Digestive System

Dr. Naim Kittana
Department of Biomedical Sciences
Faculty of Medicine & Health Sciences
An-Najjah National University
Declaration

• The content and the figures of this seminar were directly adopted from the text book “Human Anatomy and Physiology / Ninth edition/ Eliane N. Marieb 2013”
Overview

The digestive system includes

- Organs of the alimentary canal: mouth, pharynx, esophagus, stomach, small and large intestines

- Accessory digestive system organs: teeth, tongue, salivary glands, liver, gallbladder, and pancreas
Digestive Processes

1. Ingestion: food intake
2. Propulsion: movement of food through the tract
3. Mechanical breakdown: processes that physically mix or break foods down into smaller fragments
4. Digestion: food breakdown by enzymatic action
5. Absorption: transport of products of digestion through the intestinal mucosa into the blood
The Stomach

- The J-shaped stomach lies in the upper left quadrant of the abdomen.

- Its major regions are: the cardia, fundus, body, and pyloric part.

- When empty, its internal surface exhibits rugae.

- The stomach muscularis contains a third (oblique) layer of smooth muscle that allows it to churn and mix food.
The Stomach

• The stomach mucosa is simple columnar epithelium dotted with gastric pits that lead into gastric glands.

• Secretory cells in the gastric glands include:
  - Pepsinogen-producing chief cells
  - Parietal cells, which secrete hydrochloric acid and intrinsic factor
  - Mucous neck cells, which produce mucus
  - Enteroendocrine cells, which secrete hormones
Microscopic anatomy of the stomach

- **Gastric pits**
- **Surface epithelium** (mucous cells)
- **Mucous neck cells**
- **Parietal cell**
- **Chief cell**
- **Enteroendocrine cell**

(c) Location of the HCl-producing parietal cells and pepsin-secreting chief cells in a gastric gland
Mechanism of HCl secretion by parietal cells

Blood capillary

Chief cell

Stomach lumen

CO₂ → CO₂ + H₂O

H₂CO₃

Carbonic anhydrase

H⁺

H⁺-K⁺ ATPase

K⁺

K⁺

HCO₃⁻

Alkaline tide

Parietal cell

H₂CO₃

H⁺

H⁺

HCO₃⁻

Cl⁻

Cl⁻

HCO₃⁻ - Cl⁻ antiporter

Interstitial fluid

HCl
Regulation of Gastric Acid secretion

- **Dicyclomine** blocks the cholinergic receptor.
- **Cimetidine** blocks the H$_2$-histamine receptor.
- **Misoprostol** stimulates the prostaglandin receptor.

**Acetylcholine**

**Histamine**

**Prostaglandin E$_2$**

**Gastrin**

**G$_s$** and **G$_i$** are membrane proteins that mediate the stimulatory or inhibitory effect of receptor coupling to adenylyl cyclase.

**Omeprazole** blocks proton pump.

**Proton pump**

**Gastric acid**
The Stomach

- The mucosal barrier protects the stomach from self-digestion and HCl.
- Protein digestion is initiated in the stomach by activated pepsin and requires acidic conditions (provided by HCl).
- Few substances are absorbed in the stomach.
Control of gastric secretory activity in the Stomach

• Controlled by Both nervous and hormonal factors.

• The three phases of gastric secretion are cephalic, gastric, and intestinal.

• Most food-related stimuli acting on the head and stomach (cephalic and gastric, respectively) stimulate gastric secretion.
Neural and hormonal mechanisms that regulate release of gastric juice

Stimulatory events

1. Sight and thought of food → Cerebral cortex → Conditioned reflex
2. Stimulation of taste and smell receptors → Hypothalamus and medulla oblongata → Vagus nerve

Gastric phase

1. Stomach distension activates stretch receptors → Vagovagal reflexes → Medulla → Vagus nerve
2. Food chemicals (especially peptides and caffeine) and rising pH activate chemoreceptors → G cells → Gastrin release to blood

