GROUP 2 PRESENTATION

DIGESTION AND ABSORPTION

DIGESTION AND ABSORPTION IN THE GASTROINTESTINAL TRACT.

The major foods on which the body lives (with the exception of small quantities of substances such as vitamins and minerals) can be classified as carbohydrates, fats, and proteins. They generally cannot be absorbed in their natural forms through the gastrointestinal mucosa and, for this reason, are useless as nutrients without preliminary digestion.

This presentation explains the processes by which carbohydrates, fats, and proteins are digested into small enough compounds for absorption.

DIGESTION OF CARBOHYDRATES

Only three major sources of carbohydrates exist in the normal human diet. They are sucrose, which is the disaccharide known popularly as cane sugar; lactose, which is a disaccharide found in milk; and starches, which are large polysaccharides present in almost all non-animal foods, particularly in potatoes and different types of grains. Other carbohydrates ingested to a slight extent are amylose, glycogen, alcohol, lactic acid, pyruvic acid, pectin, dextrin, and minor quantities of carbohydrate derivatives in meats. The diet also contains a large amount of cellulose, which is a carbohydrate. However, no enzymes capable of hydrolysing cellulose are secreted in the human digestive tract. Consequently, cellulose cannot be considered a food for humans.

DIGESTION OF CARBOHYDRATES IN THE MOUTH AND STOMACH.

When food is chewed, it is mixed with saliva, which contains the digestive enzyme ptyalin (an α-amylase) secreted mainly by the parotid glands. This enzyme hydrolyses starch into the disaccharide maltose and other small polymers of glucose that contain three to nine glucose molecules. However, the food remains in the mouth only a short time, so probably not more than 5 percent of all the starches will have become hydrolysed by the time the food is swallowed. However, starch digestion sometimes continues in the body and fundus of the stomach for as long as 1 hour before the food becomes mixed with the stomach secretions. Then the activity of the salivary amylase is blocked by acid of the gastric secretions because the amylase is essentially non active as an enzyme once the pH of the medium falls below about 4.0. Nevertheless, on the average, before food and its accompanying saliva do become completely mixed with the gastric secretions, as much as 30 to 40 percent of the starches will have been hydrolysed mainly to form maltose.

DIGESTION OF CARBOHYDRATES IN THE SMALL INTESTINE.

- Digestion by Pancreatic Amylase

Pancreatic secretion, like saliva, contains a large quantity of α-amylase that is almost identical in its function with the α-amylase of saliva but is several times as powerful. Therefore, within 15 to 30 minutes after the chyme empties from the stomach into the duodenum and mixes with pancreatic juice, virtually all the carbohydrates will have become digested. In general, the carbohydrates are almost totally converted into maltose and/or other small glucose polymers before passing beyond the duodenum or upper jejunum.

- Hydrolysis of Disaccharides and Small Glucose Polymers into Monosaccharides by Intestinal Epithelial Enzymes

The enterocytes lining the villi of the small intestine contain four enzymes (lactase, sucrase, maltase, and α-dextrinase), which are capable of splitting the disaccharides lactose, sucrose, and maltose, plus other small glucose polymers, into their constituent monosaccharides. These enzymes are located in the enterocytes covering the intestinal microvilli brush border, so the disaccharides are digested as they come in contact with these enterocytes. Lactose splits into a molecule of galactose and a molecule of glucose. Sucrose splits into a molecule of fructose and a molecule of glucose. Maltose and other small glucose polymers all split into multiple molecules of glucose. Thus, the final products of carbohydrate digestion are all monosaccharides. They are all water soluble and are absorbed immediately into the portal blood. In the ordinary diet, which contains far more starches than all other carbohydrates combined, glucose represents more than 80 percent of the final products of carbohydrate digestion, and galactose and fructose each represent seldom more than 10 percent.

