Chapter 24
Dietary Fat: The Good, the Bad, and the Ugly

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Key Points

- Depending on their chemical structure, fatty acids can be saturated, monounsaturated, or polyunsaturated.
- Some fats are called essential fatty acids and must be provided by the diet. Essential fats include $n-3$ fatty acids and $n-6$ fatty acids.
- Trans-fatty acids are formed during hydrogenation of oils but are also present naturally in some foods. They increase the risk of heart disease.
- Fish contains long-chain $n-3$ fatty acids. These fats help prevent heart disease and other chronic conditions.

Keywords Dietary fat • Saturated fatty acids • Polyunsaturated fatty acids • $n-3$ fatty acids • $n-6$ fatty acids • Hydrogenation • Trans-fatty acids • Heart disease

Introduction

Health professionals are often asked questions regarding fat intake:

- Are all fats bad for you?
- Are fats all the same?
- How much is too much fat?

The objective of this chapter is to shed light on dietary fat and the controversies that surround it. The human body needs a certain amount of fat in the diet in order to survive. Each gram of fat provides 9 kcal whereas protein and carbohydrate only provide 4 kcal/g. Fat provides energy and supplies raw materials for hormones, fat-soluble vitamins, and cell membranes. Dietary fat is important for the

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absorption of fat-soluble vitamins (vitamins A, D, E, and K, and carotenoids) from food. Fat also helps to insulate the body against high or low temperatures and provides padding for internal organs, which protects them from shock. Fats in food contribute to taste and texture, making foods more appealing. Essential fatty acids (EFA) cannot be synthesized in the human body (liver) and must therefore be provided by diet, much like vitamins. EFA play many important roles in the body and are examined later in this chapter.

Although fat is essential for survival, its consumption may be associated with obesity and coronary heart disease (CHD). These associations are discussed in more detail in Chaps. 8 and 11. The recommendation in this chapter provides a balanced, nutritious diet that includes adequate amounts of EFA as a way to help prevent obesity and chronic diseases.

Types of Fat

General Chemical Characteristics

Fatty acids are composed of a carboxyl group, a series of hydrocarbons that can be saturated ($-CH_2-CH_2-$) or unsaturated ($-CH{=}CH-$) with a methyl group (CH3) at the other end. They differ from each other according to their chemical structure including the number of carbon atoms, the degree of unsaturation, location of double bonds, and the configuration of their carbon structure. Biological systems contain only carbon–carbon bonds in the cis-configuration, although industrial food processing can produce carbon–carbon bonds in the trans-configuration. In the body fatty acids are transported as fatty acids that are carried by plasma protein albumen or transported as triglycerides (glycerol with ester linkages to three fatty acids) in either chylomicrons or very low density lipoproteins (VLDL).

Saturated Fatty Acids

Saturated fats contain no double bonds. Major food sources include red meat, poultry, fish, dairy foods (milk, eggs, cheese, and butter), and tropical oils (palm and coconut oil). Butter is an example of a food product rich in saturated fats and solid at room temperature and less solid when the summer kitchen temperature is 80 °F. In the human body, cell membranes also need some degree of rigidity and hence saturated fatty acids in the plasma membrane prevent cells from being too flexible (fragile). For this reason plants (e.g., the palm tree) and fish (e.g., snapper) that thrive in warmer growing environments typically contain more saturated fatty acids.

Unsaturated Fatty Acids

Unsaturated fatty acids contain one or more double bonds in the carbon chains. They are of two types: monounsaturated fatty acids (MUFA) that contain only one double bond and polyunsaturated fatty acids (PUFA) that contain two or more double bonds. Food sources of MUFA include olive and canola oils, nuts, and seeds. Major sources of PUFA include plant oils such as sunflower oils, soybean, safflower, and corn. Unsaturated fats have a lower melting point than saturated fats. For that reason many animal fats are solid at room temperature while unsaturated fats are typically liquid at room temperature. Too much rigidity in a cell plasma membrane can also be detrimental and unsaturated fatty acids in the lipid bilayer prevent this. For this reason plants and fish that thrive in colder growing environments (e.g., walnut and cod) typically contain more unsaturated fatty acids.

Essential Fatty Acids

Essential fatty acids (EFA) are fatty acids that cannot be produced by the body or cannot be produced in sufficient amounts. They therefore need to be consumed in the diet. EFA are long-chain PUFA and fall into two groups, namely $n-3$ fatty acids (also known as omega-3 fatty acids) and $n-6$ fatty acids (also known as omega-6 fatty acids). The nomenclature stems from the position of the first double bond in relation to the methyl end (i.e., it is located in the third carbon in the case of $n-3$ or the sixth carbon with $n-6$).

