CC5:UNIT III: Nutrients

LIPIDS/ FATS (Part -1)

Part 1(Introduction& importance of lipids in foods)

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Introduction:

The term lipid is applied to a group of natural substances characterised by their insolubility in water and their solubility in such “fat solvents” as ether, chloroform, boiling alcohol and benzene.

However, a novel definition and comprehensive system of classification of lipids were proposed in 2005 (Fahy *et al*., 2005).

The novel definition is chemically based and defines lipids as small hydrophobic or amphipathic (or amphiphilic) molecules that may originate entirely or in part through condensations of thioesters and/or isoprene units. (FAO, 2008)

Chemically, the lipids are either esters of fatty acids or substances capable of forming such esters. The word ‘Lipid’ is used when discussing the metabolism of fats in the body whereas the term ‘Fats’ is used the fatty component of foods and diets. It encompasses not only dietary sources of energy and the lipid constituents of cell and organelle membranes but also the fat-soluble vitamins, corticosteroid hormones, and certain mediators of electron transport, such as coenzyme Q.

Fats like carbohydrates are composed of three elements carbon, hydrogen and oxygen. The amount of oxygen is lower in relation to the other two elements. Therefore, fat is more concentrated source of energy than carbohydrates.

Lipids are wide spread in nature among all vegetable and animal matter. Some compounds of this group, such as phosphatide and sterols are found in all living cells. Lipids, with the proteins and carbohydrates form an essential part of the colloidal complex of protoplasm. Complex lipids are also found in large quantities in brain and nervous tissue. Chemically lipids are all esters of glycerol with higher fatty acids **(Figure 1)**.

This episode deals with the following important sub headings.

- ✓ Importance of fats and oils in Indian foods and cookery
- ✓ Classification of fats based on structure
- ✓ The principal lipids present in the foodstuff, which we take in normal diet
- ✓ Digestion of dietary lipids in GI tract
- ✓ Absorption of lipids

1. Importance of fats & oils in Indian foods and cookery

- ➢ Fat is used in shallow, pan-frying and deep fat frying. Shallow frying uses moderate temperatures thus it prevents smoking.
- ➢ On the other hand, deep frying causes smoking and there is a direct transfer of heat from hot to cold food till food cooks. This causes loss of moisture from food surface and makes the food lighter. This leads to cooking of the entire food by heat transfer to the interior. Therefore, the outer surface is crisp and brown due to rapid evaporation of water from the surface.
- ➢ Foods fried in fats get caramelized, gelatinized and dextrinised.
- ➢ Fats are an integral component in baking cakes, pastries and breads. They act as leavening and shortening agents in the above products.
- ➢ Fats and oils are important constituents of emulsions.
- ➢ Fats affect the smooth texture of products by interfering with sugar crystallization. They retard crystallization in crystalline candies. They also retard gelatinization in starch in mixtures thickened by starch.
- ➢ Fats improve the taste and palatability of foods cooked in it.
- ➢ They improve the flavour and aroma of foods and give them a characteristic taste.

2 Classification of Lipids based on structure

Lipids are important as dietary energy sources or as functional or structural constituents within the cell. The classification of lipids are as follows (**Figure 2**).

2.1. Simple lipids: These are esters of fatty acids with various alcohols. They are usually further classified according to the nature of the alcohols.

a) **Fats and Oils:** These are esters of fatty acids and glycerol, a form in which lipids are present in food. At room temperature, oils are liquids and fats are solids.

b) **Waxes:** These are esters of fatty acids with long chain aliphatic alcohols or with cyclic alcohols. These may be subdivided into true waxes, cholesterol esters, vitamin A and its carotenoid esters and Vitamin D esters.

2.2. Compound Lipids:

The compound lipids are esters of fatty acids containing groups other than, and in addition, to an alcohol and fatty acids, phosphorous, carbohydrate or protein.

a) **Phospholipids:** contain a phosphoric acid in addition to the alcohol and fatty acids and a nitrogenous base.
   Eg: lecithin, cephalin, sphingomyelin

b) **Glycolipids:** contain a fatty acid, carbohydrate and a nitrogenous base. Glycolipids can be subclassified into cerebrosides and gangliosides.

c) **Aminolipids, sulpholipids:** The sulpholipids yield sulphuric acid on hydrolysis.

d) **Lipoproteins**: are macromolecular complex of lipids with proteins. These compounds are found in mammalian plasma bound with proteins.
   There are four types of lipoproteins, they are:
   i) chylomicrons,
   ii) very low-density lipoprotein (VLDL)
   iii) low-density lipoprotein (LDL)
   iv) high-density lipoproteins (HDL)

2.3. Derived Lipids:

These are substances liberated during hydrolysis of simple and compound lipids which still retain the properties of lipids.

