# Fats

Fat is one of the three macronutrients of the human diet. Dietary fat is important for our survival and has many important functions in our bodies, such as being a major source of energy, metabolising fat-soluble vitamins (A, D, E, and K), and obtaining essential fatty acids. Unlike protein and carbohydrates, fat is hydrophobic and is not soluble in water. In other words, water and oil do not mix, no matter how much you shake or stir these two substances.

Another difference between the macronutrients is that carbohydrates and protein contain 4 kcals/gram (0.14 kcals/ounce), whereas fat contains 9 kcals/gram (0.32 kcals/ounce). The fact that fat has over twice as many calories per gram than protein and carbohydrates has made it the targeted nutrient for weight loss and reducing cardiovascular disease (CVD). While overconsumption of the high-energy density of fat can lead to weight problems and cardiovascular disease, consuming the recommended amount of dietary fat, as well as eating heart-healthy fats and oils, is important for promoting overall health and well-being.

## Structure of lipids

Lipids consist of repeating units of fatty acids, which are comprised of hydrogen, carbons, and oxygen. There are a number of types of lipids, each important in various functions in the body. These include simple lipids such as fatty acids, compound lipids such as phospholipids, and derived lipids such as cholesterol.

**Simple lipids**

Fatty acids are the building blocks of fats. They are comprised of long hydrocarbon chains. At one end of the hydrocarbon chain is a carboxyl group (COOH). This carboxyl group is what makes a fatty acid an acid (carboxylic acid). Fatty acids are categorised into saturated fatty acids or unsaturated fatty acids.

Have you ever kept a cube of butter on the counter (at room temperature) for a few hours? When you come back it is still a cube shape, not melted.

Saturated fatty acids have single bonds between the carbon atoms and are saturated with hydrogen atoms. It is the hydrogenation of the carbon atoms that makes these fats stable, giving them a long shelf life. Saturated fats, such as butter, are usually solid or semi-solid at room temperature. Saturated fatty acids are found mostly in animal products: cheese, beef, pork, chicken, butter, full fat dairy and egg yolks. There are also a few unique plant sources of saturated fatty acids such as chocolate and cocoa butter, coconut, and palm kernel oils. See Table: Examples of Foods Containing Saturated Fats for examples of foods high in saturated fat.

| **Food Categories** | **Examples** |
| --- | --- |
| Dairy | * Regular cheese * Dairy desserts * Whole and 2% milk * Coffee creamer and cream * Mixed dishes made with dairy such as pasta and cream sauce or pizza |
| Animal Proteins | * Chicken and chicken mixed dishes * Sausage, franks, bacon, and ribs * Beef and beef-mixed dishes |
| Grains | * Grain-based desserts (cakes, pastries, or biscuits) |
| Fats and Oils | * Lard * Palm oil * Coconut oil * Margarine * Butter |

Unsaturated fatty acids contain one (monounsaturated) or more (polyunsaturated) double bonds between the carbon atoms. Unsaturated fatty acids are normally liquid at room temperature, found primarily in plant sources, and are relatively unstable. This instability makes unsaturated fatty acids more prone to oxidative damage compared to saturated fatty acids, which gives them a shorter shelf life. Unsaturated fatty acids can be categorised into monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs).

Foods that are excellent sources of MUFAs include olive oil; nuts such as almonds, cashews, and pecans; canola oil; avocados; olives; and nut butters like peanut or almond butter, for example. MUFAs are an important part of a heart-healthy diet, such as with the Mediterranean diet, for example. Polyunsaturated fats are also a central part of a heart-healthy diet.

Good sources of PUFAs include walnuts, sunflower seeds, flax oil, or salmon and corn, soybean, and safflower oil. Research has shown that substituting these fats for saturated or trans fats or refined carbohydrates can significantly decrease a person’s risk of cardiovascular disease. Another fatty acid category is trans fat or trans-fatty acid. Trans fat is the resulting fat from taking an oil and forcing hydrogen into it so it becomes saturated—an example of hydrogenation. The primary source of trans fat is partially hydrogenated oils (PHOs) such as margarine and vegetable shortening, as well as fried foods such as French fries, doughnuts, fried chicken, baked goods, snacks, and non-dairy coffee whitener. These fats adversely affect a range of CVD risk factors, including raising low-density lipoproteins (LDLs) and triglycerides, lowering high-density lipoproteins (HDL), increasing inflammation, and promoting endothelial dysfunction.

