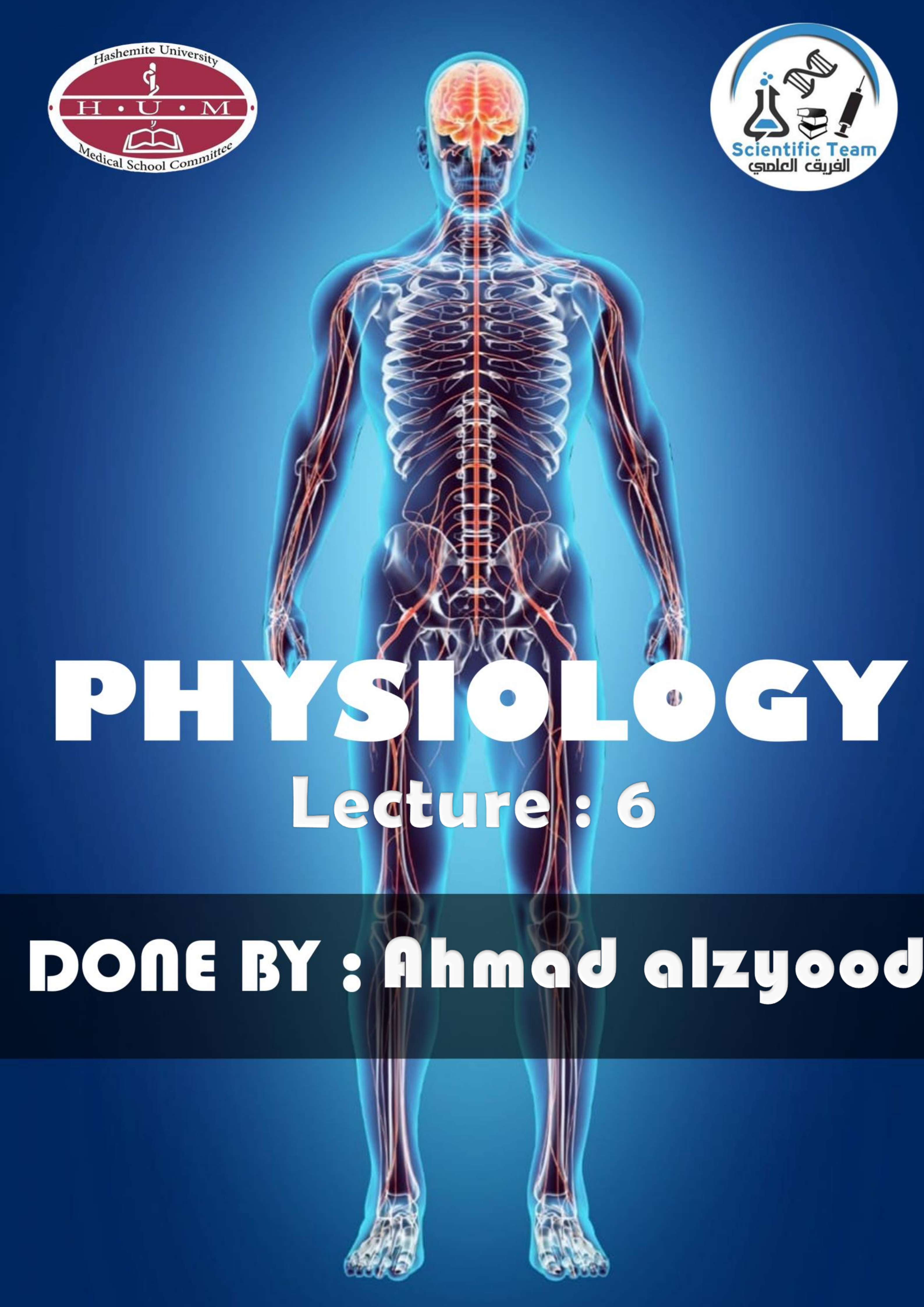
Hashemite University
H · U · M
Medical School Committee

Scientific Team
الفريق العلمي



PHYSIOLOGY

Lecture : 6

DONE BY : Ahmad alzyood

Digestion

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, they are useless as nutrients without preliminary digestion. This chapter discusses the processes by which carbohydrates, fats, and proteins are digested into small enough compounds for absorption and the mechanisms by which the digestive end products, as well as water, electrolytes, and other substances, are absorbed.

