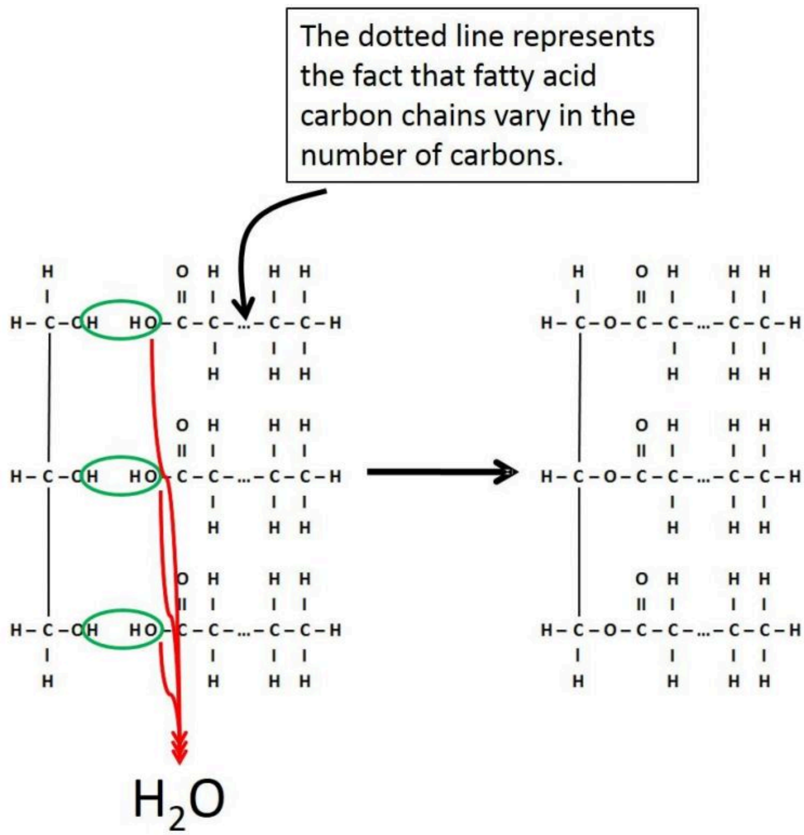
8.2.3

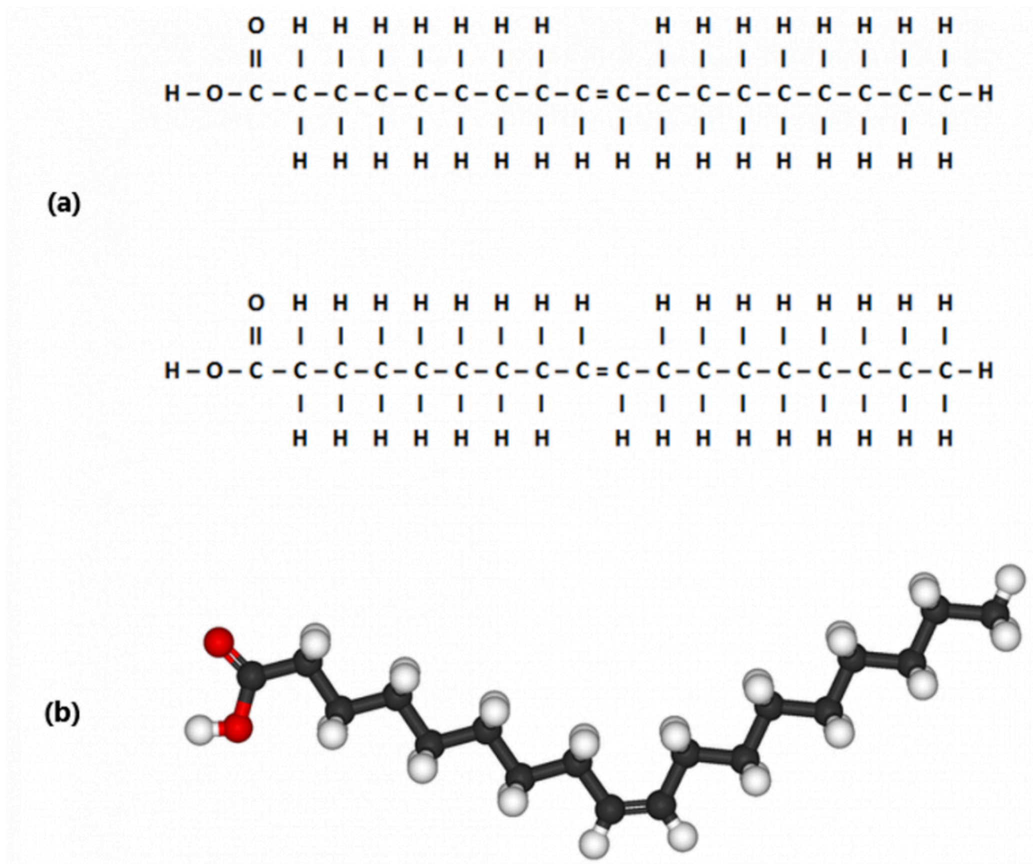
Lipid Digestion

The digestion and absorption of lipids presents a whole new set of complexities because most lipids are hydrophobic and the entire digestive tract is full of watery secretions. You could say lipids have a love/hate relationship with our intestinal system. Most of the lipids we eat (> 90%) are in the form of **triacylglycerols (triglycerides).** Triacylglycerols are composed of two molecular building blocks - **glycerol** and **fatty acids.** Fatty acids are chains of carbons that vary in length and the number and type of double bonds between carbons (see lipid module from BIO 264). Each fatty acid bonds to the glycerol through a dehydration synthesis reaction resulting in an "E" shaped molecule.



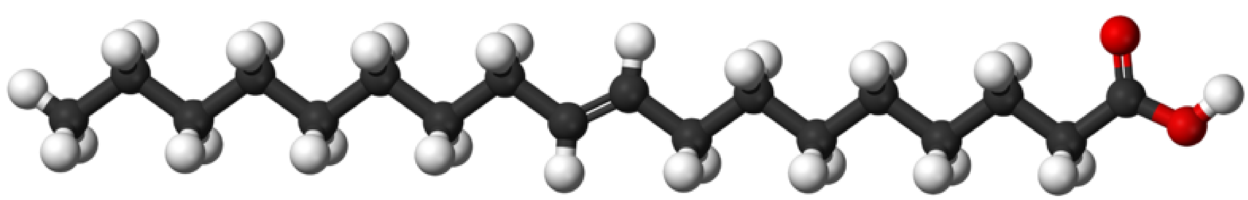
Bonding of Glycerol and Three Fatty Acids by Dehydration Synthesis Reaction to Form Triglyceride.
From Bio 264 textbook. Image created by JS at BYU-Idaho 2014

Fatty acid chains with no double bonds are referred to as saturated. This means that every carbon - carbon bond in the chain is a single bond which allows the linking of 2 hydrogen atoms to every carbon in the chain and 3 hydrogen atoms bonded to the last carbon. If a double bond occurs between two carbons in the hydrocarbon chain, then the carbon atoms connected by a double bond will each bond with one less hydrogen atom in order to maintain 4 bonds per carbon atom. We could say that because of the double bond, the fatty acid hydrocarbon chain is no longer "saturated" with hydrogen atoms at every carbon. Therefore, an unsaturated fatty acid will contain one or more double bonds. A fatty acid with one double bond is referred to as a monounsaturated fat and fatty acids with two or more double bonds are polyunsaturated fats. Additionally, some fats are named after the location of the double bond, such as omega 3 or omega 6 fats. This nomenclature refers to the location of the double bond on the carbons counting from the bottom of the chain up. All lipid-containing foods have a specific mixture of saturated and unsaturated fatty acids. Saturated fatty acids tend to be straight and do not have "kinks" or angles that would make "packing" or "stacking" together more difficult. The more tightly packed molecules of fat are, the more likely to be a solid at room temperature. Unsaturated fats can have either "cis" or "trans" double bonds in the hydrocarbon chains. "Cis" bonds allow for a kinked or angled geometry that makes it more difficult to "pack" together. Unsaturated fats with "cis" bonds include vegetable oils.



(a) Cis & Trans Double Bond in Monounsaturated Fatty Acid; (b) Cis Double Bond in Unsaturated Fatty Acid creating kink.