DIGESTION OF PROTEINS

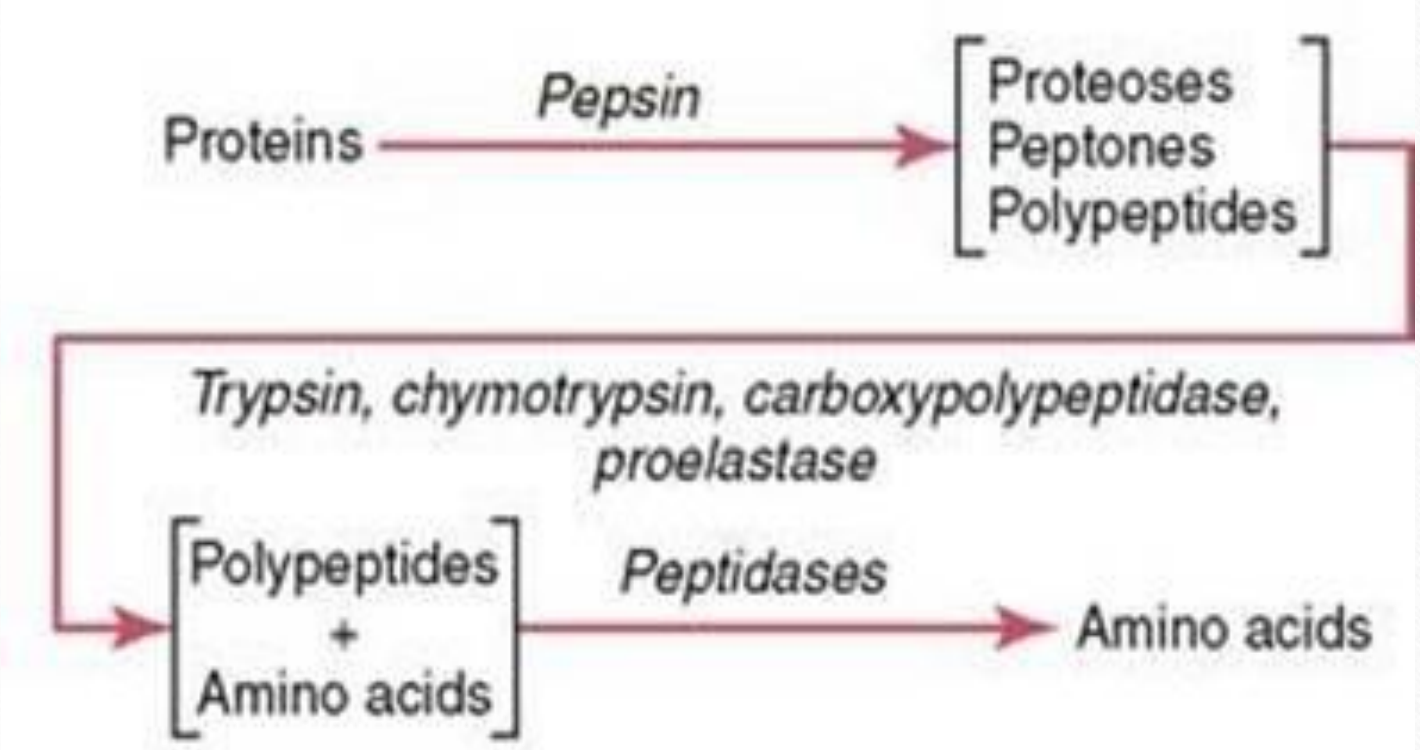
The dietary proteins are chemically long chains of amino acids bound together by peptide linkages. The characteristics of each protein are determined by the types of amino acids in the protein molecule and by the sequential arrangements of these amino acids.

DIGESTION OF PROTEINS IN THE STOMACH.

Pepsin, the important peptic enzyme of the stomach, is most active at a pH of 2.0 to 3.0 and is inactive at a pH above about 5.0. Consequently, for this enzyme to cause digestion of protein, the stomach juices must be acidic. The gastric glands secrete a large quantity of hydrochloric acid. This hydrochloric acid is secreted by the parietal (oxyntic) cells in the glands at a pH of about 0.8, but by the time it is mixed with the stomach contents and with secretions from the non oxyntic glandular cells of the stomach, the pH then averages around 2.0 to 3.0.

One of the important features of pepsin digestion is its ability to digest the protein collagen. Collagen is a major constituent of the intercellular connective tissue of meats; therefore, for the digestive enzymes of the digestive tract to penetrate meats and digest the other meat proteins, it is necessary that the collagen fibres be digested. Consequently, in persons who lack pepsin in the stomach juices, the ingested meats are less well penetrated by the other digestive enzymes and, therefore, may be poorly digested.

