DIGESTION AND ABSORPTION OF FATS

DIETARY FATS

Types of fats. Fats are of three types:

- Simple fats or neutral fats, e.g. triglycerides and cholesterol.
- Compound fats, e.g. phospholipids.
- Associated fats, e.g. steroids and fat soluble vitamins.

Dietary fat is of both vegetable and animal origin. Mostly it is in the form of neutral fat (triglycerides). It also includes small amounts of phospholipids, cholesterol, some free fatty acids, lecithin and cholesterol esters.

Daily intake of fats in the diet varies widely, from about 25-160 gm.

DIGESTION OF FATS

Site of digestion

Although lipolytic enzymes are secreted in the mouth (*lingual lipase*) and stomach (*gastric lipase*), their action is so insignificant that practically digestion of all the dietary fats occurs in the small intestine. Gastric lipase which initiates fat digestion acts only on butter. Under normal conditions gastric lipase is soon inactivated by gastric juice (pH 1-2), as it is inactivated at pH 2.5 and acts at an optimum pH of 4.5. Some fat digestion in stomach may occur under following exceptional circumstances:

- Achlorhydria (i.e. gastric juice cannot inactivate gastric lipase),
- Regurgitation of pancreatic lipase from the duodenum into the stomach, and
- In young suckling animals which ingest large quantities of milk, the fat of milk is present in an emulsified form and digested, and inhibit the secretion of gastric juice.

Mechanism of digestion of fats

The digestion of fat includes three steps:

- Emulsification of fat by bile salts,
- Hydrolysis of fat by pancreatic and intestinal lipolytic enzymes, and
- Acceleration of fat digestion by micelle formation.

1. Emulsification of fat by bile salts

- Emulsification, i.e. breaking of large fat drops into smaller droplets is a prerequisite for action of pancreatic lipase. It is so, because the pancreatic lipase being water soluble acts only on the oil-water interface of fat. The surface area available for the action of lipase is increased many thousand times by the emulsification of fats.

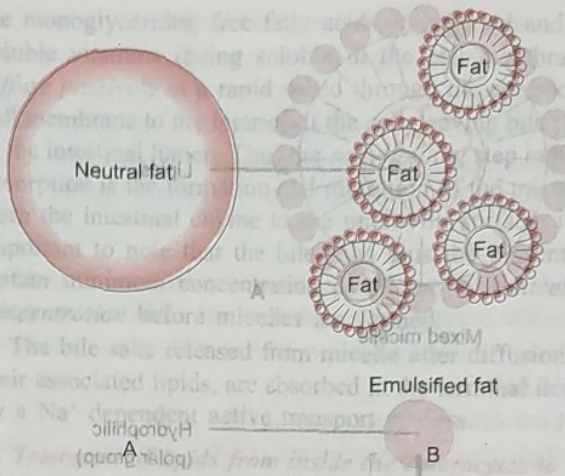


Fig.7.7-5. Emulsification of fats by bile salts: A, a large fat particle; and B, small fat particles surrounded by bile salts.

- Emulsification of fat is caused by bile salts because of their property of lowering the surface tension (detergent like action). With the lowered surface tension of the fats, the segmentation movements of small intestine break up large fat globules into fine droplets (1 µm in diameter). Lecithin (a component of bile) which has a stabilization action on the emulsions, greatly enhances the emulsifying action of bile salts. The bile salts surround the fine fat droplets in such a way that their lipophilic non-polar ends are towards the fat and their hydrophilic polar ends separate the fat droplets from the aqueous phase (Fig. 7.7-5).

2. Hydrolysis of fat droplets by pancreatic and intestinal lipolytic enzymes

Pancreatic juice is markedly alkaline (pH 7.8 to 8.4). When it mixes with the acidic chyme (pH 6.0) coming from stomach into the duodenum, the pH of chyme is adjusted to about 7 (which is optimal pH for the action of pancreatic lipases).

Pancreatic lipolytic enzymes. Pancreatic juice contains three types of lipolytic enzymes. Their hydrolysing effects on fats are given:

i. ***Pancreatic lipase.*** Pancreatic lipase is a very powerful lipolytic enzyme. Fat digestion by it occurs very rapidly after emulsification because of the large-surface-to-volume ratio of the small globules. The colipase a protein present in the pancreatic juice displaces the bile salts from the fat droplet and allows the action of lipase. The pancreatic lipase hydrolyses almost all the triglycerides (neutral fat) of the food to produce two fatty acids and a 2-monoglycerides.

ii. ***Cholesterol ester hydrolase.*** Most of the dietary cholesterol is in the form of cholesterol esters which are

