3 Macronutrient Digestion

You probably do not think too much about what actually happens to the food you eat. This section will describe in depth how what you eat is digested. The desired end result for the learner will be an integrated understanding of the process. This will require higher levels of thinking, but will prove to be well worth it in the end.

Sections:

3.1 Digestion at a Glance
3.2 Mouth to the Stomach
3.3 Stomach
3.4 Small Intestine
3.5 Macronutrient Digestion Review
3.6 Large Intestine

No References
3.1 Digestion at a Glance

Digestion is the process of breaking down food to be absorbed or excreted. The gastrointestinal (GI, digestive) tract, the passage through which our food travels, is a "tube within a tube." The trunk of our body is the outer tube and the GI tract is the interior tube, as shown below. Thus, even though the GI tract is within the body, the actual interior of the tract is technically outside of the body. This is because the contents have to be absorbed into the body. If it's not absorbed, it will be excreted and never enter the body itself.

Figure 3.11 The digestive tract, also known as the gastrointestinal tract, is a "tube within a tube"

A number of organs are involved in digestion, which collectively are referred to as the digestive system.
The organs that form the gastrointestinal tract (mouth, esophagus, stomach, small intestine, large intestine (aka colon), rectum, and anus) come into direct contact with the food or digestive content.
The journey through the gastrointestinal tract starts in the mouth and ends in the anus as shown below:

Mouth --> Esophagus --> Stomach --> Small Intestine --> Large Intestine --> Rectum --> Anus

In addition to the GI tract, there are digestion accessory organs (salivary glands, pancreas, gallbladder, and liver) that play an integral role in digestion. The accessory organs do not come directly in contact with food or digestive content.

Figure 3.14 Digestion accessory organs

There are a number of enzymes that are involved in digestion. We will go through each one in detail, but this table should help give an overview of which enzymes are active at each location of the GI tract.

Table 3.11 Digestive enzymes

<table>
<thead>
<tr>
<th>Location</th>
<th>Enzyme/Coenzyme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td>Salivary amylase</td>
</tr>
<tr>
<td></td>
<td>Lingual lipase</td>
</tr>
<tr>
<td>Stomach</td>
<td>Pepsin</td>
</tr>
<tr>
<td></td>
<td>Gastric lipase</td>
</tr>
<tr>
<td></td>
<td>Pancreatic alpha-amylase</td>
</tr>
<tr>
<td>Small Intestine</td>
<td>Brush border disaccharidases</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td>Pancreatic lipase</td>
</tr>
<tr>
<td></td>
<td>Colipase</td>
</tr>
<tr>
<td></td>
<td>Phospholipase-A2</td>
</tr>
<tr>
<td></td>
<td>Cholesterol esterase</td>
</tr>
<tr>
<td></td>
<td>Proteases</td>
</tr>
<tr>
<td></td>
<td>Brush border peptidases</td>
</tr>
</tbody>
</table>

**References & Links**

**Video**
Enzymes and Digestion - http://www.youtube.com/watch?v=bNMsNHqxszc
3.2 Mouth to the Stomach

Digestion begins in the mouth, both mechanically and chemically. Mechanical digestion is called mastication, or the chewing and grinding of food into smaller pieces. The salivary glands release saliva, mucus, and the enzymes, salivary amylase and lysozyme.

Salivary amylase cleaves the alpha 1-4 glycosidic bonds in the starch molecules, amylose and amyllopectin. However, salivary amylase cannot cleave the branch points in amyllopectin where there are alpha 1-6 glycosidic bonds, as shown in the figure below. Overall this enzyme accounts for a minor amount of carbohydrate digestion.
Lysozyme helps break down bacteria cell walls to prevent a possible infection. Another enzyme, lingual lipase, is also released in the mouth. Although it is released in the mouth, it is most active in the stomach where it preferentially cleaves short-chain fatty acids in the sn-3 position. Lingual lipase has a small role in digestion in adults, but may be important for infants to help break down triglycerides in breast milk².