Pepsin only initiates the process of protein digestion, usually providing only 10 to 20 percent of the total protein digestion to convert the protein to proteoses, peptones, and a few polypeptides. This splitting of proteins occurs due to hydrolysis at the peptide linkages between amino acids.


Proteins
Pepsin
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Trypsin, chymotrypsin, carboxypolypeptidase,
proelastase
Polypeptides
+
Amino acids
Peptidases
Amino acids

Most Protein Digestion Results from Actions of Pancreatic Proteolytic Enzymes

Most protein digestion occurs in the upper small intestine, in the duodenum and jejunum, under the influence of proteolytic enzymes from pancreatic secretion. Immediately on entering the small intestine from the stomach, the partial breakdown products of the protein foods are attacked by major proteolytic pancreatic enzymes: trypsin, chymotrypsin, carboxypolypeptidase, and proelastase.

Both trypsin and chymotrypsin split protein molecules into small polypeptides; carboxypolypeptidase then cleaves individual amino acids from the carboxyl ends of the polypeptides. Proelastase, in turn, is converted into elastase, which then digests elastin fibres that partially hold meats together.

Only a small percentage of the proteins are digested all the way to their constituent amino acids by the pancreatic juices. Most remain as dipeptides and tripeptides.

Digestion of Peptides by Peptidases in the Enterocytes That Line the Small Intestinal Villi

The last digestive stage of the proteins in the intestinal lumen is achieved by the enterocytes that line the villi of the small intestine, mainly in the duodenum and jejunum. These cells have a brush border that consists of hundreds of microvilli projecting from the surface of each cell. In the membrane of each of these microvilli are multiple peptidases that protrude through the membranes to the exterior, where they come in contact with the intestinal fluids. The two important peptidase enzymes are aminopolypeptidase and several dipeptidases. They succeed in splitting the remaining larger polypeptides into tripeptides and dipeptides and a few into amino acids. Finally, inside the cytosol of the enterocyte are multiple other peptidases that are specific for the remaining types of linkages between amino acids.

Within minutes, virtually all the last dipeptides and tripeptides are digested to the final stage to form single amino acids; these then pass on through to the other side of the enterocyte and thence into the blood. More than 99 percent of the final protein digestive products that are absorbed are individual amino acids, with only rare absorption of peptides and very rare absorption of whole protein molecules.

DIGESTION OF FAT

By far the most abundant fats of the diet are the neutral fats, also known as triglycerides, each molecule of which is composed of a glycerol nucleus and three fatty acid side chains.

In the usual diet are also small quantities of phospholipids, cholesterol, and cholesterol esters. The phospholipids and cholesterol esters contain fatty acid and therefore can be considered fats. Cholesterol, however, is a sterol compound that contains no fatty acid, but it does exhibit some of the physical and chemical characteristics of fats; plus, it is derived from fats and is metabolized similarly to fats. Therefore, cholesterol is considered, from a dietary point of view, a fat.

DIGESTION OF FATS IN THE INTESTINE.

A small amount of triglycerides is digested in the stomach by lingual lipase that is secreted by lingual glands in the mouth and swallowed with the saliva. This amount of digestion is less than 10 percent and generally unimportant. Instead, essentially all fat digestion occurs in the small intestine as follows.

The First Step in Fat Digestion Is Emulsification by Bile Acids and Lecithin

The first step in fat digestion is physically to break the fat globules into small sizes so that the water-soluble digestive enzymes can act on the globule surfaces. This process is called *emulsification of the fat* and it begins by agitation in the stomach to mix the fat with the products of stomach digestion. Then, most of the emulsification occurs in the duodenum under the influence of *bile*, the secretion from the liver that does not contain any digestive enzymes. However, bile does contain a large quantity of *bile salts*, as well as the phospholipid *lecithin*.

