

CHAPTER 3

Fats

KEY CONCEPTS

- Dietary fat supplies essential body tissue needs as both an energy fuel and a structural material.
- Foods from animal and plant sources supply distinct forms of fat that affect health in different ways.
- Excess dietary fat, especially from animal food sources, is a risk factor for poor health.

General awareness regarding health concerns and the risk of chronic disease from excess saturated fat in the diet has influenced overall dietary choices. More knowledge of “heart-healthy” fats is helpful for the public to distinguish beneficial sources of dietary fat from unfavorable sources.

This chapter examines the various aspects of fat as an essential nutrient, a concentrated storage fuel, and a savory food component. In addition, the types of fat and the health implications when dietary fat or body fat goes unchecked are reviewed.

THE NATURE OF FATS

Dietary Importance

Fats are a concentrated fuel source for the human energy system. A large amount of energy can be stored in a relatively small space within adipose tissue as compared with carbohydrates that are stored as glycogen. As such, fats supplement carbohydrates (the primary fuel) as an additional energy source. In food, fats may be in the form of either solid fat or liquid oil. Fats are not soluble in water, and they have a greasy texture.

Structure and Classes of Fats

The overall name of the chemical group of fats and fat-related compounds is *lipids*, which comes from the Greek word *lipos*, meaning “fat.” The word *lipid* appears in combination words that are used for fat-related health conditions. For example, an elevated level of blood fat is called *hyperlipidemia*.

All lipids are composed of the same basic chemical elements as carbohydrates: carbon, hydrogen, and oxygen. The majority of dietary fats are *glycerides*, which are

composed of *fatty acids* attached to glycerol. Most natural fats, whether in animal or plant sources, have three fatty acids attached to their glycerol base, thus the chemical name of *triglyceride* (Figure 3-1).

Classification of Fatty Acids

Fatty acids, which are the building blocks of triglycerides, can be classified by their length as short-, medium-, or long-chain fatty acids. The chains contain carbon atoms with a methyl group (CH_3) on one end (also known as the *omega end*) and an acid carboxyl group (COOH) on the other end. Short-chain fatty acids have two to four carbons, whereas medium and long chains have 6 to 10 and more than 12 carbons, respectively. Fatty acids can also be classified according to their saturation or essentiality, both of which are significant characteristics.

Saturated Fatty Acid

When a substance is described as *saturated*, it contains all of the material that it is capable of holding (Figure 3-2, A). For example, a sponge is saturated with water when it holds all of the water that it can contain. Similarly, fatty

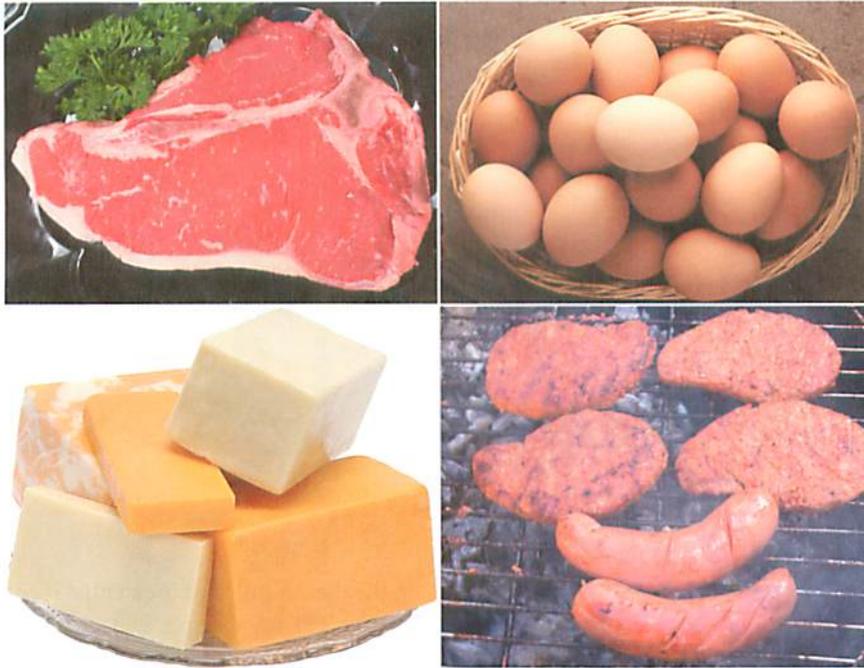


Figure 3-3 Dietary sources of saturated fats. (Copyright JupiterImages Corp.)

between the carbon atoms), the fat is called a *monounsaturated fat* (see Figure 3-2, B). Examples of foods that contain some monounsaturated fats include olive oil, peanut oil, canola (rapeseed) oil, almonds, pecans, and avocados. If the fatty acids have two or more unfilled spots (i.e., more than one double bond between the carbon atoms), the fat is called a *polyunsaturated fat* (see Figure 3-2, C and D). Examples of foods that contain some polyunsaturated fats are the vegetable oils: safflower, corn, cottonseed, and soybean. Fats from plant and fish sources are mostly unsaturated (Figure 3-4). However, notable exceptions are the tropical oils, which are saturated. Although the world production of saturated tropical oils (e.g., palm, palm kernel, coconut) has increased rapidly since the 1970s, the use of these oils in the United States has not followed suit.

Trans-Fatty Acids. Naturally occurring unsaturated fatty acid molecules have a bend in the chain of atoms at the point of the carbon double bond. This form is called *cis*, meaning “same side,” because both of the hydrogen atoms around the carbon double bond are on the same side of the bond. When vegetable oils are partially hydrogenated to produce a more solid, shelf-stable fat, the normal bend is changed so that the hydrogen atoms around the carbon double bond are on opposite sides. This form is called *trans*, meaning “opposite side,” and the process is called *hydrogenation*. The illustration on

page 34 shows the *cis* form and the *trans* form of a molecule of oleic acid, which is a common monounsaturated fatty acid with a chain of 18 carbon atoms.

Commercially hydrogenated fats in margarine, snack items, fast food, and many other food products are typically high in trans fat. Trans fats are unnecessary in

lipids the chemical group name for organic substances of a fatty nature; the lipids include fats, oils, waxes, and other fat-related compounds such as cholesterol.

glycerides the chemical group name for fats; fats are formed from a glycerol base with one, two, or three fatty acids attached to make monoglycerides, diglycerides, and triglycerides, respectively; glycerides are the principal constituents of adipose tissue, and they are found in animal and vegetable fats and oils.

fatty acids the major structural components of fats.

triglycerides the chemical name for fats in the body or in food; three fatty acids attached to a glycerol base.

saturated the state of being filled; the state of fatty acid components being filled in all their available carbon bonds with hydrogen, thus making the fat harder and more solid; such solid food fats are generally from animal sources.

