

Functional Medicine University's
Functional Diagnostic Medicine Training Program
Module 2

Digestion, Secretion, and Absorption in the Gastrointestinal Tract & An Overview of Cell Metabolism
By Wayne L. Sodano, D.C., D.A.B.C.I., & Ron Grisanti, D.C., D.A.B.C.O., M.S.
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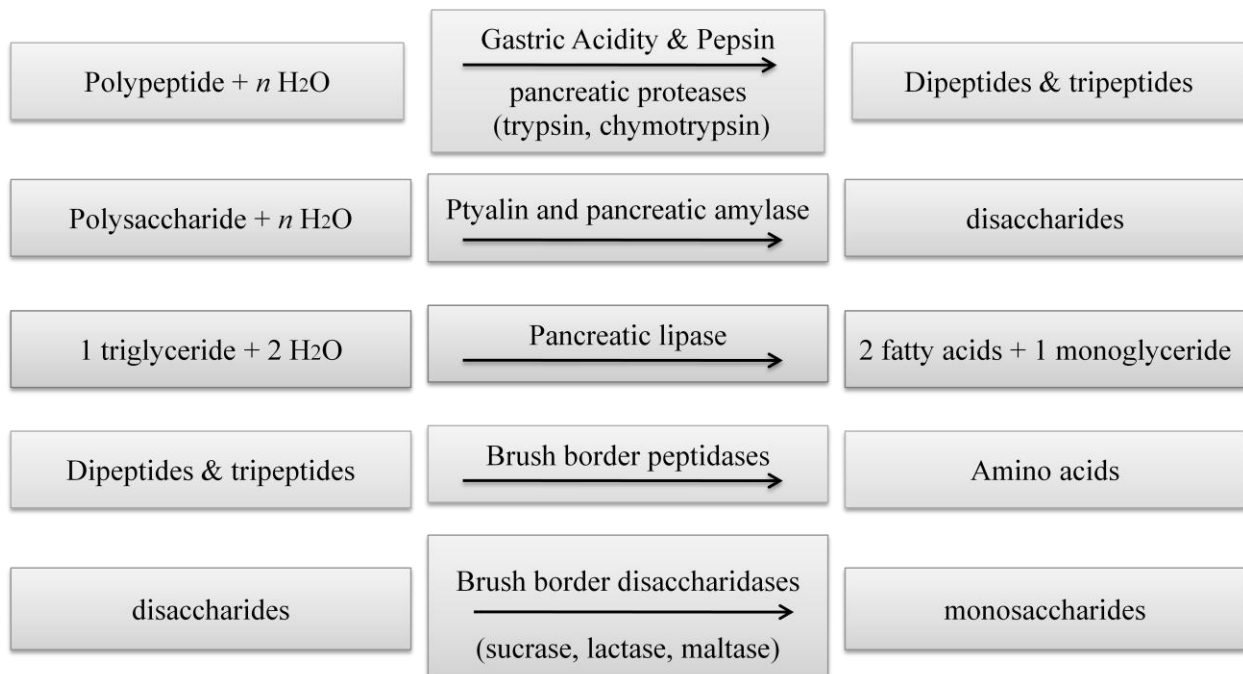
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The Digestive System

The digestive system extends from the mouth to the anus. It consists of the alimentary canal and appendage organs. The liver and gallbladder serve as exocrine organs with the pancreas having a dual role as both exocrine and endocrine.

The major foods (proteins, carbohydrates, and fats) generally cannot be absorbed in their natural forms. They must be broken down to smaller units to be absorbed. Digestion is the process of breaking down polymers of protein, fats, and starch into their building blocks. This breakdown is accomplished by enzymatic hydrolysis.

Enzymatic Hydrolysis



Digestion of Carbohydrates

- The three major carbohydrates are:
 - Sucrose (cane sugar) disaccharide
 - Lactose (milk sugar) disaccharide
 - Starches polysaccharides

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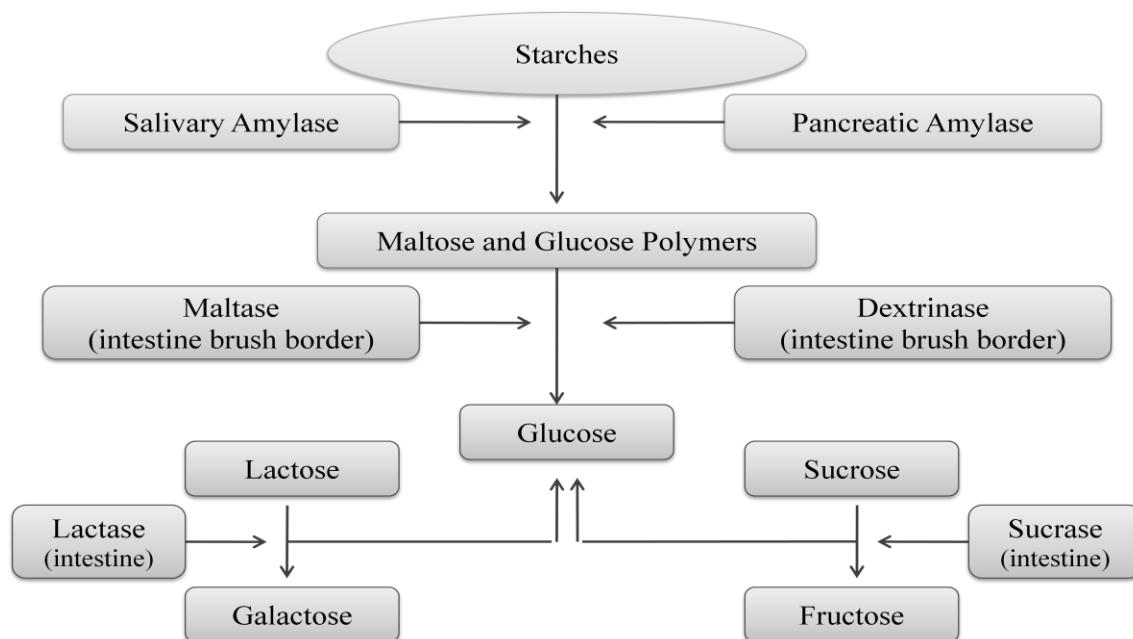
Saliva contains the enzyme ptyalin, which is an amylase that is mainly secreted by the parotid glands. This enzyme hydrolyses starch into maltose (disaccharide) and polymers of glucose. It is important that food be chewed and mixed properly in the mouth before swallowing because the acidity of the stomach will block the enzymatic activity of salivary amylase.