The important members of this group are sterols, fatty acids and alcohol.

a) ***Sterols***: Sterols are solid alcohols and form esters with fatty acids. In nature they occur in the free state in the form of esters.

Based on their origin sterols are classified as cholesterol (animal origin) and phytosterol (in plants).

Cholesterol is a complex type of lipid that is regularly synthesised by and stored in the liver. It is present in all animal products.

b) ***Fatty acids:*** Fatty acids are the main building blocks of fat. They have a methyl group (CH_3) at one end and a carboxyl group (COOH) at the other end with a chain of carbon and hydrogen atom in the middle. They have a basic formula $CH_3(CH_2)_nCOOH$. Where 'n' denotes the number of carbon atoms which may vary from 2 to 2l.

Fatty acids can be classified into three broad classes according to the degree of unsaturation;

i. saturated fatty acids (SFA) have no double bonds,
ii. monounsaturated fatty acids (MUFA) have one double bond and
iii. polyunsaturated fatty acids (PUFA) have two or more double bonds.

In general, these fatty acids have an even number of carbon atoms and have unbranched structures. The double bonds of naturally occurring unsaturated fatty acids are very often of the cis orientation **(Figure 3)**.

***Trans* fatty acids:** The orientation of hydrogen atoms around the double bond distinguishes *cis* fatty acids from ***trans* fatty acids (Figure 3)**. Most unsaturated fatty acids found in nature have double bonds in the *cis* configuration.

i. **Saturated Fatty Acids**

Saturated fatty acids (SFA) are those that are unable to absorb more hydrogen, usually stiff, hard fats. They are further classified into four subclasses according to their chain length **(Table 1)**:

- **Short - chain fatty acids**: Fatty acids with from 3 - 7 carbon atoms.
  Sources: Dairy fat (Butter)
- **Medium - chain fatty acids**: Fatty acids with from 8 - 13carbon atoms.
  Sources: dairy fat, coconut and palm kernel oils
- **Long - chain fatty acids**: Fatty acids with from 14 - 20 carbon atoms. (**Figure 4**)
  Sources: most fats and oils

- **Very - long-chain fatty acids**: Fatty acids with twenty - one or more carbon atoms.

  Sources: peanut oil

ii. **Unsaturated Fatty Acids**

Unsaturated fatty acids have one or more double bond in their molecule. Thus they are not saturated with hydrogen. They are liquid at room temperature.

Eg. Sunflower oil.

Unsaturated fatty acids may be monounsaturated or polyunsaturated depending on the number of double bonds. The unsaturated fatty acids are further classified into three sub - groups according their chain lengths.

- **Short - chain unsaturated fatty acids**: Fatty acids with 19 or fewer carbon atoms.
- **Long - chain unsaturated fatty acids**: Fatty acids with 20 - 24 carbon atoms.
- **Very – long - chain unsaturated fatty acids**: Fatty acids with 25 or more carbon atoms.

a) Monounsaturated fatty acids (MUFA): MUFA have only one double bond in their molecule (**Table 2)**.

Eg. olive oil, mustard oil, sunflower, safflower oil, fish oils

Oleic acid (OA - **Figure 4)** is the most common MUFA and it is present in considerable quantities in both animal and plant sources.

b) Polyunsaturated fatty acids (PUFA): PUFA can be divided into 12 families, ranging from double bonds located at the n-1 position to the n-12 position. The most important families, in terms of extent of occurrence and human health and nutrition, are the n-6 and n-3 families. The parent fatty acid of n-6 family is Linoleic acid (LA-**Figure 5**) and n-3 is α-linolenic acid (ALA-**Figure 5**). Linoleic (ω-6) and α-linolenic (ω-3) acids are the simple PUFA, which attain major proportions in most vegetable oils. Soyabean, rapeseed, green-leafy vegetables and mustard oils contribute significant proportion of α linolenic (ω-3) acid. Eiocosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are the most important n-3 fatty acids in human nutrition. EPA and DHA are components of marine lipids.