Cephalic phase

1. Presence of partially digested foods in duodenum or distension of the duodenum when stomach begins to empty → Intestinal (enteric) gastrin release to blood → Brief effect

Intestinal phase

1. Distension of duodenum; presence of fatty, acidic, or hypertonic chyme; and/or irritants in the duodenum → Intero-gastric reflex
2. Distension; presence of fatty, acidic, partially digested food in the duodenum

Inhibitory events

1. Loss of appetite, depression → Cerebral cortex
2. Excessive acidity (pH < 2) in stomach → Gastrin secretion declines
3. Sympathetic nervous system activation

Local reflexes

- Vagal nuclei in medulla
- Pyloric sphincter
- Vagovagal reflexes

Enterogastric reflex

- Release of enterogastrones (secretin, cholecystokinin, vasoactive intestinal peptide)

Stimulate

Inhibit
Vagovagal reflexes
Control of gastric secretory activity in the Stomach

- Most stimuli acting on the small intestine trigger the enterogastric reflex and release of **Secretin** and **cholecystokinin (CCK)**: inhibit gastric secretory activity

- Sympathetic activity also inhibits gastric secretion
Mechanical breakdown in the stomach

- Triggered by stomach distension and coupled to food propulsion and stomach emptying.

- Food movement into the duodenum is controlled by the pylorus and feedback signals from the small intestine.

- Pacemaker cells in the smooth muscle sheet set the maximal rate of peristalsis
The Small Intestine and Associated Structures

• The small intestine is the major digestive and absorptive organ.

• It extends from the pyloric sphincter to the ileocecal valve.

• **Its three subdivisions are:** the duodenum, jejunum, and ileum.

• The bile duct and pancreatic duct join to form the **hepatopancreatic ampulla** and empty their secretions into the duodenum through the hepatopancreatic sphincter.
Ducts from the pancreas, gallbladder, and liver empty into the duodenum.

The duodenum of the small intestine, and related organs.
The Small Intestine and Associated Structures

- Circular folds, villi, and microvilli increase the intestinal surface area for digestion and absorption.

- The duodenal submucosa contains elaborate mucus-secreting duodenal glands.

- The mucosa of the ileum contains Peyer’s patches (lymphoid follicles).
The Small Intestine and Associated Structures

• The duodenum is covered not with a serosa but an adventitia.

Intestinal juice
• Slightly alkaline (7.4–7.8)
• Isotonic with blood plasma.
• Largely water but also contains some mucus (secreted both by the duodenal glands and by goblet cells of the mucosa).
• Enzyme-poor because intestinal enzymes are limited to the bound enzymes of the brush border.
The liver

• The structural and functional units of the liver are the liver lobules.

• Blood flowing to and out of the liver via the hepatic artery and hepatic portal vein

• Stellate macrophages remove debris and hepatocytes remove nutrients.
The liver

• **Function of Hepatocytes:**
  - Process blood-borne nutrients in various ways (e.g., they store glucose as glycogen and use amino acids to make plasma proteins)
  - Store fat-soluble vitamins
  - Play important roles in detoxification, such as ridding the blood of ammonia by converting it to urea
  - Detoxify chemicals and drugs
The liver

- Bile is made continuously by the hepatocytes.
- Bile salts and secretin stimulate bile production.
- The gallbladder, a muscular sac that lies beneath the right liver lobe, stores and concentrates bile.
Bile

Bile is a yellow-green, alkaline solution containing:

• Bile salts
• Bile pigments (Bilirubin)
• Cholesterol
• Triglycerides
• Phospholipids (lecithin and others)
• A variety of electrolytes: Of these, only bile salts and phospholipids aid the digestive process.
Bile

- Bile salts, primarily cholic and chenodeoxycholic acids, are cholesterol derivatives.

- Their role is to emulsify fats—break them down into smaller pieces and distribute them throughout the watery intestinal contents, just as a dish detergent breaks up a pool of fat drippings in a roasting pan.
Bile

• Bile salts physically separate large fat globules entering the small intestine into millions of smaller, more accessible fatty droplets that provide large surface areas for the fat-digesting enzymes to work on.