Image created by JS at BYU-Idaho 2014: Modified File: Oleic-acid-3D-ball-&-stick.png; Author: Benjah-bmm27; Site: https://commons.wikimedia.org/wiki/File:Oleic-acid-3D-ball-%26-stick.png; License: Public Domain

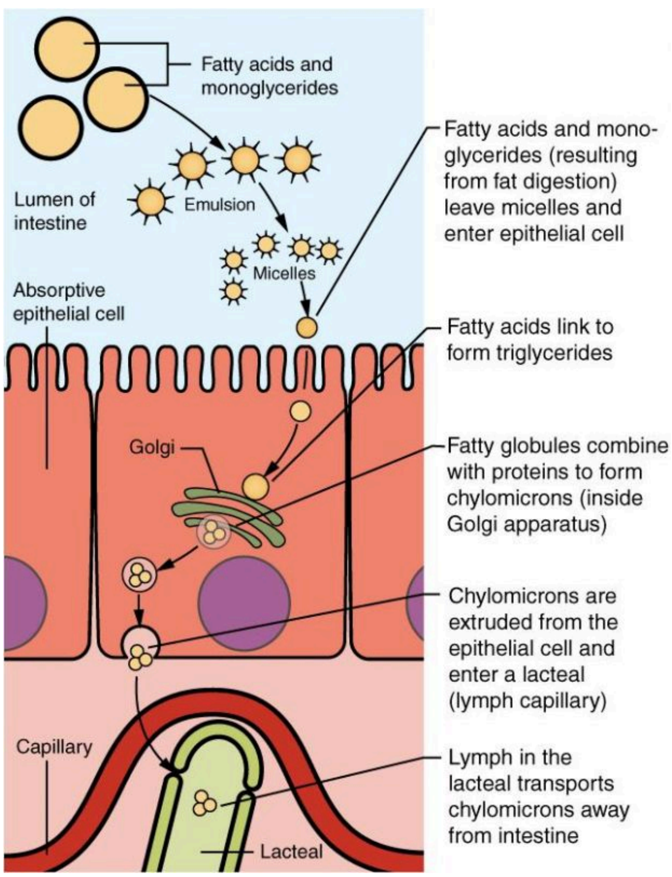


Trans Double Bonds in Unsaturated Fatty Acid.

Title: File: Tridecylic-acid-3D-balls.png; Author: Jynto and Ben Mills; Site: https://commons.wikimedia.org/wiki/File:Tridecylic-acid-3D-balls.png; License: public domain

Unsaturated fats with "Trans" bonds contain a geometry that resembles the straight line of a saturated fat. This geometry allows for trans unsaturated fats to pack together tightly enough that they will be found as a solid at room temperature. Products like Crisco and Margarine often have substantial quantities of "trans fats". Cis fats are the most common type found in nature, although there are some naturally occurring trans fats. Although trans fats are rare in nature they have appeared in the American diet as a product of oil processing. Food manufacturers take naturally occurring oils and use high pressures, high temperatures and hydrogen gas to artificially "hydrogenate" unsaturated fats, making them a creamy solid. A byproduct of this process is the formation of fats with rearranged double bonds (trans fats). This type of fat is usually listed as "partially hydrogenated oil" in the food ingredients list. Food companies are interested in the "hydrogenation" of oils so that they might get fat that has the texture, flavor and chemistry necessary for many of the food products we enjoy (i.e. many pastries, puddings, sauces, creamers, and confectioneries). Unfortunately, this switch of hydrogen arrangement has been shown to increase the risk of coronary heart disease.

The hydrophobic nature of lipids presents problems for the digestive process. Because lipids do not interact well with water they tend to form large fat droplets. These droplets make it difficult for the enzymes to access the molecular structure of the fat. To alleviate this problem the fats are **emulsified** (dispersed) by the actions of bile released from the liver and gallbladder into the small intestine. Components of bile act like detergents and help to break up the large masses of fat into smaller more manageable pieces. The emulsified products form small vesicles called micelles. **Lipases** secreted from the pancreas then act on the products of the micelles, forming smaller digested products of the fat molecules.