3. Digestion

The digestion of fats and other lipids poses a special problem because of (a) their insolubility in water, (b) lipolytic enzyme solubility in an aqueous medium has limits. However, in the gut this problem is solved by emulsification of fats. Particularly by bile salts, present in bile and phospholipids. This emulsification greatly increases the surface area of the dietary lipid targeted for digestion. Consequently, the accessibility of the fat to digestive enzymes is greatly increased by bile salt action.

Triacylglycerols (TAG), **phospholipids**, and **sterols** (mainly cholesterol) provide the lipid component of the Indian diet. Of these, triacylglycerols, customarily called fats or triglycerides. The consumption rate of TAG on an average is about 150g daily. Compare this to the cholesterol, which is typically 300-600mg/day, depending on the quantity of animal products in the diet.

Digestive enzymes involved in breaking down dietary lipids in the gastrointestinal tract are esterases. They cleave the ester bonds within triacylglycerols (lipase), phospholipids (phospholipases), and cholesteryl esters (cholesterol esterase).

a) Triacylglycerol Digestion

Most dietary triacylglycerol digestion is completed in the lumen of the small intestine (SI). The process begins in the stomach with lingual lipase released by the serous gland and gastric lipase produced by the chief cells of the stomach. Basal secretion of these lipases occurs continuously. These get stimulated by neural, dietary, and mechanical factors. These lipases account for much of the limited digestion (10% – 30%) of TAG that occurs in the stomach. The lipase activity is made possible by the enzymes at the low pH of the gastric juices. Both lingual and gastric lipases act on triacylglycerols containing medium- and short- chain fatty acids. They hydrolyze fatty acids, releasing a fatty acid and 1,2-diacylglycerols as products.

Dietary fat in the stomach will be hydrolyzed by lingual, gastric lipases and emulsification. Emulsification takes place through muscle contractions and shearing forces, which squirt the surface of a fat. Along with the muscle contraction, some of the emulsifiers in the acid medium include complex polysaccharides, phospholipids, and peptic digests of dietary proteins. The presence of undigested lipid in the stomach delays the rate at which the stomach contents empty. This inhibits the gastric motility and therefore, fats have a “high satiety value.”

Most TAG digestion occurs in the small intestine. Hydrolysis of the long chain fatty acids, require less acidity, appropriate lipases, more effective emulsifying agents (bile-salts). These conditions are provided in the lumen of the upper small intestine. The partially hydrolyzed lipid emulsion leaves the stomach and enters the duodenum as fine lipid droplets. Effective emulsification takes place with continuation of mechanical shearing and bile. Triacylglycerol breakdown products with bile salts acts as emulsifying agents. The action of pancreatic lipase on ingested triacylglycerols results in a complex mixture of diacylglycerols, monoacylglycerols, and FFAs. Therefore, the main path of this digestion progresses from triacylglycerols $\longrightarrow$ 2,3-diacylglycerols $\longrightarrow$ 2-monoacylglycerols. Only a small percentage of the triacylglycerols is hydrolyzed totally to free glycerol.

b). Cholesterol and Phospholipid Digestion

Cholesterol esters and phospholipids are hydrolyzed by a specific process. Esterified cholesterol undergoes hydrolysis to free cholesterol and a fatty acid. This reaction is catalyzed by the enzyme cholesterol esterase. Lecithin is hydrolytically removed by a specific esterase, phospholipase, producing lysolecithin and a FFA The products of the partial digestion of lipids, primarily 2-monoacylglycerols, lysolecithin, cholesterol, and fatty acids, combine with bile salts to form micelles. A summary of the digestion of lipids is shown in **Table 1** and **Figure 6.**