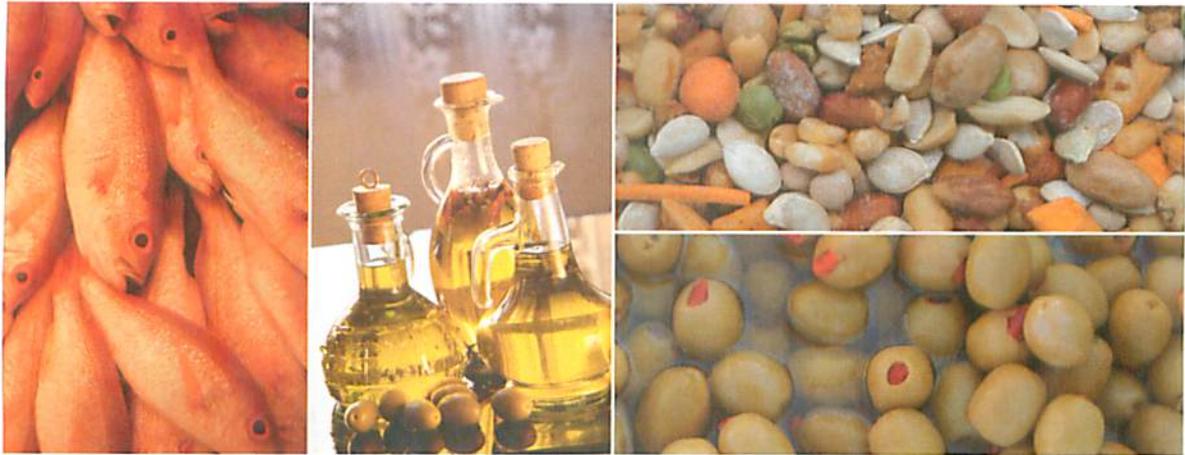
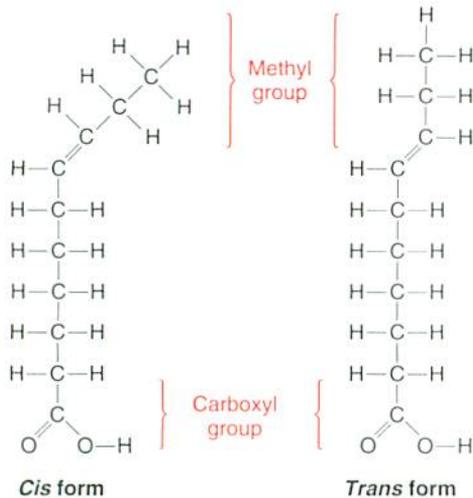


Figure 3-4 Dietary sources of monounsaturated and polyunsaturated fats. (Copyright JupiterImages Corp.)



human nutrition and pose a great number of negative health consequences related to cardiovascular disease.¹ The current dietary recommendations by the American Heart Association, the Academy of Nutrition and Dietetics, the Institute of Medicine, and the *Dietary Guidelines for Americans* are to avoid all trans fat in the diet.

Omega-3 and Omega-6 Fatty Acids. Unsaturated fatty acids can be distinguished by the occurrence of the first carbon involved in the double bond from the omega end (i.e., the methyl group end). When the first carbon double bond starts on the third carbon from the omega end, it is known as an *omega-3 fatty acid* (see Figure 3-2, D). When the first carbon double bond starts on the sixth carbon from the omega end, it is known as an *omega-6 fatty acid* (see Figure 3-2, C).

Essentiality of Fatty Acids. The term *essential* or *non-essential* is applied to a nutrient according to its necessity

in the diet. A nutrient is essential if either of the following is true: (1) its absence will create a specific deficiency disease; or (2) the body cannot manufacture it in sufficient amounts and must obtain it from the diet. A diet with 10% or less of its total kilocalories from fat cannot supply adequate amounts of essential fatty acids. The only fatty acids known to be essential for complete human nutrition are the polyunsaturated fatty acids **linoleic acid** (an omega-6 fatty acid), and **alpha-linolenic acid** (an omega-3 fatty acid). Both essential fatty acids serve important functions related to tissue strength, **cholesterol** metabolism, muscle

linoleic acid an essential fatty acid that consists of 18 carbon atoms and two double bonds; found in vegetable oils.

alpha-linolenic acid an essential fatty acid with 18 carbon atoms and three double bonds; found in soybean, canola, and flaxseed oil.

cholesterol a fat-related compound called a *sterol* that is synthesized only in animal tissues; a normal constituent of bile and a principal constituent of gallstones; in the body, cholesterol is primarily synthesized in the liver; in the diet, cholesterol is found in animal food sources.

lipoproteins chemical complexes of fat and protein that serve as the major carriers of lipids in the plasma; they vary in density according to the size of the fat load being carried (i.e., the lower the density, the higher the fat load); the combination package with water-soluble protein makes possible the transport of non-water-soluble fatty substances in the water-based blood circulation.

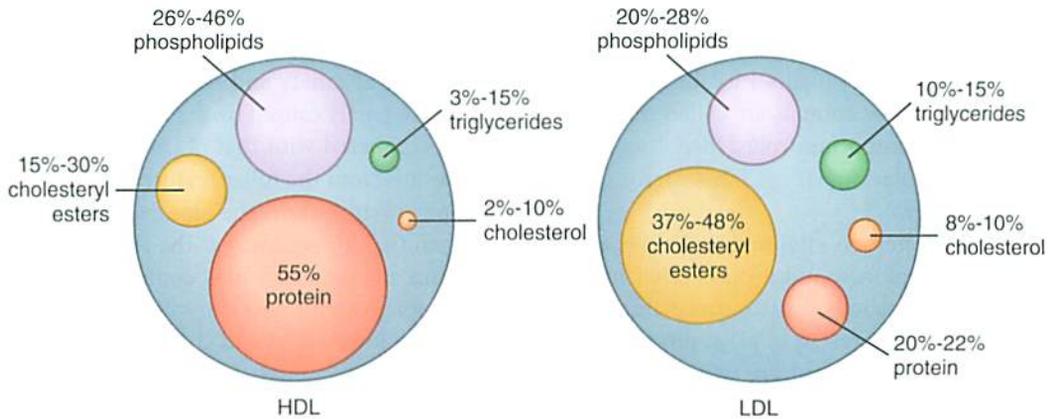


Figure 3-5 Composition of high-density lipoproteins (HDL) and low-density lipoproteins (LDL).

tone, blood clotting, and heart action. Essential fatty acids must come from the foods we eat. The body is capable of producing saturated fatty acids, monounsaturated fatty acids, and cholesterol. Therefore, no set recommendations of daily intake exist for these.

Lipoproteins

Lipoproteins, which are the major vehicles for lipid transport in the blood stream, are combinations of triglycerides, protein (apoprotein), phospholipids, cholesterol, and other fat-soluble substances (e.g., fat-soluble vitamins). Because fat is insoluble in water and because blood is predominately water, fat cannot freely travel in the bloodstream; it needs a water-soluble carrier. The body solves this problem by wrapping small particles of fat in a covering of protein, which is hydrophilic (i.e., “water loving”). The blood then carries these packages of fat to and from the cells to supply needed nutrients. A lipoprotein’s relative load of fat and protein determines its density. The higher the protein load, the higher the lipoprotein’s density. The higher the fat load, the lower the lipoprotein’s density. Low-density lipoproteins carry fat and cholesterol to cells. High-density lipoproteins carry free cholesterol from body tissues to the liver for breakdown and excretion (Figure 3-5). All lipoproteins are closely associated with lipid disorders and with the underlying blood-vessel disease atherosclerosis. These relationships are discussed in greater detail in Chapter 19.