Lipid Absorption.
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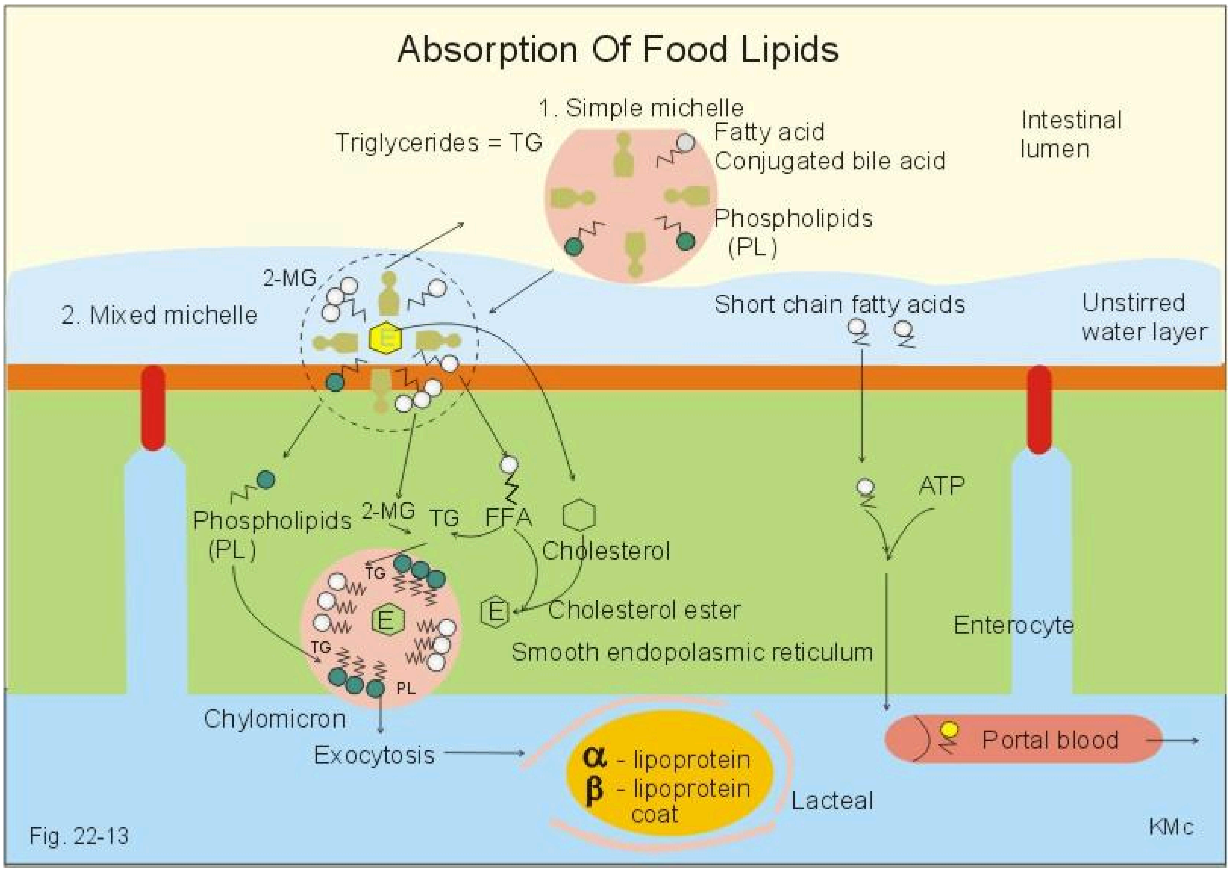
Lipid Absorption

Because the partially digested products inside the micelles are lipophilic, absorption across the lipid bilayer of the small intestinal cell occurs primarily through diffusion. However, once inside the cell, the lipids are again forced to interact with water. This issue is solved through the use of intracellular proteins called fatty acid-binding proteins that bind the digested lipids and transport them to the smooth endoplasmic reticulum. Once inside the smooth endoplasmic reticulum the fats are "reassembled" into triacylglycerols, phospholipids or cholesterol esters. The newly re-synthesized fats are packaged into new vesicles called chylomicrons that are formed from the smooth endoplasmic reticulum and modified in the Golgi apparatus. The chylomicron vesicles are then exocytosed from the basal portion of the small intestinal cell. Because of the rather large size of the chylomicrons they cannot be directly absorbed by the capillaries of the lamina propria, therefore they must pass through the larger channels of the associated lymphatic capillaries found in the center of the villi and enter the lymphatic system. The chylomicrons will eventually enter the blood circulation through the left subclavian vein.



Absorption of Proteins.

Author: New Human Physiology, Paulev-Zubieta 2nd ed., illustrator Kirsten McCord. License: CC BY-NC-ND-4.0 Creative Commons Attribution-Noncommercial-No Derivatives 4.0 International. Link: https://books.byui.edu/-tcgj

Fat Transport

As previously mentioned, the majority of dietary fats are triacylglycerols that contain varying amounts of four types of fatty acids: monounsaturated fatty acids, polyunsaturated fatty acids, saturated fatty acids and trans-fatty acids (a type of unsaturated fatty acid). It is generally accepted that the healthy fatty acids are monounsaturated and polyunsaturated, although as a general rule, total fat consumption should still be kept low. So, what makes a fat healthy or unhealthy? The "health" of a fat is determined by how it is transported in the blood. Because fat and water do not mix well, and blood is 50% water, fat must be transported on structures that can bridge the fat-water barrier. These structures are called lipoproteins. Lipoproteins are composed of phospholipids, fatty acids, cholesterol and proteins and transport the lipids through the lymphatic and circulatory systems.