4. Absorption and Utilisation of Lipids

Small molecules of digested triglycerides (glycerol, short & medium chain fatty acids) are absorbed directly into the blood stream. They bind with albumin and are transported directly to the liver. As mentioned earlier larger molecules merge into spherical complexes known as micelles. The lipid contents of the micelles diffuse into the intestinal cells. Within the intestinal cells, micelles are placed into transport vehicle called chylomicrons. The intestinal cells then release chylomicrons into the lymphatic system. The lymph circulation empties the chylomicrons into the blood stream. The blood transport lipids to the rest of the body and cells absorb them and utilize for energy. This breakdown of fat to yield energy is called lipolysis. Majority of lipids enter via the lymph to the liver where the protein and lipid (cholesterol, triglycerides) are bound together to form lipoproteins. As we have seen in classification, there are four types of lipoproteins. They are chylomicrons, VLDL, LDL and HDL. Chylomicrons, VLDL and LDL serve to transport and deposit lipids from the intestine and liver to the tissues for absorption. LDL, has the highest cholesterol fraction. LDL favours lipid deposition in tissues including blood vessels and hence termed 'bad' cholesterol. HDL cholesterol removes the lipids from the tissues and transports it back to liver for disposal. Hence, it is termed as 'good cholesterol'. High levels of LDL cholesterol indicates a high risk of cardiovascular disease. Key features of intestinal absorption of lipid digestion products are depicted in **Figure 6.**

5. Conclusion:

The term lipid is applied to a group of naturally substances characterised by their insolubility in water and their solubility in "fat solvents". Fats like carbohydrates are composed of three elements carbon, hydrogen and oxygen. Fats and oils are important components of Indian foods. They have many functional role in bakery products, like shortening and leavening agents. Fats improve flavour, taste and palatability of food. Lipids are classified as simple lipids, compound lipids and derived lipids. The digestion lipids poses a special problem because of insolubility in water. The solubility can be solved by emulsification of fats by bile salts and phospholipids. Digestive enzymes involved in breaking down dietary lipids in the gastrointestinal tract are esterases, phospholipases, and cholesterol esterase. On digestion of lipids it first forms diacylglycerols and then monoacylglycerols. SCFAs are absorbed directly into the blood stream. Micelles formed by partial digestion of lipids diffuse into the intestinal cells. Micelles helps in the absorption of digested lipid contents which include FFA, 2-monoacylglycerols, cholesterol, cholesterol esters, and lysolecithin. Lipids are transported in blood by lipoproteins.

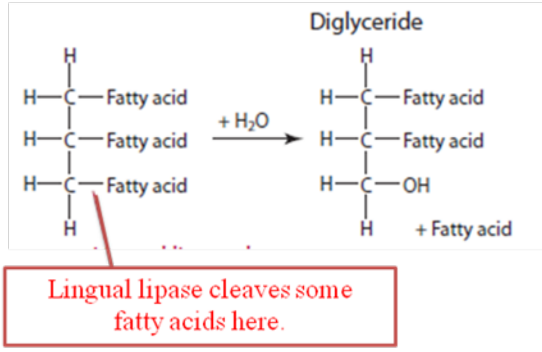
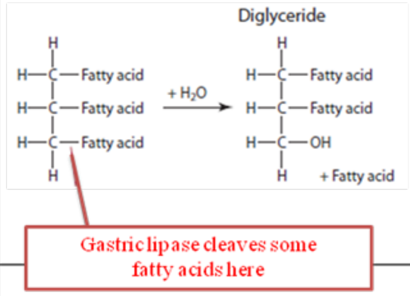
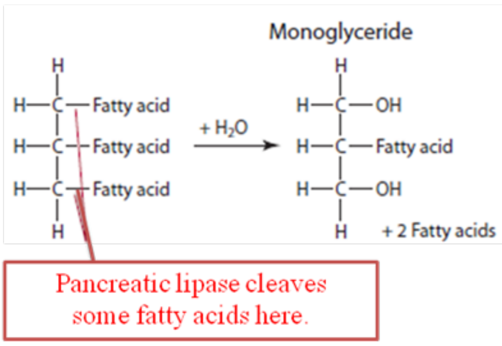
Table 1: Common saturated fatty acids in food fats and oils

Trivial name	Systematic name	Abbreviation	Typical sources
butyric	butanoic	C4:0	dairy fat (butter)
caproic	hexanoic	C6:0	dairy fat
caprylic	octanoic	C8:0	dairy fat, coconut and palm kernel oils
capric	decanoic	C10:0	dairy fat, coconut and palm kernel oils
lauric	dodecanoic	C12:0	coconut oil, palm kernel oil
myristic	tetradecanoic	C14:0	dairy fat, coconut oil, palm kernel oil
palmitic	hexadecanoic	C16:0	most fats and oils
stearic	octadecanoic	C18:0	most fats and oils
arachidic	eicosanoic	C20:0	peanut oil
behenic	docosanoic	C22:0	peanut oil
lignoceric	tetracosanoic	C24:0	peanut oil