Most dietary fat is comprised of triglycerides. The chemical structure of triglycerides is a glycerol backbone with three fatty acids (Figure: Triglyceride Chemical Structure). In addition to triglycerides being the main chemical form for most fat in the food supply, it is also the main component of adipose tissue (body fat) in our bodies. This layer of fat under the skin insulates the body from extreme temperature changes, acts as a cushion around our internal organs to protect against mechanical trauma, and is storage for vitamins A, D, E, and K.

In addition, triglycerides are involved in the transportation of fats in the bloodstream. Triglycerides get into our bloodstream in two ways: they come directly from the fats or from the carbohydrates we eat.

This material can be intimidating, but it does not have to be. The following are some word tricks, visualisations, and other ways to remember the material in this chapter.

* Prefixes. Mono-, di-, tri- and poly- mean *one*, *two*, *three* or *many,* respectively. Therefore, when you see *mono*unsaturated fatty acid, that means there is one fatty acid per glycerol. Triglycerides are three fatty acids per glycerol.
* Fat is hydrophobic. Think *phobic*, which is defined as having an extreme fear or aversion to something. Fat has an aversion to water.
* There are compound lipids that contain hydrophobic (hates water) and hydrophilic (loves water) components. This is necessary to be able to get along with all compounds, such as fat-soluble and water-soluble vitamins, proteins, carbohydrates, and lipids when it comes to moving elements through the blood and into the cells.
* Visualise what happens when you mix oil and vinegar. They separate because oil does not want to mix with vinegar. When making salad dressing, an emulsifier, such as mustard, mayonnaise, egg yolks, or honey, is used to bind the oil and the vinegar.
* Saturated fat means there are the largest number of hydrogens per carbon and this makes the fat solid at room temperature. Think butter, cheese, or the fat around a piece of steak. Trans fat is taking oil and forcing hydrogen into it so it becomes saturated. Think shortening. Unsaturated fat means not every carbon has hydrogen. Think canola oil.
* Suffixes. Whenever you see -ase, that means it is an enzyme, like lip*ase*. A word ending in -genesis means *the formation of*, like gluco*genesis*– the creation of glucose. One ending in -lysis means *the breakdown of something*, like hydro*lysis*.
* Lipoproteins are a lipid plus protein. Are you confused about what are the good lipoproteins and what are the bad ones? Try this. You want high HDLs. These remove cholesterol to the liver. Hello liver, goodbye cells. You want low LDLs. These lipoproteins bring cholesterol to cells. Leave us alone, LDLs.
* How do you remember whether a food is low or high in a nutrient based on the percent DV? Give me five (5% or less) means a food is low in the nutrient. Think 20/20 vision for those foods that are high in a nutrient (20% or higher).

**Compound lipids**

The compound lipids include phospholipids and lipoproteins. A phospholipid is a compound lipid, meaning it is composed of at least two separate components. Phospholipids contain two fatty acids, a phosphate group and a glycerol molecule. They are the main component of the cell membrane. The phosphate group head and glycerol are water soluble (hydrophilic); this means these elements do not repel water but rather mix with it. Other substances that are water soluble include salt, sugar, alcohol, and water-soluble vitamins. The fatty acid tail is water-insoluble or hydrophobic.

Lipoproteins are particles in the blood comprised of proteins, phospholipids, triglycerides and cholesterol. Lipoproteins transport triglycerides and cholesterol to and from the tissues of the body, particularly between the liver and adipose tissue.

**Derived lipids**

Cholesterol helps in the production of steroid hormones as well as vitamin D. Some cholesterol is obtained from foods like eggs, cheese, and shellfish; however, most cholesterol is produced by the liver.

## Functions of lipids

Dietary fat is necessary as a source of essential fatty acids and fat-soluble vitamins. Within the body, fat has some very specific functions; being an integral part of cell membranes provides insulation and temperature regulation and is a major storage form of energy in the body.

### Function of dietary fats

From a nutritional standpoint, dietary fats are necessary as a source of energy and to obtain the essential fatty acids, Omega-3s (a-Linolenic) and Omega-6s (a-Linoleic), as well as to metabolise fat-soluble vitamins.