Once in the small intestines, mainly the duodenum and upper jejunum, pancreatic amylase continues the digestive process. Pancreatic amylase enzymatic capability is superior to salivary amylase and with normal digestion most of the carbohydrate is in the form of maltose or small polymers of glucose.

As the carbohydrates proceed through the alimentary tract past the upper jejunum they are acted upon by what are known as 'intestinal brush border' enzymes. Four brush border enzymes have been identified:

- Lactase
- Sucrase
- Maltase
- α -dextrinase

These enzymes continue in the digestive process of carbohydrates to smaller absorbable molecules. The following illustrates carbohydrate digestion.



These simple sugars (glucose, fructose, and galactose) are absorbed in the small intestine by the process of active transport.

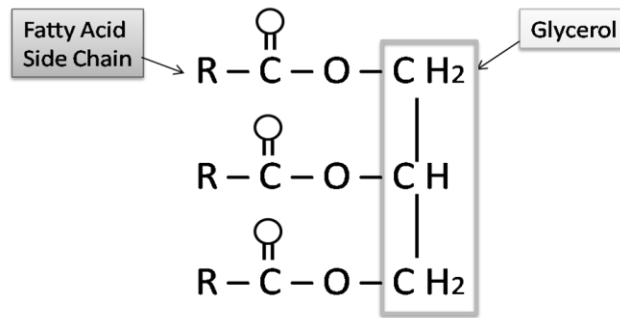
Note: Impairment of brush-border enzyme activity causes CHO Malabsorption, which causes excessive bacterial fermentation (diarrhea and flatulence).

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Digestion of Fats

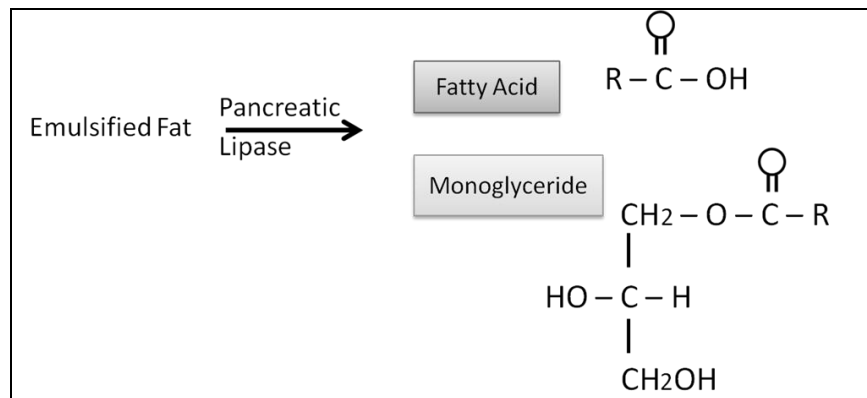
Triglycerides are the most abundant fats in the diet. Each molecule of triglyceride is composed of a glycerol and three fatty acid side chains.



- Other fats in the diet include:
 - Phospholipids (contains fatty acid)
 - Cholesterol (no fatty acid, but chemically similar)
 - Cholesterol esters (contain fatty acid)

Although digestion of fats begin in the stomach by lingual lipase (secreted by lingual glands in the mouth), the majority of digestion occurs in the small intestine.

Fat must be physically broken down into smaller sizes to allow the water soluble digestive enzymes to work on the surface. This process is called emulsification. The majority of emulsification occurs in the duodenum orchestrated by the bile that is secreted by the liver. Bile is composed of bile salts and lecithin and does not contain any digestive enzymes. Bile acts as a detergent by breaking up fat into smaller molecules, allowing lipase enzymes to attack the surface. Pancreatic lipase is the major fat digesting enzyme with enteric lipase playing a small role. Pancreatic lipase splits the triglyceride molecules into fatty acids and two monoglycerides.

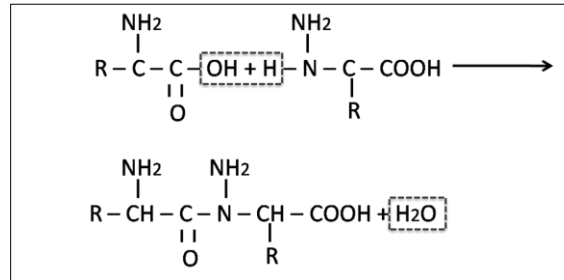


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Digestion of Proteins

Proteins are amino acids bound together by a peptide linkage.