Table 2: Common monounsaturated fatty acids in food fats and oils

Common name	Systematic name	Delta abbreviation	Typical sources
palmitoleic	cis-9-hexadecenoic	16:1Δ9c (9c-16:1)	fish oils, most animal and vegetable oils.
oleic	cis-9-octadecenoic	18:1Δ9c (9c-18:1) (OA)	all fats and oils, especially olive oil, mustard oil and high-oleic sunflower and safflower oil
cis-vaccenic	cis-11-octadecenoic	18:1Δ11c (11c-18:1)	most vegetable oils
gadoleic	cis-9-eicosenoic	20:1Δ9c (9c-20:1)	fish oils
	cis-11-eicosenoic	20:1Δ11c (11c-20:1)	fish oils
erucic acid	cis-13-docosenoic	22:1Δ13c (13c-22:1)	mustard seed oil, high erucic rapeseed oil
nervonic	cis-15-tetracosenoic	24:1Δ15c (15c-24:1)	fish oils

Table 3: Overview of Triacylglyceride Digestion

Location	Major events	Required Enzymes or Secretion	Details
Mouth	Triglycerides ↓ minor amount of digestion Triglycerides, diglycerides, and fatty acids	Lingual lipase produced in the salivary glands	
Stomach	↓ Additional digestion Triglycerides, diglycerides, and fatty acids	Gastric lipase produced in the stomach	
Small intestine	↓ Phase I: Emulsification Emulsified triglycerides, diglycerides, and fatty acid micelles ↓ Phase II: Enzymatic digestion Monoglycerides and fatty acids	Bile ; no lipase Pancreatic lipase produced in pancreas	