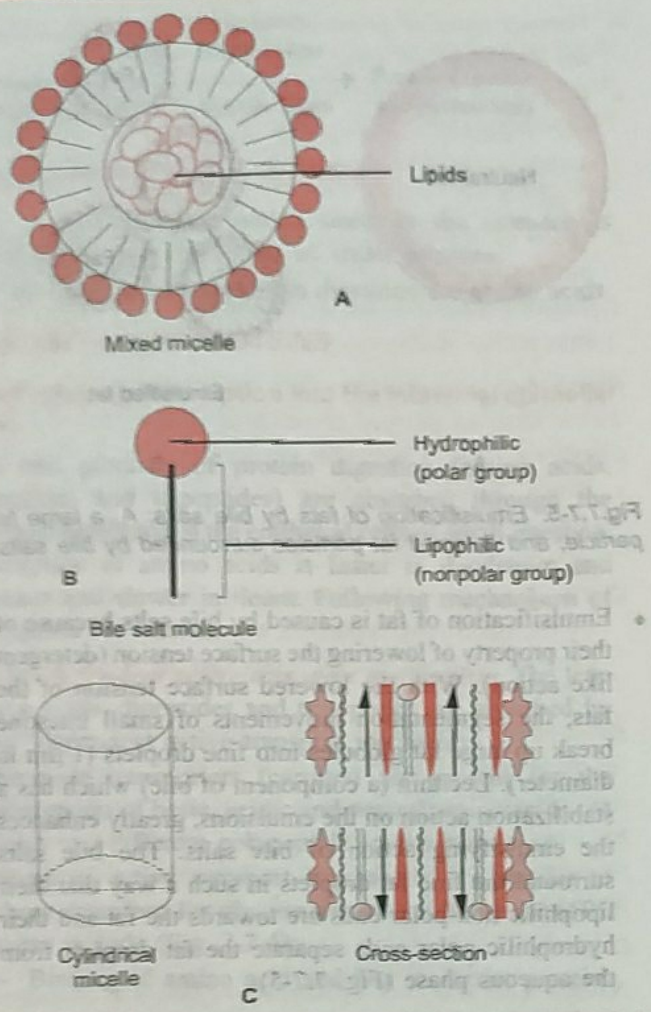
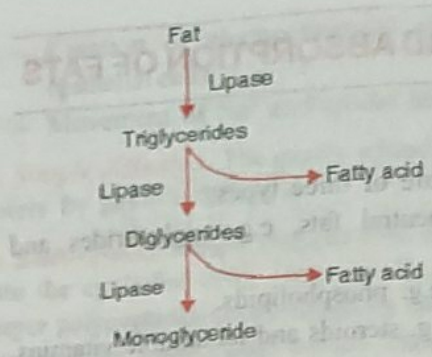


Fig. 7.7-6. Structure of micelle: A, a mixed micelle composed of lipids (monoglycerides, fatty acids, cholesterol) in the centre surrounded by bile salts; B, bile salt molecule showing globular (hydrophilic or polar) end and lipophilic (non-polar) end; C, a model of the structure of mixed (bile salt, and lipid) micelle and its cross-section showing arrangement of various lipid molecules; and D, diagrammatic structure of different lipid molecules.



hydrolysed to cholesterol and fatty acid by the cholesterol ester hydrolase.

iii. ***Phospholipase A_2.*** It is secreted in an inactive form pro-phospholipase A_2 and gets converted to active form. It hydrolyses phospholipids and separates fatty acid from them.

Intestinal lipolytic enzymes. Brush border of epithelial cells covering the intestinal villi contain small amount of lipase and cholesterol esterase. Their effects though minor, but are similar to that of pancreatic lipase.

3. Acceleration of fat digestion by micelle formation

The hydrolysis of triglycerides is highly reversible; therefore accumulation of monoglycerides and free fatty acids in the vicinity of digesting fats quickly blocks further digestion. This problem is solved by the property of bile salts to form micelle. The micelles are small water soluble cylindrical disc-shaped particles. Each micelle is composed of a central fat globule surrounded by about 30 molecules of bile salts in such a way that their lipid soluble non-polar ends are in the central fat globule and water soluble polar ends fan out to form the outer covering of micelle. The monoglycerides and free fatty acids released from the digestion of fat are quickly incorporated into the central fatty portion of the micelles forming, what are known as the *mixed micelles* (Fig. 7.7-6). In this way bile salts accelerate the fat digestion by allowing the lipolytic action to continue.

ABSORPTION OF FATS

Most of the fat absorption occurs in the duodenum; almost all the digested lipids are totally absorbed by the time the chyme reaches the mid jejunum. Absorption of fats is accomplished by following steps (Fig. 7.7-7):

1. Transportation as micelles to the brush border membrane. The micelle so formed (as described above) not only accelerates the fat digestion, but are also essential for the fat absorption as explained.

