exposed to lipases.
  - **Biliary system (Figure 20.12):** Liver synthesizes bile; gallbladder stores bile and common bile duct transports bile from liver and/or gallbladder to duodenum.
  - **Hepatic portal system (Figure 20.7):** The vasculature that delivers absorbed nutrients to liver before entering general circulation.

**Table 20.1 GI Organs and Their Functions**

### 20.3 Digestion and Absorption of Nutrients and Water


#### Carbohydrates (Figure 20.13):
- Typical diet: 250–800 grams
  - Most consumed as disaccharides: sucrose, lactose and maltose.
  - Polysaccharides: starch, glycogen and cellulose (fiber, cannot be digested).

- **Digestion of Carbohydrates (Figure 20.14):**
  - Salivary amylases digest polysaccharides in the mouth.
  - No digestion in the stomach.
  - In small intestine, pancreatic amylase digests the polysaccharides; brush border enzymes complete digestion of carbohydrates to monosaccharides.

#### Carbohydrate Absorption
- Only monosaccharides absorbed.
- Glucose and galactose absorbed by secondary active transport across apical membrane and facilitated diffusion across basolateral membrane.
- Fructose absorbed by facilitated diffusion across both membranes.

#### Proteins
- Typical diet: 125 grams/day, only require 40–50 grams.
- Proteins to be digested and absorbed include: consumed in diet, secreted into lumen of intestinal tract and sloughed off with cells lining intestinal tract.

#### Protein Digestion
- Begins in the stomach by pepsin.
- In duodenum: By pancreatic endopeptidases: trypsin, chymotrypsin. Exopeptidases: pancreatic carboxypeptidases and brush border aminopeptidases. The final produces are amino acids, dipeptides and tripeptides.

#### Absorption of Amino Acids
- Cross apical membrane by sodium-linked secondary active transport or facilitated diffusion.
- Cross basolateral membrane by facilitated diffusion.

#### Absorption of Dipeptides and Tripeptides
- Cross apical membrane by active transport; broken down inside cell to amino acids.
- Amino acids cross basolateral membrane by facilitated diffusion.
• **Lipids**
  o Typical diet: 25–160 grams lipids; 90% triglycerides. Lipids are water soluble. They do not mix with stomach, intestinal contents. They form fat droplets
  
  • **Triglycerides Digestion**
    ▪ In mouth and the stomach: by lingual lipase
    ▪ In the stomach: by gastric lipase
    ▪ In the small intestine: by pancreatic lipases
    ▪ Final products: fatty acids and monoglyceride

• **Absorption of Monoglycerides and Fatty Acids (Figure 20.21)**
  ▪ Equilibrium between free fatty acids and monoglycerides and those in micelles
  ▪ Free form can be absorbed by simple diffusion across epithelium
  ▪ Inside epithelial cell: Enter smooth ER and reform triglycerides and other lipids. Lipids enter Golgi apparatus to be packaged into chylomicrons. Chylomicrons secreted by exocytosis into interstitial fluid enter lymphatic system via lacteal

• **Enterohepatic Circulation (Figure 20.20):** Bile salts are absorbed in the ileum and transported back to the liver via enterohepatic circulation

• **Absorption of Vitamins**
  o Fat-soluble vitamins (A, D, E, and K) are absorbed with lipids: dissolve in lipid droplets, micelles, chylomicrons.
  o Water-soluble vitamins require special transport proteins through active transport or facilitated diffusion. Vitamin B\(_{12}\): Absorbed only when bound to intrinsic factor

• **Absorption of Minerals: Na\(^+\), and Cl\(^-\)**
  o Sodium: Solvent drag with water reabsorption; actively absorbed in jejunum, ileum, and colon. It is coupled with chloride absorption
  o Chloride is passively follows sodium absorption in Jejunum. In the ileum and colon: counter-transport with bicarbonate ions at the apical membrane and facilitated diffusion at the basolateral membrane

• **Absorption of Potassium:** Potassium ions is passively absorbed in the small intestine. It is secreted when lumenal concentrations very low in the colon

• **Absorption of Calcium:** Calcium is actively absorbed in duodenum and jejunum. It binds to brush border protein = calcium-binding protein; transported into epithelial cell by unknown mechanism. It is transported out of cell across basolateral membrane by Ca\(^{2+}\) pump. 1,25-(OH)\(_2\)D\(_3\) increases calcium absorption by increasing concentration of calcium-binding protein

• **Absorption of Iron:** Transferrin-iron complex binds receptor, taken into cell by receptor-mediated endocytosis

• **Absorption and Secretion of Bicarbonate**
  o Jejunum: bicarbonate ions passively absorbed
  o Ileum and colon: bicarbonate secreted in exchange for chloride ions

• **Absorption of Water:** Water follows absorption of solutes by osmosis

### 20.4 General Principles of GI Regulation Table 20.2 and Figure 20.22)

• **GI Regulation** is not based on the concept of homeostasis. It is to maximize absorption, regardless of whether nutrients are needed. It involves short and long reflexes via ANS, enteric nerve system, and hormones released from the stomach and small intestine

• **Neural Pathways (Figure 20.22)**
  o Enteric nervous system (ENS)
    ▪ Intrinsic nerve system containing own neurons
      ▪ Short reflex pathway: CNS is not involved
• Long reflex pathway
  o Parasympathetic nerve system promotes GI activity by increasing muscle activity or secretion
  o Sympathetic activity works the opposite way

• Endocrine Pathways (Table 20.2)
  o GI hormones secreted from endocrine cells in stomach and small intestine
  o Sensory receptors in GI tract detect environment in lumen to initiate reflexes