Phospholipids

Phospholipids are triglyceride derivatives in which the one fatty acid has been replaced with a phosphate group. The result is a molecule that is partially hydrophobic (i.e., “water fearing”) and partially hydrophilic (because of the

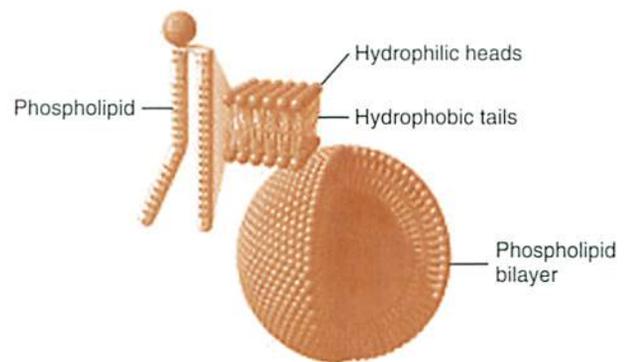


Figure 3-6 Phospholipid bilayer. (Reprinted from the NASA Astrobiology Institute. *Project 4. Prebiotic Molecular Selection and Organization* (website): <http://nai.nasa.gov>. Accessed July 6, 2007.)

phosphate group). This combination results in what is called an *amphiphilic molecule*, in which the hydrophilic heads face outward to the aqueous environment and the hydrophobic heads bind fats and oils and face each other (Figure 3-6). Phospholipids are major constituents in cell membranes and allow for the transport of fats through the bloodstream.

Lecithin. Lecithin, which is a lipid substance produced by the liver, is a key building block of the cell membranes. It is a combination of **glycolipids**, triglycerides, and phospholipids. The amphiphilic quality in lecithin makes it ideal for transporting fats and cholesterol.

Eicosanoids. Eicosanoids are signaling hormones that exert control over multiple functions in the body (e.g., the inflammatory response, immunity), and they are messengers for the central nervous system. Eicosanoids are divided into four classes: (1) prostaglandins; (2) prostacyclins; (3) thromboxanes; and (4) leukotrienes. Eicosanoids are derived from the essential fatty acids.

Sterols

Sterols are a subgroup of steroids, and they are amphipathic in nature. Sterols made by plants are called *phytosterols*, and sterols produced by animals are called *zoosterols*. Sterols play a variety of important roles, including membrane fluidity and cellular signaling. Cholesterol is the most significant zoosterol.

Cholesterol. Cholesterol is vital to membranes; it is a precursor for some hormones, and it plays other important roles in human metabolism. It occurs naturally in animal foods, and it is not present in plant products. The main food sources of cholesterol are egg yolks, organ meats (e.g., liver, kidney), and other meats (see Appendix A). To ensure that it always has the relatively small amount of cholesterol necessary for sustaining life, the human body synthesizes endogenous cholesterol in many body tissues, particularly in the liver as well as in small amounts in the adrenal cortex, the skin, the intestines, the testes, and the ovaries. Consequently, no biologic requirement for dietary cholesterol exists, and no Dietary Reference Intake (DRI) has been set for cholesterol consumption. The *Dietary Guidelines for Americans* and the DRIs recommend consuming a diet that is low in cholesterol.^{2,3} Epidemiologic studies have found strong correlations between the dietary intake of saturated fats and trans fats with coronary heart disease. The association with such risk factors and dietary cholesterol is less well defined; however, research shows that a diet that is low in cholesterol is beneficial, and current recommendations are to limit cholesterol intake.⁴

FUNCTIONS OF FAT

Fat in Foods

Energy

In addition to carbohydrates, fats serve as a fuel for energy production. Fat is also an important storage form of body fuel. Excess caloric intake from any macronutrient source is converted into stored fat. Fat is a much more concentrated form of fuel, yielding 9 kcal/g when burned by the body as compared with carbohydrate's yield of 4 kcal/g.

Essential Nutrients

Dietary triglycerides supply the body with essential fatty acids. As long as an adequate amount of essential fatty acids are consumed, the body is capable of endogenously producing other fats and cholesterol as needed. Food fats are also a source of fat-soluble vitamins (see Chapter 7), and they aid in the absorption of those vitamins.

Flavor and Satisfaction

Some fat in the diet adds flavor to foods and contributes to a feeling of satiety and satisfaction after a meal. These effects are partly caused by the slower rate of digestion of fats as compared with that of carbohydrates. This satiety also results from the fuller texture and body that fat gives to food mixtures and the slower emptying time of the stomach that it necessitates. The absence of this satiation while on a low-fat diet may contribute to dissatisfaction and problems with necessary changes in food habits to establish a lowered fat and cholesterol intake for the long term.

Fat Substitutes

Several fat substitutes, which are compounds that are not absorbed and thus contribute little or no kilocalories, are available to provide improved flavor and physical texture to low-fat foods and to help reduce total dietary fat intake. Fat substitutes that are currently on the market are considered safe by the U.S. Food and Drug Administration (FDA); however, the safety of long-term use is not well established. Two examples of these fat substitutes are Simplese (CP Kelco, Atlanta, Ga), which is made by reshaping the protein of milk whey or egg whites, and Olean (Olestra) (Procter & Gamble, Cincinnati, Ohio), which is an indigestible form of sucrose.

Fat in the Body

Adipose Tissue

Fat that is stored in various parts of the body is called *adipose tissue*, from the Latin word *adiposus*, meaning "fatty." A web-like padding of fat tissue supports and protects vital organs, and a layer of fat directly under the skin is important for the regulation of body temperature. In addition, the protective myelin sheath that surrounds neurons is largely composed of fat.

Cell Membrane Structure

Fat forms the fatty center of cell membranes, thereby creating the selectively permeable lipid bilayer. Proteins are embedded within this layer and allow for the transport of various nutrients in and out of the cells.

glycolipid a lipid with a carbohydrate attached.

adipose fat stored in the cells of adipose (fatty) tissue.