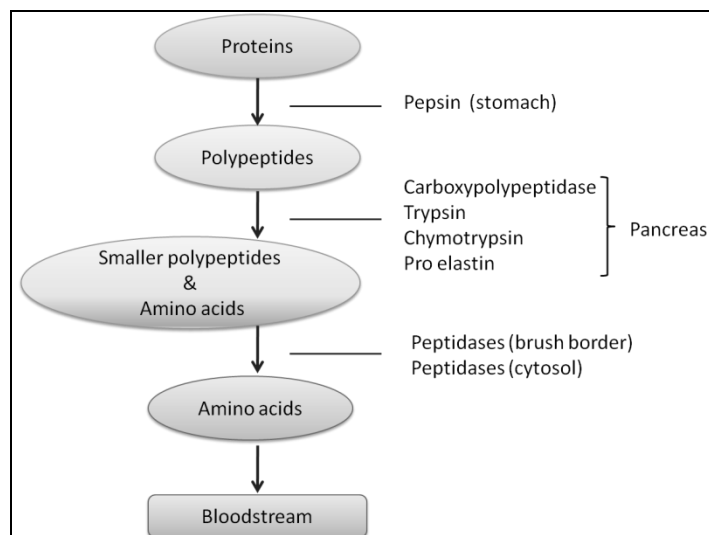


Gastric secretion of hydrochloric acid is essential for digestion of proteins, sterilization of stomach contents, and assimilation of elements such as zinc and calcium. A low pH is also required for the release of vitamin B12 from food. The proteolytic activity of pepsin requires a pH of less than 5 and is most active at a pH of 2.0 to 3.0. Pepsin initiates protein digestion by hydrolyzing the peptide bonds. The majority of protein digestion occurs in the duodenum and jejunum under the influence of the following pancreatic enzymes:

- Trypsin
- Chymotrypsin
- Proelastase → Elastase (digest elastin fibers in meat)
- Polypeptidase

These enzymes further breakdown protein to dipeptides and tripeptides. The dipeptides and tripeptides are further broken down to amino acids by the enzymes that are on the microvilli of duodenum and jejunum. These enzymes are called peptidases. There are also protein digestive enzymes within the cytosol of the enterocytes that continue to breakdown the dipeptides and tripeptides to amino acids which are eventually transported into circulation.

Note: Only amino acids should be absorbed. If the gastrointestinal system is dysfunctional, a peptide or whole protein may be absorbed and can cause serious immunological disturbances (leaky gut, IBD, etc)



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Gastric Secretion

Glands of the stomach

- Gastric (oxyntic)
 - o Secretes HCl, pepsinogen, intrinsic factor, and mucous
- Pyloric
 - o Secretes mucus and the hormone gastrin

In addition to mucus being secreted by the gastric gland and mostly by the pyloric gland, the entire surface of the stomach also has continuous layer of surface mucous cells which lubricates the food and protects the stomach from acid secretions.

The gastric gland is composed of chief cells (peptic) which secrete pepsinogen, parietal cells which secrete hydrochloric acid and intrinsic factor and mucus neck cells which secrete mucous.



The diagram illustrates a cross-section of a gastric gland. The lumen of the stomach is at the top. The gland is composed of several cell types: Mucous neck cells, Parietal cells, Enterochromaffin-like cells, Chief cells, D cells, and G cells. Each cell type is associated with specific secretions. The table below summarizes this information.

Cell Types	Substance Secreted
Mucous neck cell	Mucus (protects lining)
	Bicarbonate
Parietal cells	Gastric acid (HCl)
	Intrinsic factor (Ca++ absorption)
Enterochromaffin-like cell	Histamine (stimulates acid)
Chief cells	Pepsin(ogen)
	Gastric lipase
D cells	Somatostatin (inhibits acid)
G cells	Gastrin (stimulates acid)

<http://anatomytopics.wordpress.com/?s=stomach+secretion>

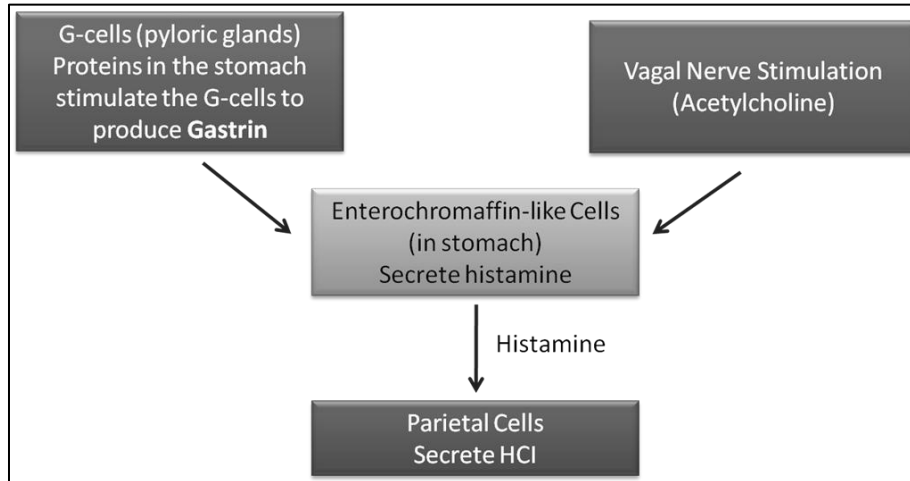
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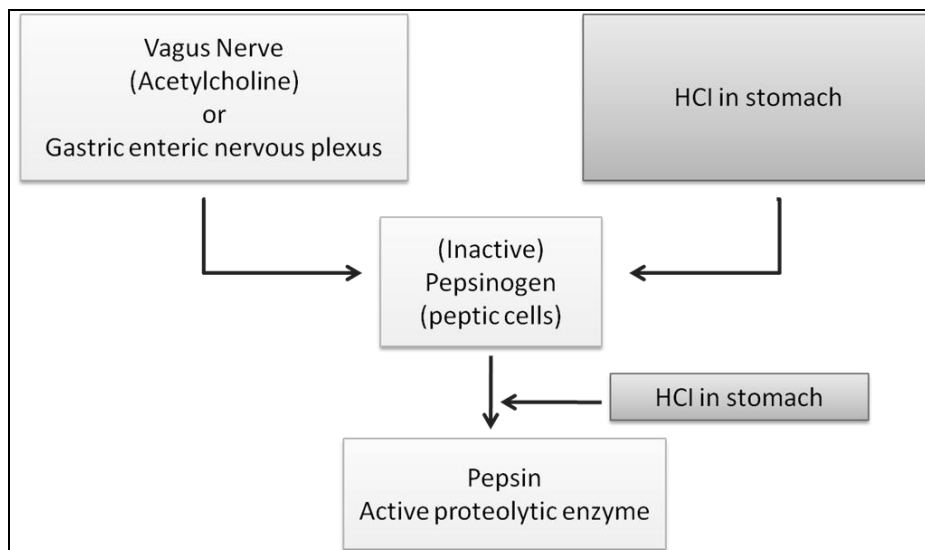
Influences on the HCl Secretion

