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Fats

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Learning Objectives

1. Classify fats according to their chemical composition.
2. Distinguish between saturated and unsaturated, monounsaturated and polyunsaturated, *cis* and *trans*, and omega-3 and omega-6 fatty acids.
3. Describe the digestion, absorption, transportation, and storage of fat.
4. Explain the metabolism of fat, including mobilization, transportation, uptake, activation, translocation, and oxidation.
5. Explain ketosis and the effect it may have on training.
6. Describe how the body uses fat to fuel exercise.
7. State fat recommendations for athletes and calculate the amount of fat needed daily.
8. Identify sources of dietary fat.
9. Assess an athlete's dietary fat intake.
10. Evaluate fat-related dietary supplements.

Pre-Test Assessing Current Knowledge of Fats

Read the following statements about fats and decide if each is true or false.

1. A low-calorie, low-carbohydrate diet that results in ketosis is dangerous for athletes because it leads to the medical condition known as ketoacidosis.
2. At rest, the highest percentage of total energy expenditure is from fat, not carbohydrate.
3. To lose body fat, it is best to perform low-intensity exercise, which keeps one in the fat burning zone.
4. To improve performance, endurance athletes should ingest caffeine because more free fatty acids are oxidized for energy and muscle glycogen is spared.
5. Athletes typically need to follow a very-low-fat diet.

The word fat is used in many different ways. In physiology, a **fat** is a long chain of carbon molecules. The fatty acid chains that are most commonly used by humans for metabolism contain either 16 or 18 carbons, such as **palmitic acid** (palmitate) and **oleic acid.** In medicine, fats are known as **lipids,** large fat-containing components in the blood. **Triglycerides, sterols** (e.g., **cholesterol**), and **phospholipids** are examples, and some play a substantial role in the development of **cardiovascular disease.** In nutrition, fats are energy-containing nutrients found in food. In all of these disciplines, fat is also used to describe the body's long-term storage site for fats, although the precise term is **adipose tissue.** To further complicate the issue, in everyday language fat is often used as an adjective, describing a body weight that is greater than desirable.

Confusion can result unless the most appropriate terms are used within the proper context. In many cases that means talking about specific chemical compounds, such as triglycerides, **saturated fats,** or cholesterol. All of these compounds are described as lipids when found in blood and as fats when found in food. What do people mean when they say "too much fat?" Too much adipose tissue? Too much fat in the diet? Too much fat in the blood? When talking about various fats in the fields of nutrition, health, and medicine, precise terms need to be used.

Fats are an important nutrient for athletes because they are a primary energy source at rest and during low-intensity activity. Along with carbohydrates, fats are an important energy source for moderate-intensity exercise. The largest amount of fat in the body is stored in adipose tissue in the form of triglycerides, while smaller amounts are stored as muscle triglycerides. Aerobic training can increase the body's ability to utilize fats.

Most of the fats found in food provide energy because the body can digest, absorb, and metabolize them. An exception is cholesterol, which cannot be broken down for energy because of its chemical structure. However, cholesterol is important for good health because it is needed for a variety of physiological functions such as a building block for essential hormones. However, in some individuals excessive amounts of cholesterol can be absorbed and ultimately deposited in the walls of arteries, potentially leading to a blockage, so limiting dietary cholesterol may be helpful. All humans need some fat in their diets to provide the essential fatty acids that the body cannot manufacture, so dietary fat should not be viewed automatically as bad. Some fat is also necessary for the absorption of the fat-soluble vitamins, and fat-containing foods taste good and satisfy hunger, making them a palatable energy source.

There are four sources of energy provided by diet—carbohydrates, fats, proteins, and alcohol. Fats are the most concentrated form of energy, with each gram containing approximately 9 kcal. Alcohol contains approximately 7 kcal/g, and proteins and carbohydrates contain approximately 4 kcal/g each, so fats have the highest caloric density. Athletes who expend a lot of energy during daily training

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It is important to know the amounts and types of dietary fats found in foods.

need to include enough fat in their diets or they risk consuming too little energy (kcal). However, many athletes do not want to be in energy balance. Reducing dietary fat is a strategy frequently used by athletes who wish to reduce energy intake and, over time, body fat. Lowering dietary fat intake can be appropriate, but too low of a fat intake can also be detrimental to performance and health.

The best way to understand the different kinds of fats is to understand their chemistry. The length of the chain, which is measured by the number of carbons contained, and the degree of saturation, which is determined by the number of hydrogen atoms attached to each carbon atom, are two characteristics used to categorize fats. The processing of food can change the chemical configuration, so processed fats may differ from naturally occurring ones. The chemical structure of the fat influences how it is digested, absorbed, and transported, so an understanding of physiology is needed. Fat is an important nutrient to support training and performance, but because fats influence **chronic** diseases, notably cardiovascular diseases, their influence on health and disease must be considered as well.

Fatty Acids, Sterols, and Phospholipids

Fats vary in their chemical composition. The predominant fats in food and in the body are triglycerides, which are made up of three fatty acids attached to a **glycerol** molecule. Sterols, such as cholesterol, and phospholipids, phosphate-containing fats, are also found in food and in the body. These three classes of fat compose the category known as lipids.

FATTY ACIDS

To understand the differences in the various fats, one must look closely at their chemical composition. This discussion begins with fatty acids, which are chains of carbon and hydrogen ending with a **carboxyl** group (a carbon with a **double bond** to oxygen and a single bond to an oxygen/hydrogen, written as COOH). The length of the fatty acid chain can range from four to 24 carbons. The number of carbons will be an even number because fatty acid chains are manufactured by adding two carbons at a time. An example of a fatty acid is shown in Figure 6.1. The fatty acid in this example, oleic acid, has 18 carbons. The fatty acids used most commonly in metabolism in humans have 16 or 18 carbons.

A saturated fatty acid contains no double bonds between carbons. The term saturated refers to the fact that no additional hydrogen atoms can be incorporated.

