Unit 3 Lecture 10

The Digestive System (2)

Small Intestine

The stomach contents empty through the pyloric sphincter into the small intestine. This is the longest section of the digestive tract, reaching 9 meters (30 ft) in length; it ends at the ileocecal sphincter where it empties into the ascending colon of the large intestine. It is divided into three segments: The first segment, the duodenum, is the shortest; the second segment is the jejunum (about a meter long); and the longest segment, making up 50% of the small intestine, is the ileum. Most of digestion and absorption occurs in the first two segments of the small intestine; the duodenum and jejunum.

The mucosa contains many cavities lined with glandular epithelium. Intestinal glands secrete intestinal juice. The submucosa of duodenum contains duodenal (Brunner's) glands which secrete alkaline mucous that helps neutralize gastric acid. Villi are finger-like projections on the mucosa. The core of the villi is the lamina propria (a connective tissue layer containing an arteriole, a vein, a capillary network, and a lacteal). Microvilli are found on the apical surface of the villi and function as the brush border which increases the surface area for absorption. The circular fold is a permanent ridge in the mucosa that enhance the chyme to spiral rather than move in a straight line. Villi, microvilli, and circular fold provide a large surface area for absorption. Two layers of muscles form the muscularis. Solitary lymphatic nodules found in the lower ileum and aggregated lymphatic follicles (Pyer's patches) prevent bacteria from entering the bloodstream.

Physiology of digestion and absorption in the small intestine

Segmentation is the mixing of the contents of the small intestine and the major movement of SI. Segmentation involves localized contractions in areas containing food and mixes chyme with digestive juices and brings substance in contact with the mucosa. Peristalsis propels the chyme along. Absorption is the passage of the end products of digestion into blood or lymph vessels. Ninety percent of all absorption occurs in SI. Absorption occurs by diffusion, facilitated diffusion, osmosis, and active transport. Monosaccharides utilize facilitated diffusion and active transport; proteins are broken down into amino acids and absorbed by active transport, and short chain fatty acids pass into the blood stream by simple diffusion. Long chain fatty acids are absorbed as part of micelles (tiny spheres) and then re-synthesized into triglycerides and formed into chylomicrons. The chylomicrons move into lymph in the lacteal of villi and are carried in the bloodstream at the R/L lymphatic ducts as a lipoprotein. The SI absorbs water, electrolytes and vitamins. About 9 liters of fluid is passed into SI of which about 8 are reabsorbed.

Activation of the intestinal phase is due to receptors in the small intestine. Starting this phase inhibits mobility, preventing overloading of small intestine, and promotes continued digestion and mixing of food in stomach. It also triggers release of gastric inhibitory peptide (GIP), secretin and cholecystokinin (CCK). GIP stimulates secretion of insulin by pancreatic cells, inhibits secretion of gastric juices, and allows gastric emptying. Secretin stimulates secretion of pancreatic juice and bile rich bicarbonate ions. CCK stimulates secretion of pancreatic juice rich in digestive juices, causes ejection of bile from gallbladder, and induces satiety.

Intestinal Juice and Brush Border Enzymes

One to two liters of intestinal juice (pH 7.6) are secreted per day. Pancreatic juice aids in the absorption of chyme. The digestion of the chyme occurs by digestive enzymes from the pancreas and epithelial cells. Bile, from the liver, helps digest fat although it is not a digestive enzyme. Brush border enzymes found in the plasma membrane of the microvilli aid in digestion. There are very specific digestive enzymes for each part of a meal. Carbohydrate digesting enzymes include a-dextranase, maltase, sucrase, and lactase. Protein digesting enzymes include peptidases. Nucleotide digesting hormones include nucleosidases and phosphatases.

There are different types of carbohydrates. Some carbohydrates are made up of a single building block called monosaccharides, (glucose and fructose, and galactose). Other carbohydrates, called disaccharides, consist of two monosaccharides. These include maltose, lactose, and sucrose. Carbohydrates made up of more than two units are called polysaccharides. The most common polysaccharides are starch and glycogen. In order to absorb the larger carbohydrates, polysaccharides must all be broken down into monosaccharides. Once in this form, they can be absorbed by transport systems in the walls of the small intestine.