FOOD SOURCES OF FAT

Variety of Sources

Animal Fats

The predominant supply of saturated fats comes from animal sources, the most concentrated of which include meat fats (e.g., bacon, sausage), dairy fats (e.g., cream, ice cream, butter, cheese), and egg yolks. Because these are animal sources, they also contain considerable amounts of cholesterol. The exceptions are coconut and palm oils, which also contain saturated fatty acids. The American diet has traditionally featured meats and other foods of animal origin. The U.S. Department of Agriculture reports that animal products in particular (e.g., meat, poultry, fish, eggs, dairy products) contribute 32.7% of the total fat to U.S. diets as well as 45.3% of the saturated fat and 95% of the cholesterol.⁵

Although animal products supply saturated fat and cholesterol to the diet, all types of animal protein are not created equal. One study found that, regardless of the protein source, when consuming lean beef, lean fish, and poultry without skin in a well-balanced diet that also includes a high ratio of polyunsaturated fat to saturated fat and ample fiber, similar benefits for blood cholesterol levels are found.⁶ In other words, although animal products can have a hefty dose of cholesterol and saturated fat, lean portions do not have the same hypercholesterolemic effects as their full-fat counterparts when they are consumed with diets that are high in fiber. However, even greater cholesterol-lowering effects can be achieved from a diet that is low in trans-fatty acids and that involves the regular moderate use of polyunsaturated oils in the place of saturated fat.⁷

Some animal fats contain small amounts of unsaturated fats. Specifically, fish oils are a good source of the polyunsaturated omega-3 fatty acids (i.e., docosahexaenoic acid and eicosapentaenoic acid).

Plant Fats

Plant foods supply mostly monounsaturated and polyunsaturated fats, including the essential fatty acids. Food sources for unsaturated fats include vegetable oils (e.g., safflower, corn, cottonseed, soybean, peanut, olive; see Figure 3-4). However, as indicated previously, coconut and palm oils are exceptions; these saturated fats are used mainly in commercially processed food items.

Characteristics of Food Fat Sources

For practical purposes, food fats can be classified as visible or invisible fats.

Visible Fat

The obvious fats are easy to see and include butter, margarine, separate cream, salad oils and dressings, lard, shortening, fatty meats (e.g., bacon, sausage, salt pork), and the visible fat of any meat. Visible fats are easier to control in the diet than those that are less apparent.

Invisible Fat

Some dietary fats are less visible, so individuals who want to control dietary fat must be aware of these food sources. Invisible fats include cheese, the cream portion of homogenized milk, nuts, seeds, olives, avocados, and lean meat. Basically, invisible fats are those that you cannot cut out of the food. Even when all of the visible fat has been removed from meat (e.g., the skin on poultry and the obvious fat on the lean portions), approximately 6% of the total fat surrounding the muscle fibers remains.

Table 3-1 provides a list of commonly eaten foods and their fat content.

FOOD LABEL INFORMATION

The FDA food-labeling regulations for nutrition facts panel content provide the following mandatory and voluntary (italicized below) information relating to dietary fat in food products⁸ (Figure 3-7):

- Calories from fat
- *Calories from saturated fat*
- Total fat
- Saturated fat
- Trans fat
- *Polyunsaturated fat*
- *Monounsaturated fat*
- Cholesterol

The nature and amount of dietary fat and cholesterol contribute to disease risk for some forms of cancer, coronary heart disease, diabetes, and obesity (see the Cultural Considerations box, “Ethnic Differences in Lipid Metabolism”). The FDA has approved a series of health claims that link one or more dietary components to the reduced risk of a specific disease.⁹ Approved and well-supported health claims that involve dietary fat include the following:

- A diet that is low in total fat may reduce the risk of some cancers.
- Diets that are low in saturated fat and cholesterol may reduce the risk of coronary heart disease.

The following are claims pending approval:

- The consumption of eicosapentaenoic acid and docosahexaenoic omega-3 fatty acids may reduce the risk of coronary heart disease.

TABLE 3-1 FAT IN FOOD SERVINGS

Food	Serving Size	Fat Content (g)	Food	Serving Size	Fat Content (g)
Fats			Dairy		
Butter or margarine	1 Tbsp	11	American cheese	2 oz	18
Cream cheese	1 Tbsp	10	Cheddar cheese	1½ oz	14
Mayonnaise	1 Tbsp	11	Frozen yogurt	½ cup	2
Salad dressing	1 Tbsp	7	Ice cream	⅓ cup	7
Vegetables			Low-fat milk	1 cup	5
Broccoli	½ cup	Trace	Skim milk	1 cup	Trace
Carrots	½ cup	Trace	Whole milk	1 cup	8
Potato, baked	1	Trace	Eggs, Fish, Meat, and Nuts		
Fruit			Bologna (2 slices)	1 oz	16
Apple	1	Trace	Egg	1	5
Banana	1	Trace	Fish	3 oz	6
Fruit juice	1 cup	Trace	Ground beef	3 oz	16
Orange	1	Trace	Lean beef	3 oz	6
Bread and Grains			Poultry	3 oz	6
Bagel	1	Trace	Nuts (⅓ cup)	1 oz	22
Muffin	1 medium	6	Other		
Rice or pasta	½ cup	Trace	Danish pastry	1 medium	13
			French fries	1 cup	8

Adapted from Grodner M, Long Roth S, Walkingshaw BC. *Foundations and clinical applications of nutrition*. 5th ed. St. Louis: Mosby; 2012.



CULTURAL CONSIDERATIONS

ETHNIC DIFFERENCES IN LIPID METABOLISM

Dietary patterns and habits form at an early age as a result of both family influence and environmental factors. The dietary fat intake of some individuals is much lower than that of others simply because of how the individuals were raised. However, since the unveiling of the human genome, we are learning that biologic differences also exist that may affect dietary patterns and determine the ways in which our bodies handle the nutrients we eat. The prevalence of obesity has long been known to differ among ethnic and racial populations, but the exact cause remains uncertain.

Women are often the subjects of study in obesity research. A significant difference in ethnicity exists with regard to the incidence of women 20 years old or older who are overweight in the United States¹:

- 79.8% of African-American women
- 73.9% of Mexican women
- 57.9% of white women

Evidence is accumulating to suggest that biologic differences in lipid metabolism among ethnic groups may be the

cause. Bower and colleagues found that African-American women have an increased capacity to synthesize fat from glucose in adipose tissue as compared with white women²; thus they are more efficient at converting excess kilocalories into stored fat. Another group found that obese African-American women have an inhibition of lipolysis (i.e., the metabolic breakdown of fat) that contributes to the difficulty that they have losing weight as compared with white women.³

These types of differences continue to unfold with ongoing genetic studies. Differences such as these will also guide individuals in their dietary choices with regard to how their bodies will respond to specific nutrients. The path from fat in our food to fat on our bodies continues to provide many questions for inspection and evaluation. The science of lipid digestion, metabolism, and use will remain a hot topic for debate and research for years to come.

1. National Center for Health Statistics. *Health, United States, 2009*, with special feature on medical terminology. Hyattsville, Md: U.S. Government Printing Office; 2010.

2. Bower JF, Vadlamudi S, Barakat HA. Ethnic differences in in vitro glyceride synthesis in subcutaneous and omental adipose tissue. *Am J Physiol Endocrinol Metab*. 2002;283(5):E988-E993.

3. Barakat H, Davis J, Lang D, et al. Differences in the expression of the adenosine A1 receptor in adipose tissue of obese black and white women. *J Clin Endocrinol Metab*. 2006;91(5):1882-1886.