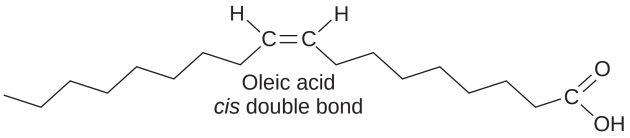


Figure 6.1 Oleic Acid

Oleic acid is an 18-carbon fat that is found in plant and animal fats.

An example of one saturated fatty acid, palmitic acid, is shown at the top of Figure 6.2.

Unsaturated fatty acids contain one or more double bonds between carbons, reducing the number of hydrogen atoms that can be bound to the structure. When only one double bond between carbons is present, it is referred to as a **monounsaturated** fatty acid (mono means "one"). When two or more double bonds are present, these fatty acids are referred to as **polyunsaturated** fatty acids (poly means "many"). Unsaturated fatty acids have 16 to 22 carbons and from one to six double bonds. Examples are shown in Figure 6.2.

Fat: A general term used to describe an energy-containing component of food and the storage of energy in adipose tissue. May also refer to excess body weight as adipose tissue.

Palmitic acid (palmitate): A fatty acid that contains 16 carbons.

Oleic acid: A fatty acid that contains 18 carbons.

Lipid: General medical term for fats found in the blood.

Triglyceride: A fat composed of three fatty acids attached to a glycerol molecule, known technically as a triacylglycerol.

Sterol: A fat whose core structure contains four rings.

Cholesterol: A fat-like substance that is manufactured in the body and is found in animal foods.

Phospholipid: A fat that is similar to a triglyceride but contains phosphate.

Cardiovascular disease: Any of a number of diseases that are related to the heart or blood vessels.

Adipose tissue: Fat tissue. Made up of adipocytes (fat cells).

Saturated fat: A fat that contains no double bonds between carbons.

Chronic: Lasts for a long period of time. Opposite of acute.

Glycerol: A carbon-, hydrogen-, and oxygen-containing molecule that is the backbone of all triglycerides. Glycerol is a sugar alcohol, not a fat.

Carboxyl group: Carbon with a double bond to oxygen and a single bond to oxygen/hydrogen.

Double bond: A chemical bond between two atoms that share two pairs of electrons.

Unsaturated fat: Fatty acids containing one or more double bonds between carbons.

Monounsaturated fat: A fat containing only one double bond between carbons.

Polyunsaturated fat: A fatty acid with two or more double bonds.

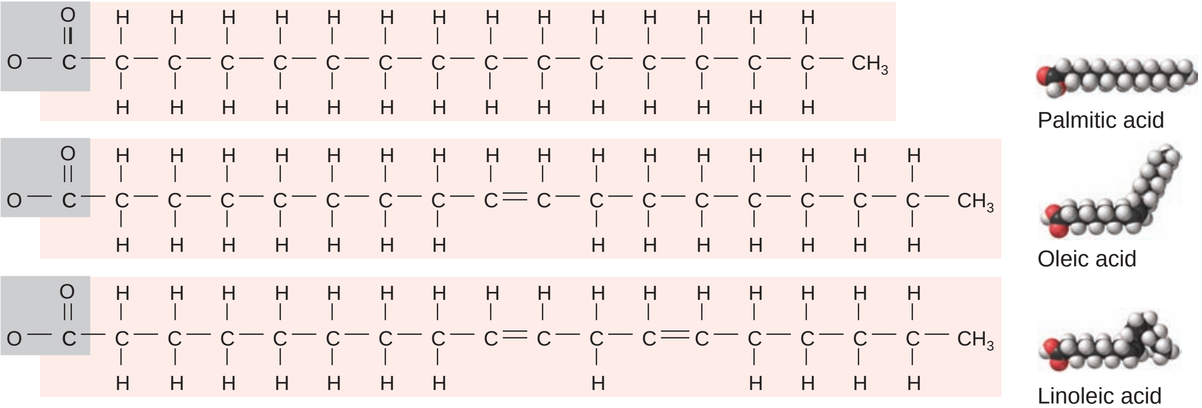


Figure 6.2 Saturated, Monounsaturated, and Polyunsaturated Fatty Acids

Palmitic acid (palmitate) is a 16-carbon saturated fat found in plant and animal fats. Oleic acid is an 18-carbon monounsaturated fat found in plant and animal fats. Linoleic acid is an 18-carbon polyunsaturated fat found in the seed and oil of plants such as corn, safflower, sunflower, soybean, and peanuts.

When double bonds between carbons are present, as in the case of mono- and polyunsaturated fatty acids, the fatty acid can be in the ***cis*** or ***trans*** formation. *Cis* refers to groups that are on the same side of the double bond between carbons. *Trans*, which means "across" or "on the other side," refers to groups that are on opposite sides of the double bond between carbons. Nearly all unsaturated fatty acids occur naturally in the *cis* form. The *cis* form allows fatty acids to "bend," which is an important feature when these fatty acids are incorporated into cell membranes. *Trans* fatty acids are not usually found in nature but are produced synthetically through the addition of hydrogen atoms to an unsaturated fatty acid. This results in the fatty acid chain being "straight." This **hydrogenation** process is used in commercial food processing to make liquid oils more solid (e.g., soybean oil made into margarine) and to increase the shelf life of the product. Figure 6.3 illustrates unsaturated fatty acids in their *cis* and *trans* forms. When the term *partially hydrogenated* appears on a food label, it indicates this type of manufactured fatty acid has been added to the food product, and the food may therefore contain *trans* fatty acids. Most food manufacturers are looking for alternative processes in an effort to reduce the amount of *trans* fat in their products.

