Learning Objectives

- Describe the digestion of lipids.
- Know the properties and functions of the different types of lipoproteins.
- Know the sources and function of common dietary lipids.

How Does Fat Differ From Lipids? The answer you receive from this question will depend on who you ask, so it is important to have an understanding of lipids and fats from a chemical and nutritional perspective.

To a chemist, lipids consist of triglycerides, fatty acids, phospholipids, waxes, and sterols. These compounds are grouped together because of their structural and physical property similarities. For instance, all lipids have hydrophobic (water-fearing) properties. Chemists further separate lipids into fats and oils based on their physical properties at room temperature:

- **Fats** are solid at room temperature
- **Oils** are liquid at room temperature

From a nutritional perspective, the definition of lipids is the same. The definition of a fat differs, however, because nutrition-oriented people define fats based on their caloric contribution rather than whether they are solid at room temperature. Thus, from a nutrition perspective, **Fats** are triglycerides, fatty acids, and phospholipids that provide 9 kcal/g. The other difference is that from a caloric perspective, an oil is a fat. For example, let's consider olive oil. Clearly, it is an oil according to a chemist definition, but from a caloric standpoint it is a fat because it provides 9 kcal/g.

---

**Digestion of Lipids**

Lipid digestion begins in the upper portion of the small intestine (Figure \(\PageIndex{1}\)). A hormone secreted in this region stimulates the gallbladder to discharge bile into the duodenum. The principal constituents of bile are the bile salts, which emulsify large, water-insoluble lipid droplets, disrupting some of the hydrophobic interactions holding the lipid molecules together and suspending the resulting smaller globules (micelles) in the aqueous digestive medium. These changes greatly increase the surface area of the lipid particles, allowing for more intimate contact with the lipases and thus rapid digestion of the fats. Another hormone promotes the secretion of pancreatic juice, which contains these enzymes.
The lipases in pancreatic juice catalyze the digestion of triglycerides first to diglycerides and then to 2-monoglycerides and fatty acids:

The monoglycerides and fatty acids cross the intestinal lining into the bloodstream, where they are resynthesized into triglycerides and transported as lipoprotein complexes known as chylomicrons. Phospholipids and cholesteryl esters undergo similar hydrolysis in the small intestine, and their component molecules are also absorbed through the intestinal lining.

**Fats, Cholesterol, and Human Health**

The primary sterol that we consume is **cholesterol**. The structure of cholesterol is shown below.
Cholesterol is frequently found in foods as a cholesterol ester, meaning that there is a fatty acid attached to it. The structure of a cholesterol ester is shown below. All sterols have a similar structure to cholesterol. Cholesterol is only found in foods of animal origin. If consumers were more knowledgeable, intentionally misleading practices, such as labeling a banana “cholesterol free”, would not be as widespread as they currently are today.

**Function**

Although cholesterol has acquired the status of a nutrition “villain”, it is a vital component of cell membranes and is used to produce vitamin D, hormones, and bile acids. You can see the similarity between the structures of vitamin D and estradiol, one of the forms of estrogen shown below.

![Figure 2](image1.png) The carbon ring structure of cholesterol

There is neither bad nor good cholesterol, despite these descriptions being commonly used for LDL and HDL, respectively. Cholesterol is cholesterol. HDL and LDL contain cholesterol but are actually lipoproteins that will be described below.

Too much cholesterol in the blood can combine with other substances to form plaque. Plaque sticks to the walls of the arteries. This buildup of plaque is known as atherosclerosis. It can lead to coronary artery disease, wherein the coronary arteries become narrow or even blocked.

The most common cause of high cholesterol is an unhealthy lifestyle. This can include:

- **Unhealthy eating habits**, such as eating lots of bad fats. One type, saturated fat, is found in some meats, dairy products, chocolate, baked goods, and deep-fried and processed foods. Another type, trans fat, is in some fried and...
processed foods. Eating these fats can raise your LDL (bad) cholesterol.

- **Lack of physical activity**, with lots of sitting and little exercise. This lowers your HDL (good) cholesterol.
- **Smoking**, which lowers HDL cholesterol, especially in women. It also raises your LDL cholesterol.

Genetics may also cause people to have high cholesterol. For example, familial hypercholesterolemia (FH) is an inherited form of high cholesterol. Other medical conditions and certain medicines may also cause high cholesterol.

### HDL, LDL, and VLDL

HDL, LDL, and VLDL are lipoproteins. They are a combination of fat (lipid) and protein. The lipids need to be attached to the proteins so they can move through the blood. Different types of lipoproteins have different purposes. The table below also shows the difference in density and diameter of different lipoproteins. Notice that as diameter decreases, density increases.