• Bile salts also facilitate fat and cholesterol absorption.

• In addition, they help solubilize cholesterol, both that contained in bile and that entering the small intestine in food.
Enterohpatic circulation conserves bile salts

• Many substances secreted in bile leave the body in feces

• But bile salts are not among them.

• Instead, a recycling mechanism called the enterohepatic circulation conserves bile salts.
Enterohepatic circulation conserves bile salts

• In this process, bile salts are:

(1) reabsorbed into the blood by the ileum
(2) returned to the liver via the hepatic portal blood
(3) Re-secreted in newly formed bile.

• This pool of bile salts re-circulates two or three times for a single meal.
Bilirubin

• A waste product of the heme of hemoglobin formed during the breakdown of worn-out erythrocytes.

• The globin and iron parts of hemoglobin are saved and recycled

• bilirubin is absorbed from the blood by liver cells, excreted into bile, and metabolized in the small intestine by resident bacteria.
Bilirubin

- **Stercobilin** a breakdown product of bilirubin’s, gives feces a brown color.

- In the absence of bile, feces are gray-white and have fatty streaks because no fats are digested or absorbed.
The liver

- Cholecystokinin released by the small intestine stimulates the gallbladder to contract and the hepatopancreatic sphincter to relax, allowing bile (and pancreatic juice) to enter the duodenum
Mechanisms promoting secretion and release of bile and pancreatic juice

1. Chyme entering duodenum causes duodenal enteroendocrine cells to release cholecystokinin (CCK) and secretin.

2. CCK (red dots) and secretin (yellow dots) enter the bloodstream.

3. CCK induces secretion of enzyme-rich pancreatic juice. Secretin causes secretion of $\text{HCO}_3^-$-rich pancreatic juice.

4. Bile salts and, to a lesser extent, secretin transported via bloodstream stimulate liver to produce bile more rapidly.

5. CCK (via bloodstream) causes gallbladder to contract and hepatopancreatic sphincter to relax. Bile enters duodenum.

6. During cephalic and gastric phases, vagal nerve stimulates gallbladder to contract weakly.
The Pancreas

- Within the pancreas are the **acini** (singular: acinus): clusters of secretory acinar cells surrounding ducts.
Composition of Pancreatic Juice

It consists mainly of

- Water
- Enzymes
- Electrolytes (primarily bicarbonate ions).

• The acinar cells produce the enzyme-rich component of pancreatic juice.

• The epithelial cells lining the smallest pancreatic ducts release the bicarbonate ions that make it alkaline (about pH 8).
Composition of Pancreatic Juice

- Normally, the amount of HCl produced in the stomach is exactly balanced by the amount of bicarbonate (HCO3-) secreted by the pancreas.

- As HCO3- is secreted into the pancreatic juice, H+ enters the blood.

- Consequently, the pH of venous blood returning to the heart remains relatively unchanged because acidic blood draining from the pancreas neutralizes the alkaline blood draining from the stomach.

- The high pH of pancreatic fluid helps neutralize acid chyme entering the duodenum and provides the optimal environment for intestinal and pancreatic enzymes.
Composition of Pancreatic Juice

• Like pepsin of the stomach, pancreatic proteases (protein-digesting enzymes) are produced and released in inactive forms, which are activated in the duodenum, where they do their work.

• This protects the pancreas from digesting itself.

• For example, within the duodenum, enteropeptidase (formerly called enterokinase), an intestinal brush border protease, activates trypsinogen to trypsin.
Composition of Pancreatic Juice

- **Trypsin activates** more trypsinogen and two other pancreatic proteases:
  
  - Procarboxypeptidase into **Carboxypeptidase**
  
  - Chymotrypsinogen into **Chymotrypsin**
Composition of Pancreatic Juice

• Other pancreatic enzymes—amylase, lipases, and nucleases—are secreted in active form, but require that ions or bile be present in the intestinal lumen for optimal activity.
The subdivisions of the large intestine are:

- the cecum (and appendix)
- Colon (ascending, transverse, descending, and sigmoid portions),
- Rectum
- Anal canal: it opens to the body exterior at the anus
The major functions of the large intestine

• Absorption of water, some electrolytes, and vitamins made by enteric bacteria, and defecation (evacuation of food residues from the body).