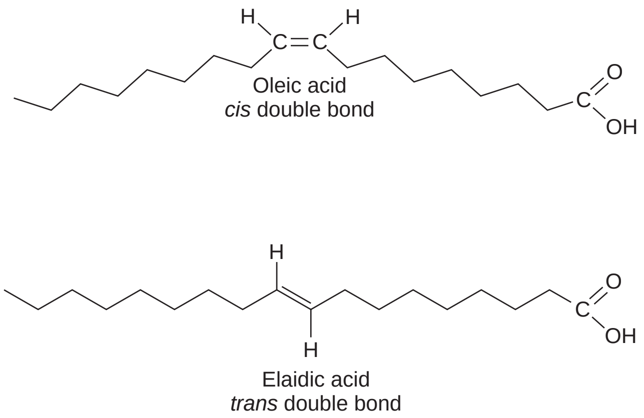


Figure 6.3 *cis* and *trans* Formations

Oleic acid, which naturally occurs in the *cis* formation, is an 18-carbon monounsaturated fat that is widely found in plant and animal fats. Elaidic acid is the *trans* isomer of oleic acid and is found in hydrogenated vegetable oils such as margarine.

Polyunsaturated fatty acids can be further distinguished by their fatty acid series. This refers to the presence of a double bond between carbons that is counted from the last carbon in the chain (farthest from the carboxyl group carbon). This terminal carbon is referred to as **omega** or n-. The three fatty acid series are termed omega-3 (n-3), omega-6 (n-6), or omega-9 (n-9) families. Figure 6.4 shows an example of each. Foods containing omega-3 fatty acids are often discussed in relation to their beneficial effect on blood lipid levels and their potential for reducing cardiovascular disease risk. Linoleic acid, one of two essential fatty acids, is an omega-6 fatty acid. Oleic acid, the predominant fatty acid in olive oil, is an omega-9 fatty acid.

TRIGLYCERIDES IN FOODS

Fatty acids are the building blocks of fat found in food. Nearly 95 percent of all the fat consumed in the diet is in the form of triglycerides. A triglyceride is composed of four parts—three fatty acids attached to a glycerol—as shown in Figure 6.5. The three fatty acids can all be the same, but a triglyceride usually contains a combination of different fatty acids. The nature of the individual fatty acids that make up a triglyceride influence the temperature at which the fat will melt. Those triglycerides with unsaturated fatty acids tend to be liquid at room temperature and are known as oils. Those triglycerides that contain primarily saturated fatty acids do not melt until the temperature is higher and

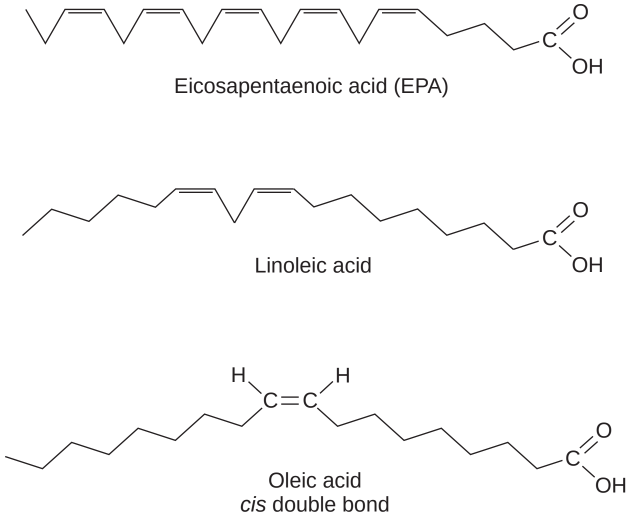


Figure 6.4 Omega-3, -6, and -9 Fatty Acids

Eicosapentaenoic acid (EPA) is an omega-3 fatty acid found in fish oils. Linoleic acid, an omega-6 fatty acid, is found in a variety of vegetable oils. Oleic acid, an omega-9 fatty acid, is widely found in plant and animal fats.

Emilio Ereza/Superstock

Vegetable oils are excellent sources of monounsaturated and polyunsaturated fatty acids.

are solid at room temperature. Although the term triglyceride is commonly used, it should be noted that the technically correct term is **triacylglycerol** and this latter term is frequently used in the scientific literature.

The triglycerides found in food contain a combination of saturated, monounsaturated, and polyunsaturated fatty acids. Foods can be grouped according to the predominant fatty acid. For example, coconut oil contains 92 percent saturated fatty acids, 6 percent monounsaturated fatty acids, and 2 percent polyunsaturated fatty acids. Coconut oil is classified as a saturated fat because saturated fatty acids predominate. Other foods that contain predominantly saturated fatty acids include palm kernel oil, beef, and milk and milk products that contain fat (e.g., whole milk, butter, ice cream).

Oils are predominantly, but not exclusively, polyunsaturated fatty acids. Most vegetable oils contain about 10 to 15 percent saturated fatty acids. Oils are usually

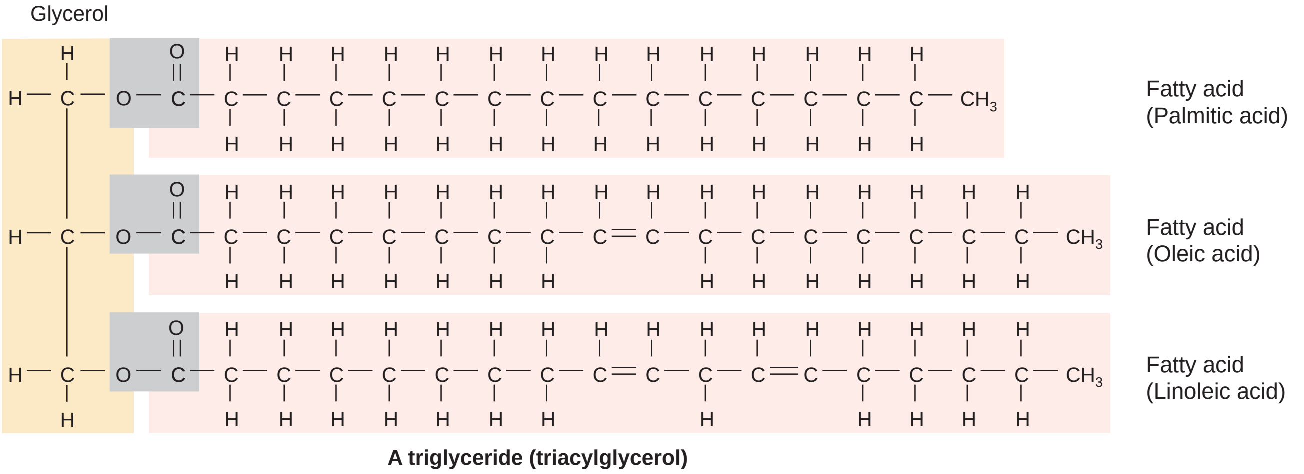
***Cis*:** Describes a chemical formation where groups are on the same side of the double bond between carbons.