Gropper *et al*, (2009). In Advanced Nutrition and Human Metabolism

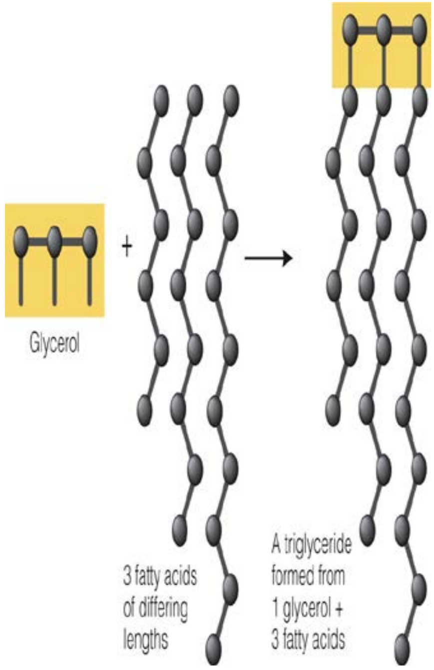


Figure 1: Structure of Lipid

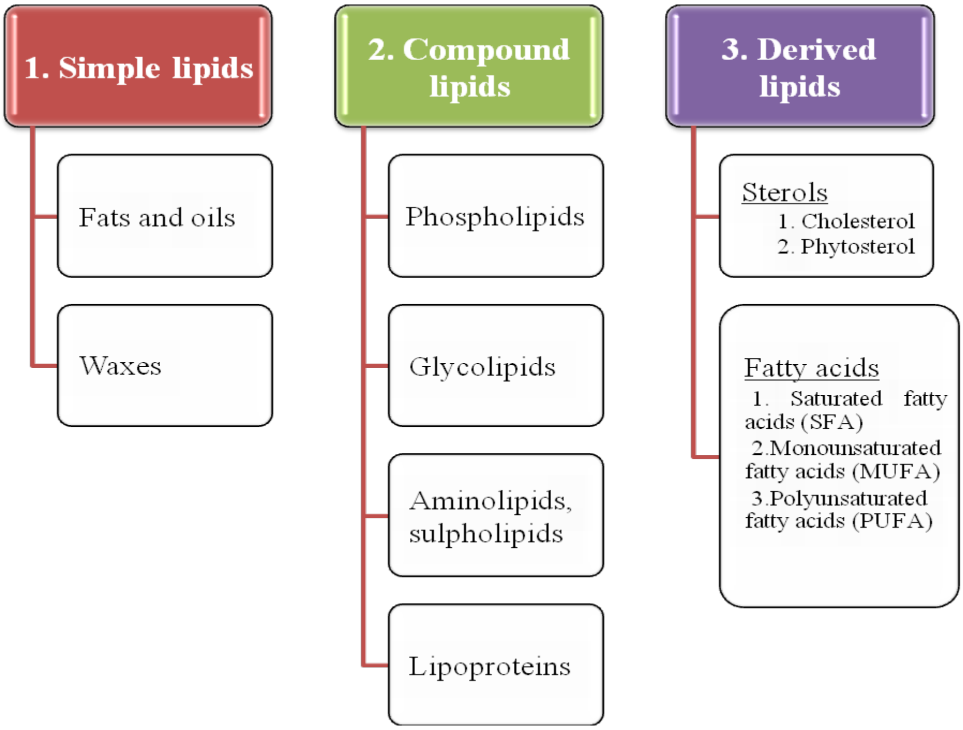


Figure 2: Classification of Lipids

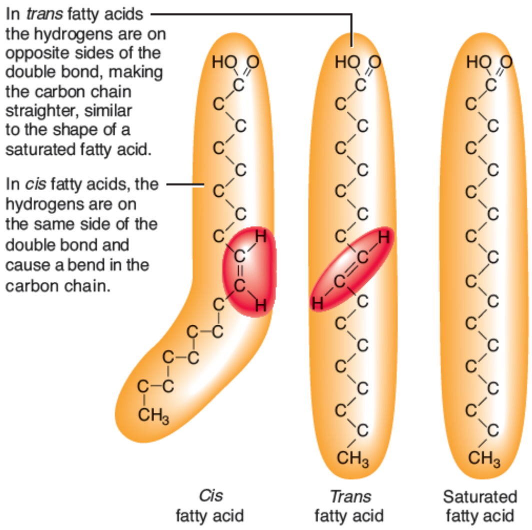


Figure 3: Structure of Different types of fat