The insolubility of fat globules prevents their diffusion

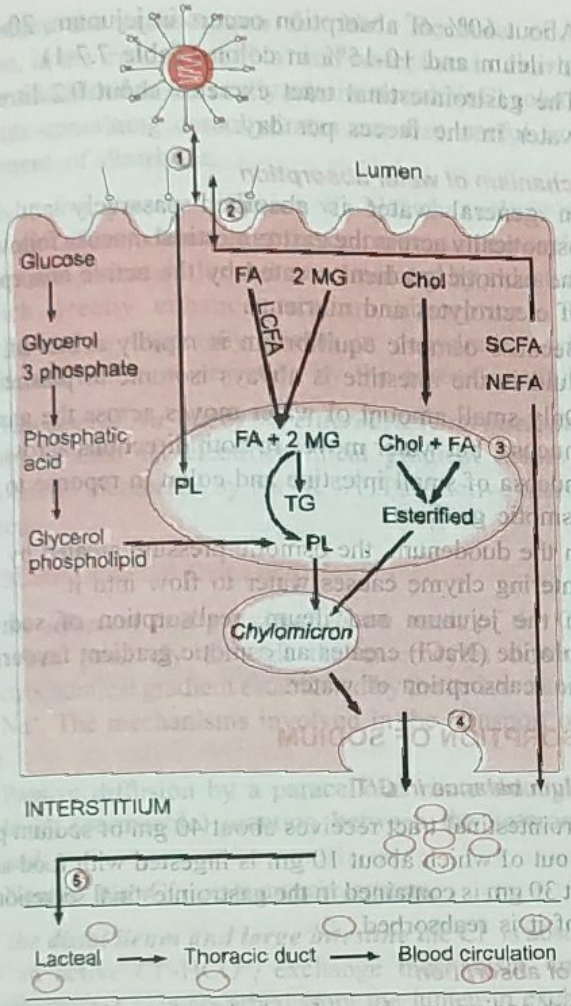


Fig. 7.7-7. Steps of fat absorption; 1, transportation of micelle to enterocytes brush border; 2, diffusion of lipids across the enterocyte membrane leaving bile salt in the lumen; 3, formation of chylomicron in the endoplasmic reticulum; 4, release of lipids into interstitium by exocytosis; and 5, diffusion of lipids from interstitium into lacteal (from where lipids enter into lymphatic circulation) and through thoracic duct into circulation. FA: fatty acid, MG: monoglycerides, chol: cholesterol, TG: triglycerides, LCFA: long chain fatty acid, SCFA: short chain fatty acids, NEFA: non-esterified fatty acids, and PL: phospholipid.

through the aqueous medium of the intestinal lumen to reach the brush border. This problem is solved by the bile salts by forming the micelle. As described above (Fig. 7.7-6) the outer surface of micelle is formed by water-soluble polar ends of bile salts, which helps the micelle to diffuse through the aqueous medium to reach the brush border membrane. Thus, the bile salt micelle acts as a transport vehicle for the products of fat digestion.

2. Diffusion of lipids across the enterocyte cell membrane. Once the micelle comes in contact with the cell membrane, the monoglycerides, free fatty acids, cholesterol and fat soluble vitamins (being soluble in the cell membrane) *diffuse passively* at a rapid speed through the enterocyte cell membrane to the interior of the cell, leaving bile salts in the intestinal lumen. Thus the *rate-limiting* step in lipid absorption is the formation and migration of the micelles from the intestinal chyme to the microvilli surface. It is important to note that the bile salts must be present in certain minimum concentration called *critical micellar concentration* before micelles are formed.

The bile salts released from micelle after diffusion of their associated lipids, are absorbed in the terminal ileum by a Na^+ dependent active transport process.

3. Transport of lipids from inside the enterocytes to the interstitial space. Once inside the cell, the end products of fat digestion enter the interstitium by two mechanisms:

i. Diffusion across the basal border of enterocyte. The small chain fatty acids (SCFA) with less than 12-14 carbon atoms are able to diffuse across the basal border of enterocytes to enter the interstitium.

ii. Formation and excretion of chylomicrons from enterocytes by exocytosis. The large chain fatty acids, cholesterol and lysophosphatides, enter the smooth endoplasmic reticulum, where they are reconstituted:

- 2-Monoglycerides are combined with fatty acids to produce triglycerides,
- Lysophosphatides are combined with fatty acids to form phospholipids, and
- Cholesterol is re-esterified.

The re-formed lipids coalesce to form a small lipid droplets (about 1 nm in diameter) called chylomicrons which are lined by β-lipoproteins synthesized. The chylomicrons are then excreted into the interstitium by *exocytosis* from the basolateral membrane of enterocyte. Covering of β-lipoproteins is essential for the exocytosis to occur. Therefore, in the absence of β-lipoprotein, exocytosis will not occur, and the enterocytes become engorged with lipids.

4. Transport of lipids into circulation. After exiting the enterocytes (i.e. in the interstitium), the chylomicrons merge into larger droplets that vary in size from 50-500 nm, depending on the amount of lipid being absorbed. From the interstitium the lipids diffuse into the *lacteals*, from which they enter the lymphatic circulation and via thoracic duct gain access into the blood circulation.

APPLIED ASPECTS

Lipid malabsorption

- Lipid malabsorption is much more common than carbohydrate and protein malabsorption.