***Trans*:** Describes a chemical formation in which groups are on opposite sides of the double bond between carbons.

Hydrogenated/hydrogenation: A chemical process that adds hydrogen. In food processing, used to make oils more solid.

Omega fatty acid: A fatty acid that contains a double bond that is counted from the omega or terminal end. These fatty acids are characterized as omega-3, omega-6, or omega-9.

Triacylglycerol (triglyceride): A fat composed of three fatty acids attached to a glycerol molecule.



A triglyceride (triacylglycerol)

Figure 6.5 Structure of Triglycerides

A triglyceride is composed of three fatty acids attached to a glycerol.

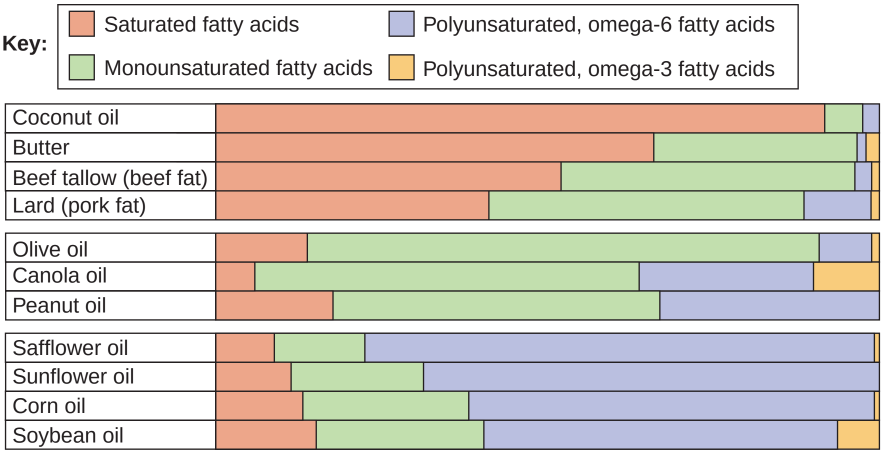


Figure 6.6 Fatty Acid Distribution in Selected Foods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Cholesterol is only found in animal foods such as milk and milk products in which the fat has not been removed.

distinguished by their predominant unsaturated fatty acid, which is either a mono- or polyunsaturated fat. Olive oil and canola oil contain primarily monounsaturated fatty acids. In other oils, such as safflower or corn oil, the polyunsaturated fatty acids predominate. Figure 6.6 illustrates the fatty acid distribution of some fat-containing foods.

Two 18-carbon fatty acids are essential fatty acids—**linoleic** and **alpha-linolenic.** The body cannot manufacture these essential fatty acids, so they must be consumed in the diet. Fortunately, these two essential fatty acids are widely found in food. Linoleic, an omega-6 fatty acid, is in many vegetable oils such as corn, soy, safflower, and sunflower oils. Alpha-linolenic, a member of the omega-3 family, is found in soy, canola, and flaxseed oils. It is also found in leafy green vegetables, fatty fish, and fish oils.

STEROLS AND PHOSPHOLIPIDS IN FOODS

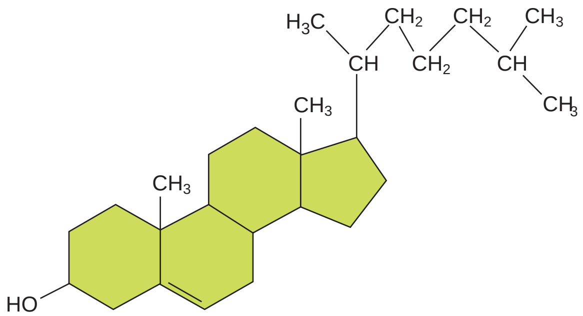
Almost 95 percent of the fat found in foods is in the form of triglycerides; the remaining fats in food are either sterols or phospholipids. Fatty acids are chains of carbon, but sterols have a different chemical composition. Sterols belong to a group of fats whose core structure is made up of four rings. This four-ringed nucleus is known as a steroid. Various side chains can be added to the steroid nucleus and many different compounds can be made, including cholesterol, vitamin D, and the steroid hormones, including the sex hormones (see Figure 6.7). If the steroid-based compound has one or more **hydroxyl** (OH) groups attached and no **carbonyl** (=C=O) or carboxyl (COOH) groups, then the compound is known as a sterol.

The most common sterol found in food is cholesterol. Cholesterol is only found in animal foods such as meat, egg yolks, and milk and milk products in which the fat has not been removed. Cholesterol is an important component of human cell membranes. No plant foods contain cholesterol. However, plants do contain other sterols, known as phytosterols, including **estrogens** similar to human sex hormones. Phytosterols are an important structural component of plant cell membranes.