The most important members of the $n-3$ family are alpha-linolenic acid, eicosapentaenoic (EPA), and docosahexaenoic acid (DHA). Alpha-linolenic acid is found in vegetable oils, including flaxseed oil (a rich source), soybean oil, and to a lesser extent, canola oil. Several species of cold-water fatty fish are rich sources of EPA and DHA, including herring, salmon, mackerel, sardines, and trout (Table 24.1). By contrast, white fish, such as cod, hake, and haddock, are poor sources. Some fish species have a possibly harmful level of mercury. The highest levels are found in king mackerel, shark, swordfish, and tilefish with lower levels in tuna. For that reason it is recommended that children and pregnant women refrain from eating these species.

Triglycerides

Triglycerides are fats formed by one molecule of glycerol as the backbone and three chains of fatty acids. Formation of triglycerides permits fatty acid transportation to the body in chylomicrons that originate in the intestine or as very low density lipoproteins for transportation out of the liver. Tissue-specific lipases in the blood cleave the fatty acids from triglycerides permitting fatty acid transport into fatty acid oxidizing cells such as cardiac myocytes. The same process transports fatty acids into adipocytes where the intracellular enzyme acyltransferase attaches free fatty acids to glycerol. By this means adipocytes can accumulate fat stores for caloric expenditure during times of low caloric intake.

Table 24.1 Content of $n-3$ fatty acids (EPA and DHA) in fish consumed in the USA

Fish	EPA + DHA (mg/100 g)
Anchovy	2060
Herring	2010
Salmon (farmed or wild)	1900
Mackerel	1200
Sardines	980
Trout	940
Tuna, white (albacore)	860
Shark	690
Pollock	540
Tuna, light (skipjack)	330
Halibut	235
Cod	160

Modified from [1]

Cholesterol and Sterols

Cholesterol is a complex lipid with a sterol-ring structure that can only be synthesized primarily by hepatocytes in the human at night. Sterols are the basic building blocks for vitamin D and steroid hormones. Cholesterol is absent from plant foods. It is found only in animal foods with eggs, shrimp, and crab representing the richest dietary sources, although paradoxically these foods are also rich in MUFA and PUFA.

Hydrogenated Fats and Trans-Fatty Acids

Hydrogenation is the chemical process by which hydrogen atoms are added to unsaturated fatty acids. By this means oils rich in unsaturated fats become more saturated and more solid. While much of the unsaturated fatty acids are converted to saturated fatty acids during hydrogenation, some are converted to an unnatural form of unsaturated fatty acids known as trans fatty acids which have the carbon-to-carbon double bonds in the trans-configuration. The process is valuable for the food industry as hydrogenated fats are more resistant to oxidation; the smell of rancid fish is the classic example of polyunsaturated fat oxidation. As a result, foods containing hydrogenated fats are more stable, less prone to rancidity, and have a longer shelf life. Trans fats have been used for many years in the production of baked goods and pastries such as doughnuts, cakes, and cookies, as well as the production of margarine. The serious negative health implications of trans-fatty acids are discussed below.

Dietary Fats and Health

Dietary fats have multiple health effects.

Dietary Fats, Body Weight, and Obesity

Fat-rich foods are energy dense and make it easy to overconsume food energy. The use of oils in cooking, processed foods, and the presence of oils in fast foods, fried foods, or the fettuccini heavy cream sauce on a plate of pasta facilitate caloric overconsumption of fat-rich foods. Caloric overconsumption is, of course, strongly predictive of excess weight gain.

The idea that a relatively high intake of dietary fat tends to cause excessive weight gain has been debated for several decades. Many prospective cohort studies have investigated whether the amount of fat in the diet is a predictor of weight change. These studies suggest only a weak association between dietary fat and excess weight gain [2, 3]. Many randomized trials have also been conducted. These have been analyzed in two systematic reviews and meta-analyses. One concluded that lowering the amount of fat in the diet leads to modest weight loss [2]. However, the other one, which was more recent and more extensive, concluded that lowering the amount of fat in the diet does not increase weight loss [4]. Taken as a whole, this evidence lends very little support to the view that diets with a high content of fat facilitate excess weight gain.

