Digestion in the Small Intestine

Pancreatic Juice

Bile secretion

Rodolfo T. Rafael, M.D.
Small Intestine

- Major site of digestion and absorption
- Action and secretions of accessory organs
- Nutrients and fluids that are not absorbed

Anatomy

- Small Intestine
- Accessory Organs
  - Pancreas
  - Liver
  - Gallbladder
Small Intestine

- Three parts
- 250 inches long, absorptive area of over 250 M²
  - Large surface area \(\rightarrow\) folds of intestinal mucosa (valvulae conniventes)
    - Villi
      - microvilli
        » Enterocytes
        » Brush border appearance
  - Blood supply
    - Each villus is supplied by an arteriole \(\rightarrow\) capillary tuft
    - Lacteals
      - Carry absorbed fats to the thoracic duct

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(a) Wall of the duodenum

Lumen of duodenum
Villi
Mucosa
Muscularis mucosae
Intestinal gland (crypt of Lieberkühn)
Duodenal (Brunner's) gland
Submucosa
Muscularis

(b) Enlarged view showing lacteal, capillaries, intestinal glands, and cell types

Absorptive cell (digests and absorbs nutrients)
Goblet cell (secretes mucus)
Enterococci cell (secretes the hormones secretin, cholecystokinin, or CCK)
Paneth cell (secretes lysozyme and is capable of phárocytosis)
Microvilli
Blood capillary
Lacteal
Lamina propria
Intestinal gland
Muscularis mucosae
Arteriole
Venule
Lymphatic vessel
(b) Three villi from the duodenum of the small intestine
Accessory Organs

- **The pancreas**
  - secretes HCO3-
- **The liver**
  - secretes bile
    - bile ducts
    - sphincter of Oddi
    - portal circulation
- **The gallbladder**
Motility

- Contractile activity
- Types of movements
- Propulsion of Chyme
- Control of intestinal motility

Contractile Activity

- **Function.**
  - Two major functions:
    - Mixing the chyme
    - Propelling the chyme

- **Transit time.**
  - 2-4 hours for the chyme to move from one end of the small intestine to the other.
Types of Movement

- Segmentation: most common
  - 2 cm of the intestinal wall contracts
  - When the muscle relaxes, the chyme returns
  - Back-and-forth movement
  - 12 times/min in the duodenum and 8 times/min in the ileum. The contraction lasts for 5-6 seconds.
  - Segmentation occurs throughout the digestive period.

- Peristaltic Contraction
  - Occurs in the small intestine.
  - Is not considered an important component.

- The Migrating Motor Complex (MMC)
  - The MMCs sweep out the chyme
  - MMCs occur every 60-90 minutes and last for about 10 minutes.

Propulsion of Chyme

- Higher frequency of segmentation in the proximal intestine (duodenum) than in the distal intestine (ileum) propels the chyme towards the colon.
Control of Intestinal Motility

- **Generation**
  - Segmentation contractions can occur only if the slow waves produce spikes, or action potentials.
- **Frequency**
  - The frequency of segmentation contractions is directly related to the frequency of the slow waves.
  - Slow wave frequency is controlled by pacemaker cells.
- **Strength**
  - The strength of a segmentation contraction is proportional to the frequency of the spikes generated by the slow wave. The amplitude of the slow wave controls the frequency of the slow waves. Therefore, the greater the slow wave amplitude, the greater the frequency of spikes generated and the greater the strength of the contraction.
  - Slow wave amplitude is controlled by the hormones released during digestion.
    - Gastrin, cholecystokinin (CCK), motilin, and insulin increase the slow wave amplitude.
    - Secretin and glucagon reduce the slow wave amplitude.
Pancreatic Secretions

• Pancreatic Cell Types and their Functions
• Composition of Pancreatic secretions
• Control of Pancreatic secretion

Pancreatic Cell Types and Functions

• The endocrine cells
  – insulin, glucagon, somatostatin, and pancreatic polypeptide
• The exocrine cells
  – peptidases, lipases, amylase, and nucleases
• The ductal cells
  – secrete about 2-2.5 liters of pancreatic juice containing a high concentration of bicarbonate.
Composition of Pancreatic Secretions