Nutrition Facts	
Serving Size 1 cup (228g)	
Servings Per Container 2	
Amount Per Serving	
Calories 260	Calories from Fat 120
% Daily Value*	
Total Fat 13g	20%
Saturated Fat 5g	25%
Trans Fat 2g	
Cholesterol 30 mg	10%
Sodium 660 mg	28%
Total Carbohydrate 31g	10%
Dietary Fiber 0g	0%
Sugars 5g	
Protein 5g	
Vitamin A 4%	Vitamin C 2%
Calcium 15%	Iron 4%
* Percent Daily Values are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs:	
	Calories: 2,000 2,500
Total Fat	Less than 65g 80g
Sat Fat	Less than 20g 25g
Cholesterol	Less than 300mg 300mg
Sodium	Less than 2,400mg 2,400mg
Total Carbohydrate	300g 375g
Dietary Fiber	25g 30g
Calories per gram:	
Fat 9	Carbohydrate 4 Protein 4

Figure 3-7 Example of nutrition facts panel listing the trans fat content. (From the U.S. Food and Drug Administration, U.S. Department of Health and Human Services. *Examples of revised nutrition facts panel listing trans fat* (website): www.fda.gov/Food/GuidanceCompliance/RegulatoryInformation/GuidanceDocuments/FoodLabelingNutrition/ucm173838.htm. Accessed August 17, 2009.)

- Eating 2 tablespoons of olive oil (monounsaturated fat) daily may reduce the risk of coronary heart disease.
- Consuming about 1½ tablespoons of canola oil (unsaturated fat) daily may reduce the risk of coronary heart disease.

See the label claim information published by the FDA at www.fda.gov/Food/LabelingNutrition/LabelClaims/default.htm for more information about FDA-approved health claims. This Web site provides updates regarding approved health claims, pending claims, and the appropriate use of the claims on food products. Food labels and health claims are discussed further in Chapter 13.

DIGESTION OF FATS

Mouth

As with other macronutrients (i.e., carbohydrates and proteins), fats are broken down into their basic building blocks, fatty acids, through the process of digestion (Figure 3-8). When foods are eaten, some initial fat breakdown may begin in the mouth by action of lingual lipase, an enzyme that is secreted by Ebner's glands at the back of the tongue. Of note is that lingual lipase is only important for digestion during infancy. For adults, the primary digestive action that occurs in the mouth is mechanical. Foods are broken into smaller particles through chewing and moistened for passage into the stomach.

Stomach

Little if any chemical digestion of fat occurs in the stomach. General muscle action continues to mix the fat with the stomach contents. No significant amounts of fat enzymes are present in the gastric secretions except gastric lipase (tributyrylase), which acts on emulsified butterfat. While the primary gastric enzymes act on other macronutrients in the food mix, fat is separated out and prepared for its major, enzyme-specific breakdown in the small intestine.

Small Intestine

Fat digestion largely occurs in the small intestine, where the major enzymes that are necessary for the chemical changes are present. These digestive agents come from three major sources: an emulsification agent from the gallbladder and two specific enzymes from the pancreas and the small intestine itself.

Bile From the Gallbladder

The bile is first produced in large dilute amounts in the liver, and the liver then sends the bile to the gallbladder for concentration and storage so that it is ready for use during fat digestion as needed. The fat that comes into the duodenum, which is the first section of the small intestine, stimulates the secretion of cholecystokinin, a hormone that is released from glands in the intestinal walls. In turn, cholecystokinin causes the gallbladder to contract, relax its opening, and subsequently secrete **bile** into the intestine by way of the common bile duct. Bile is not an enzyme that acts in the chemical digestive process; rather, it functions as an **emulsifier**. This preparation process accomplishes two important tasks: (1) it breaks the fat into small particles, thereby greatly increasing the total surface area

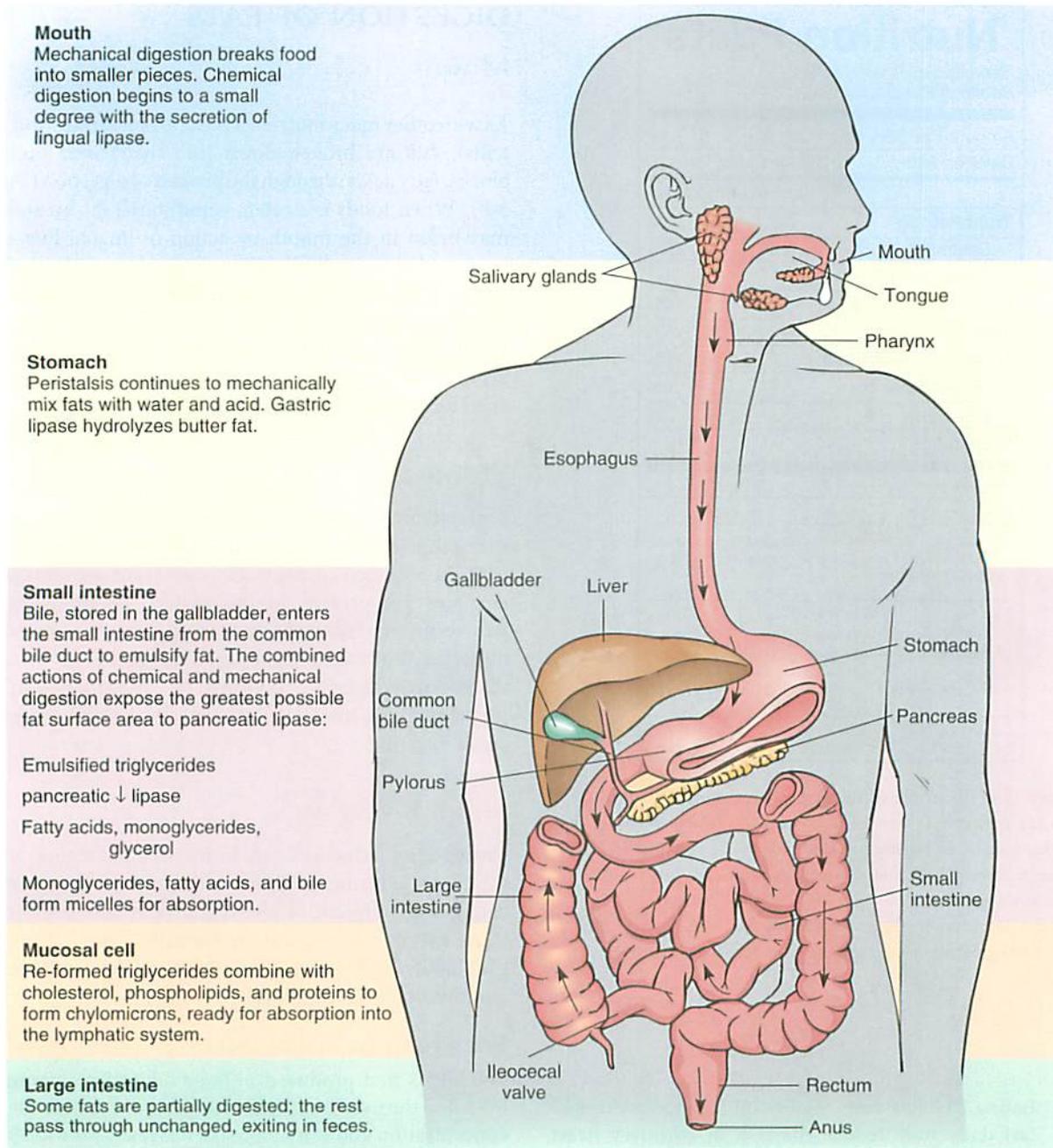


Figure 3-8 Summary of lipid digestion. (Courtesy Rolin Graphics.)

available for enzymatic action; and (2) it lowers the surface tension of the finely dispersed and suspended fat particles, thus allowing the enzymes to penetrate more easily. This process is similar to the emulsification action of detergents. The bile also provides an alkaline medium that is necessary for the action of pancreatic lipase, which is the chief lipid enzyme.