**Fats as major source of energy**

As mentioned before, dietary fat is the most concentrated source of energy at 9 kcals/gram, which is more than two times the number of calories in carbohydrates and protein at 4 kcals/gm. The majority of excess fat intake is stored as triglycerides. While carbohydrates are the body’s preferred fuel source during physical activity, the body’s system turns to fat stored in the adipose tissue when carbohydrates are not available.

**Fats as source of essential fatty acids**

Omega-3 and Omega-6 fatty acids are PUFAs. Alpha-linolenic acid (ALA) is mostly found in plant oils such as walnuts, flaxseeds and flaxseed oil, and chia seeds. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) omega-3 fatty acids are found in cold-water fatty fish and shellfish such as salmon, mackerel, and crab. EPA and DHA are more biologically active than ALA, and, therefore, are more important for health. For instance, omega-3s, particularly EPA and DHA from fish and shellfish, may help decrease the risk of developing CVD, heart failure, coronary disease, and experiencing a fatal coronary heart disease. However, more research is needed to fully substantiate these claims.

The anti-inflammatory properties of omega-3s may be beneficial for those who have rheumatoid arthritis. They are also imperative in the development of eye and brain development in a growing foetus, especially in the late stages of pregnancy. In addition, there is some evidence that eating high levels of omega-3s may lower levels of depression, as well as research suggesting that omega-3s may be protective against Alzheimer’s disease and dementia.

The other essential fatty acid the body does not produce is omega-6 fatty acid (or linoleic acid). The primary sources of omega-6 fatty acids are plant oils, including soybean, safflower, and canola, as well as nuts and seeds, including pecans, walnuts, sesame seeds, and sunflower seeds. Replacing saturated fats found in meats and dairy products with these plant-based foods containing omega-6 fatty acids can be beneficial for heart health. However, the issue is that most of the general public's omega-6 intake comes from processed foods, such as chips, crackers, and pastries. It is important for nutrition coaches to emphasise healthier sources for omega-6 fats such as nuts, seeds, and plant oils versus processed chips, crackers, or pastries, which are typically energy dense (lots of calories), high in sugar or salt, and provide little nutritive value.

### Dietary essential fatty acid recommendations

Dietary Reference Intakes (DRIs) have been established for the essential fatty acids linolenic (omega-3s) and linoleic (omega-6s).

The adequate intake (AI) for omega-3 fatty acid is 1.6 grams and 1.1 grams per day for males and females (ages 14 to 51+ years), respectively. Consumption of EPA and DHA from food contributes a very small amount (about 40 milligrams daily or 0.04 grams / 0.0014 ounces) to total daily omega-3 intake. It is not difficult to meet this recommendation if the right foods are chosen. Yet, omega-3 supplements, comprised of usually fish oils, can be used to meet the RDIs. In fact, omega-3 supplements were the most popular supplements compared to other natural products such as probiotics, ginseng, and glucosamine, with 7.8% of U.S. adults using an omega-3 supplement in 2012.

Should women, while pregnant, eat fish to get their omega-3s? The answer is yes. The recommendation is that pregnant women eat at least 8- to 12-ounces of a variety of seafood that is low in mercury. Mercury is a metal that has been found to cause birth defects. Examples of seafood with high mercury levels are: shark, swordfish, king mackerel, and tilefish. The good news is the seafood that is high in DHA and EPA, like salmon, herring, trout, and mackerel are low in mercury. A couple more tips for pregnant women is to avoid uncooked fish or shellfish, and cook seafood properly.

For omega-6s, the AI is 17 grams for men and 12 grams for women. Because omega-6 food sources are readily available, such as plant oils, including soybean, safflower, and canola, it is easy to meet the dietary recommendations. In addition, a number of processed foods have large amounts of omega-6s in them. A cup of corn chips has 14.5 grams. Regular-flavored microwave popcorn popped in oil has 22.3 grams and hard peanut granola bars contain 12.0 grams of omega-6 fatty acids.

How do vegans get EPA or DHA in their diet? While foods like chia and flax seeds have large amounts of ALA, they do not have the more biologically active versions of omega-3s: EPA and DHA. In fact, the conversion of ALA to EPA and DHA is quite small (<5%). There is evidence that seaweed is a good source of DHA, with one ounce of wakame seaweed containing 52 milligrams (0.05 grams) of DHA.