Swallowing

Now that the food has been thoroughly chewed and formed into a bolus, it can proceed down the throat to the next stop in digestion. It will move down the pharynx where it reaches a "fork in the road", with the larynx as one road and the esophagus as the other. The esophagus road leads to the stomach; this is the direction that food should go. The other road, through the larynx, leads to the trachea and ultimately the lungs. This is definitely not where you want your food or drink going, as this is the pathway for the air you breathe.

Figure 3.23 Cross section of face. The epiglottis covers larynx to prevent food and drink from entering the lungs³

Fortunately, our body was designed in such a way that a small tissue, called the epiglottis, covers the opening to the trachea. It directs the food down the correct road as shown below.
Figure 3.24 Epiglottis is like a traffic cop guiding food down the correct digestion road.

**Esophagus**

Before being correctly guided into the esophagus, the bolus of food will travel through the upper esophageal sphincter. Sphincters are circular muscles that are found throughout the gastrointestinal tract that essentially serve as gates between the different sections. Once in the esophagus, wavelike muscular movements, known as peristalsis, occur, as shown in the animation and video in the links below.

**Web Links**
- Peristalsis Animation
- Video: Peristalsis (0:57)

At the end of the esophagus the bolus will encounter the lower esophageal sphincter. This sphincter keeps the harmful acids of the stomach out of the esophagus. However, in many people this sphincter is leaky, which allows stomach acid to reflux, or creep up, the esophagus. Stomach acid is very acidic (has a low pH). The ruler below will give you an idea of just how acidic the stomach is. Notice that the pH of gastric (term used to describe the stomach) fluid is lower (more acidic) than any of the listed items besides battery acid.
The leaking of the very acidic gastric contents results in a burning sensation, commonly referred to as "heartburn." If this occurs more than twice per week and is severe, the person may have gastroesophageal reflux disease (GERD). The following videos explain more about these conditions.

**Web Links**
- Video: Acid Reflux (1:28)
- Video: GERD 101 (0.55)

**Table 3.21 Review of Chemical Digestion in the Mouth**

<table>
<thead>
<tr>
<th>Macronutrient</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrates</td>
<td>Salivary amylase cleaves 1,4-glycosidic bonds</td>
</tr>
<tr>
<td>Lipids</td>
<td>Release of lingual lipase</td>
</tr>
<tr>
<td>Protein</td>
<td>None</td>
</tr>
</tbody>
</table>

**References & Links**

**Link**

**Videos**
Peristalsis Animation - http://www.youtube.com/watch?v=o18UycWRsaA
Acid Reflux - https://www.youtube.com/watch?v=SW-QfyDSY5I
3.3 Stomach

After going through the lower esophageal sphincter, food enters the stomach. Our stomach is involved in both chemical and mechanical digestion. Mechanical digestion occurs as the stomach churns and grinds food into a semisolid substance called chyme (partially digested food).

The lining of the stomach is made up of different layers of tissue. The mucosa is the outermost layer (closest to stomach cavity) as shown in the figure below.

![Stomach Diagram](image)

**Figure 3.31 The anatomy of the stomach**

The mucosa is not a flat surface. Instead, its surface is lined by gastric pits, as shown in the figure below.
Gastric pits are indentations in the stomach's surface that are lined by four different types of cells.

The following video is a nice introduction to gastric pits and talks about chief and parietal cells that are covered in more detail below.
At the bottom of the gastric pit are the G cells that secrete the hormone gastrin. Gastrin stimulates the parietal and chief cells that are found above the G cells. The chief cells secrete the zymogen pepsinogen and the enzyme gastric lipase. A zymogen is an inactive precursor of an enzyme that must be cleaved or altered to form the active enzyme. The parietal cells secrete hydrochloric acid (HCl), which lowers the pH of the gastric juice (water + enzymes + acid). The HCl inactivates salivary amylase and catalyzes the conversion of pepsinogen to pepsin. Finally, the top of the pits are the neck cells that secrete mucus to prevent the gastric juice from digesting or damaging the stomach mucosa. The table below summarizes the actions of the different cells in the gastric pits.