- HCO₃⁻, Cl⁻
- Enzymes
  - amylases, lipases, and proteases

Bicarbonate

- The high concentration of HCO₃⁻ and low concentration of Cl⁻ is produced by a HCO₃⁻ Cl⁻ exchanger on the apical membrane of the ductal cells.
  - The Ductal cells secrete fluid similar to plasma.
    - Cl⁻ is secreted by CFTR (cystic fibrosis transport regulator).
    - HCO₃⁻ is transported in exchange for Cl⁻
  - Acinar cells secrete pancreatic enzymes, secretes fluid mostly NaCl
- The concentration of HCO₃⁻ increases when pancreatic flow rates increase.
  - At low flow rates, equal volumes of pancreatic juice come from ductal and acinar cells.
  - At high flow rates, the proportion of the pancreatic juice secreted by the ductal cells, which have a high HCO₃⁻, concentration increases
Enzymes

- **Pancreatic alpha-amylase**
  - Active form
  - It hydrolyzes glycogen, starch, and most other complex CHO, except cellulose, to form disaccharides.

- **Pancreatic lipases** (lipase, cholesterol lipase, and phospholipase)
  - Active forms
  - The enzymes that hydrolyze water-insoluble esters require bile salts to work.
  - Water-soluble esters can be hydrolyzed without the action of bile salts.

- **Pancreatic proteases** (trypsin and the chymotrypsin)
  - Inactive zymogen form (trypsinogen and the chymotrypsinogens)
  - Trypsinogen
    - Converted to trypsin by enterokinase (also called endopeptidase) or by trypsin itself (autocatalysis).
  - Chymotrypsinogens converted to their active form by trypsin.

- **Trypsin inhibitor**
  - Secreted by the same cells and at the same time as the pancreatic proenzymes.

Control of Pancreatic Secretion

- Cephalic phase
- Gastric phase
- Intestinal Phase
Cephalic Phase

- Enzyme secretion by the acinar cells
  - stimulated directly by vagal fibers that release acetylcholine or by cholinergic interneurons that are stimulated by the vagal preganglionic fibers.
- Vagus nerve can also cause HCO₃⁻ secretion by ductal cells
  - its ability to stimulate HCO₃⁻ secretion is not nearly as great as its ability to stimulate the release of enzymes.

Gastric Phase

- **Distention** of the antrum and corpus
  - initiates a vagal reflex resulting in a low volume of pancreatic secretion containing both HCO₃⁻ and enzymes.
  - Ach is the transmitter.
- **Food breakdown products** (acids and peptides)
  - stimulate pancreatic secretions because of their ability to cause the G cells of the stomach to release gastrin.
  - **Gastrin** produces a low-volume, high-enzyme pancreatic secretion.
Intestinal Phase

- CCK
- Secretin
- Control of CCK and secretin release
- A vagovagal reflex
- Ach

Cholecystokinin (CCK)

- Stimulant of pancreatic enzyme secretion
- Like gastrin, CCK is found in two physiologically active forms, an octapeptide called CCK-8 and a 33-chain polypeptide, CCK-33.
- The actions of CCK are potentiated by secretin.
  - Secretin has no effect on enzyme secretion
Secretin

- Increase HCO$_3^-$ secretion by pancreas
- The actions of secretin are potentiated by CCK.
  - CCK has no effect on HCO$_3$ secretion.
- Because they are potentiators of each other’s action, small concentrations of CCK and secretin together can produce significant amounts of pancreatic HCO$_3$ and enzyme secretions
  - either one alone would have little or no effect.

