

## The Digestive System

### Anatomy of the Digestive System

- Intracellular Digestion: involves the oxidation of glucose and fatty acids for energy. This is a part of **metabolism**.
- Extracellular Digestion: The process by which nutrients are obtained from food. Occurs within the lumen of the **alimentary canal**.
  - Is outside of the cell borders and runs from the mouth to the anus and is sectioned off by **sphincters**
- **Digestion** involves the breakdown of food to its constituent organic molecules. Starches and carbs into polysaccharides, lipids into fatty acid and glycerol, proteins into amino acids
  - Mechanical Digestion: physical breakdown of large food particles into smaller ones.
  - Chemical Digestion: enzymatic cleavage of chemical bonds.
- **Absorption**: transport of products of digestion from the digestive tract into the circulatory system.
- The digestive tract: *Oral Cavity* → *pharynx* → *esophagus* → *stomach* → *small intestine*.
  - Salivary glands, pancreas, liver and gallbladder help to provide enzymes and aid in digestion of food
- Enteric Nervous System: one hundred million neurons that govern the function of the gastrointestinal system
  - Trigger **peristalsis** through neurons in the walls of the digestive tract.
  - Functions independently of the brain and spinal cord, but is regulated by the autonomic nervous system

### Ingestion and Digestion

#### Oral Cavity

- Mechanical digestion through breaking up food with teeth, tongues and lips (**mastication**). Helps to increase surface area and allows for quicker enzymatic digestion.
- Chemical digestion through **saliva** produced by three pairs of **salivary glands**.
  - Aids mechanical by moistening and lubricating the food
  - Parasympathetic innervation is stimulated when food enters the mouth, or by sight, touch and smell of food.
  - Saliva contains *salivary amylase (ptyalin and lipase)*. This is capable of hydrolyzing starch into smaller sugars.
  - **Lipase** catalyzes the hydrolysis of lipids.
- Food is formed into a **bolus** by the tongue and this is swallowed

#### Pharynx

- Mouth to posterior nasal cavity to the esophagus

- **Nasopharynx** (behind the nasal cavity), **oropharynx** (at back of mouth), and **laryngopharynx** (above the vocal cords)/
- **Epiglottis** prevents food from entering larynx during swallowing.

### Esophagus

- Muscular tube that connects pharynx to stomach.
- Top third is voluntary (somatic) skeletal muscle, bottom third is involuntary (autonomic) smooth muscle, and middle third is a mix of both.
- **Peristalsis** is the rhythmic contraction of the smooth muscle that propels food forward.
  - Emesis (vomiting) is the opposite of this and is caused by exposure to stimulants
- Swallowing initiated by the **upper esophageal sphincter** (muscles in the oropharynx).
- Muscular ring at the bottom of the stomach is known as the **lower esophageal sphincter** and allows food to enter stomach

### Stomach

- Digestion of lipids and carbohydrates is minimal until it reaches the stomach, and protein digestion only starts in the stomach.
- Capacity of approximately two liters and is highly muscular to allow for strong churning mechanisms.
- Uses HCl and enzymes to digest food. As such mucosa is thick in order to prevent auto-digestion.
- Acidic environment kills microbes, denatures proteins, activates pepsin and can break down intramolecular bonds.
- Consists of four divisions: **fundus & body** (gastric glands) and the **antrum & pylorus** (pyloric glands)
  - Lining of stomach is in folds called **rugae**.
- **Gastric Glands:** respond to signals from the **vagus nerve** of parasympathetic nervous system, and are activated in response to the taste, sight or smell of food. Have three different cell types:
  - **Mucous Cells:** produce bicarbonate rich mucus that protects the stomach lining from the harsh acidic environment
  - **Chief Cells:** secrete **pepsinogen** which is the inactive (**zymogen**) form of **pepsin** (proteolytic enzyme). This digests proteins by cleaving peptide bonds near aromatic amino acids, which results in short peptide fragments.
  - **Parietal Cells:** secrete H<sup>+</sup> ions as hydrochloric acid in order to aid in the activation of pepsin by creating an acidic environment.
    - Also secrete **intrinsic factor**, which is a glycoprotein involved in the proper absorption of vitamin B<sub>12</sub>.
- **Pyloric Glands:** contain **G-cells** that secrete gastrin.
  - **Gastrin** stimulates parietal cells to secrete more HCl and also signals the stomach to contract in order to mix its contents.
- **Chyme** is the resultant liquid acidic mixture that leaves the stomach after the food has been churned. This increases the surface area and the larger particles and bonds have been significantly broken down. Both of which contribute to the maximization of absorption of nutrients in the small intestine.