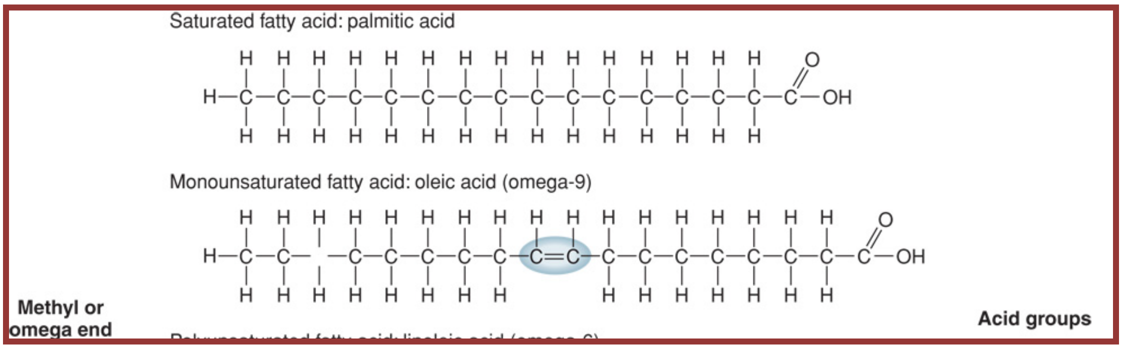


Figure 4: Saturated Fatty acid and Monounsaturated Fatty acid

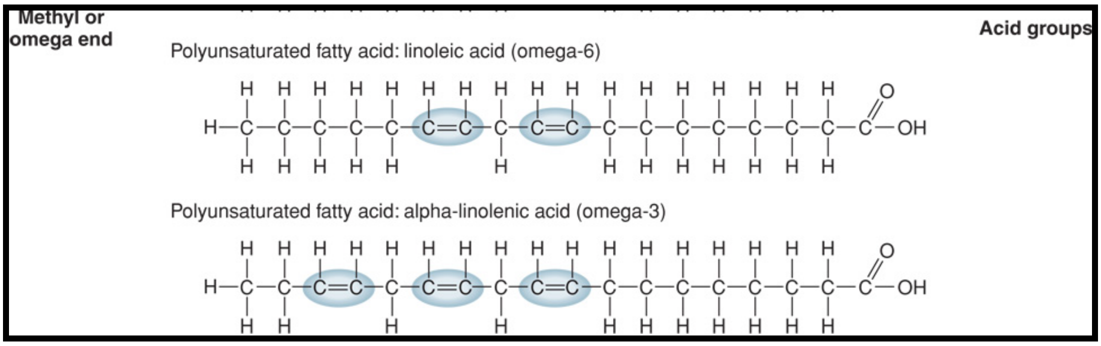


Figure 5: Polyunsaturated Fatty acids – ω3 and ω6

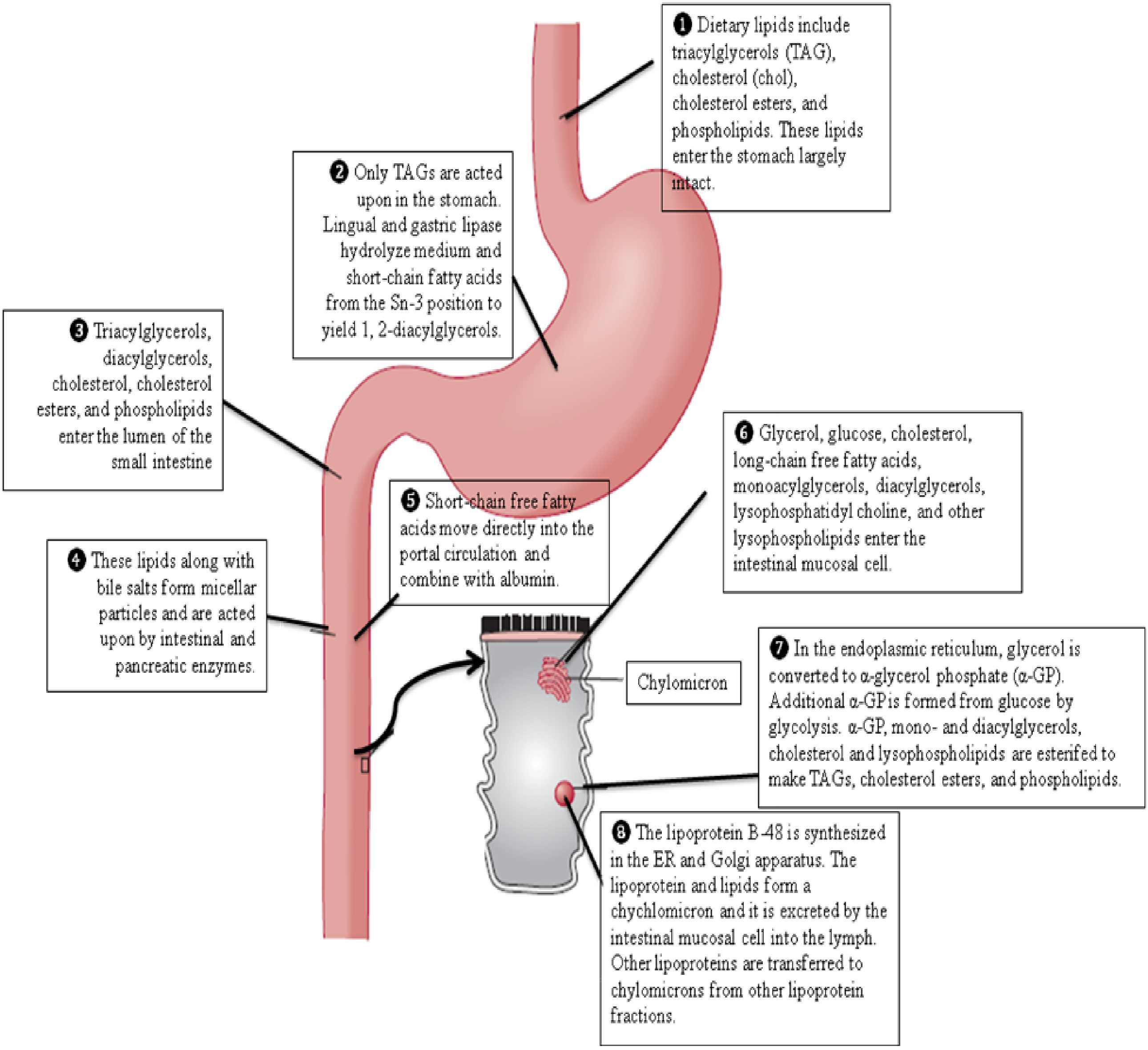


Figure 6: Summary of digestion and absorption of dietary lipids