Table 3.41 Cells involved in the digestive processes in the stomach

<table>
<thead>
<tr>
<th>Type of Cell</th>
<th>Secrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neck</td>
<td>Mucus</td>
</tr>
<tr>
<td>Chief</td>
<td>Pepsinogen and gastric lipase</td>
</tr>
<tr>
<td>Parietal</td>
<td>HCl</td>
</tr>
<tr>
<td>G</td>
<td>Gastrin</td>
</tr>
</tbody>
</table>

The figure below shows the action of all these different secretions in the stomach.
To reiterate, the figure above illustrates that the neck cells of the gastric pits secrete mucus to protect the mucosa of the stomach from essentially digesting itself. Gastrin from the G cells stimulates the parietal and chief cells to secrete HCl and enzymes, respectively.

The HCl in the stomach denatures salivary amylase and other proteins by breaking down the structure and, thus, the function of it. HCl also converts pepsinogen to the active enzyme pepsin. Pepsin is a protease, meaning that it cleaves bonds in proteins. It breaks down the proteins in food into individual peptides (shorter segments of amino acids). The other enzyme that is active in the stomach is gastric lipase. This enzyme preferentially cleaves the sn-3 position of triglycerides to produce 1,2-diglyceride and a free fatty acid, as shown below. It is responsible for up to 20% of triglyceride digestion.

The chyme will then leave the stomach and enter the small intestine via the pyloric sphincter (shown below).
Table 3.32 Summary of chemical digestion in the stomach

<table>
<thead>
<tr>
<th>Chemical or Enzyme</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrin</td>
<td>Stimulates chief cells to release pepsinogen</td>
</tr>
<tr>
<td></td>
<td>Stimulates parietal cells to release HCl</td>
</tr>
<tr>
<td>HCl</td>
<td>Denatures salivary amylase</td>
</tr>
<tr>
<td></td>
<td>Denatures proteins</td>
</tr>
<tr>
<td></td>
<td>Activates pepsinogen to pepsin</td>
</tr>
<tr>
<td>Pepsin</td>
<td>Cleaves proteins to peptides</td>
</tr>
<tr>
<td>Gastric lipase</td>
<td>Cleaves sn-3 FA of triglycerides</td>
</tr>
</tbody>
</table>

References & Links

Video
Gastric Pits - http://www.youtube.com/watch?v=6hquzCXYNg
3.4 Small Intestine

The small intestine is the primary site of digestion. It is divided into three sections: the duodenum, jejunum, and ileum (shown below). After leaving the stomach, the first part of the small intestine that chyme will encounter is the duodenum.

![Diagram of the small intestine with the duodenum, jejunum, and ileum labeled.](image)

Figure 3.41 Three sections of the small intestine

The small intestine consists of many layers, which can be seen in the cross section below.

![Cross section of the small intestine.](image)

Figure 3.42 Cross section of the small intestine

Examining these layers closer, we are going to focus on the epithelium, which comes into contact with the chyme and is responsible for absorption. The lumen is the name of the cavity that is considered “outside the body” that chyme moves through.
The organization of the small intestine is in such a way that it contains circular folds and finger-like projections known as villi. The folds and villi are shown in the next few figures.
If we were to zoom in even closer, we would be able to see that enterocytes (small intestine absorptive cells) line villi as shown below.
The side, or membrane, of the enterocyte that faces the lumen is not smooth either. It is lined with microvilli, and is known as the brush border (aka apical) membrane, as shown below.

Together these features (folds + villi + microvilli) increase the surface area ~600 times versus if it was a smooth tube. More surface area leads to more contact with the enterocytes and thus, increased absorption.
Going even closer, we discover that the surface of the microvilli is covered by the hair-like glycocalyx, which is glycoproteins and carbohydrates as shown below.

![Glycocalyx lines the microvilli](image)

Figure 3.49 Glycocalyx lines the microvilli

Now that you have learned about the anatomy of the small intestine, the following subsections go through the different digestive processes that occur there.

Subsections:

3.41 Digestive Hormones, Accessory Organs, & Secretions
3.42 Carbohydrate Digestion in the Small Intestine
3.43 Protein Digestion in the Small Intestine
3.44 Lipid Digestion in the Small Intestine

References & Links
1. http://commons.wikimedia.org/wiki/Image:Illu_small_intestine_catal%C3%A0.png
Before we go into the digestive details of the small intestine, it is important that you have a basic understanding of the anatomy and physiology of the following digestion accessory organs: pancreas, liver, and gallbladder. Digestion accessory organs assist in digestion, but are not part of the gastrointestinal tract. How are these organs involved?