• The defecation reflex is triggered when feces enter the rectum.

• It involves parasympathetic reflexes leading to contraction of the rectal walls
The major functions of the large intestinal normal flora

• Synthesize B complex vitamins and vitamin K (the liver needs to produce several clotting proteins)
• Metabolize some host-derived molecules (mucin, heparin, and hyaluronic acid)
• Ferment some of the indigestible carbohydrates (cellulose, xylan, and others),
• Releasing irritating acids and a mixture of gases (including dimethyl sulfide, H2, N2, CH4, and CO2)
• Suppress the growth of pathogenic bacteria
Flowchart of digestion and absorption of foodstuffs

<table>
<thead>
<tr>
<th>Carbohydrate digestion</th>
<th>Foodstuff</th>
<th>Enzyme(s) and source</th>
<th>Site of action</th>
<th>Path of absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starch and disaccharides</td>
<td>Salivary amylase</td>
<td>Mouth</td>
<td>Glucose and galactose are absorbed via cotransport with sodium ions. Fructose passes via facilitated diffusion. All monosaccharides leave the epithelial cells via facilitated diffusion, enter the capillary blood in the villi, and are transported to the liver via the hepatic portal vein.</td>
</tr>
<tr>
<td></td>
<td>Oligosaccharides and disaccharides</td>
<td>Pancreatic amylase</td>
<td>Small intestine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lactose</td>
<td>Brush border enzymes in small intestine (dextrinase, glucoamylase, lactase, maltase, and sucrase)</td>
<td>Small intestine</td>
<td></td>
</tr>
</tbody>
</table>
Flowchart of digestion and absorption of foodstuffs

Protein digestion

Proteins

Large polypeptides

- Pepsin (stomach glands) in presence of HCl

Small polypeptides, small peptides

- Pancreatic enzymes (trypsin, chymotrypsin, carboxypeptidase)

Amino acids (some dipeptides and tripeptides)

- Brush border enzymes (aminopeptidase, carboxypeptidase, and dipeptidase)

Stomach

- Amino acids are absorbed via cotransport with sodium ions.
- Some dipeptides and tripeptides are absorbed via cotransport with H⁺ and hydrolyzed to amino acids within the cells.

Small intestine

- Infrequently, transcytosis of small peptides occurs.
- Amino acids leave the epithelial cells by facilitated diffusion, enter the capillary blood in the villi, and are transported to the liver via the hepatic portal vein.
Flowchart of digestion and absorption of foodstuffs

- Unemulsified triglycerides
  - Lingual lipase
  - Gastric lipase
  - Emulsification by the detergent action of bile salts ducted in from the liver
  - Pancreatic lipases

- Monoglycerides (or diglycerides with gastric lipase) and fatty acids

- Fatty acids and monoglycerides enter the intestinal cells via diffusion.
- Fatty acids and monoglycerides are recombined to form triglycerides and then combined with other lipids and proteins within the cells. The resulting chylomicrons are extruded by exocytosis.
- The chylomicrons enter the lacteals of the villi and are transported to the systemic circulation via the lymph in the thoracic duct.
- Some short-chain fatty acids are absorbed, move into the capillary blood in the villi by diffusion, and are transported to the liver via the hepatic portal vein.
Flowchart of digestion and absorption of foodstuffs

Nucleic acid digestion

- Nucleic acids
  - Pancreatic ribonuclease and deoxyribonuclease
  - Brush border enzymes (nucleosidases and phosphatases)

- Pentose sugars, N-containing bases, phosphate ions

- Small intestine
  - 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.