Controlled by

- Endocrine
- Nervous system



Secretion and Activation of Pepsinogen

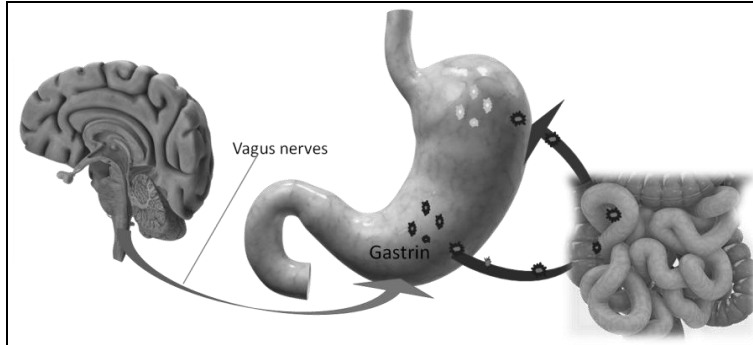


Chronic gastritis can destroy the parietal cells which will result in hypochlorhydria or achlorhydria. As stated earlier, low pH is required for proper release of B12 from food sources. Additionally, the parietal cells also produce and secrete intrinsic factor which is essential for absorption of B12 in the ileum. A decrease in intrinsic factor will result in pernicious anemia. This finding will be reflected on the CBC

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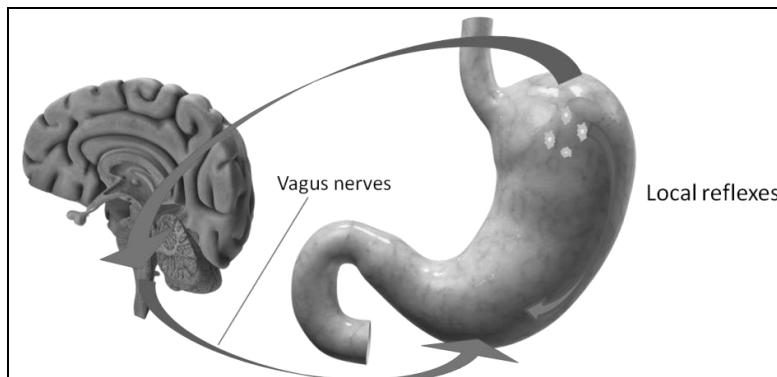
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Phases of Gastric Secretion



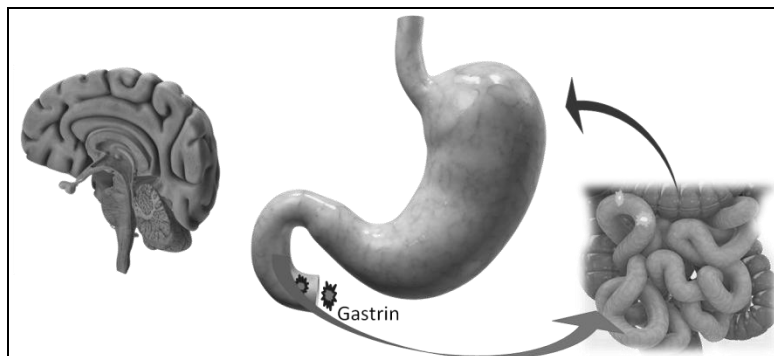
Cephalic Phase (20%)

- Sight, smell, taste or thought of food stimulates the limbic system to stimulate the vagus nerve



Gastric Phase (70%)

- Food entering the stomach
 - Vagovagal reflex
 - Local enteric reflexes stimulated by stomach distention
 - Gastrin



Intestinal Phase

- Food in upper portion of small intestine
- Some gastrin is released by duodenal mucosa

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Inhibition of Gastric Secretion

As chyme enters the small intestines, it can stimulate gastric secretion, however, it can paradoxically inhibit gastric secretion in order to slow passage of chyme from the stomach when the small intestine is full.