Upon entering the duodenum, the chyme causes the release of two hormones from the small intestine: secretin and cholecystokinin (CCK, previously known as pancreozymin) in response to acid and fat, respectively. These hormones have multiple effects on different tissues. In the pancreas, secretin stimulates the secretion of bicarbonate (HCO₃), while CCK stimulates the secretion of digestive enzymes. The bicarbonate and digestive enzymes released together are collectively known as pancreatic juice, which travels to the small intestine, as shown below.

![Image of digestive hormones and accessory organs](image)

Figure 3.411 The hormones secretin and CCK stimulate the pancreas to secrete pancreatic juice

In addition, CCK also stimulates the contraction of the gallbladder causing the secretion of bile into the duodenum.

Pancreas

The pancreas is found behind the stomach and has two different portions. It has an endocrine (hormone-producing) portion that contains alpha and beta cells that secrete the hormones glucagon and insulin, respectively. However, the vast majority of the pancreas is made up of acini, or acinar cells, that are responsible for producing pancreatic juice. The following video does a nice job of showing and explaining the function of the different pancreatic cells.
Bicarbonate is a base (high pH) meaning that it can help neutralize acid. You can find sodium bicarbonate (NaHCO₃, baking soda) on the ruler below to get an idea of its pH.

![pH of some common items](image)

Figure 3.412 pH of some common items²

The main digestive enzymes in pancreatic juice are listed in the table below. Their function will be discussed further in later subsections.

<table>
<thead>
<tr>
<th>Enzyme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pancreatic alpha-amylase</td>
</tr>
<tr>
<td>Proteases</td>
</tr>
<tr>
<td>Pancreatic Lipase &amp; Procolipase*</td>
</tr>
<tr>
<td>Phospholipase A₂</td>
</tr>
<tr>
<td>Cholesterol Esterase</td>
</tr>
</tbody>
</table>

*Not an enzyme
Liver

The liver is the largest internal and most metabolically active organ in the body. The figure below shows the liver and the accessory organs position relative to the stomach.

Figure 3.413 Location of digestion accessory organs relative to the stomach

The liver is made up two major types of cells. The primary liver cells are hepatocytes, which carry out most of the liver’s functions. Hepatic is another term for liver. For example, if you are going to refer to liver concentrations of a certain nutrient, these are often reported as hepatic concentrations. The other major cell type is the hepatic stellate (also known as Ito) cells. These are fat storing cells in the liver. These two cell types are depicted below.

Figure 3.414 Hepatocytes (PC) and hepatic stellate cells (HSC) along with an electron microscope image showing the lipid droplets within a stellate cell

The liver's major role in digestion is to produce bile. This is a greenish-yellow fluid that is composed primarily of bile acids, but also contains cholesterol, phospholipids, and the pigments
bilirubin and biliverdin. Bile acids are synthesized from cholesterol. The two primary bile acids are chenodeoxycholic acid and cholic acid. In the same way that fatty acids are found in the form of salts, these bile acids can also be found as salts. These salts have an (-ate) ending, as shown below.

![Figure 3.415 Structures of the 2 primary bile acids](image)

Bile acids, much like phospholipids, have a hydrophobic and hydrophilic end. This makes them excellent emulsifiers that are instrumental in fat digestion. Bile is then transported to the gallbladder.

**Gallbladder**

The gallbladder is a small, sac-like organ found just off the liver (see figures above). Its primary function is to store and concentrate bile made by the liver. The bile is then transported to the duodenum through the common bile duct.

**Why do we need bile?**

Bile is important because fat is hydrophobic and the environment in the lumen of the small intestine is watery. In addition, there is an unstirred water layer that fat must cross to reach the enterocytes in order to be absorbed.
Figure 3.416 Fat is not happy alone in the watery environment of the small intestine.

Here triglycerides form large triglyceride droplets to keep the interaction with the watery environment to a minimum. This is inefficient for digestion, because enzymes cannot access the interior of the droplet. Bile acts as an emulsifier, or detergent. It, along with phospholipids, forms smaller triglyceride droplets that increase the surface area that is accessible for triglyceride digestion enzymes, as shown below.