Both of these, *but especially the lecithin*, are extremely important for emulsification of the fat. The polar parts (the points where ionization occurs in water) of the bile salts and lecithin molecules are highly soluble in water, whereas most of the remaining portions of their molecules are highly soluble in fat. Therefore, the fat-soluble portions of these liver secretions dissolve in the surface layer of the fat globules, with the polar portions projecting. The polar projections, in turn, are soluble in the surrounding watery fluids, which greatly decreases the interfacial tension of the fat and makes it soluble as well.

When the interfacial tension of a globule of nonmiscible fluid is low, this nonmiscible fluid, on agitation, can be broken up into many tiny particles far more easily than it can when the interfacial tension is great. Consequently, a major function of the bile salts and lecithin, especially the lecithin, in the bile is to make the fat globules readily fragmentable by agitation with the water in the small bowel. This action is the same as that of many detergents that are widely used in household cleaners for removing grease.

Each time the diameters of the fat globules are significantly decreased as a result of agitation in the small intestine, the total surface area of the fat increases many fold. The lipase enzymes are water-soluble compounds and can attack the fat globules only on their surfaces. Consequently, this detergent function of bile salts and lecithin is very important for digestion of fats.

Triglycerides Are Digested by Pancreatic Lipase

By far the most important enzyme for digestion of the triglycerides is *pancreatic lipase*, present in enormous quantities in pancreatic juice, enough to digest within 1 minute all triglycerides that it can reach. In addition, the enterocytes of the small intestine contain additional lipase, known as *enteric lipase*, but this is usually not needed

Most of the triglycerides of the diet are split by pancreatic lipase into *free fatty acids* and *2-monoglycerides*

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ABSORPTION OF NUTRIENTS.

Carbohydrates Are Mainly Absorbed as Monosaccharides

Essentially all the carbohydrates in the food are absorbed in the form of monosaccharides; only a small fraction is absorbed as disaccharides and almost none as larger carbohydrate compounds. By far the most abundant of the absorbed monosaccharides is *glucose*, usually accounting for more than 80 percent of carbohydrate calories absorbed. The reason for this is that glucose is the final digestion product of our most abundant carbohydrate food, the starches. The remaining 20 percent of absorbed monosaccharides is composed almost entirely of *galactose* and *fructose*, the galactose derived from milk and the fructose as one of the monosaccharides digested from cane sugar.

Virtually all the monosaccharides are absorbed by an active transport process. Let us first discuss the absorption of glucose.

Glucose Is Transported by a Sodium Co-Transport Mechanism

In the absence of sodium transport through the intestinal membrane, virtually no glucose can be absorbed. The reason is that glucose absorption occurs in a co-transport mode with active transport of sodium.

There are two stages in the transport of sodium through the intestinal membrane. First is active transport of sodium ions through the basolateral membranes of the intestinal epithelial cells into the blood, thereby depleting sodium inside the epithelial cells. Second, decrease of sodium inside the cells causes sodium from the intestinal lumen to move through the brush border of the epithelial cells to the cell interiors by a process of *secondary active transport*. That is, a sodium ion combines with a *transport protein*, but the transport protein will not transport the sodium to the interior of the cell until the protein also combines with some other appropriate substance such as glucose. Intestinal glucose also combines simultaneously with the same transport protein and then both the sodium ion and glucose molecule are transported together to the interior of the cell. Thus, the low concentration of sodium inside the cell literally “drags” sodium to the interior of the cell and along with it the glucose at the same time. Once inside the epithelial cell, other transport proteins and enzymes cause facilitated diffusion of the glucose through the cell’s basolateral membrane into the paracellular space and from there into the blood.

To summarize, it is the initial active transport of sodium through the basolateral membranes of the intestinal epithelial cells that provides the eventual motive force for moving glucose also through the membranes.

Absorption of Other Monosaccharides

Galactose is transported by almost exactly the same mechanism as glucose. Conversely, fructose transport does not occur by the sodium co-transport mechanism. Instead, fructose is transported by facilitated diffusion all the way through the intestinal epithelium but not coupled with sodium transport.

Much of the fructose, on entering the cell, becomes phosphorylated, then converted to glucose, and finally transported in the form of glucose the rest of the way into the blood. Because fructose is not co-transported with sodium, its overall rate of transport is only about one half that of glucose or galactose.