Determination of Stomach Acid

Heidelberg Capsule Test & Gastro Test: (Visit the on-line library at www.FunctionalMedicineUniversity.com for Heidelberg Capsule Test video and [link](#) to the Gastro Test video)

Heidelberg Capsule Test (Accurate – 40 minutes to complete)

- A miniature radio transmitter (pH probe) is swallowed by the patient. The capsule can be retrieved by attaching a string or allowed to pass through the rest of the GI tract
 - Initial pH reading: 7.0
 - Drops to 1.0 as capsule settles to bottom of stomach
 - Challenge drink of baking soda
 - Within 30 seconds pH should rise to 7.0
 - If acid secretion is normal, pH will be between 1.0 and 2.0 within 20 minutes
 - Challenge solution is repeated several times
- Hypochlorhydria is indicated if it takes longer than 20 minutes to re-acidify. Achlorhydria is indicated if the pH will not fall below 4.0 even on the first challenge

Pancreatic Secretion

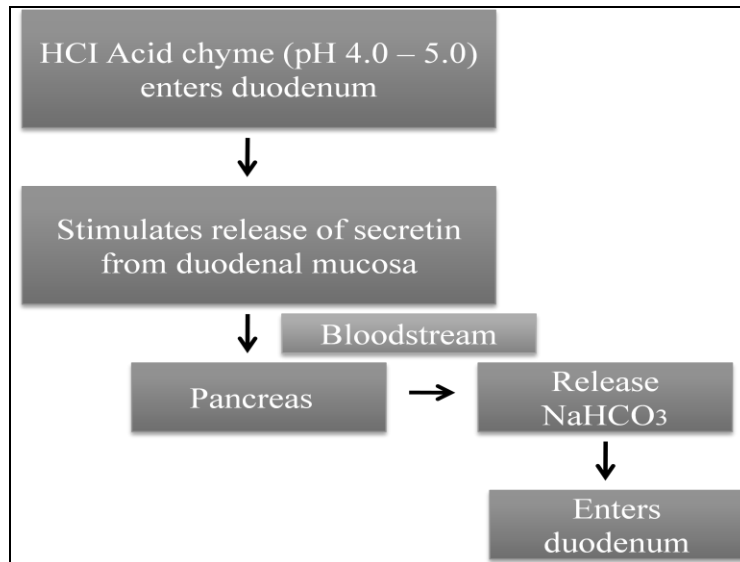
- Exocrine Pancreas
 - Sodium bicarbonate (alkaline)
 - | | | |
|---------------------------|---|---------------------------|
| – Trypsin (most abundant) | } | protein digesting enzymes |
| – Chymotrypsin | | |
| – Carboxypolypeptidase | | |
 - Pancreatic amylase — CHO digesting enzyme
 - | | | |
|------------------------|---|-----------------------|
| – Pancreatic lipase | } | fat digesting enzymes |
| – Cholesterol esterase | | |
| – Phospholipids | | |
- Endocrine pancreas
 - Islets of langerhans secrete insulin directly into the blood stream

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Pancreatic Secretion (con't)

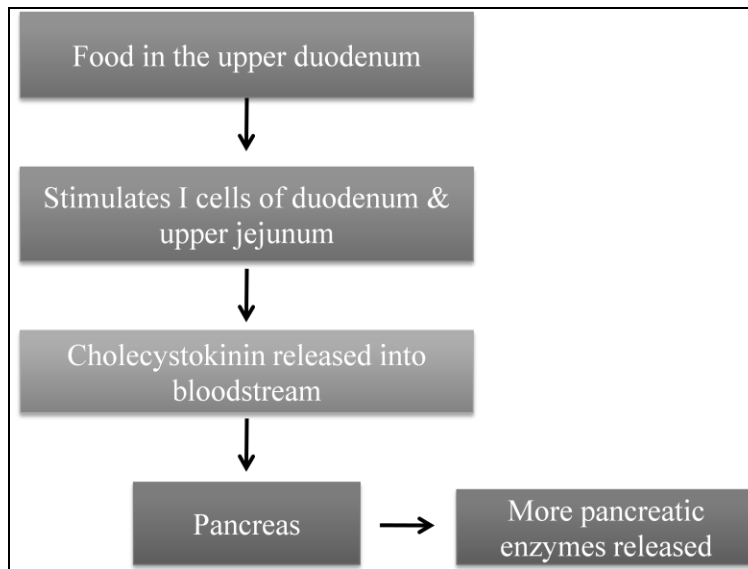
- The pancreatic proteolytic digestive enzymes are initially synthesized in an inactive form to prevent digestion of the pancreas. The pancreas also produces *trypsin inhibitor* that prevents digestion of the pancreas. Acute pancreatic disorders can occur when the pancreas becomes damaged or when the duct is blocked.
 - Trypsinogen
 - Chymotrypsinogen
 - Procarboxypolypeptidase
- Once in the intestine Trypsinogen is activated by an intestinal mucosa enzyme called 'enterokinase' and converts to trypsin. Trypsin then acts on chymotrypsinogen and procarboxypolypeptidase to their active forms.
- Pancreatic secretions are regulated by the parasympathetic nervous system, the enteric nervous system, cholecystokinin and secretin.
- Stimulation of Secretin
 - The sodium bicarbonate raises the pH in the duodenum to 7.0 to 8.0 allowing the pancreatic enzymes to function optimally.



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- Release of Cholecystokinin



Secretion of Bile

Bile has a dual physiological role; one, it serves as a way for excretion of bilirubin and cholesterol, and two, for fat emulsification. The liver produces between 600 and 1000 milliliters of bile per day. The composition of bile consists mainly of water with a mixture of bile salts, bilirubin, cholesterol, fatty acids, lecithin and the electrolyte sodium, chloride, potassium, and calcium and bicarbonate ion.

The gallbladder can only hold 30 to 60 ml of bile at a time. Electrolytes and water are continually absorbed through the gallbladder mucosa causing the bile salts, bilirubin, cholesterol and lecithin to be concentrated.

Emptying of the gallbladder is caused by the hormone cholecystokinin. Cholecystokinin enters the blood stream and causes contraction of the gallbladder as well as relaxation of the sphincter of Oddi, allowing bile to enter into the bloodstream.