**Emulsifier or Detergent**

Figure 3.417 Bile acids and phospholipids facilitate the production of smaller triglyceride droplets.

Secretin and CCK also control the production and secretion of bile. Secretin stimulates the flow of bile from the liver to the gallbladder. CCK stimulates the gallbladder to contract, causing bile to be secreted into the duodenum, as shown below.
Figure 3.418 Secretion stimulates bile flow from liver; CCK stimulates the gallbladder to contract³

References & Links
4. http://www.comparative-hepatology.com/content/6/1/7

Video
The Pancreas - http://www.youtube.com/watch?v=j5WF8wUFNkI
3.42 Carbohydrate Digestion in the Small Intestine

The small intestine is the primary site of carbohydrate digestion. Pancreatic alpha-amylase is the primary carbohydrate digesting enzyme. Pancreatic alpha-amylase, like salivary amylase, cleaves the alpha 1-4 glycosidic bonds of carbohydrates, reducing them to simpler carbohydrates, such as glucose, maltose, maltotriose, and dextrins (oligosaccharides containing 1 or more alpha 1-6 glycosidic bonds). Pancreatic alpha-amylase is also unable to cleave the branch point alpha 1-6 bonds.

![Figure 3.421 The function of pancreatic alpha-amylase](image1)

![Figure 3.422 Products of pancreatic alpha-amylase](image2)

The pancreatic alpha-amylase products, along with the disaccharides sucrose and lactose, then move to the surface of the enterocyte. Here, there are disaccharidase enzymes (lactase, sucrase, maltase) on the outside of the enterocyte. Enzymes, like these, that are on the outside of cell walls are referred to as ectoenzymes. Individual monosaccharides are formed when lactase cleaves lactose, sucrase cleaves sucrose, and maltase cleaves maltose. There is also another brush border enzyme, alpha-dextrinase. This enzyme cleaves alpha 1-6 glycosidic bonds in dextrins, primarily the branch point bonds in amylopectin. The products from these
brush border enzymes are the single monosaccharides glucose, fructose, and galactose that are ready for absorption into the enterocyte.

Figure 3.423 Disaccharidases on the outside of the enterocyte.

References & Links
3.43 Protein Digestion in the Small Intestine

The small intestine is the major site of protein digestion by proteases (enzymes that cleave proteins). The pancreas secretes a number of proteases as zymogens into the duodenum where they must be activated before they can cleave peptide bonds. This activation occurs through an activation cascade. A cascade is a series of reactions in which one step activates the next in a sequence that results in an amplification of the response. An example of a cascade is shown below.

![Diagram of a cascade](image)

Figure 3.431 An example of a cascade, with one event leading to many more events

In this example, A activates B, B activates C, D, and E, C activates F and G, D activates H and I, and E activates K and L. Cascades also help to serve as control points for certain process. In the protease cascade, the activation of B is really important because it starts the cascade.

The protease/colipase activation scheme starts with the enzyme enteropeptidase (secreted from the intestinal brush border) that converts trypsinogen to trypsin. Trypsin can activate all the proteases (including itself) and colipase (involved in fat digestion) as shown in the 2 figures below.
The products of the action of the proteases on proteins are dipeptides, tripeptides, and individual amino acids, as shown below.
At the brush border, much like disaccharidases, there are peptidases that cleave some peptides down to amino acids. Not all peptides are cleaved to individual amino acid, because small peptides can be taken up into the enterocyte, thus, the peptides do not need to be completely broken down to individual amino acids. Thus the end products of protein digestion are primarily dipeptides and tripeptides, along with individual amino acids. 

References & Links
3.44 Lipid Digestion in the Small Intestine

The small intestine is the major site for lipid digestion. There are specific enzymes for the digestion of triglycerides, phospholipids, and cleavage of esters from cholesterol. We will look at each in this section.

Triglycerides

The pancreas secretes pancreatic lipase into the duodenum as part of pancreatic juice. This major triglyceride digestion enzyme preferentially cleaves the sn-1 and sn-3 fatty acids from triglycerides. This cleavage results in the formation of a 2-monoglyceride and two free fatty acids as shown below.