Control of CCK and Secretin Release

- Major stimuli for CCK secretion
  - Amino acids (primarily phenylalanine)
  - fatty acids
  - Monoglycerides
- Stimulus for the Release of Secretin
  - Low pH (<4.5), caused by the presence of gastric acid in the intestine
A Vagovagal Reflex

- potentiates the effects of secretin and CCK
- activated during the intestinal phase of digestion

ACh

- potentiates the effects of both CCK and secretin
- vagal stimulation is much more potent in stimulating pancreatic secretions when CCK and secretin are present in the plasma
<table>
<thead>
<tr>
<th>Pancreas (EXOCRINE)</th>
<th>Chemical Produced</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pancreatic ductule cells</td>
<td>Bicarbonate</td>
<td>Neutralizes Stomach acid</td>
</tr>
<tr>
<td>Exocrine cells (secretion stimulated by vagus, cholecystokinin, and secretin)</td>
<td>Pancreatic Amylase</td>
<td>Changes starch to oligosaccharides</td>
</tr>
<tr>
<td>Trypsinogen (activated by enterokinase)</td>
<td>Breaks down proteins to peptides and amino acids</td>
<td></td>
</tr>
<tr>
<td>Chymotrypsinogen (activated by trypsin)</td>
<td>Breaks down triglycerides to fatty acids and monoglycerides</td>
<td></td>
</tr>
<tr>
<td>Procarboxypolypeptidase (activated by trypsin)</td>
<td>Cleaves cholesterol esters to free cholesterol and fatty acids</td>
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<tr>
<td>Pancreatic Lipase</td>
<td>Removes fatty acids from phospholipids</td>
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<tr>
<td>Cholesterol Esterase</td>
<td></td>
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<tr>
<td>Phospholipase</td>
<td></td>
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</tr>
<tr>
<td>Nucleases</td>
<td>Change Nucleic acids to nucleotides</td>
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<td>Alpha islet cells</td>
<td>Glucagon</td>
<td>Decrease intestinal motility</td>
</tr>
<tr>
<td>Delta islet cells</td>
<td>Somatostatin</td>
<td>General effects in decreasing digestion and absorption; inhibits insulin and glucagon secretion</td>
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Biliary Secretions

- General Features
- Composition
- Enterohepatic Circulation
- Control of Biliary Secretions
- Gallbladder

General Features of Bile

- **Function.**
  - digestion and absorption of fats
  - excretion of water-insoluble substances such as cholesterol and bilirubin.
- **Formation.**
  - hepatocytes
  - ductal cells.
  - 250 and 1100ml
- **Storage.**
  - bile is stored in the gallbladder during the interdigestive period.
- **Release.**
  - after chyme has triggered the release of CCK → contraction of the gallbladder and relaxation of the sphincter of Oddi.
Composition of Bile

- Bile acids
- Bile pigments
- Phospholipids
- Cholesterol
- Electrolytes

Bile Acids

- **Primary bile acids**
  - are synthesized from cholesterol and converted into bile salts by the hepatocytes.
  - Cholesterol is absorbed through microvilli lining the serosal border of the hepatic epithelial cells.
  - The bile acids are conjugated with either taurine or glycine to form bile salts.
  - The bile salts are actively secreted into a canaliculus on the lateral surface of the hepatocyte, from which they then drain into the bile duct.
  - Because bile salts are not lipid soluble, they remain the intestine until reaching the ileum, where they are actively absorbed.

- **Secondary bile acids**
  - are formed by deconjugation and dehydroxylation of the primary bile salts by intestinal bacteria, forming deoxycholic acid and lithocholic acid.
Bile Pigments

- **Bilirubin and biliverdin**
  - the two principal bile pigments,
  - metabolites of hemoglobin formed in the liver and conjugated as glucuronides for excretion
  - They are responsible for the golden yellow color of bile.
- **Intestinal bacteria**
  - metabolize bilirubin further to urobilin
  - responsible for the brown color of stool.
- If bilirubin is not secreted by the liver, it builds up in the blood and tissues, producing jaundice.