Be careful when searching for those foods high in omega-6 fatty acids. Often, these foods are in milligrams and need to be converted to grams by dividing by 1000. Good sources of omega-6s can be found in flaxseed oil and seeds, hemp seeds, acai, and nuts, including pecans, walnuts, sesame seeds, and sunflower seeds (Table: Selected Food Sources of Omega-6s).

| **Food** | **Serving Size** | **Grams Per Serving** |
| --- | --- | --- |
| Walnuts | 1 ounce | 10.7 |
| Pecans | 1 ounce | 5.8 |
| Sunflower seeds, kernels, dried | 1 ounce | 6.4 |
| Sesame seeds, whole, dried | 1 ounce | 6.0 |

It has been argued that the ratio of omega-6 to omega-3 fatty acids in the Westernised diet may be involved in some chronic disease processes. Some anthropologic data suggest that tens of thousands of years ago, when humans were hunters and gatherers, the ratio of omega-6 to omega-3 was about 1. However, this is based on limited data of selective groups. Today, with traditional Western diets, the ratio of omega-6 to omega-3 fatty acids is closer to 15/1 and sometimes higher. The excessive intake of omega-6s and the very-high omega-6 to omega-3 ratio may increase the risk of many diseases such as CVD, cancer, and inflammatory and autoimmune diseases. Currently, this is a hypothesis and something to consider, but more research is needed to determine the most beneficial ratio of omega-6 to omega-3 PUFAs.

**Fats metabolise fat-soluble vitamins**

The fat-soluble vitamins, including vitamins A, D, E, and K, use fat to be absorbed and stored within the body. These essential vitamins are a vital part of the daily diet. Therefore, since fat-soluble vitamins are hydrophobic (do not like water) consuming sufficient amounts of dietary fat is necessary. In addition, fat is required to support the absorption of these vitamins in the small intestine. Finally, fat-soluble vitamins are stored in the liver or adipose tissue until they are needed by the body.

### Function of fat within the body

Beside the roles of dietary fat, body fat is important for a number of reasons, including the body’s cell membrane structure and function, as well as insulation and temperature regulation.

**Cell membrane structure and function**

Cells are encircled by a membrane. This membrane is responsible for protecting the inside of the cell and for selective permeability. Phospholipids are the main component of the cell’s membrane. These phospholipids are arranged in a phospholipid bilayer, which has the hydrophilic (water-loving) heads pointing outwards and their hydrophobic (water-repelling) fatty acid tails inward (Figure: Structure of the Cell and Phospholipid Bilayer).

## Digestion and absorption

While most dietary fat is consumed and stored within the body in the form of triglycerides, these fats must be broken down into component parts by the process of digestion, transported into the bloodstream by the process of absorption, and delivered to the cells to either be used as energy or rebuilt into triglycerides and stored in adipocytes in the adipose tissue.

### The mouth and stomach

The first step to digestion of triglycerides begins in the mouth when fats encounter saliva. The chewing of food combined with a small amount of phospholipids, which act as an emulsifier, allow the digestive enzymes to work. The enzyme lingual lipase breaks down the triglycerides, separating fat from the water-soluble components of food, such as protein and carbohydrates. After swallowing, the fat moves to the stomach where gastric lipase begins breaking down triglycerides into diglycerides and free fatty acids. The stomach contracts and churns, further separating the fat molecules before they enter the small intestine. Note that minimal digestion of fat occurs in the mouth and stomach as compared to the small intestine.

Enzymes are an integral part of the digestion process. Enzymes are proteins that speed up biochemical reactions in the body. For lipid digestion, enzymes help break down triglycerides into glycerol and fatty acids. Enzymes are identified by the suffix -ase. For instance, the first enzyme involved in digestion is the enzyme lingual lipase, which is secreted in the mouth.

### The small intestine

In the small intestine, a small amount of bile, an emulsifier, is released, which attracts fat molecules and holds onto them while being held by the water. Next, pancreatic lipases break down triglycerides into monoglycerides and free fatty acids.

For absorption to occur, the bile salts surround the monoglycerides and free fatty acids to form micelles. Inside of the micelle are products of lipid digestion and fat-soluble vitamins (all the water-phobic substances). On the outside of the micelle is a water-soluble lining, allowing it to travel through the bloodstream. The micelles go to the absorptive surface of the intestinal cells and release the monoglycerides, fatty acids, and fat-soluble vitamins into the digestive tract lining.