Digestion of carbohydrates begins in the mouth with the salivary enzyme amylase. This enzyme breaks up the large polysaccharides into smaller polysaccharides and maltose. Once the food reaches the stomach, the digestion of the carbohydrates essentially stops because of the acidic environment, which denatures the salivary amylase. When the food reaches the small intestine, digestion of the carbohydrates begins again because the pancreas secretes amylase into the duodenum.

The pancreas also secretes bicarbonate ions which neutralize the acid from the stomach. The neutralized environment permits the pancreatic amylase to perform its digestive function. The pancreatic amylase digests the polysaccharide starch to the disaccharide maltose. This disaccharide cannot be absorbed yet because it still must be digested to a monosaccharide. Each disaccharide requires a specific enzyme to break it down to its component monosaccharides. These enzymes are located in the brush border of the microvilli located on the intestinal epithelial cells. The enzyme lactase breaks down lactose to galactose and glucose. The enzyme maltase breaks down maltose to two glucose monosaccharides. The enzyme sucrase breaks down sucrose to glucose and fructose. Now the carbohydrates are ready for absorption.

Proteins consist of long chains of amino acids linked together. There are 20 different amino acids: 11 nonessential amino acids that can be produced by the body and 9 essential amino acids that must come from the diet. Just like carbohydrates, the different groups of amino acids require different enzymes to break them apart. Likewise, the proteins must be broken down into the amino acid building blocks before they can be absorbed by transport systems in the small intestine.

Digestion of proteins begins in the stomach. Here, hydrochloric acid (HCl) converts the inactive pepsinogen to the active enzyme pepsin. Pepsin digests the long protein chains into smaller chains called polypeptides. These polypeptides then pass through the pyloric sphincter into the small intestine where they continue to be digested and absorbed into the body. The pancreatic enzymes that will continue protein digestion must have an environment with a neutral pH in order to work optimally. Therefore, the chyme from the acidic stomach must be neutralized. This is achieved by bicarbonate, which is secreted from the pancreas. As a result of the neutral pH environment, the pepsin, which was secreted by the stomach to begin the process of digestion, now becomes inactivated. Now, the enzymes trypsin and chymotrypsin from the pancreas continue the job in the small intestine that was begun by pepsin in the stomach.

A class of enzymes called proteases can continue digesting proteins into amino acids. These enzymes are produced in the pancreas and are secreted into the small intestine. Likewise, some proteases are found along the brush border of the intestinal epithelial cells. There are two different classes of protease enzymes, each of which is responsible for breaking apart amino acids located in different parts of the protein. The endopeptidases break the bonds between amino acids in the inner part of the protein. Exopeptidases break the bonds between amino acids at the ends of the protein. Now that the proteins are broken into single amino acids with a few remaining very small polypeptides (dipeptides or tripeptides), absorption can take place. Much like carbohydrates, the absorption of amino acids is through secondary active transport requiring the presence of a $Na+$ concentration gradient. As $Na+$ move into the intestinal epithelial cell and down their concentration gradient, they power a co-transporter that also moves the amino acids into the cell. The remaining small peptides are absorbed by endocytosis.

Fats include substances such as triglycerides, phospholipids, cholesterol, and long-chain fatty acids. These substances are not water soluble and do not mix well with water. Therefore, a complex set of steps is necessary to digest fats and then absorb them into our "watery environment." The churning action of the stomach helps break up the large drops of fat into smaller ones, a process called emulsification. The process of emulsification is extremely important because it is much easier for the lipid-digesting enzymes to do their work on very small droplets than on very large ones. The main problem is keeping the small droplets from forming back into large ones. Therefore, it is very important to keep the lipids emulsified throughout the whole digestion process.

Bile is produced in the liver and is transported to the gallbladder where it is stored and concentrated. Bile is not a digestive enzyme; rather, it is a substance that contains, among other things, water, bile salts (the most abundant component), cholesterol, fatty acids, and many ions. The gallbladder releases bile into the duodenum of the small intestine during a meal. The bile salts keep the lipid droplets emulsified, preventing them from forming back into large droplets.

The fat droplets can contain different types of lipids, including phospholipids and cholesterol. The pancreatic lipase attacks the phospholipids and removes two fatty acid chains, leaving monoglycerides behind. As the lipase slowly digests the lipid interior of the fat droplets, the droplets get smaller and smaller. Eventually they form small sphere-shaped structures called micelles that consist of a single layer of bile salts surrounding a very small lipid droplet. These micelles help to ferry the lipid droplets to the intestinal epithelial cells where the lipids are absorbed.