• Phases of Gastrointestinal Control
  o Cephalic phase—stimuli originate in head such as thoughts, taste, and smell. It requires input from CNS (long reflexes)
  o Gastric phase—stimuli originate in stomach; long and short reflex and GI hormones
  o Intestinal phase—stimuli originate in small intestine; long and short reflex and GI hormones

• Regulation of Food Intake
  o Short-term regulation: satiety versus orexigenic factors
  o Satiety factors: hunger suppressing factors such as insulin, CCK and neural input from mechano- and chemo-receptors
  o Orexigenic factors: Feeding such as ghrelin, neuropeptide (NPY) and agouti-related peptide

• Long-Term Regulation of Food Intake (Figure 20.23)
  o Leptin (hormone) is released from adipose cells when calories exceeds demands. It suppresses hunger and increases metabolism rate

20.5 Gastrointestinal Secretion and Its Regulation

• Saliva Secretion
  Taste and texture of food ➔ mechano receptors and taste receptors in mouth ➔ salivary center of medulla ➔ Autonomic nervous system ➔ Stimulate salivation

• Autonomic Input to Salivary Glands
  o Parasympathetic: watery saliva
  o Sympathetic: more mucus; thick saliva with more proteins

• Regulation of Acid Secretion into Stomach (Figure 20.25): Stimulate acid secretion: parasympathetic nervous system; gastrin and histamine (paracrine)

• Regulation of Pepsinogen Secretion into Stomach:
  o Pepsinogen secretion regulated in sync with acid secretion. Exit of food removes stimuli for secretion. Increased acidity inhibits gastrin release.
  o Inhibition of Secretion: Intestinal phase
    ▪ Entry of food into duodenum causes increased osmolarity; fat and acid; and distension
    ▪ Long and short reflex pathways inhibit acid and pepsinogen secretion
    ▪ Increased the secretion of CCK, secretin and GIP suppress acid and pepsinogen secretion
  o Pancreatic Juice Secretion (Figure 20.26)
    o Acinar cells: Small volume of primary secretion of water, electrolytes, and digestive enzymes
    o Duct cells: Large volume of bicarbonate rich secretion

• CCK and Secretin—Primary Stimulants
  o Enzyme and bicarbonate secretion regulated somewhat independently. Composition of pancreatic juice varies based on lumenal contents
  o CCK stimulates acinar cells to secrete enzymes. CCK potentiates effects of secretin on bicarbonate release
  o Secretin stimulates duct cells to secrete bicarbonate. Secretin potentiates effects of CCK on

6
enzyme release
  o Stimuli for CCK release: fat and amino acids in duodenum
  o Stimuli for secretin release: acidity in duodenum

- **Secretion of Bile (Figure 20.27)**
  o In duodenum: increased acidity stimulates the secretion of secretin. Secretin stimulates liver to increase bile secretion.
  o Increased protein digestion and fat increased the plasma CCK level. CCK allows more bile to enter duodenum.

- **Fluid Flows in the GI System (Figure 20.28)**

### 20.6 Gastrointestinal Motility and Its Regulation

- **Electrical Activity in GI Smooth Muscle**
  o Spontaneous slow waves of depolarization = slow waves
  o Frequency of waves = basic electric rhythm (BER), BER varies in areas of GI tract
  o Height of BER affected by neural and hormonal input.
  o Parasympathetic $\rightarrow$ excitation
  o Sympathetic $\rightarrow$ inhibition

- **GI Smooth Muscle Activity (Figure 20.29)**

- **Relationship between Electrical and Mechanical Activity in Smooth Muscle**
  o Stomach: Larger depolarizations $\rightarrow$ stronger contractions; action potentials $\rightarrow$ even stronger contractions
  o Intestines: Action potentials required for force

- **Peristalsis (Figure 20.30)**: Waves of contraction in muscularis mucosae in response to basic electrical rhythm. Peristalsis propels contents forward

- **Segmentation (Figure 20.30)** is a type of motility of the small intestine. It requires circular muscle layer that alternates contractions between intestinal segments. It mixes chime.

- **Chewing is under** voluntary and involuntary control. Chewing reflex—cyclical reflex
  o Normally, jaw muscles active—hold mouth closed
  o Food enters mouth—inhibits jaw muscles
  o Jaw dropping relieves pressure of food—contract
  o Pressure from food restored—inhibited

- **Swallowing Reflex (Figure 20.31)**
  o Chewed food + saliva = bolus
  o Tongue moves bolus to pharynx
  o Initiates swallowing reflex
  o Integration center = swallowing center of medulla oblongata

- **Regulation of Gastric Motility**: Regulate force of contractions
  o Increase force: gastrin
  o Decrease force: CCK, secretin and GIP

- **Phases of Gastric Motility Regulation**
  o Cephalic phase excitations: anger, aggression
  o Cephalic phase inhibitions: pain, fear, depression
  o Gastric phase, excitatory stimulus: distension of stomach
  o Intestinal phase, inhibitory stimuli: distension of duodenum; contents: osmolarity, acidity, fat

- **Vomiting**
  o Stimuli: Illness, emotions, pain, distension in GI tract, rotation of head, ingestion of certain
substances (emetics)
  o Vomiting reflex: Mediated through vomiting center in medulla

• **Regulation of Motility in Small Intestine**
  o Distension—increases motility
  o Parasympathetic → excites
  o Sympathetic → inhibits
  o Hormones—gastrin stimulates motility

• **Regulation of Colon Motility**
  o Colonocolonic reflex: the distension of colon in one area causes relaxation of other areas of colon
  o Gastrocolic reflex: Food in stomach increases colonic motility

**Defecation is the elimination of waste**

![Defecation Diagram](image)