Two major types of lipoproteins are low-density lipoproteins (LDL) and high-density lipoproteins (HDL). In common literature these proteins are referred to as "good" (HDL) cholesterol and "bad" (LDL) cholesterol. Although not exactly accurate, the names have stuck and seem to be an effective way of transmitting information to the general public. The good and bad refer to the effects of the lipoproteins on cardiovascular health. At the most basic level, HDLs take lipids (i.e. cholesterol) from the tissues to the liver so that the liver can modify the cholesterol for excretion (a good thing). The LDLs take lipids from the liver for delivery to the tissue, also a good thing, because cells need lipids to repair membranes etc.

However, the stigma "bad" comes when there is an overabundance of the LDLs in the blood. If the blood concentration of LDLs is too high, then when cells signal for lipid delivery they get overwhelmed with LDLs. The excess LDLs accumulate in the walls of the blood vessel and become oxidized. To help clear out the excess LDLs white blood cells are recruited and engulf the LDL's. Once these cells phagocytose the LDL they have a foamy appearance and are thus called foam cells. These foam cells release cytokines which trigger an inflammatory response, attracting other macrophages and eventually resulting in the formation of a plaque in the wall of the blood vessel. These plaques bulge into the lumen of the blood vessel and restrict blood flow. If they become too extensive they can rupture initiating the coagulation cascade and completely stop blood flow through the vessel. This is the most common cause of a heart attack. What is the take home message? While both HDLs and LDLs are required for normal cardiovascular health, excess LDLs can be very detrimental.

Clinical note: The statement that LDL cholesterol is bad, like most things in biology, is becoming too simplistic each passing year. For example; sometimes high LDL levels are not correlated with atherosclerosis, and sometimes atherosclerosis can happen with normal LDL levels. Then again, really low LDL levels are not correlated with atherosclerosis at all. Still, it would appear that some LDL is required for atherosclerosis but is most likely not the only factor. Joining the list of suspects are the number of oxidized phospholipids being carried by the LDL as well as different “modified” forms of LDL particles like lipoprotein a (Lpa). Lpa has been strongly implicated in cardiovascular risk and is expressed at different levels from one person to the next, in part because of genetic diversity.

So, what do trans-fats and LDLs have in common? LDLs and trans-fat have the liver in common. The liver produces lipoproteins and it does so in response to dietary triacylglycerol.

Dietary Triacylglycerol	**Liver Response**	
Monounsaturated	Increase HDL	Decrease LDL
Polyunsaturated	Increase HDL	Decrease LDL
Saturated	Increase HDL	Increase LDL
Trans	Decrease HDL	Increase LDL

Thus, consuming trans-fats decreases the amount of "good" HDLs and increases the amount of "bad" LDLs, a lethal combination. But wait, aren't manufactures required to label the amount of trans-fat in their products? Yes, but this labeling can be misleading because the government regulations require that if a serving size has less than 0.5grams of trans fat it can be labeled as 0 grams trans-fat. Here is a general rule, if the ingredient list shows partially hydrogenated or fully hydrogenated in it, then the product has some amount of trans-fat.

The next item you should check is the serving size. If the serving size says 1 then the product should contain less than

0.5g. If the serving size is 35 and you eat 25 servings…. well…you may have other issues. At any rate, the table below shows some common foods and their estimated trans-fat amounts. Why use trans-fat in your product? Well try having a competition at home making a pie crust or baked homemade cookies with Butter vs Crisco. There is really no competition, Crisco laden cookies and pie crust simply taste better, their texture is better and they never go bad. This is why we use trans-fats, they make food taste better and last longer. Perhaps a general rule to follow is this: if it tastes good, spit it out quick, it is probably not good for you. 😊 jk

Food Item	Estimated Trans Fat
Spreads: margarine etc.	0.6 to 4.2 g trans-fat/serving
French fries, processed, not cut in store	14.5 g trans-fat/medium size order
Frozen pot pies	1.0 g trans-fat/pie
Donuts	5.0 g trans-fat/donut
Small bag of potato chips	3.2 g trans-fat/bag
Chips Ahoy Cookies	1.5 g trans-fat/3 cookies