Dietary Fat and Heart Disease

For several decades, saturated fats were widely considered as being a major causal factor in coronary heart disease (CHD). The presumed mechanism of action was that saturated fat consumption raised LDL-cholesterol. Saturated fats worsen the blood lipid profile and increase the risk of CHD when they replace unsaturated fats. However, saturated fats have little or no harmful effect on risk when they replace refined carbohydrates in an isocaloric fashion; this is because any rise in LDL-cholesterol is cancelled out by the simultaneous rise in HDL-cholesterol. Thus, it is an oversimplification to say that "saturated fats raise the blood cholesterol." Another important finding to emerge from the prospective cohort studies was a failure to show any clear association between intake of saturated fats and risk of CHD [5]. Clinical studies that replace saturated fats with PUFA (mainly $n-6$ fatty acids) not only improve the lipid profile but also decrease CHD risk [6, 7]. Based on the balance of evidence, it is prudent to reduce the intake of saturated fat and replace them with foods containing PUFA, and perhaps also sources of MUFA such as olive oil and canola oil. However, this is just one component of a much broader dietary strategy against CHD.

The evidence is much more clear-cut for trans-fatty acids. Solid evidence has emerged demonstrating that these fats have a harmful effect on the blood lipid profile, both by raising the blood level of LDL-cholesterol and by lowering the blood level of HDL-cholesterol [8]. Cohort studies also clearly link trans-fatty acid intake with increased CHD risk [9]. It is therefore important to minimize their consumption (preferably well below 1% of energy intake). In response to this evidence, regulatory agencies in the USA and other countries have taken steps to reduce the amount of trans fats present in the diet. Hopefully, in coming years, their presence in food will be completely eliminated (with the exception of the small amounts found in some animal foods). As documented in Table 24.2, the cost-benefits of removal of these fats from the US food chain is strongly positive.

The beneficial effect of fish with a higher fat content in preventing heart disease has attracted much attention. A large body of evidence from cohort studies provides strong evidence that persons who regularly eat fish are at significantly reduced risk of cardiac death (~20–38% lower) than are people who seldom eat fish [11]. It is widely believed that long-chain $n-3$ fatty acids are mainly responsible for this benefit [1]. This has been tested numerous times in randomized clinical trials. However, the findings reveal that the reduction in risk of cardiac death is fairly small, roughly 9% [12]. However, CHD is associated with $320 billion in health costs and causes 376,000 annual deaths in the USA [13], and a 9% reduction in this statistic could potentially amount to $39 billion and 37,000 lives.

The major mechanisms responsible for the cardioprotective effect of $n-3$ fatty acids are believed to be related to antiarrhythmic effects, the stabilization of atherosclerotic plaques, and an improvement in endothelial relaxation and vascular compliance [14].

On balance, the evidence provides strong support for the view that people should be encouraged to eat fatty fish twice a week as a means to prevent heart disease. Fish is also a source of various other nutrients including vitamin D and selenium. However, eating fish can represent a challenge for individuals who are vegan or simply don't like fish. Fish can also be expensive and their availability on a

Table 24.2 Costs and benefits for the removal of partially hydrogenated fats

20-year net present value	Low estimate	Mean	High estimate
Costs	$2.8	$6.2	$11
Benefits	$11	$140	$440
Net benefits	$5	$130	$430

Costs are shown in billions of dollars. Modified from [10] global scale is limited by ecological limits. For these individuals, supplementation with fish oil (one or two teaspoons daily) can be the next best option, although the efficacy of this is still to be confirmed. The extent to which *n*−3 fatty acids from plant sources are also preventive against heart disease is also unclear [6].

n−*3 Fatty Acids and Health Benefits*

A body of evidence suggests that the health benefits of *n*−3 fatty acids extend beyond heart disease. These dietary fats may also protect against the development of a number of other diseases such as some cancers, rheumatoid arthritis, and dementia. These benefits are generally more strongly associated with *n*−3 fatty acids from fish than from plant sources.

Conclusion

Fat has been the central point of many controversies in nutrition. Choosing healthy types of fat is important in health maintenance and the prevention of chronic diseases. Doubts have been raised regarding whether saturated fatty acids play a major role in the etiology of CHD. Looking at the evidence as a whole, it makes most sense to reduce the intake of saturated fatty acids and replace them with foods containing PUFA, and perhaps also MUFA. This dietary strategy improves the lipid profile and may decrease CHD risk. The major sources of these fats are oils of plant origin such as olive, canola, sunflower, soybean, and corn.