Hydrolysis → breakdown of molecules by adding H2O

- Carbohydrates : There are 3 types of sugar in our food : Poly- ,di- and mono-saccharide. Starch for example is a polysaccharide consist of glucose that bound to one another by condensation. This phenomenon means that a hydrogen ion (H+) has been removed from one of the monosaccharides, and a hydroxyl ion (OH−) has been removed from the next one.
- Neutral fat or Triglycerides : Consist of three fatty acids and one glycerol. (three molecules of water are removed) Proteins Consist of Amino acids that are linked by peptide linkage
- Therefore, the chemistry of digestion is simple because, in the case of all three major types of food, the same basic process of hydrolysis is involved. **<u>The only difference</u>** lies in the types of enzymes required to promote the hydrolysis reactions for each type of food.

$$R''-R'+H_2O \xrightarrow[\text{enzyme}]{\text{Digestive}} R''OH+R'H$$

➢ Digestion of carbohydrates :

Carbohydrate Foods of the Diet. 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, pectins, dextrins, and minor quantities of carbohydrate derivatives in meats.

The diet also contains a large amount of cellulose, which is a carbohydrate. However, enzymes capable of hydrolyzing cellulose are not secreted in the human digestive tract. Consequently, cellulose cannot be considered a food for humans.

Digestion of Carbohydrates Begins 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 hydrolyzes starch into the disaccharide maltose and other small polymers of glucose that contain three to nine glucose molecules.

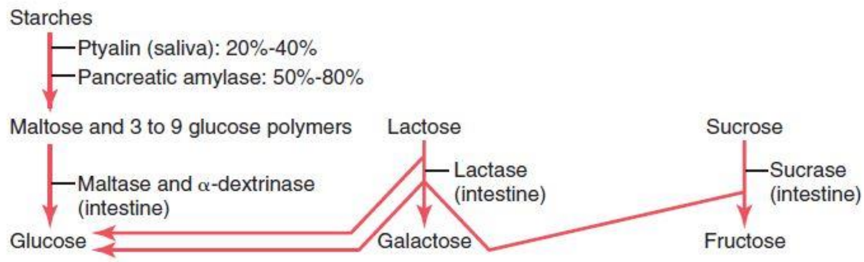


Figure 66-1. Digestion of carbohydrates.

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 hydrolyzed by the time the food is swallowed. 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. Activity of the salivary amylase is <u>then blocked by acid of the gastric secretions</u> because the amylase is essentially inactive as an enzyme once the pH of the medium falls below about 4.0. Nevertheless, on average, before food and its accompanying saliva become completely mixed with the gastric secretions, as much as 30 to 40 percent of the starches will have been hydrolyzed, mainly to form maltose.

Digestion of carb. In small intestine. Digestion by Pancreatic Amylase. Pancreatic secretion, like saliva, contains a large quantity of α-amylase that is almost identical in its function to 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 seldom represent more than 10 percent.

➢ Digestion of Protein

Proteins of the Diet. 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. The physical and chemical characteristics of different proteins important in human tissues are discussed in Chapter 70.

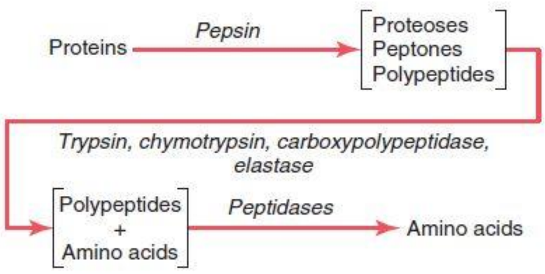


Figure 66-2. Digestion of proteins.

Digestion of Proteins in the Stomach. Pepsin, an 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. As explained in Chapter 65, 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 about0.8, 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, a highly favorable range of acidity for pepsin activity. One of the important features of pepsin digestion is its ability to digest the protein collagen, an albuminoid type of protein that is affected little by other digestive enzymes. Collagen is a major constituent of the intercellular connective tissue of meats; therefore, for the digestive enzymes to penetrate meats and digest the other meat proteins, it is necessary that the collagen fibers 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 as a result of hydrolysis at the peptide linkages between 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 upon entering the small intestine from the stomach, the partial breakdown products of the protein foods are attacked by the major proteolytic pancreatic enzymes trypsin, chymotrypsin, carboxypolypeptidase, and elastase. 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 fibers 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. Two types of peptidase enzymes are especially important, aminopolypeptidase and several dipeptidases. They split the remaining larger polypeptides into tripeptides and dipeptides and a few into amino acids. The amino acids, dipeptides, and tripeptides are easily transported through the microvillar membrane to the interior of the enterocyte. 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, which 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. Even these few absorbed molecules of whole protein can sometimes cause serious allergic or immunologic disturbances.