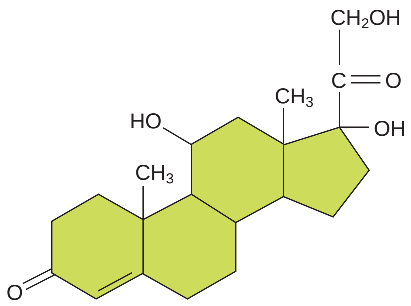
Phospholipids are similar in structure to triglycerides but are distinguished by the inclusion of phosphate. They are a structural component of all living tissues, especially the cell membranes of animal cells. Lecithin is an example of a phospholipid. Although sterols and phospholipids are physiologically important, the primary nutritional focus in this chapter is the predominant fat found in foods and in the body—triglycerides.

FATS AND THEIR INFLUENCE ON PERFORMANCE AND HEALTH

While the chemical differences between the various fats may be obvious, the impact of these differences on performance or health may not be immediately clear. From a performance perspective, fat intake is important because fat is metabolized to provide energy for



Cholesterol



Cortisol

Figure 6.7 Structure of Sterols

Note the four-ring nucleus (steroid) in these sterols.

low- to moderate-intensity exercise. The vast majority of fat used to provide this energy will come from triglycerides stored either in adipose tissue or muscle cells. The adipose and muscle triglycerides are manufactured from fatty acids originally found in food. From a purely metabolic perspective, the original source of the fat (saturated or unsaturated fatty acids found in food) is not important. What is important to the body is that it can metabolize the triglycerides for immediate energy or store them for future use as energy.

From a health perspective, there are certain fats that should be emphasized because they have been shown to lower the risk of cardiovascular disease. Unsaturated fatty acids (i.e., mono- and polyunsaturated fats) and omega-3 fatty acids are examples. Conversely, it is recommended that the consumption of saturated fatty acids be limited and that *trans* fatty acids be eliminated from the diet, as excessive amounts of both may be detrimental to health. In some people, excess saturated fats and dietary cholesterol raise blood cholesterol concentration, and therefore, limiting these fats in the diet is recommended. The role that the various fats play in the development of cardiovascular and other chronic diseases is discussed in Chapter 12.

Because performance and health are both important, athletes first determine the total amount of fat appropriate in their daily diet. Then they can choose foods that contain certain kinds of fatty acids (e.g., almonds are high in monounsaturated fat). The appropriate amount of fat intake for the athlete will depend on two factors: 1) overall energy (caloric) need and 2) **macronutrient** balance (i.e., meeting carbohydrate, protein, and fat recommendations within the context of energy needs). These two factors will be explained later in this chapter.

What's the point? Triglycerides are the most abundant type of fat in both food and in the body. A triglyceride contains three fatty acids attached to a glycerol molecule. Differences in the fatty acids are due to their chemical composition.

Digestion, Absorption, and Transportation of Fats

Digestion is the breakdown of foods into smaller parts. Absorption involves taking these smaller parts through the cells of the intestine where they will then be transported to other parts of the body. Fats present a particular digestion and absorption challenge because they are large molecules. Additionally, they do not mix well with water, the main component of blood, so transport in the blood requires fat to be bound to protein.

DIGESTION OF FATS

The process of fat digestion begins in the mouth and continues in the stomach to a small degree, but digestion of fat occurs predominantly in the small intestine. Undigested fat in the stomach has two effects: 1) it delays the emptying of the stomach contents (known as the gastric emptying rate) and 2) it results in a feeling of fullness (known as satiety). Athletes limit their fat intake temporarily in certain situations when they do not want gastric emptying delayed, such as during endurance events when rapid movement of carbohydrate-containing fluids into the intestine is beneficial. Conversely, athletes may include fat-containing foods in their meals when they want to avoid feeling hungry for several hours.

Fats are large and complex molecules that do not mix easily with water. Therefore, fats must be exposed to digestive enzymes before they can cross the membranes of the intestinal cells. An important digestive enzyme is

Linoleic acid: An essential fatty acid.

Alpha-linolenic acid: An essential fatty acid.

Hydroxyl group: Formed when oxygen attaches to hydrogen (OH).

Carbonyl group: A group of atoms (=C=O).

Estrogen: A steroid hormone associated with the development of female sex characteristics.

Macronutrient: A nutrient needed in large amounts such as carbohydrate, protein, or fat.

pancreatic lipase. As the name implies, this enzyme is secreted by the pancreas into the small intestine and helps to break down the large fatty acids into smaller components. Recall that all but 5 percent of the fat found in food is triglyceride (i.e., triacylglycerol), which is composed of three fatty acids attached to a glycerol molecule. These three-unit fats are broken down by enzymes to two-unit fats known as **diglycerides** (i.e., **diacylglycerols**) and to one-unit fats, **monoglycerides** (i.e., **monoacylglycerols**). Phospholipids are involved in a similar digestive process, although the enzymes are different. Cholesterol is not broken down at this point. The process of digestion reduces the size of the fat particles and readies them for absorption by the mucosal cells of the intestine.

ABSORPTION OF FATS

The fat particles enter the mucosal cells by passive diffusion, a process in which molecules move from an area of higher concentration to an area of lower concentration. Recall that the original triglyceride had three fatty acids and that each fatty acid could be a different length (from four to 24 carbons). Once in the mucosal cells, one-unit fats (monoglycerides) are resynthesized into triglycerides. The enzymes that assist in the resynthesis prefer to incorporate long-chain fatty acids (those with 12 to 18 carbons) into the newly synthesized triglycerides. The short- (four carbons) and medium- (six to 10 carbons) chain fatty acids will be unchanged as they pass through the mucosal cell. The majority of dietary triglycerides are long-chained fatty acids (usually 16 to 18 carbons); thus, the majority of fat eaten is broken down and then reincorporated into triglycerides by the mucosal cells. The newly synthesized triglyceride then becomes part of a large protein and fat molecule known as a **chylomicron.** A chylomicron is one example of a **lipoprotein.** Lipoproteins transport fat throughout the body. Cholesterol and the partially digested phospholipids also become part of the chylomicron. The chylomicrons and the short- and medium-chain fatty acids are then ready to be transported out of the mucosal cells of the intestine.