Enzymes From the Pancreas

Pancreatic juice flowing into the small intestine contains one enzyme for triglycerides and another for cholesterol. First, pancreatic lipase breaks off one fatty acid at a time from the glycerol base of triglycerides. One fatty acid plus a diglyceride and then another fatty acid plus a monoglyceride are produced in turn. Each succeeding step of this

breakdown occurs with increasing difficulty. In fact, the separation of the final fatty acid from the remaining monoglyceride is such a slow process that less than one third of the total fat present reaches complete breakdown. The final products of fat digestion to be absorbed are fatty acids, monoglycerides, and glycerol. Some remaining fat may pass into the large intestine for fecal elimination. The enzyme cholesterol esterase acts on cholesterol esters (not free cholesterol) to form a combination of free cholesterol and fatty acids in preparation for absorption into the lacteal (lymph vessel) and finally into the bloodstream (see Chapter 5).

Enzyme From the Small Intestine

The small intestine secretes an enzyme in the intestinal juice called *lecithinase*, which breaks down lecithin for absorption. Figure 3-8 summarizes fat digestion in the successive parts of the gastrointestinal tract.

Absorption

Fat absorption into the gastrointestinal cells and bloodstream is more involved than the absorption of other macronutrients (i.e., the products of digestion of carbohydrate and protein). Triglycerides are not soluble in water and thus cannot directly enter the bloodstream, which is mostly water. Within the small intestines, bile salts surround the monoglycerides and fatty acids to form **micelles**. The non-water-soluble fat particles (e.g., fatty acids, monoglycerides) are found in the middle of the packaged micelle, whereas the water-soluble part faces outward. This structure allows the products of lipid digestion to travel to the brush border membrane. Once there, fats are absorbed into the epithelial cells of the intestine, and bile is absorbed and transported by the portal vein to the liver for reprocessing; this process is called *enterohepatic circulation*. Inside the intestinal cells, monoglycerides and fatty acids again form triglycerides, which are then packaged into a **chylomicron**. Chylomicrons are made of triglycerides, cholesterol, phospholipids, and proteins (Figure 3-9). This structure also forms within the intestinal cell and allows the products of fat digestion to enter the circulation. Chylomicrons first enter the lacteals, then the lymphatic circulatory system, and then eventually the bloodstream. A summary of fat absorption through the process of micelle production and the formation of chylomicrons is provided in Figure 3-10.

Digestibility of Food Fats

The digestibility of fats varies somewhat according to the food source and the cooking method used. Butter digests

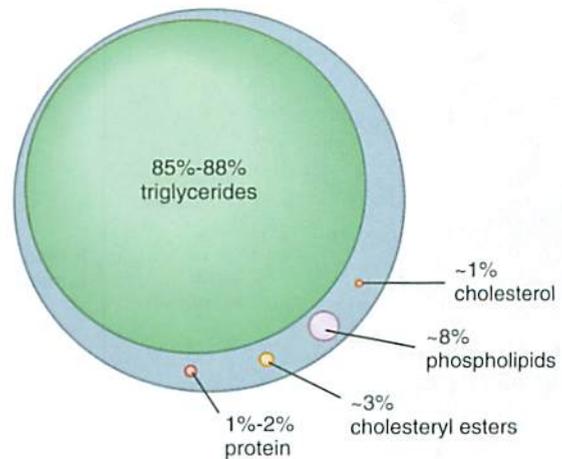


Figure 3-9 Composition of a chylomicron.

more completely than meat fat. Fried foods, especially those that are saturated with fat during the frying process, are digested more slowly than baked or broiled foods. When fried foods are cooked at too high of a temperature, they are more difficult to digest, and substances in the fat break down into carcinogenic materials. Fried foods should be consumed sparingly, and the temperature of the fat should be carefully controlled during frying, grilling,

bile an emulsifying agent produced by the liver and transported to the gallbladder for concentration and storage; it is released into the duodenum with the entry of fat to facilitate enzymatic fat digestion by acting as an emulsifier.

emulsifier an agent that breaks down large fat globules into smaller, uniformly distributed particles; the action is chiefly accomplished in the intestine by bile acids, which lower the surface tension of the fat particles, thereby breaking the fat into many smaller droplets and thus greatly increasing the surface area of fat and facilitating contact with the fat-digesting enzymes.

micelles packages of free fatty acids, monoglycerides, and bile salts; the non-water-soluble fat particles are found in the middle of the package, whereas the water-soluble part faces outward and allows for the absorption of fat into intestinal mucosal cells.

chylomicron a lipoprotein formed in the intestinal cell that is composed of triglycerides, cholesterol, phospholipids, and protein; chylomicrons allow for the absorption of fat into the lymphatic circulatory system before entering the blood circulation.