## Transport and storage of lipids

Just as lipids require special handling for digestion and absorption to occur, fats need the same kind of treatment when it comes to travelling through the bloodstream. Since fats are hydrophobic and the blood is approximately 92% water, fats (fatty acids) need a way to be transported through the blood. In other words, lipids need some way to move from the small intestine through the bloodstream to the cells of the body to be used for energy or to be stored.

### Transport of lipids

Once monoglycerides, fatty acids, and fat-soluble vitamins are released into the digestive tract lining of the small intestine, the monoglycerides and free fatty acids reassemble themselves into triglycerides. Triglycerides, cholesterol, and phospholipids, plus a protein carrier, form a lipoprotein. This large lipoprotein, called a chylomicron, enters the lymphatic system and moves toward a large vein that drains into the heart. The chylomicrons (from digestion) and very-low-density lipoproteins (VLDLs) both move through the bloodstream to deliver triglycerides to the cells of the body. Chylomicrons and VLDLs get triglycerides into the cells with the help of lipoprotein lipase, an enzyme found in the endothelium of the cells. The lipoprotein lipase binds the chylomicrons and VLDLs and triglycerides are released into the cells. Once in the cell, the lipoprotein lipase breaks down the triglycerides into fatty acids and a glycerol for the cell to use.

**The liver**

Besides chylomicrons and VLDLs, there are two other important lipoproteins: low-density lipoprotein (LDL) and high-density lipoprotein (HDL). As mentioned, both chylomicrons and VLDLs bring triglycerides to the cells in the body (see the pink arrows in the Figure: The Relationship Between the Liver, Lipoproteins and Cells). However, LDLs and HDLs carry cholesterol (not triglycerides). Back at the liver, the VLDLs are stripped of their triglycerides, which makes them denser. VLDL is stripped and turns into LDL, which delivers cholesterol to the cells, which are modified and transformed into HDLs.

The function of LDL is to deliver cholesterol *to* the cells, where it can be used in cell membranes or to help in the synthesis of steroid hormones. On the other hand, HDL is responsible for retrieving excess cholesterol from the cells and bringing it *back* to the liver. Excess cholesterol is eliminated by the liver, which secretes the cholesterol in bile (which can begin the whole process again of fat digestion and absorption in the small intestine).

Healthy cholesterol levels are important for improving overall cardiovascular health and minimising the risk of a heart attack or stroke. Table: Recommended Cholesterol Levels contains recommendations for total cholesterol, LDL cholesterol, HDL cholesterol and triglycerides from various sources.

### Fat metabolism and storage

To recount, chylomicrons and VLDLs deliver triglycerides to the cells, which, once in the cell, are broken down to fatty acids and glycerol for the cells to use. In adipose (fat) cells, the fatty acids are combined with a glycerol to become a triglyceride for storage in the adipose tissue. Once in the cell, the triglycerides go through beta-oxidation within the cells where the byproducts are glycerol and free fatty acids. However, in other cell types, particularly muscle cells, the fatty acids may be stored or made into acetyl-CoA. In the liver, acetyl-CoA is broken down into ketone bodies when rates of fatty oxidation are very high. In addition, the liver converts glycerol into glucose via gluconeogenesis.

In recent decades, we have gained a greater understanding of the importance of consuming an adequate amount of dietary fat (between 20% and 35%) and the benefits of consuming plant-based unsaturated fats for the reduction of CVD risk. In fact, the latest research supports the use of higher-fat diets (such as the Mediterranean-style diet) to lose weight and reduce CVD risk. Bottom line is to follow this advice:

* Avoid trans fats. These fats adversely affect a range of CVD risk factors, including raising LDLs and triglycerides, lowering HDLs, increasing inflammation, and promoting endothelial dysfunction.
* Consume 10% or less of dietary calories from saturated fat. Replace saturated fats with PUFAs.
* Focus on consuming PUFAs, including omega-3s and omega-6s food sources. Dietary PUFAs may lower serum VLDL and LDL concentrations. This is because the liver converts PUFAs into ketone bodies instead of VLDLs, which transport triglycerides to the cells.
* Reduce refined carbohydrates and added sugars.
* Reduce saturated fats and replace them with unsaturated fats