Absorption of the Gastrointestinal System

The stomach can only allow for absorption of alcohol and some medications like aspirin. The majority of nutrients are absorbed in the small intestine. In contrast, the large intestine's primarily absorbs water and electrolytes.

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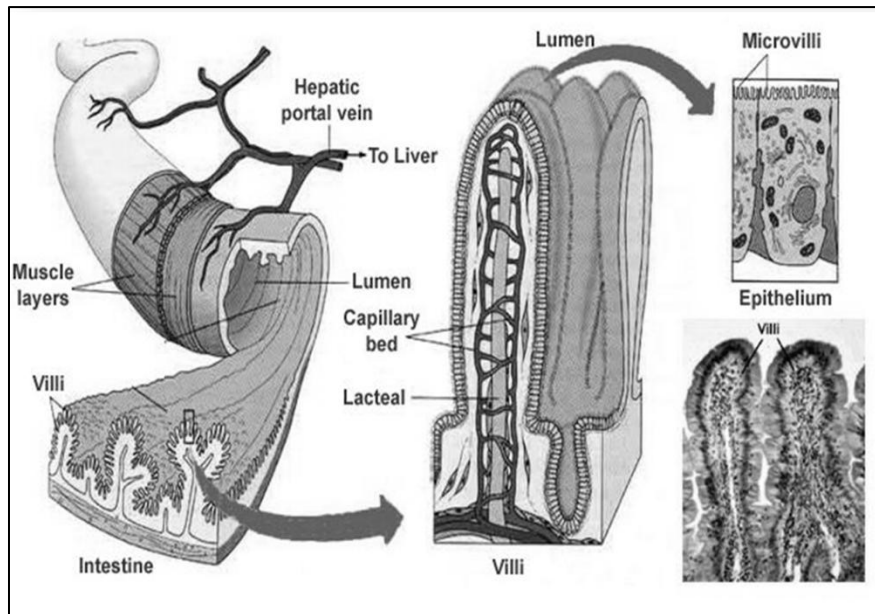
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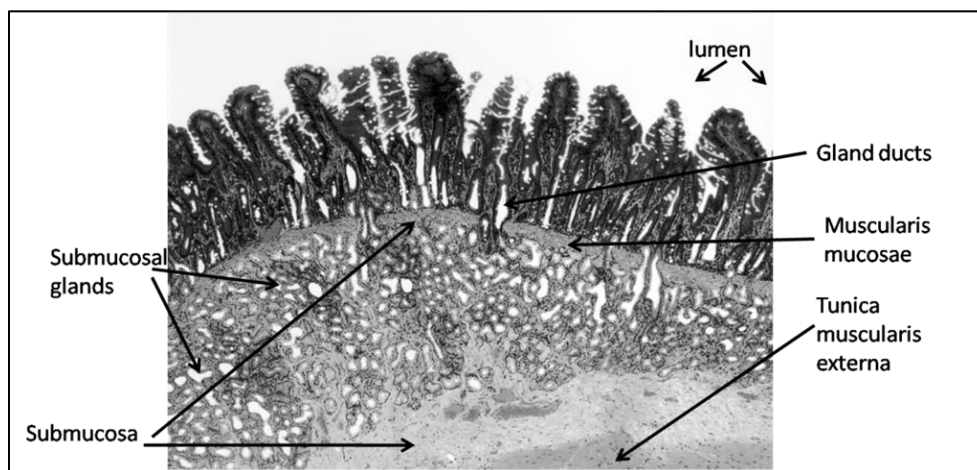
The key features of the small intestine that allows for maximal absorption are:

- The length
- The villi
- The microvilli



<http://www.colorado.edu/intphys/Class/IPHY3430-200/image/villi.jpg>

The villi are finger-like projections of the intestinal wall that extend into the lumen. The microvilli are microscopic foldings of the cell membrane forming what is known as the brush border.

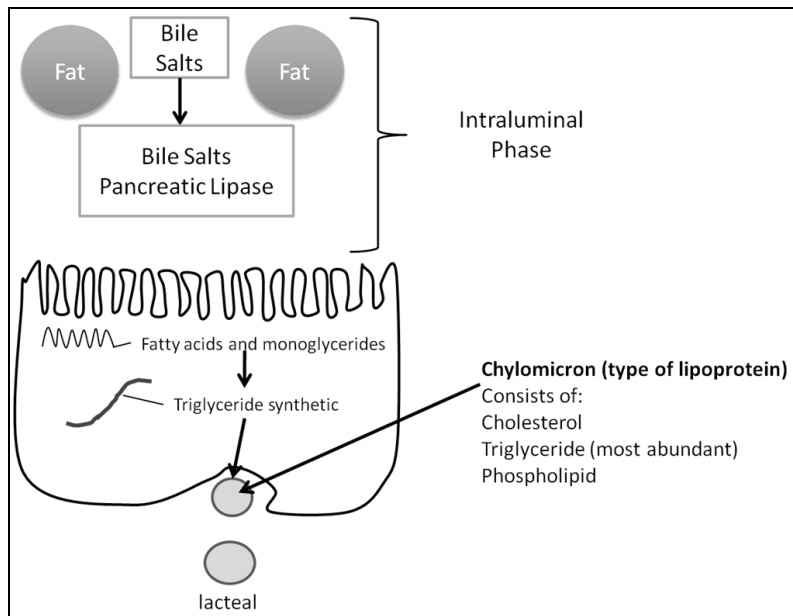


<http://education.vetmed.vt.edu/Curriculum/VM8054/Labs/Lab19/Lab19.html>

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Capillaries from the villi eventually merge to form the hepatic portal vein. Amino acids and carbohydrates are transported in the hepatic portal vein to the liver. The villi also contain lacteals, which are small lymphatic vessels. This is where absorption of dietary fats takes place. Fat is transported to the thoracic duct and eventually empties into the blood stream. Small quantities of short chain and medium chain fatty acids are absorbed directly into portal circulation.