![Pancreatic lipase cleaves the sn-1 and sn-3 fatty acids of triglycerides](image)

To assist lipase, colipase serves as an anchor point to help lipase attach to the triglyceride droplet.

![The products of pancreatic lipase are a 2-monoglyceride and two free fatty acids](image)
Phospholipids

The enzyme phospholipase A₂ cleaves the C-2 fatty acid of lecithin, producing lysolecithin and a free fatty acid.

Figure 3.444 Phospholipase A₂ cleaves the C-2 fatty acid of lecithin

Fatty Acid

Lysolecithin

Figure 3.445 Products of phospholipase A₂ cleavage

Cholesterol Esters

The fatty acid in cholesterol esters is cleaved by the enzyme, cholesterol esterase, producing cholesterol and a free fatty acid.
Formation of Mixed Micelles

If nothing else happened at this point, the 2-monoglycerides and fatty acids produced by pancreatic lipase would form micelles. The hydrophilic heads would be outward and the fatty acids would be buried on the interior. These micelles are not sufficiently water-soluble to cross the unstirred water layer to get to the brush border of enterocytes. Thus, mixed micelles are formed containing cholesterol, bile acids, and lysolecithin in addition to the 2-monoglycerides and fatty acids, as illustrated below.1
Mixed micelles are more water-soluble, allowing them to cross the unstirred water layer to the brush border of enterocytes for absorption.

References & Links
3.5 Macronutrient Digestion Review

The following figures review the digestion of the different macronutrients.

**Carbohydrate Digestion**

![Carbohydrate Digestion Diagram](image1)

Figure 3.51 Review of carbohydrate digestion

**Protein Digestion**

![Protein Digestion Diagram](image2)

Figure 3.52 Review of protein digestion

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1. Source: [REPLACE WITH SOURCE]
Lipid Digestion

- Lingual Lipase released, minor amount of digestion in stomach
- CCK (duodenum) stimulates gall bladder contraction, bile release into duodenum
- Gastrin stimulates gastric lipase release, cleaves sn-3 FAs
- Liver produces bile, sends to gall bladder in response to secretin (duodenum)
- Pancreatic lipase (sn-3 & sn-1) & procolipase (trypsin cleaves) are released from pancreas in response to CCK (duodenum), major site of digestion

Figure 3.53 Review of triglyceride digestion

Cholesterol Ester and Phospholipid Digestion

- Cholesterol esterase cleaves FA from cholesterol esters and phospholipase A2, cleaves the C2 FA from phospholipids
- Cholesterol esterase and phospholipase A2 are released from pancreas in response to CCK (duodenum)

Figure 3.54 Review of cholesterol ester and phospholipid digestion
After digestion, the products below are ready for uptake into the enterocyte.

![Diagram of Macronutrient digestion products ready for uptake into the enterocyte](http://www.wpclipart.com/medical/anatomy/digestive/Digestive_system_diagram_page.png.html)

Figure 3.55 Macronutrient digestion products ready for uptake into the enterocyte

**References & Links**
3.6 The Large Intestine

We have reached a fork in the road. We could follow the uptake of the digested compounds into the enterocyte or we could finish following what has escaped digestion and is going to continue into the large intestine. Obviously from the title of this section we are going to do the latter. As we learned previously, fiber is a crude term for what has survived digestion and has reached the large intestine.

![Image of uptake and large intestine](image1)

Figure 3.61 The fork in the road between finishing digestion in the colon and absorption into the enterocyte

The ileocecal valve is the sphincter between the ileum and the large intestine. This name should make more sense as we go through the anatomy of the large intestine.

![Image of ileocecal valve](image2)

Figure 3.62 The ileocecal valve

The large intestine consists of the colon, the rectum, and the anus. The colon can be further divided into the cecum (hence the -cecal in ileocecal valve, ileo- refers to ileum), ascending colon, transverse colon, descending colon, and sigmoid colon as shown below.
The large intestine is responsible for absorbing remaining water and electrolytes (sodium, potassium, and chloride). It also forms and excretes feces. The large intestine contains large amounts of microorganisms like those shown in the figure below.