Trans-fatty acids increase the risk of CHD. Reducing their content in food has been proven to be a particularly important public health approach for the prevention of CHD. Evidence indicates that eating fatty fish regularly is another effective dietary strategy for the prevention of CHD. The active ingredient is believed to be long-chain *n*−3 fatty acids (EPA and DHA). These fats may also help prevent other chronic conditions. The extent to which alpha-linolenic acid, the major *n*−3 fatty acid from plant sources, achieves the same health benefits as *n*−3 fatty acids from fish is still uncertain.

With the realization that the type of dietary fat, rather than the amount, is the critically important factor, there has been less focus in recent years on reducing the total amount of fat in the diet. As a result, the trend for recommendations has shifted from "no more than 30%" to a more liberal 20–35% of calories.

References

1. Mozaffarian D, Wu JH. Omega-3 fatty acids and cardiovascular disease: effects on risk factors, molecular pathways, and clinical events. J Am Coll Cardiol. 2011;58:2047–67.
2. Hooper L, Abdelhamid A, Moore HJ, Douthwaite W, Skeaff CM, Summerbell CD. Effect of reducing total fat intake on body weight: systematic review and meta-analysis of randomised controlled trials and cohort studies. BMJ. 2012;345:e7666.
3. Forouhi NG, Sharp SJ, Du H, et al. Dietary fat intake and subsequent weight change in adults: results from the European Prospective Investigation into cancer and nutrition cohorts. Am J Clin Nutr. 2009;90:1632–41.
4. Tobias DK, Chen M, Manson JE, Ludwig DS, Willett W, Hu FB. Effect of low-fat diet interventions versus other diet interventions on long-term weight change in adults: a systematic review and meta-analysis. Lancet Diabetes Endocrinol. 2015;3:968–79.
5. Siri-Tarino PW, Sun Q, Hu FB, et al. Meta-analysis of prospective cohort studies evaluating the association of saturated fat with cardiovascular disease. Am J Clin Nutr. 2010;91:535–46.

6. Mozaffarian D. Dietary and policy priorities for cardiovascular disease, diabetes, and obesity: a comprehensive review. Circulation. 2016;133:187–225.
7. Mozaffarian D, Micha R, Wallace S. Effects on coronary heart disease of increasing polyunsaturated fat in place of saturated fat: a systematic review and meta-analysis of randomized controlled trials. PLoS Med. 2010;7:e1000252.
8. Mozaffarian D, Aro A, Willett WC. Health effects of trans-fatty acids: experimental and observational evidence. Eur J Clin Nutr. 2009;63(Suppl 2):S5–S21.
9. Mente A, de Koning L, Shannon HS, et al. A systematic review of the evidence supporting a causal link between dietary factors and coronary heart disease. Arch Intern Med. 2009;169:659–69.
10. Food and Drug Administration. Final determination regarding partially hydrogenated oils. A notice by the Food and Drug Administration on 06/17/2015. Federal Register. https://www.federalregister.gov/articles/2015/06/17/2015-14883/final-determination-regarding-partially-hydrogenated-oils#h-25. Accessed 16 Mar 2016.
11. Zheng J, Huang T, Yu Y, Hu X, Yang B, Li D. Fish consumption and CHD mortality: an updated meta-analysis of seventeen cohort studies. Public Health Nutr. 2012;15:725–37.
12. Rizos EC, Ntzani EE, Bika E, Kostapanos MS, Elisaf MS. Association between omega-3 fatty acid supplementation and risk of major cardiovascular disease events: a systematic review and meta-analysis. JAMA. 2012;308:1024–33.
13. American Heart Association. Heart disease and stroke statistics—2015 update. Circulation. 2015;131:e29–e322.
14. Mozaffarian D, Rimm EB. Fish intake, contaminants, and human health: evaluating the risks and the benefits. JAMA. 2006;296:1885–99.

Suggested Further Readings

Flock MR, Kris-Etherton PM. Diet, the control of blood lipids, and the prevention of heart disease. In: Temple NJ, Wilson T, Jacobs DR, eds. Nutritional health: strategies for disease prevention, 3rd ed. New York: Humana Press; 2012. p. 169–220.

McEvoy C, Young IS, Woodside JV. Fish, n-3 polyunsaturated fatty acids, and cardiovascular disease. In: Temple NJ, Wilson T, Jacobs DR, eds. Nutritional health: strategies for disease prevention, 3rd ed. New York: Humana Press; 2012. p. 221–246.