Gastric Juice is a combination of the secretions from these two cells



## Duodenum

- Responsible for the majority of chemical digestion and has minor involvement in absorption. Most absorption occurs at the jejunum and ileum
- Food leaves stomach through **pyloric sphincter**. Presence of chyme in duodenum causes the release of brush-border enzymes like *disaccharidases* (maltase, isomaltase, lactase, and sucrose) and *peptidases* (dipeptidase).
  - **Brush Border Enzymes** are present on the luminal surface of cells lining the duodenum. These enzymes break down dimers and trimers into absorbable monomers.
- Also secretes **enterpeptidase** which activates other digestive enzymes from the accessory organs
- Secretin and cholecystokinin are also released into the bloodstream

## Brush Border Enzymes

- All names break down what they are named to break down.
- **Aminopeptidase** is secreted by duodenum glands and removes the N-terminal amino acid from a peptide
- **Dipeptidase** cleaves the bonds of dipeptides to release free amino acids.
  - Di and tri peptides can be absorbed

## Other Secretions

- **Enteropeptidase** is needed for the activation of **trypsinogen** which activates **trypsin** in the pancreas. Can also activate **procarboxypeptidases A & B**.
- **Secretin** is a peptide hormone that causes pancreatic enzymes to be released into the duodenum.
  - **Regulates** pH of digestive tract by reducing HCl secretion from parietal cells and increasing bicarbonate secretion from pancreas.
  - **Enterogastrone**: slows the speed through the digestive tract which allows for increased time for digestive enzymes to act. (mainly on fat)
- **Cholecystokinin (CCK)** is secreted in response to entry of the chyme.
  - Stimulates the release of bile and pancreatic juices and also promotes feeling of satiety (fullness) in the brain.
  - Promotes secretion of pancreatic juices into duodenum
- **Bile Salts** are derivatives of cholesterol and do not directly perform chemical digestion.
  - Have a hydrophobic and hydrophilic region which acts as a bridge between the lipid and aqueous environments. Act like soaps and detergents.
  - These **emulsify** fats and cholesterol into **micelles**.
  - If not present, fats would separate out of solution and be inaccessible to *pancreatic lipase*
- **Pancreatic Juices** are complex mixture of several enzymes in an alkaline solution.
  - Functions to neutralize chyme and provide ideal environment for each digestive enzyme (pH around 8.5).
  - Contain enzymes that can digest all types of nutrients: carbs, fats and proteins.

## Accessory Organs of Digestion

### Pancreas

- Endocrine function uses insulin, glucagon and somatostatin from the islets of Langerhans
- Exocrine functions are carried out by **acinar cells**, these cells produce pancreatic juices.
- Pancreatic Juice is a bicarbonate rich solution that contains enzymes to break down the three major nutrients
  - **Pancreatic Amylase** breaks down large polysaccharides into small disaccharides
  - **Pancreatic Peptidases:** trypsinogen, chymotrypsinogen, and carboxypeptidases A & B. These break down protein once they are activated.
    - Peptidases are activated by Enteropeptidase, which is produced in the duodenum). This activates Trypsinogen to trypsin, which subsequently activates other zymogen form enzymes.
    - Also activates carboxypeptidases A & B to their active form
  - **Pancreatic Lipase:** breaks down fats into free fatty acids and glycerol.
- Juice is transferred to duodenum through ducts and these ducts empty into the **major and minor duodenal papillae**.