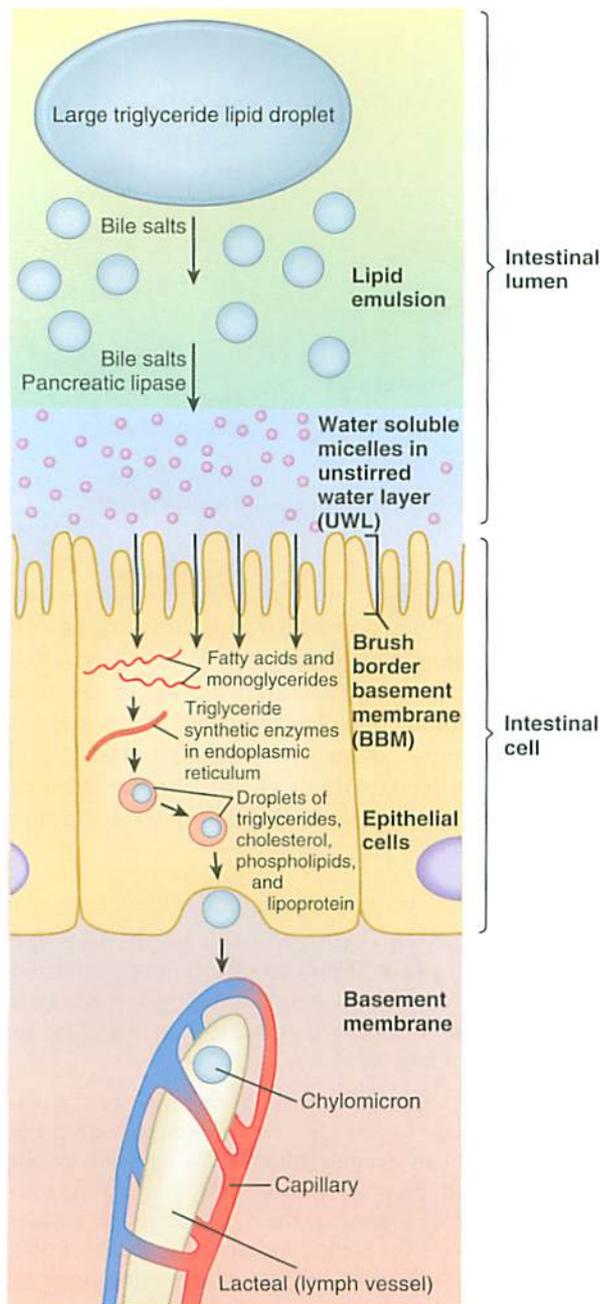


Figure 3-10 Summary of fat absorption. (From Mahan LK, Escott-Stump S. *Krause's food & nutrition therapy*. 12th ed. St. Louis: Saunders; 2008.)

and broiling. Although lower-fat food products are now generally more available in food markets, many high-fat products still compete for the customer's attention. Fat is an essential part of a healthy, well-balanced diet. However, one of the overall health goals is to reduce the amount of excessive fat used in the diet.

RECOMMENDATIONS FOR DIETARY FAT

Dietary Fat and Health

American Diet

Fats in the diet supply flavor to food, thereby providing a sense of satisfaction and an enhancement of eating pleasure. The American diet has traditionally been high in fat. The U.S. Department of Agriculture nutrient intake records show that 31% of the total kilocalories came from fat in 1909, with an increase to 33% in 2008. However, Americans have succeeded in reducing the amount of fat coming from decidedly unhealthy saturated fat from 13% of total kcals to 11% over the same time frame.^{5,10} Still, the average amount of saturated fat consumed per person in the United States for all individuals 2 years old and older exceeds the recommendations of the DRIs. Total kilocalories coming from fat should not exceed 20% to 35%, with a maximum of 10% of total kilocalories from saturated and trans fats combined.³ Many individuals with health problems are encouraged to adjust to lower amounts of fat, with goals such as 15% to 25% of the total kilocalories and no more than 7% of total kilocalories from saturated and trans fats combined. This amount could easily provide an adequate amount of the essential fatty acids (i.e., linolenic acid and linoleic acid) to meet the physiologic needs of the body.

Health Problems

If fat is vital to human health, what is the concern about fat in the diet? Research continues to indicate that health problems from fat are related to too much dietary fat and specifically to saturated fat.

Amount of Fat. Too many kilocalories in the diet, regardless of the source—fat, carbohydrates, or protein—will exceed the requirement of immediate energy needs. The surplus is stored as body fat. Excess body fat is associated with risk factors for chronic diseases such as diabetes, hypertension, and heart disease. How much fat is in your own daily diet? See the Clinical Applications box entitled “How Much Fat Are You Eating?” to assess your fat intake.

Type of Fat. An excess of cholesterol and saturated fat in the diet, which comes from animal food sources, has been identified as a specific risk factor for atherosclerosis, the underlying blood vessel disease that contributes to heart attacks and strokes (see Chapter 19). A decrease in dietary saturated fats (e.g., using polyunsaturated and monounsaturated fats instead) has been shown to produce favorable lipid profiles.^{7,11} When substituted for saturated fat in the diet, monounsaturated fats reduce low-density lipoprotein cholesterol levels and



CLINICAL APPLICATIONS

HOW MUCH FAT ARE YOU EATING?

Keep an accurate record of everything that you eat and drink for one day. Be sure to include all fat or other nutrient seasonings used with your foods (e.g., salad dressing, sugar, mayonnaise). If you want a more representative picture, use the nutrient analysis program that came with this text or another program to which you have access, and keep a 3- to 7-day record.

Step 1: Calculate the total kilocalories and grams for each of the energy-yielding nutrients (i.e., carbohydrates, fat, and protein) in everything that you eat. Multiply the total grams of each energy nutrient by its respective fuel value:

Fat: _____ g \times 9 = _____ kcal

Protein: _____ g \times 4 = _____ kcal

Carbohydrate: _____ g \times 4 = _____ kcal

Step 2: Add the kcals from each macronutrient to determine the total kcals consumed.

Step 3: Calculate the percentage of each energy nutrient in your total diet:

Example: (Fat kcal/Total kcal) \times 100 = % fat kcal in diet

Step 4: Compare the amount of fat in your diet with the amount of fat in a typical American diet (31% to 35% fat) and with the U.S. dietary goal (20% to 35% fat).

increase high-density lipoprotein levels, thereby improving overall cardiovascular health risk.

Essential Fatty Acid Deficiency. Fat-free diets may lead to essential fatty acid deficiency with clinical manifestations. Because essential fatty acids play an important role in maintaining the integrity of biologic membranes, one indication of essential fatty acid deficiency is dermatitis. Omega-3 fatty acids are especially required for normal function of the brain, the central nervous system, and the cell membranes. Low levels of omega-3 and omega-6 fatty acids are linked to hair loss, low blood platelet levels, impaired vision, compromised brain function, and growth retardation in children.

Trans-Fatty Acids. Observed effects of diets that are high in trans-fatty acids include an elevation of total cholesterol and low-density lipoprotein cholesterol levels, reduced high-density lipoprotein cholesterol levels, endothelial dysfunction, and the increased production of atherosclerotic inflammatory cytokines.¹² In response to these growing health concerns, the FDA now requires that all food products identify the amount of trans fats on the nutrition facts label, thereby making the identification of these products much easier (see Figure 3-7). This has motivated the food industry to develop alternative fats and oils to avoid the use of trans fats and to improve the fatty acid composition with regard to cardiovascular health risk.

Health Promotion

The ongoing movement in American health care is toward health promotion and disease prevention through the reduction of risk factors related to chronic disease. Heart disease continues to be a leading cause of death, and much attention is given to reducing the various risk factors that lead to this disease. Excess dietary fat—particularly saturated fat, trans fat, and cholesterol—contributes to these risk factors, which include obesity,

diabetes, elevated triglycerides, and elevated blood pressure. Such risk factors have previously been thought of as only affecting adults, but they are becoming increasingly apparent among obese children and adolescents. The Centers for Disease Control and Prevention reported that 20.3% of all youth between the ages of 12 and 19 years have abnormal lipid levels. Overweight children have a significantly higher prevalence of cardiovascular health risk than normal-weight children.¹³ Healthier eating habits are especially important for children in high-risk families (e.g., families with identified lipid disorders and heart disease at young ages).

Additional lifestyle risk factors include smoking, increased stress, and physical inactivity, especially among middle-aged and older individuals. Emphasis is placed on the importance of keeping the body's total daily energy use in balance with the total daily caloric intake to maintain an ideal body weight. Low-fat diets, fad diets, and other issues that affect weight loss are discussed in more detail in Chapter 15.