The fatty acids and the monoglycerides, which are both lipid soluble, can diffuse directly through the membrane of the epithelial cells that line the small intestine. The cholesterol molecules, on the other hand, are transported into the cells by a specific active transport system. What gets left behind after the lipids are absorbed is the bile salt that kept the lipid droplets emulsified. The bile salts are reabsorbed by a transport system in the cells in the ileum; this occurs at the very end of the small intestine. The bile salts are then returned to the liver where they are reused.

The absorbed lipids are still inside the intestinal epithelial cells. Here, the monoglycerides and the fatty acids will enter the smooth endoplasmic reticulum where they will combine with cholesterol and proteins to form chylomicrons. These chylomicrons are packaged up into secretory vesicles by the Golgi apparatus. From here, the chylomicrons leave the cell and enter the lacteals of the lymphatic system, which eventually drains into the circulatory system. If you were to draw blood after ingestion of a "fatty" meal, the plasma portion of the blood would be very cloudy due to the excess chylomicrons present.

Vitamins and minerals are also absorbed by the small intestine.

The total amount of water absorbed by the intestine is roughly 9 liters a day. Not all of this water comes from drinking and eating. About 80% of the water (7 liters) is reabsorbed from water contained in saliva, the digestive enzymes from the stomach and pancreas, bile, and the secretions from the intestine. Only 20% (2 liters) comes from drinking and food. The amount of water absorbed in the intestine varies along its length. The first half of the small intestine, the duodenum and jejunum, absorb about 4 liters. The last half of the small intestine, the ileum, absorbs roughly approximately 3.5 liters, and the large intestine absorbs roughly 1.4 liters. The remaining 100 ml is excreted in the feces. Water is absorbed in the small intestine much in the same way as it is in the kidney. As the molecules of glucose, amino acids, and lipids are absorbed, an osmotic gradient begins to build up across the intestinal epithelial. These cells develop a higher solute concentration inside (lower water concentration), causing water to flow into the cells by osmosis and down its concentration gradient. As the solutes move out of the cell into the circulation, water continues to follow by osmosis into the blood.

Large Intestine

The large intestine (also called the colon) begins at the ileocecal valve and is roughly five feet in length. It consists of an ascending, transverse, and descending limb, a curved sigmoid section, and the rectum that ends at the anus. Structurally the LI is attached to the abdominal wall by the mesocolon and attached to the small intestine at the ileocecal sphincter. The cecum is a pouch below the ileocecal valve. The vermiform appendix is attached to lower cecum. Bends are the right colic (hepatic) flexure and left colic (splenic) flexure. The rectum is inferior to the sigmoid colon followed by the anal canal and anus. Teniae coli are a muscularis that consists of longitudinal muscles which are thickened and gather the colon into series of pouches called haustra. Epiploic appendages are small pouches filled with fat and attached to Teniae coli.

The diameter of the large intestine is much larger than the small intestine, but it lacks the many folds and villi of its smaller counterpart. The main function of the large intestine is to absorb water and electrolytes and to store and concentrate the feces. Sodium is absorbed by active transport mechanism, and water follows by osmosis -similar to the small intestine. Most of this absorption takes place in the first half of the colon. The large intestine also secretes mucus to protect its lining from chemical and mechanical damage and to lubricate the forming feces. Some K+ and bicarbonate are secreted into the colon. A very small amount of digestion occurs when undigested polysaccharides are metabolized by bacteria to free fatty acids that are absorbed by passive diffusion. The bacteria also produce gas (flatus) and vitamin K for blood coagulation.

Mechanical movements include haustral churning, peristalsis, and mass peristalsis. Haustra remain relaxed until they fill, then squeeze contents into next haustra. Mass peristalsis occurs about four times per day after eating and is called a gastrocolic reflex because food in stomach initiates reflex. The last stages of chemical digestion occur through activity of bacteria. Absorption water, electrolytes and vitamins occurs. The remainder of what is left becomes feces and includes water, inorganic salts, epithelial cells, bacteria and undigested food.

Defecation is the elimination of feces from the rectum. It is a reflex action stimulated by stretch receptors in the rectum and is aided by voluntary contractions of the diaphragm and abdominal muscles and relaxation of the anal sphincter.