TRANSPORTATION OF FATS

To understand how fats are transported, one must understand the body's main transport fluids: blood and **lymph.** Blood consists of water, red and white blood cells, and many other constituents, including oxygen and nutrients. Blood enters tissues through arteries, leaves tissues through veins, and circulates within the tissues via the capillaries. Some components of blood are filtered out of the capillaries into the spaces of the tissue. This fluid is known as **interstitial fluid.** Most of the interstitial fluid is returned to the capillaries but some is not. That which is not returned is referred to as lymph. Lymph consists of white blood cells (which play an important role in immune function), proteins, fats, and other compounds. Lymph moves through its own set of vessels (the lymphatic system) that are separate from capillaries. Eventually, the lymph and blood vessels are joined near the heart.

The chylomicrons formed in the mucosal cells will be released slowly into lymphatic vessels. The release of the chylomicrons is an intentionally slow process that prevents a sudden increase in fat-containing compounds in the blood. Blood lipid (fat) levels are usually highest about three hours after fat consumption, but it may take as long as six hours for the dietary fat to be transported into the blood. The short- and medium-chain fatty acids in the mucosal cells that are not incorporated into chylomicrons will be released directly into the blood via the **portal** (liver) **vein,** where each will immediately be bound to a plasma protein, albumin.

The majority of the dietary fat consumed will have been incorporated into chylomicrons. This chapter will focus only on the transport and cellular absorption of the triglycerides contained in the chylomicrons, although fatty acids that are attached to albumin are absorbed in a similar manner. The transport and cellular absorption of the cholesterol found in the chylomicrons are more complicated and an explanation is included in the discussion of the development of **atherosclerosis** in Chapter 12.

The chylomicrons circulate through all the tissues, but adipose, muscle, and liver tissues play very important roles in fat metabolism. The triglyceride portion of the chylomicron can be absorbed by adipose and muscle cells. As the chylomicron circulates in the blood, it comes in contact with **lipoprotein lipase** (LPL), an enzyme. LPL is found on the surface of small blood vessels and capillaries within the adipose and muscle tissues. This enzyme stimulates the release of the fatty acids from the triglyceride, which are then rapidly absorbed by the fat and muscle cells.

The absorption of fatty acids into the fat and muscle cells is of great importance to the athlete and will be the focus of the metabolism section that follows. However, the liver also plays a substantial role that deserves mention here. In the liver, the triglyceride portion of the chylomicron is broken down and becomes part of the fatty acid pool, which will provide the fatty acids for the lipoproteins that the liver manufactures. Recall that a chylomicron is one example of a lipoprotein. Chylomicrons transport dietary (exogenous) fat. Other lipoproteins transport endogenous fats, that is, fats that are manufactured in the body by liver and other tissues. The functions of these lipoproteins, which include **low-** and **high-density lipoproteins,** are explained further in Chapter 12.

Metabolism of Fats

Once fats are digested, absorbed, and circulated, they are stored in the body largely in the form of triglycerides. The main sites of fat storage in the body are adipose tissue (in **adipocytes** [fat cells]), liver, muscle (as intramuscular triglycerides), and to a small degree in the blood. As has been previously discussed in Chapter 3, fats are metabolized for energy through oxidative phosphorylation, the aerobic energy system. In order to be metabolized, fats must be removed from storage, transported to cells, and taken up into mitochondria. There they are oxidized via the Krebs cycle and ATP is produced via the electron transport chain.

FAT STORAGE

The process of triglyceride formation is called **esterification**. The enzyme lipoprotein lipase exists in the walls of the capillaries that **perfuse** fat cells. When this enzyme is activated, it results in the breakdown of circulating triglycerides from lipoproteins, freeing fatty acids for uptake into the fat cells. Once taken up into adipocytes, the fatty acids are re-formed into triglycerides for storage. The activity of LPL and the process of triglyceride formation are primarily stimulated by the hormone insulin. The pancreas secretes insulin in response to food consumption, particularly a meal containing carbohydrate. Therefore, in the hours after a meal (particularly a meal containing fat and carbohydrate), the body has the hormonal environment and the substrates that favor triglyceride formation and fat storage. An abundance of adipocytes can be found just beneath the skin **(subcutaneous fat)** and deep within the body surrounding the internal organs **(visceral fat).**

Muscle can also store fat, referred to as intramuscular triglycerides. Fat storage in muscle occurs primarily in muscle that is highly aerobic, for example, heart (myocardial) muscle and slow-twitch (Type I) skeletal muscle. LPL in the capillary walls in muscle initiates this process in the same way that it does in adipocytes. Circulating lipoproteins are stimulated to break down the triglycerides they contain and release the fatty acids. The fatty acids are then taken up by muscle cells and reassembled into triglycerides for storage.

Fats are an excellent storage form of energy for several reasons. Compared to carbohydrates and proteins, fats contain more than twice the number of kcal per unit of weight—9 kcal/g for fat versus 4 kcal/g each for carbohydrate and protein. Therefore, fats are a very "energy dense" nutrient. When carbohydrate is stored in the form of glycogen, approximately 2 g of water are stored along with every gram of glycogen, increasing the weight without increasing the energy content. Fat is anhydrous, meaning it does not have water associated with it, making it an even more efficient storage form of energy on a per unit weight basis.

The importance of fat as a storage form of energy can be seen in comparison to carbohydrate storage. As discussed in Chapter 4, an average-sized person stores approximately 500 g of carbohydrate in the form of muscle glycogen, liver glycogen, and blood glucose. At 4 kcal/g, these carbohydrate reserves can provide approximately 2,000 kcal of energy. To illustrate this point, assume that a runner could use purely carbohydrate as a fuel source during an endurance run. These carbohydrate reserves would be essentially depleted in about 1½ hours. This same athlete, however, has in excess of 100,000 kcal of energy stored as fat in adipocytes and as intramuscular triglycerides, enough energy to fuel more than 100 hours of running (assuming the runner could rely solely on fat metabolism).