<table>
<thead>
<tr>
<th>Lipoprotein</th>
<th>Density (g/dL)</th>
<th>Diameter (nm)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDL (high-density lipoproteins)</td>
<td>1.063-1.21</td>
<td>5-12</td>
<td>It is sometimes called &quot;good&quot; cholesterol because it carries cholesterol from other parts of your body back to your liver. Your liver then removes the cholesterol from your body.</td>
</tr>
<tr>
<td>LDL (low-density lipoproteins)</td>
<td>1.019-1.063</td>
<td>18-25</td>
<td>It is sometimes called &quot;bad&quot; cholesterol because a high LDL level leads to the buildup of plaque in your arteries.</td>
</tr>
<tr>
<td>VLDL (very low-density lipoproteins)</td>
<td>0.95-1.006</td>
<td>30-80</td>
<td>Some people also call VLDL a &quot;bad&quot; cholesterol because it too contributes to the buildup of plaque in your arteries. VLDL mainly carries triglycerides.</td>
</tr>
</tbody>
</table>

You are probably familiar with HDL and LDL being referred to as "good cholesterol" and "bad cholesterol," respectively. This is an oversimplification to help the public...
interpret their blood lipid values, because cholesterol is cholesterol; it's not good or bad. LDL and HDL are lipoproteins, and as a result you can't consume good or bad cholesterol, you consume cholesterol. A more appropriate descriptor for these lipoproteins would be HDL "good cholesterol transporter" and LDL "bad cholesterol transporter."

What's so bad about LDL? LDL enters the endothelium where it is oxidized. This oxidized LDL is engulfed by white blood cells (macrophages), leading to the formation of what are known as foam cells. The foam cells eventually accumulate so much LDL that they die and accumulate, forming a fatty streak. From there the fatty streak, which is the beginning stages of a lesion, can continue to grow until it blocks the artery. This can result in a myocardial infarction (heart attack) or a stroke. HDL is good in that it scavenges cholesterol from other lipoproteins or cells and returns it to the liver. The figure on the left shows the formation of the fatty streak and how this can progress to a point where it greatly alters blood flow.

**Figure \(\PageIndex{5}\) The formation of a lesion in an artery**

Web links

The video below does an excellent job of illustrating this process. However, there are two caveats to point out. First, it incorrectly refers to cholesterol (LDL-C etc.), and second, it is clearly made by a drug company, so keep these factors in mind. The link below is the American Heart Association’s simple animation of how atherosclerosis develops.

**Video: Atherosclerosis (5:36)**

**Cholesterol and CAD**

Despite what you learned above about HDL, a recent study questions its importance in preventing cardiovascular disease. It found that people who have genetic variations that lead to higher HDL levels were not at decreased risk of developing cardiovascular disease. You can read more about this interesting finding in the first link below. In addition, another recent study is questioning whether saturated fat is associated with an increased risk of cardiovascular disease.

**Doubt Cast on the 'Good' in 'Good Cholesterol'**

**Study Questions Fat and Heart Disease Link**

The following video gives a general overview of macronutrient digestion, uptake, and absorption.
Saturated Fats, Unsaturated Fats, and Trans Fats

**Saturated fat** is one of the unhealthy fats, along with trans fat. Saturated fats raise the LDL (bad) cholesterol level in the blood. High LDL cholesterol puts one at risk for heart attack, stroke, and other major health problems. One should avoid or limit intake of any foods that are high in saturated fat. Sources of saturated fat include whole-milk dairy products, like cheese, ice cream and butter. Animal fats such as beef, pork or chicken, but not most fish, are also a source of saturated fats. Vegetable sources of saturated fat include coconut and palm oils. When looking at a food label, pay close attention to the percentage of saturated fat. The American Heart Association recommends aiming for a dietary pattern that achieves 5% to 6% of calories from saturated fat. For example, if one needs about 2,000 calories a day, no more than 120 calories should come from saturated fats, which equals about 13 grams.

Eating **unsaturated fats** instead of saturated fats can help lower your LDL cholesterol. Most vegetable oils that are liquid at room temperature have unsaturated fats. There are two kinds of unsaturated fats:

- **Monounsaturated fats** protect against cardiovascular disease by providing more fluidity than saturated fats, but they are more vulnerable to lipid peroxidation. Foods containing monounsaturated fats reduce (LDL) cholesterol, while possibly increasing (HDL) cholesterol. Monounsaturated fats are found in animal flesh such as red , whole milk products, , and high fat fruits such as olives and . is about 75% monounsaturated fat. The high oleic variety contains as least 70% monounsaturated fat. and are both about 58% monounsaturated fat. (beef fat) is about 50% monounsaturated fat. and is about 40% monounsaturated fat. Other sources include , , , , , , , , , , , and .

- **Polyunsaturated fat** can be found mostly in nuts, seeds, fish, seed oils, and . "

In preliminary research, in algal oil, fish oil, fish and seafood have been shown to lower the risk of . Other preliminary research indicates that in and may also reduce the risk of cardiovascular disease.

Among omega-3 fatty acids, neither long-chain nor short-chain forms were consistently associated with breast cancer risk. High levels of (DHA), however, the most abundant omega-3 in erythrocyte () membranes, were associated with a reduced risk of breast cancer. The obtained through the consumption of polyunsaturated fatty acids is positively associated with cognitive and behavioral performance. In addition is vital for the , as well as retinal stimulation and .