Phospholipids

- **Insoluble in water**
  - are solubilized by bile salt micelles
- **The micelles**
  - solubilize other lipids more effectively
    - bile salts
    - phospholipids
Cholesterol

- Insoluble in water
  - solubilized by bile salt micelles
- Biliary secretion of cholesterol is important

Electrolyte

- The electrolyte composition of bile is similar to that of pancreatic juice and plasma
Enterohepatic Circulation

- Path of Circulation
- Circulating pool
- Bile salt synthesis and replacement
- Clinical Implication

Path of Circulation

- Bile salts are reabsorbed only in the terminal ileum.
  - No reabsorption of bile salts occur in the duodenum or jejunum.
- From 90%-95% of the bile salts that enter the small intestine are actively reabsorbed from the lower ileum back into the portal circulation.
- The remaining bile salts are excreted into the feces.
Circulating Pool

• The total circulating pool of bile 3.6g.
  – Required to digest and absorbed a meal (4-8 g of bile salts)
  • Circulate twice during the digestion of each meal.
    – Circulate 6-8 times daily.

Bile Salt Synthesis and Replacement

• The rate of bile salt synthesis is determined by the rate of return to the liver
• The usual rate is 0.2-0.4g/day, which replaces normal fecal losses
• The maximal rate is 3-6g/day
• If fecal losses exceed this rate, the total pool size decreases.
Clinical Implication

- Bile salts are required for proper digestion and absorption of fats
  - Condition that disrupts the enterohepatic circulation leads
    - decreased bile acid pool and malabsorption of fat and fat-soluble vitamins
    - The clinical manifestations of such conditions are steatorrhea and nutritional deficiency
    - An increase in fecal losses of bile salts results in watery diarrhea

Control of Biliary Secretion

- **The bile-independent fraction of biliary secretion**
  - refers to the amount of fluid, composed of electrolytes and water, that is secreted each day by the liver
  - Secretion of this fluid is controlled by the hormone secretin.
  - The fluid resembles the secretion of the pancreatic ductal cells
  - Secreted by ductal cells
  - High concentration of bicarbonate
- **The bile-dependent fraction of biliary secretion**
  - Refers to the quantity of bile salts secreted by the liver
  - The amount of bile salts secreted is directly related to the amount of bile reabsorbed by the hepatocytes
  - The synthesis and secretion of bile by the liver is
Gallbladder

- Functions
- Control
- Effects of Cholecystectomy
- Gallstone

Function

- **Storage**
  - During the interdigestive period, the bile secreted by the liver is collected in the gallbladder
  - stores 20-50ml of bile.
    - highly concentrated
    - water is reabsorbed by osmotic gradient produced by the active reabsorption of Na+ and HCO3-
- **Contraction**
  - Digestion
Control

- **CCK**
  - *major stimulus* for gallbladder contraction and sphincter of Oddi relaxation
  - When chyme enters the small intestine, **fat** and **protein digestion products** directly stimulate the secretion of CCK

- **Vagal stimulation**
  - Gallbladder contraction and sphincter of Oddi relaxation
  - Vagal stimulation occurs directly during the cephalic phase of digestion and indirectly via a vasovagal reflex during the gastric phase of digestion.
Effects of Cholecystectomy

- Bile, not the gallbladder, is essential to digestion.
  - After removal of the gallbladder, bile empties slowly but continuously into the intestine, allowing digestion of fats sufficient to maintain good health and nutrition.
- Only high-fat meals need to be avoided.

Gallstones

- form 10%-30% of the population
- 20% of these, ever produce symptoms
- In western societies, about 85% of gallstones are composed chiefly of cholesterol; the remainder are calcium bilirubinate

- **Cholesterol and lecithin**
  - insoluble in water, are kept in solution in bile through the formation of micelles
  - When the proportions of lecithin, cholesterol, and bile salts are altered, cholesterol crystallizes, leading to stone formation
  - Cholesterol stones are radiolucent

- **Calcium bilirubinate stones**
  - infection of the biliary tree leads to bacterial deconjugation of conjugated bilirubin.
  - Unconjugated bilirubin, which is insoluble in bile, then precipitate to begin the ston-forming process
  - Calcium bilirubinate stones are radioopaque.
THANK YOU!

FOR NOT LISTENING