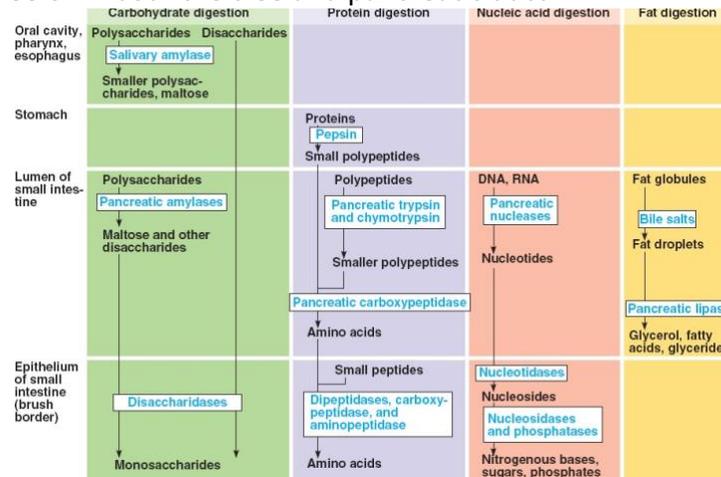
### Liver

- Located in upper right quadrant of the quadrant
- **Bile ducts** connect the liver with the small intestine and the gallbladder.
  - **Bile:** produced at the liver and stored in gallbladder or secreted in small intestine
- **Hepatic Portal Vein:** the liver receives all blood draining from the abdominal portion of the digestive tract.
  - Nutrient rich blood is processed first by liver and then drained into the inferior vena cava.
  - Liver takes up excess sugar to create **glycogen**, and stores fat as **tricylglycerols**.
  - **Glycogenolysis/gluconeogenesis:** is the conversion of glycogen to glucose
  - **Lipoproteins:** mobilizing of fats in the liver.
- **Detoxification:** liver detoxes both endogenous (from the body) and exogenous (from outside of the body) compounds.
- **Bilirubin:** major pigment in bile and is a byproduct from hemoglobin breakdown.
  - Travels down the liver and it is **conjugated** and secreted into the bile for excretion.
  - **Jaundice:** occurs when the liver is not able to handle bilirubin and an excess builds up.
- **Synthesis of Proteins:** **Albumin** maintains plasma oncotic pressure and acts as a carrier for many drugs and hormones. **Clotting factor** is used during blood coagulation

### Gallbladder

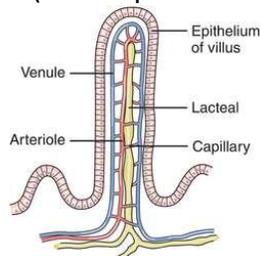
- Is located beneath the liver and both stores and concentrates bile.
- When CCK, gallbladder contracts and pushes bile out into the **biliary tree**.
- Bile duct system merges with pancreatic duct before entering duodenum

- A site for cholesterol and bilirubin stone formation. Can potentially cause blockage in the biliary tree or in both the tree and pancreatic duct.



## Absorption & Defecation

- **Jejunum/Ileum** are mainly involved in absorption of nutrients.
- **Villi:** are small fingerlike projections that line the walls of the small intestine.
  - **Microvilli:** drastically increase surface area of each villi.
  - The middle of each villus has a capillary bed (for the absorption of water-soluble nutrients)), and a **lacteal** (takes up fat and transports them into the lymph system)



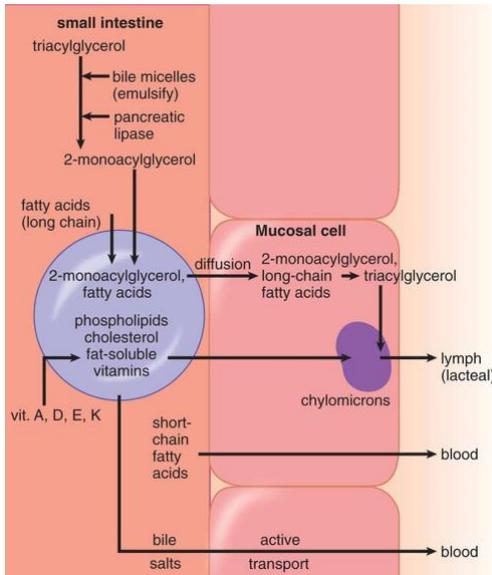
### Absorption of simple sugars & Amino Acids

- Simple sugars are glucose, fructose, and galactose. These and amino acids are absorbed through secondary active transport and facilitated diffusion into the epithelial cells of the digestive tract.
- Absorb into the bloodstream through simple diffusion since there is always blood passing by the epithelial cells and this creates a concentration gradient. Once in the capillaries, the absorbed molecules go to the liver via the hepatic portal circulation.

### Absorption of fats

- Small fatty acids will follow the same process as carbs and amino acids by directly diffusing into the intestinal capillaries. They do not require energy since they are non-polar and can easily go across cellular membranes.
- Larger fats, glycerol, and cholesterol move separately into the intestinal cells and then reform into triglycerides.

- Triglycerides and cholesterol molecules are packaged into **chylomicrons** and enter the lymphatic circulation through **lacteals**. These lacteals converge and enter venous circulation through the **thoracic duct**.



- Fat soluble vitamins (A, D, E, K) dissolve directly into chylomicrons
- Water soluble vitamins are absorbed across the endothelial cells and then directly into the plasma
- Water travels both **transcellularly** (across the cell membrane) and **paracellularly** (squeezing between cells) to reach the blood.

### Large Intestine

- Primarily involved in reabsorption of water. Has three major areas: cecum, colon and rectum
- Cecum: accepts fluid from small intestine through the **ileocecal valve**. Appendix is also located here.
- Colon: divided into ascending, transverse, descending and sigmoid colons. Its main function is to absorb water and salts. Mainly concentrates undigested material into **feces**. Small intestine absorbs much more water.
- Rectum: storage site for feces (indigestible material, water and bacteria).
  - Anus: opening through which wastes are eliminated. Has two sphincters: **internal and external (voluntary) anal sphincter**.
- 30% of dry matter in feces is bacterial. This is a symbiotic relationship since the bacteria are provided with a steady source of food and byproducts (vitamin B<sub>7</sub> & K) are beneficial to humans.