Absorption in the Large Intestine

The first half of the colon is responsible for most of the absorption of water and electrolytes. The second half is mostly for the storage of feces. About 1500 milliliters of chime enter the colon on a daily basis. Approximately 1400 milliliters are absorbed leaving 100 ml to be excreted in the feces. The colon has a significant amount of beneficial bacteria present, usually bacilli. The bacteria are capable of producing vitamins B1, B2, B12, and K.

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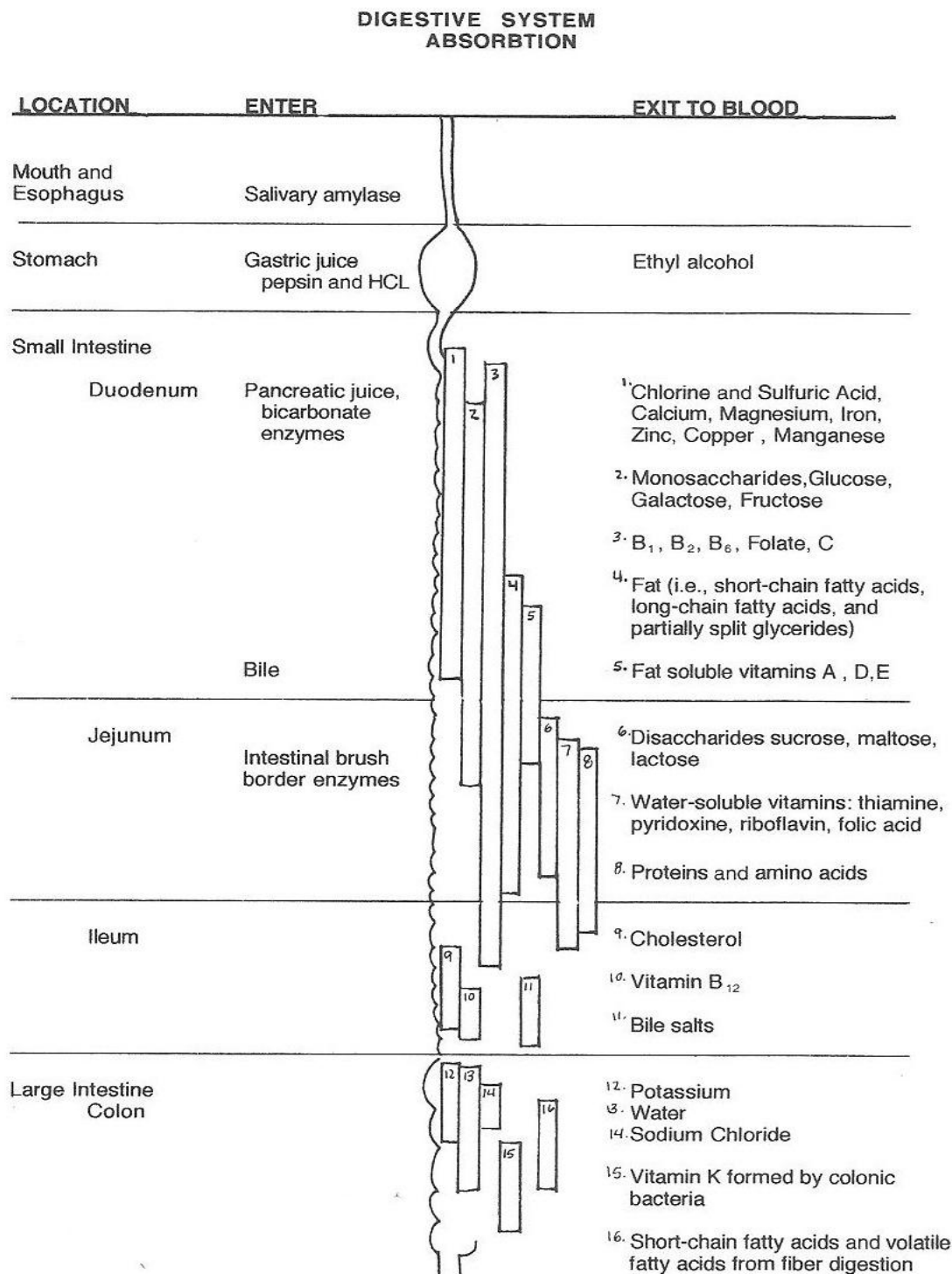
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Summary of the Sites of Secretion and Absorption in the Gastrointestinal Tract