DIGESTION OF FATS.

Fats of the Diet. 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, as shown in Figure 66-3. Neutral fat is a major constituent in food of animal origin but much less so in food of plant origin. Small quantities of phospholipids, cholesterol, and cholesterol esters are also present in the usual diet. The phospholipids and cholesterol esters contain fatty acid and therefore can be considered fats. Cholesterol is a sterol compound that contains no fatty acid, but it does exhibit some of the physical and chemical characteristics of fats; in addition, it is derived from fats and is metabolized similarly to fats. Therefore, cholesterol is considered, from a dietary point of view, to be a fat.

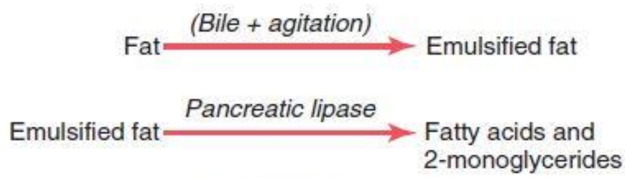


Figure 66-4. Digestion of fats.

Digestion of Fats Occurs Mainly in the Small Intestine. A small amount of triglycerides is digested in the stomach by lingual lipase secreted by lingual glands in the mouth and swallowed with the saliva. This amount of digestion is less than 10 percent and is 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 to physically 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. Most of the emulsification then 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 substances, but especially the lecithin, are extremely important for emulsification of the fat. The polar parts (i.e., 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 non-miscible fluid, upon 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 manyfold. Because the average diameter of the fat particles in the intestine after emulsification has occurred is less than 1 micrometer, this represents an increase of as much as **1000-fold** in total surface areas of the fats caused by the emulsification process. 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. The enterocytes of the small intestine contain additional lipase, known as enteric lipase, but it is usually not needed. End Products of Fat Digestion Are Free Fatty Acids. Most of the triglycerides of the diet are split by pancreatic lipase into free fatty acids and 2-monoglycerides, as shown in Figure 66-4.

Bile Salts Form Micelles That Accelerate Fat Digestion. The hydrolysis of triglycerides is a highly reversible process; therefore, accumulation of monoglycerides and free fatty acids in the vicinity of digesting fats quickly blocks further digestion. However, the bile salts play the additional important role of removing the monoglycerides and free fatty acids from the vicinity of the digesting fat globules almost as rapidly as these end products of digestion are formed. This process occurs in the following way. When bile salts are of a high enough concentration in water, they have the propensity to form micelles, which are small spherical, cylindrical globules 3 to 6 nanometers in diameter composed of 20 to 40 molecules of bile salt. These micelles develop because each bile salt molecule is composed of a sterol nucleus that is highly fat-soluble and a polar group that is highly water-soluble. The sterol nucleus encompasses the fat digestate, forming a small fat globule in the middle of a resulting micelle, with polar groups of bile salts projecting outward to cover the surface of the micelle. Because these polar groups are negatively charged, they allow the entire micelle globule to dissolve in the water of the digestive fluids and to remain in stable solution until the fat is absorbed into the blood. The bile salt micelles also act as a transport medium to carry the monoglycerides and free fatty acids, both of which would otherwise be relatively insoluble, to the brush borders of the intestinal epithelial cells. There the monoglycerides and free fatty acids are absorbed into the blood, as discussed later, but the bile salts are released back into the chyme to be used again and again for this "ferrying" process.

Digestion of Cholesterol Esters and Phospholipids. Most cholesterol in the diet is in the form of cholesterol esters, which are combinations of free cholesterol and one molecule of fatty acid. Phospholipids also contain fatty acid within their molecules. Both the cholesterol esters and the phospholipids are hydrolyzed by two other lipases in the pancreatic secretion that free the fatty acids—the enzyme cholesterol ester hydrolase to hydrolyze the cholesterol ester, and phospholipase A2 to hydrolyze the phospholipid. The bile salt micelles play the same role in "ferrying" free cholesterol and phospholipid molecule digestates that they play in ferrying monoglycerides and free fatty acids. Indeed, essentially no cholesterol is absorbed **without** this function of the micelles.

Lecture : #