FAT UTILIZATION IN METABOLISM

Fat is an excellent storage form of energy, and the metabolism of fat provides a high yield of ATP. However, there are a number of steps in the metabolism of fats that make the process complex and relatively slow. Fats must be mobilized from storage, transported to the appropriate tissues, taken up into those tissues, **translocated** (moved from one place to another) and taken up by mitochondria, and prepared for oxidation. At the onset of moderate-intensity, **steady-state** exercise,

Pancreatic lipase: An enzyme secreted by the pancreas that helps to break down large fatty acids.

Diglyceride: A two-unit fat, known technically as a diacylglycerol.

Diacylglycerol: A two-unit fat.

Monoglyceride: A one-unit fat, known technically as a monoacylglycerol.

Monoacylglycerol: A one-unit fat.

Chylomicron: A large protein and fat molecule that helps to transport fat.

Lipoprotein: A protein-based lipid (fat) transporter.

Lymph: A fluid containing mostly white blood cells.

Interstitial fluid: Fluid located between organs and systems. Not blood or lymph.

Portal vein: The vein that carries blood to the liver; usually refers to the vein from the intestine to the liver.

Atherosclerosis: Narrowing and hardening of the arteries.

Lipoprotein lipase: An enzyme that releases fatty acids from circulating triglycerides so the fatty acids can be absorbed by fat or muscle cells.

Low-density lipoprotein: A lipid carrier with an affinity to deposit cholesterol on the surface of arteries.

High-density lipoprotein: A lipid carrier with an affinity to remove cholesterol from the surface of arteries and transport it to the liver where the cholesterol can be metabolized.

Adipocytes: Cells that store fat.

Esterification: The process of forming a triglyceride (triacylglycerol) from a glycerol molecule and three fatty acids.

Perfuse: To spread a liquid (e.g., blood) into a tissue or organ.

Subcutaneous fat: Fat stored under the skin.

Visceral fat: Fat stored around major organs.

Translocation: Moving from one place to another.

Steady-state: Exercise or activity at an intensity that is unchanging for a period of time.

it may take 10–20 minutes for fat oxidation to reach its maximal rate of activity.

Fat Mobilization, Circulation, and Uptake. In order for fats to be used in metabolism, triglycerides must first be taken out of storage. Triglycerides stored in adipocytes are broken down into the component parts—glycerol and the fatty acid chains. This process of **lipolysis** is catalyzed by an enzyme found in fat cells, **hormone-sensitive lipase** (HSL). Hormone-sensitive lipase is stimulated by catecholamines (epinephrine and norepinephrine), growth hormone, glucocorticoids (cortisol), and thyroid-stimulating hormone (TSH), and is inhibited by insulin. Therefore, mobilization of stored fat is inhibited after meals have been consumed when insulin is high, and is encouraged during the post-absorptive state (the period from approximately three to four hours after eating until food is eaten again), fasting, starvation, and when stressed. Stress, such as exercise, stimulates the sympathetic nervous system, which releases epinephrine and glucocorticoids such as cortisol from the adrenal glands, and growth hormone from the anterior pituitary gland into the blood. These hormones then interact with fat cells to promote lipolysis. Norepinephrine is released by nerve endings of sympathetic nervous system cells and also contributes to the activation of HSL and the mobilization of fat.

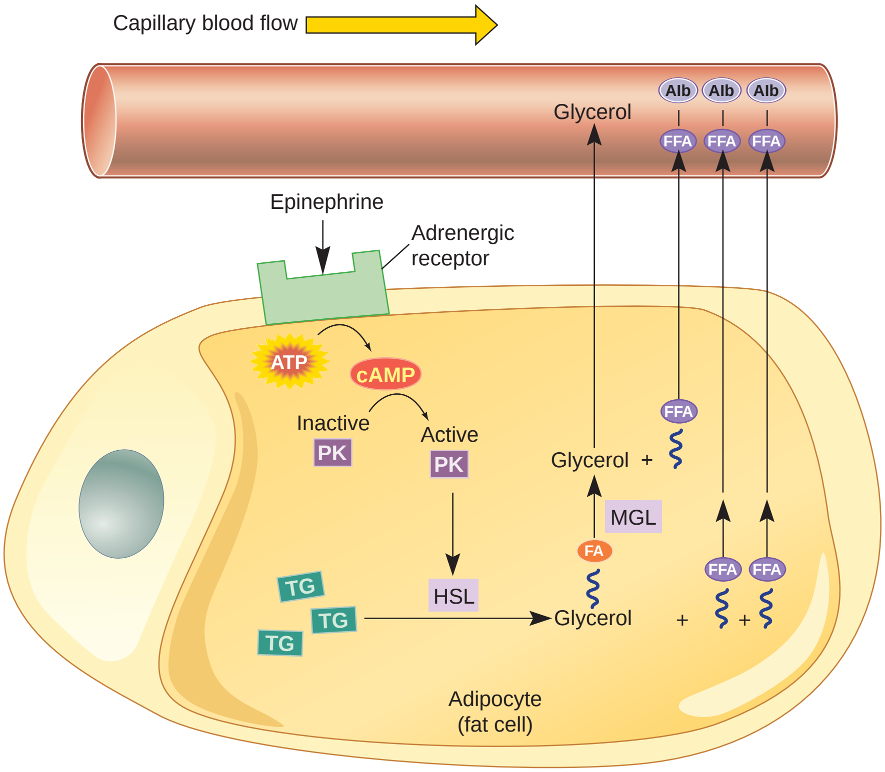
Following lipolysis, the fatty acid chains and glycerol circulate in the blood. Glycerol, a sugar alcohol, is water soluble and is easily carried in the blood. The liver contains the enzymes necessary to metabolize glycerol, so the liver takes up most of the glycerol that enters the circulation. There it can be converted to glucose via **gluconeogenesis** or eventually reassembled into triglycerides. The fatty acid chains liberated in lipolysis are not water soluble, however, and must be attached to a carrier to be transported in the blood. The carrier is typically a plasma protein, the most common of which is albumin. When mobilized and circulated, these fatty acid chains are often referred to as free fatty acids (FFA), which is somewhat of a misnomer, as very few of them exist “free” in the circulation. Transport in the blood by albumin is crucial to the metabolism of fat. Disruption of the ability of albumin to transport fatty acids impairs fat metabolism, particularly during higher-intensity exercise, and will be discussed later in the chapter. The mobilization and transport of stored triglyceride is illustrated in Figure 6.8.