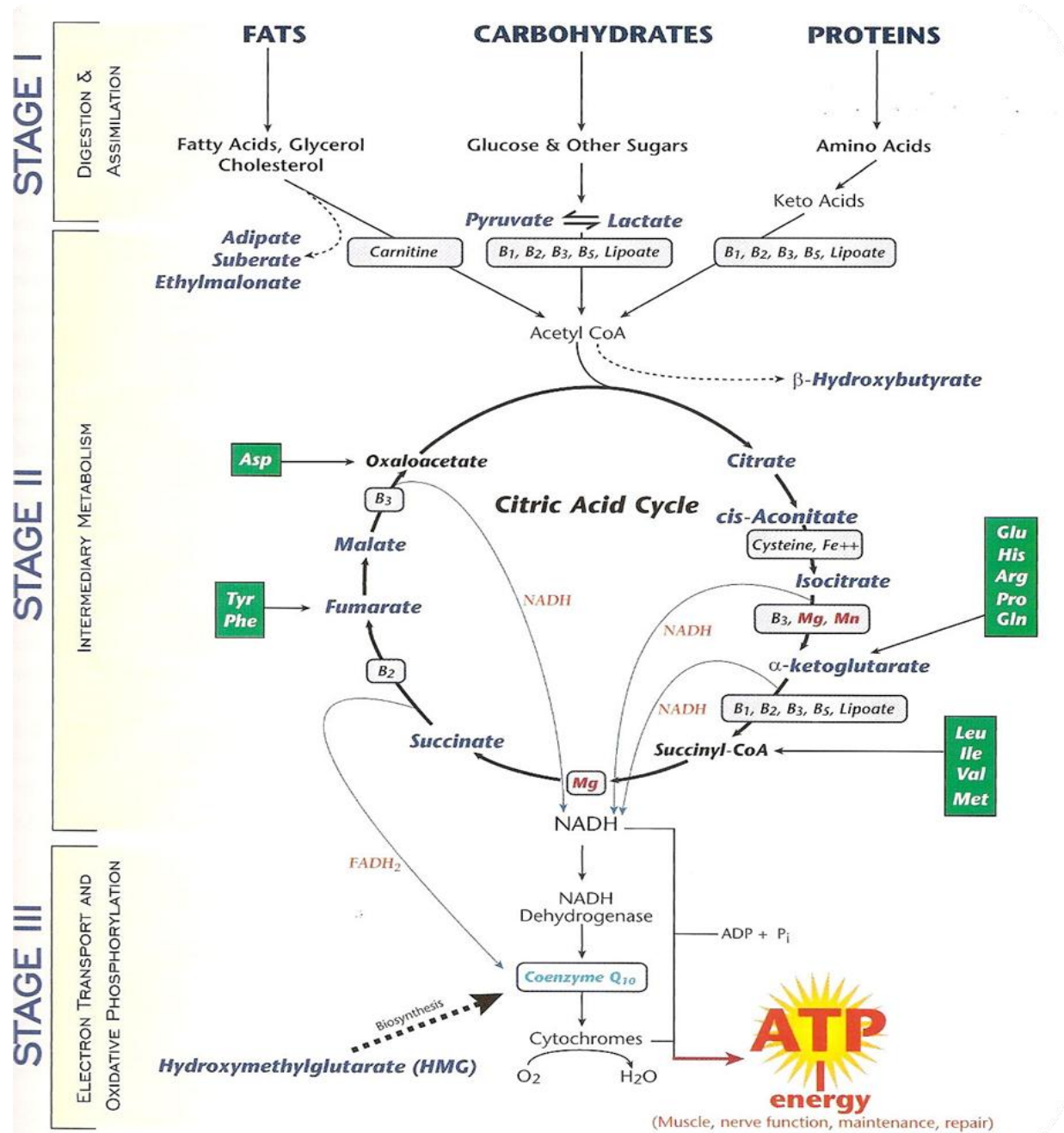


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Cell Metabolism



Ref: Laboratory Evaluations for Integrative and Functional Medicine; 2nd edition; Richard S. Lord, PhD; J. Alexander Bralley, PhD

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2. Laboratory Evaluations for Integrative and Functional Medicine; 2nd edition; Richard S. Lord, PhD; J. Alexander Bralley, PhD
3. Food, Nutrition, and Diet Therapy, 6th ed., Krause and Mahan
4. <http://www.nlm.nih.gov/medlineplus/encyclopedia.html>
5. <http://anatomytopics.wordpress.com/?s=stomach+secretion>
6. Heidelberg Medical, www.phcapsule.com/prodinfo.htm

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Appendix

GASTRO-TEST® INSTRUCTIONS

To optimize the Gastro-Test® the following procedure should be used:

1. Fast for ten to twelve hours prior to the administration of the Gastro-Test®. i.e. Do it first thing in the morning for best results.
2. Water, but not food, is allowed anytime during the fast.
3. 30-minutes prior to the Gastro-Test® drink a 240ml/8oz cup of black coffee or take a 400mg caffeine pill to stimulate secretion of stomach acid.
4. (If you are sensitive to caffeine, you may take 15ml (1tbsp) of the herb, Gentiana lutea, 15 minutes prior to the Gastro-Test since its bitter properties also stimulate the secretion of gastric juices.)
5. Have a ¼ cup of water, some tape, and a white paper towel or a piece of white paper handy.
6. In a seated position, firmly hold the protruding string at one end of the capsule outside the mouth while placing the capsule in your mouth.
7. Tape the free end of the string to the outside of your cheek.
8. Drink no more than ¼ cup of water (30-60 ml) to swallow the capsule.
9. Lay down on your left side for 15 minutes. This allows for maximal contact between the floss and your stomach acid.
10. After 15 the minutes, sit in a comfortable chair with your head tilted slightly back. Remove the tape from your cheek and withdraw the floss from your mouth.
11. Place the floss on a piece of white paper to clearly see the color change.
12. Rub the pH stick along the floss, little by little, starting at the end that was taped to your cheek and ending at the side that was in your stomach.
13. Compare the colors on the floss to the pH color chart.
14. If you find a pH of 3 or less anywhere between the end that was taped to your cheek and the third or fourth blue marking on the floss, there is acid in the esophagus, supporting a diagnosis of GERD.
15. A pH of 3 or less below the 3rd or 4th marking on the floss indicates that the stomach is secreting hydrochloric acid properly.
16. A pH greater than 3 below the 3rd or 4th marking on the floss indicates hypochlorhydria (low stomach acid).
17. A pH of 5 or greater below the 3rd or 4th marking on the floss indicates achlorhydria (no stomach acid).