Absorption of Proteins as Dipeptides, Tripeptides, or Amino Acids

Most proteins, after digestion, are absorbed through the luminal membranes of the intestinal epithelial cells in the form of dipeptides, tripeptides, and a few free amino acids. The energy for most of this transport is supplied by a sodium co-transport mechanism in the same way that sodium co-transport of glucose occurs. That is, most peptide or amino acid molecules bind in the cell's microvillus membrane with a specific transport protein that requires sodium binding before transport can occur. After binding, the sodium ion then moves down its electrochemical gradient to the interior of the cell and pulls the amino acid or peptide along with it. This is called *co-transport* (or *secondary active transport*) *of the amino acids and peptides.* A few amino acids do not require this sodium co-transport mechanism but instead are transported by special membrane transport proteins in the same way that fructose is transported, by facilitated diffusion.

At least five types of transport proteins for transporting amino acids and peptides have been found in the luminal membranes of intestinal epithelial cells. This multiplicity of transport proteins is required because of the diverse binding properties of different amino acids and peptides.

Absorption of Fats

When fats are digested to form monoglycerides and free fatty acids, both of these digestive end products first become dissolved in the central lipid portions of *bile micelles*. In this form, the monoglycerides and free fatty acids are carried to the surfaces of the microvilli of the intestinal cell brush border and then penetrate into the recesses among the moving, agitating microvilli. Here, both the monoglycerides and fatty acids diffuse immediately out of the micelles and into the interior of the epithelial cells, which is possible because the lipids are also soluble in the epithelial cell membrane. This leaves the bile micelles still in the chyme, where they function again and again to help absorb still more monoglycerides and fatty acids.

Thus, the micelles perform a “ferrying” function that is highly important for fat absorption. In the presence of an abundance of bile micelles, about 97 percent of the fat is absorbed; in the absence of the bile micelles, only 40 to 50 percent can be absorbed.

After entering the epithelial cell, the fatty acids and monoglycerides are taken up by the cell’s smooth endoplasmic reticulum; here, they are mainly used to form new triglycerides that are subsequently released in the form of *chylomicrons* through the base of the epithelial cell, to flow upward through the thoracic lymph duct and empty into the circulating blood.

Maximum Absorption Capacity of the Large Intestine

The large intestine can absorb a maximum of 5 to 8 liters of fluid and electrolytes each day. When the total quantity entering the large intestine through the ileocecal valve or by way of large intestine secretion exceeds this amount, the excess appears in the feces as diarrhea. As noted earlier in the chapter, toxins from cholera or certain other bacterial infections often cause the crypts in the terminal ileum and in the large intestine to secrete 10 or more liters of fluid each day, leading to severe and sometimes lethal diarrhea.

Bacterial Action in the Colon

Numerous bacteria, especially colon bacilli, are present even normally in the absorbing colon. They are capable of digesting small amounts of cellulose, in this way providing a few calories of extra nutrition for the body. In herbivorous animals, this source of energy is significant, although it is of negligible importance in human beings.

Other substances formed as a result of bacterial activity are vitamin K, vitamin B_{12}, thiamine and various gases that contribute to *flatus* in the colon, especially carbon dioxide, hydrogen gas, and methane. The bacteria-formed vitamin K is especially important because the amount of this vitamin in the daily ingested foods is normally insufficient to maintain adequate blood coagulation.

Composition of the Feces

The feces normally are about three-fourths *water* and one-fourth *solid matter* that is composed of about 30 percent *dead bacteria*, 10 to 20 percent *fat*, 10 to 20 percent *inorganic matter*, 2 to 3 percent *protein*,and 30 percent *undigested roughage* from the food and dried constituents of digestive juices, such as bile pigment and sloughed epithelial cells. The brown color of feces is caused by *stercobilin* and *urobilin*,derivatives of bilirubin. The odor is caused principally by products of bacterial action; these products vary from one person to another, depending on each person’s colonic bacterial flora and on the type of food eaten. The actual odoriferous products include *indole*, *skatole*, *mercaptans*, and *hydrogen sulfide*.

Reference

Guyton and Hall Textbook of Medical Physiology, 12th Edition.

Chapter 65

Digestion and Absorption in the Gastrointestinal Tract.