The large intestine can also be referred to as the gut. There are a large number of microorganisms found throughout the gastrointestinal tract that collectively are referred to as the flora, microflora, biota, or microbiota. Technically, microbiota is the preferred term because
flora means "pertaining to plants". There are 10 times more microorganisms in the gastrointestinal tract than cells in the whole human body\(^4\). As can be seen in the figure below, the density of microorganisms increases as you move down the digestive tract.

![Figure 3.65 Relative amount of bacteria in selected locations of the GI tract. cfu/ml = colony forming unit, a measure of the number of live microorganisms in 1 mL of digestive sample\(^5,6\)](image)

As described in the fiber sections, there are two different fates for fiber once it reaches the large intestine. The fermentable, viscous fiber is fermented by bacteria. Fermentation is the metabolism of compounds by the microorganisms in the gut. An example of fermentation is the utilization of the oligosaccharides raffinose and stachyose by microorganisms that results in the production of gas, which can lead to flatulence. Also, some bile acids are fermented by microorganisms to form secondary bile acids that can be reabsorbed. These secondary bile acids represent approximately 20% of the total bile acids in our body. Fermentable fibers can be used to form short-chain fatty acids that can then be absorbed and used by the body. The nonfermentable, nonviscous fiber is not really altered and will be a component of feces, that is then excreted through the rectum and anus. This process involves both an internal and external sphincter that are shown in figure 3.63 above.

Subsection:

3.61 Probiotics & Prebiotics

**References & Links**
6. Adapted from:
3.61 Probiotics & Prebiotics

Recently there has been increased attention given to the potential of a person's microbiota to impact health. This is because there are beneficial and non-beneficial bacteria inhabiting our gastrointestinal tracts. Thus, theoretically, if you can increase the beneficial or decrease the non-beneficial bacteria, there may be improved health outcomes. In response to this, probiotics and prebiotics have been identified/developed. A probiotic is a live microorganism that is consumed, and colonizes in the body as shown in the figures below.

![Probiotics](image1)

Figure 3.611 Probiotics the consumption of the bacteria itself

A prebiotic is a nondigestible food component that selectively stimulates the growth of beneficial intestinal bacteria. An example of a prebiotic is inulin, which is shown in the figure below.

![Prebiotics](image2)

Figure 3.612 Inulin, an indigestible food component that is a commonly used prebiotic
The net result is the same for both prebiotics and probiotics, an increase in the beneficial/non-beneficial microorganism ratio.

Figure 3.613 An effective prebiotic or probiotic should result in an increase in the beneficial bacteria

The following video does a nice job of explaining and illustrating how probiotics work. The NCCAM website is a good source of information if you have further questions on the topic.

Web Links
Video: Probiotics (3:40)
NCCAM: Probiotics

Some common examples of probiotics are DanActive® and Activia®.

Web Links
DanActive®
Activia®

The claims that companies made about their produce probiotic products have come under scrutiny. Dannon settled with the US Federal Trade Commission to drop claims that its probiotic products will help prevent colds or alleviate digestive problems, as seen in the top link below. General Mills also settled a lawsuit that accused them of a falsely advertising the digestive benefits of Yo-Plus a product it no longer sells, as seen in the second link.
Some examples of prebiotics include inulin, other fructose-containing oligosaccharides and polysaccharides, and resistant starch. Inulin is a polysaccharide that contains mainly fructoses that are joined by beta-bonds, which allows them to survive digestion. The structure of inulin is shown below.

![Inulin Structure](http://en.wikipedia.org/wiki/File:Inulin_strukturformel.png)

Figure 3.614 Structure of inulin

Resistant starch is so named because it is a starch that is resistant to digestion. As a result, it arrives in the colon to be fermented.

**References & Links**

**Links**
- DanActive - http://www.danactive.com/
- Activia - http://www.activia.us.com/
- General Mills Settles Yo-Plus Lawsuit - http://www.foodbusinessnews.net/articles/news_home/Site_News/2013/02/General_Mills_settles_Yo-Plus.aspx?ID={40F62478-1AA4-49DF-9330-E41E19E946D0}&cck=1

**Video**
- Probiotics - http://www.youtube.com/watch?v=2k8Puxz54FQ&NR=1