In addition, changes are gradually being made in the fast-food industry to reduce the traditional high-fat content of menu items. For example, most of the fast-food chains are shifting to leaner meat for hamburgers; more variety in food choices (e.g., grilled chicken and fish sandwiches; breakfast items such as fruit, waffles, pancakes, and hot and cold cereals; baked potatoes; fresh and packaged salads and fruit); and using vegetable oil for frying.

Dietary Reference Intakes

Healthy diet guidelines stress the benefits of a diet that is low in fat, saturated fat, trans-fatty acids, and cholesterol. All guidelines recommend that the fat content of the diet not exceed 20% to 35% of the total kilocalories, that less than 10% of the kilocalories should come from saturated

fats, and that dietary cholesterol be limited to a maximum of 300 mg/day (see Chapter 1). No DRI or Tolerable Upper Intake Level is set for trans-fatty acids. The National Academy of Sciences recommends limiting trans-fat intake to as low as possible while maintaining a nutritionally adequate diet.³ As mentioned previously, fat is an essential part of the diet; therefore, diets that are completely devoid of fat are equally unhealthy and can result in a deficiency of essential fatty acids.

The DRI for linoleic acid, which is found in polyunsaturated vegetable oils, is set at 17 g/day for men and 12 g/day for women. Linolenic acid is primarily found in fish, soybeans, and flaxseed oil, and it is generally consumed in much lesser quantities than linoleic acid. The recommendation for linolenic acid intake is 1.6 and 1.1 g/day for men and women, respectively.³ The average American diet contains significantly more omega-6 fatty acids than omega-3 fatty acids at a ratio of approximately 15-20:1 and 1-4:1. However, consuming more omega-3 fatty acids from vegetables and fish would help to achieve a preferred omega-6 to omega-3 ratio of 1-4:1 and thus reduce the risk for several chronic diseases.¹⁴

Dietary Guidelines for Americans

In line with the current national health goal of health promotion through disease prevention by reducing identified risks of chronic disease, the *Dietary Guidelines for Americans* recommends the general control of fat in the

diet, especially saturated fat and cholesterol. The following guidelines address dietary fat intake²:

- Consume less than 10% of calories from saturated fatty acids by replacing them with monounsaturated and polyunsaturated fatty acids.
- Consume less than 300 mg/day of cholesterol.
- Keep trans-fatty acid consumption as low as possible by limiting foods that contain synthetic sources of trans fats (e.g., partially hydrogenated oils) and by limiting other solid fats.
- Reduce the intake of calories from solid fats.
- Choose fat-free or low-fat milk and milk products.
- Replace protein foods that are higher in solid fats with choices that are lower in solid fats and calories and/or are sources of oils.
- Use oils to replace solid fats where possible.

MyPlate

The MyPlate food guidance system provides recommendations for designing a diet that reflects the DRI and *Dietary Guidelines for Americans* recommendations for fat intake within a well-balanced diet. After an individual plan is determined on the basis of age, gender, height, weight, and physical activity level, other helpful tips and resources are available through the free Web site, www.choosemyplate.gov/, such as information about how to choose lean meats, where to find essential fatty acids, how to avoid saturated fat intake, tips for eating out, and sample menus.¹⁵

SUMMARY

- Fat is an essential body nutrient that serves important body needs as a backup storage fuel (secondary to carbohydrate) for energy. Fat also supplies important tissue needs as a structural material for cell membranes, a protective padding for vital organs, an insulation to maintain body temperature, and a covering for nerve fibers.
- Food fats have different forms and health implications. Saturated fats primarily come from animal food sources and carry health risks for the body. Plant food sources are the richest source of unsaturated fats and may reduce health risks when used in place of saturated and trans fats.
- Cholesterol is a sterol that is synthesized only by animals. When it is consumed in excessive amounts, cholesterol also contributes to health risks for the development of cardiovascular disease.
- When various foods that contain triglycerides and cholesterol are eaten, specific digestive agents, including bile and pancreatic lipase, prepare and break down fats. Fatty acids and monoglycerides are incorporated into chylomicrons and absorbed through the lymphatic system into the bloodstream.
- Americans generally consume more saturated fat than recommended. Reducing saturated and trans-fat intake and maintaining a low-cholesterol diet are ideal for health promotion and disease prevention.

CRITICAL THINKING QUESTIONS

1. Compare fat and carbohydrate as fuel sources in the body's energy system. Name several other important functions of fat in human nutrition and health.
2. Differentiate the components of lipids, triglycerides, fatty acids, cholesterol, and lipoproteins.
3. Compare the structure of a saturated fat, a monounsaturated fat, a polyunsaturated fat, and a trans fat. Give food sources for each.
4. Why is a controlled amount of dietary fat recommended for health promotion? How much fat should a healthy diet contain?

CHAPTER CHALLENGE QUESTIONS

True-False

Write the correct statement for each statement that is false.

1. *True or False:* Fat has the same energy value as carbohydrate.
2. *True or False:* Fat is composed of the same basic chemical elements as carbohydrate.
3. *True or False:* Corn oil is a saturated fat.
4. *True or False:* Polyunsaturated fats predominantly come from animal food sources.
5. *True or False:* Lipoproteins, which are produced mainly in the liver, carry fat in the blood.

Multiple Choice

1. The fuel form of fat found in food sources is
 - a. triglyceride.
 - b. fatty acid.
 - c. glycerol.
 - d. lipoprotein.
2. Which of the following statements about the saturation of fats is correct?
 - a. The degree of saturation does not depend on the amount of hydrogen in the fatty acids that make up the fat.
 - b. Unsaturated fats come from animal food sources.
 - c. The more saturated the fat, the softer it tends to be.
 - d. Fats that are composed of fatty acids with two or more double bonds in their structure are called *polyunsaturated*.
3. If an individual implemented a diet that was low in saturated fat to lower the risk for heart disease, which of the following foods would be consumed more frequently than the others?
 - a. Whole milk
 - b. Olive oil and vinegar salad dressing
 - c. Butter
 - d. Cheddar cheese
4. Once absorbed into the enterocyte, monoglycerides and fatty acids again form triglycerides, which are then packaged into lipoproteins called _____ for absorption into the lymphatic structure.
 - a. low-density lipoprotein cholesterol
 - b. high-density lipoprotein cholesterol
 - c. micelles
 - d. chylomicrons

 **Evolve** Please refer to the Students' Resource section of this text's Evolve Web site for additional study resources.

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FURTHER READING AND RESOURCES

- Lipids in Health and Disease. www.lipidworld.com
An online journal of peer-reviewed articles about all aspects of lipids that is open access and free to the public
- Mayo Clinic. www.mayoclinic.com
A site search for "dietary fat" results in several informative articles.
- USDA Nutrient Data Laboratory. www.nal.usda.gov/fnic/foodcomp/search
A useful Web site for finding the nutrient content of the foods that you most enjoy, including their trans fat content
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