**Trans fats** are unhealthy fats that form when vegetable oil hardens in a process called hydrogenation. Hydrogenated fats, or "trans fats," are often used to keep some foods fresh for a long time. Trans fats are also used for cooking in some restaurants. They can raise LDL cholesterol levels in the blood. They can also lower HDL (good) cholesterol levels. Trans fats are under review for their health effects. Experts are working to limit the amount of trans fats used in packaged foods and restaurants. One should avoid foods made with hydrogenated and partially hydrogenated oils (such as hard butter and margarine). They contain high levels of trans-fatty acids.
Food Sources of Fatty Acids

oils and oil-based foods. As you can see, most foods contain a mixture of fatty acids. Stick margarine is the only product in the figure that contains an appreciable amount of trans fatty acids. Corn, walnut, and soybean are rich sources of n-6 polyunsaturated fatty acids, while flax seed is fairly unique among plants in that it is a good source of n-3 polyunsaturated fatty acids. Canola and olive oil are rich sources of monounsaturated fatty acids. Lard, palm oil, butter and coconut oil all contain a significant amount of saturated fatty acids.

Figure \(\PageIndex{6}\) Fatty acid composition of foods and oils

Hydrogenation Reaction

Unsaturated fatty acids may be converted to saturated fatty acids by the relatively simple hydrogenation reaction. Recall that the addition of hydrogen to an alkene (unsaturated) results in an alkane (saturated). A simple hydrogenation reaction is:

\[
\ce{H_2C=CH_2 + H_2 \rightarrow CH_3CH_3}
\]

alkene plus hydrogen yields an alkane

Hydrogenation of oleic acid is shown in Figure \(\PageIndex{7}\). Vegetable oils are commonly referred to as "polyunsaturated". This simply means that there are several double bonds present. Vegetable oils may be converted from liquids to solids by the hydrogenation reaction. Margarines and shortenings are "hardened" in this way to make them solid or semi-solids.

Figure \(\PageIndex{7}\) Hydrogenation of an oleic fatty acid.

Vegetable oils which have been partially hydrogenated, are now partially saturated so the melting point increases to the point where a solid is present at room temperature. The degree of hydrogenation of unsaturated oils controls the final consistency of the product. What has happened to the healthfulness of the product which has been converted from
unsaturated to saturated fats?

**Trans Fat**

A major health concern during the hydrogenation process is the production of trans fats. Trans fats are the result of a side reaction with the catalyst of the hydrogenation process. This is the result of an unsaturated fat which is normally found as a cis isomer converts to a trans isomer of the unsaturated fat. Isomers are molecules that have the same molecular formula but are bonded together differently. Focusing on the sp$^2$ double bonded carbons, a cis isomer has the hydrogens on the same side. Due to the added energy from the hydrogenation process, the activation energy is reached to convert the cis isomers of the unsaturated fat to a trans isomer of the unsaturated fat. The effect is putting one of the hydrogens on the opposite side of one of the carbons. This results in a trans configuration of the double bonded carbons. The human body does not recognize trans fats.

Although trans fatty acids are chemically "monounsaturated" or "polyunsaturated," they are considered so different from the cis monounsaturated or polyunsaturated fatty acids that they can not be legally designated as unsaturated for purposes of labeling. Most of the trans fatty acids (although chemically still unsaturated) produced by the partial hydrogenation process are now classified in the same category as saturated fats.

The major negative is that trans fat tends to raise "bad" LDL-cholesterol and lower "good" HDL-cholesterol, although not as much as saturated fat. Trans fat are found in margarine, baked goods such as doughnuts and Danish pastry, deep-fried foods like fried chicken and French-fried potatoes, snack chips, imitation cheese, and confectionery fats.

**Summary**

- Digestion of lipids by lipases in pancreatic juice occurs primarily in the small intestines. The monoglycerides and fatty acids cross the intestinal lining into the bloodstream, where they are resynthesized into triglycerides and transported as chylomicrons. Phospholipids and cholesteryl esters undergo similar hydrolysis in the small intestine, and their component molecules are also absorbed through the intestinal lining.
- Two lipoproteins (composed of a lipid and a protein) of great interest are HDL "good cholesterol transporter" and LDL "bad cholesterol transporter."
• Trans fats are unhealthy fats that form when vegetable oil hardens in a process called hydrogenation. They can raise LDL cholesterol levels in the blood. They can also lower HDL (good) cholesterol levels. Trans fats are under review for their health effects.

• Saturated fats are also considered as unhealthy fats.

• Studies indicate that the consumption of monounsaturated fats and polyunsaturated fats (specifically those with omega-3 fatty acids) have numerous health benefits.

Sources

• Wikipedia

• National Institute of Health (NIH) MedlinePlus

Contributors

• Template:ContribLindshield

• Marisa Alviar-Agnew (Sacramento City College)