Once in the blood, fatty acids can be distributed to other tissues throughout the body for use in metabolism. A key element for the utilization of fat as a fuel is the delivery of adequate amounts of fatty acids to the tissue. Some fat-utilizing tissues have a greater number of receptor sites and transport mechanisms embedded in the cell wall that are unique for fatty acids and facilitate the movement of fatty acids from the blood into the cells. For example, heart muscle cells have a higher capacity for fat utilization than slow-twitch muscle fibers, which in turn have a higher capacity than fast-twitch muscle fibers. Certain tissues also have a more extensive network of capillaries that allow a more effective delivery of fatty acids, and therefore enhanced fat oxidation. Examples again include heart muscle and slow-twitch muscle fibers, particularly compared to fast-twitch muscle fibers, which have a less dense capillary network.

Activation and Translocation Within the Cell. After mobilization, circulation, and uptake into the cells, the fatty acids must go through an activation step before being transported into the mitochondria. Similar to the beginning of glycolysis where two ATP are used in the first three steps to initiate the process, one ATP is used along with coenzyme A (CoA) to convert the fatty acid chain to a compound called fatty acyl-CoA, and one ATP is used to ensure that the reaction is irreversible. This process takes place in the outer mitochondrial membrane prior to the translocation of the fatty acid into the mitochondrial matrix. As with the beginning steps of glycolysis, this initial investment of energy is recouped by the subsequent production of ATP.

Once the fatty acid chain has been converted to fatty acyl-CoA in the mitochondrial membrane, it must be transported into the mitochondria where it goes through the process of β-oxidation and is eventually metabolized aerobically. Fatty acyl-CoA is translocated into the mitochondria by a carnitine transport mechanism, catalyzed by a group of enzymes, known collectively as carnitine acyl transferases (e.g., CAT I and CAT II). This process involves removing the CoA, translocating the long fatty acid chain that is attached to carnitine into the mitochondria, then removing the carnitine and replacing the CoA (see Figure 6.9). Each fatty acid chain has a specific carnitine acyl transferase. Palmitate, for example, is translocated into the mitochondria through the use of carnitine palmitate transferase (CPT1). Because this important transportation step involves carnitine, one approach that has been used to attempt to increase fat metabolism to improve endurance exercise performance has been the use of dietary carnitine supplements, which are discussed later in the chapter.

Because fatty acids are ultimately metabolized inside mitochondria, translocating the fatty acids into the mitochondria is a critical and potentially limiting step. Cells that have a large number of and large-sized mitochondria, such as slow-twitch muscle fibers, have an increased capacity to take up and metabolize fat. Athletes with a genetic disposition for a greater number of slow-twitch muscle fibers have an increased ability to metabolize fat. Regular endurance exercise training also results in an increase in the number and size of mitochondria in the trained muscles, which further enhances an athlete’s ability to metabolize fat.



Alb = albumin
cAMP = cyclic AMP
PK = protein kinase
HSL = hormone sensitive lipase
TG = triglyceride (triacylglycerol)
FA = fatty acid
FFA = free fatty acid
MGL = monoacylglycerol lipase
ATP = adenosine triphosphate

Figure 6.8 Mobilization and Transportation of Stored Triglyceride

Within an adipocyte, hormone-sensitive lipase will break down a stored triglyceride into glycerol and three fatty acids, which diffuse into the capillary circulation. The fatty acids are bound to albumin for transport. This process is initiated with the stimulation of adrenergic receptors on the cell membrane by stress hormones such as epinephrine and norepinephrine.

Beta Oxidation. There is an additional series of steps that must be completed before fatty acids can be metabolized to produce ATP—beta oxidation. Beta oxidation is a series of four chemical steps during which two-carbon segments are cleaved off the fatty acid chain, and converted to acetyl CoA. In a fatty acid chain, the first carbon is labeled alpha (α) and the second is labeled beta (β)—the carbons are clipped off the chain at the location of the second carbon, therefore the name β oxidation. Once the two-carbon segment has been converted to acetyl CoA it can enter the Krebs cycle as previously explained in Chapter 3. Each acetyl CoA that is derived from a fatty acid chain can be oxidized to eventually form 12 ATP. Each fatty acid that is metabolized contains an even number of carbons, so a series of acetyl CoA can be formed by β oxidation. The final two carbons of the fatty acid chain are already formed as acetyl CoA, so they do not have to go through the process of β oxidation and can proceed directly to the Krebs cycle. In addition to forming acetyl CoA that can be oxidized, the process of β oxidation involves two oxidation-reduction reactions, during which one NAD (nicotinamide adenine dinucleotide) and one FAD (flavin adenine dinucleotide) pick up electrons that can be shuttled through the electron transport chain to produce ATP. A detailed figure of β oxidation can be found in Appendix K.

The value of fat metabolism can be seen in the number of acetyl CoA that are formed and oxidized, leading to a very large number of ATP produced. Palmitate, a 16-carbon fatty acid, is used as an example. Metabolism of palmitate results in a total of eight acetyl CoA available for oxidation. After accounting for the ATP utilized in the activation steps, the complete oxidation of the acetyl CoA, and the additional electrons from β oxidation, the final ATP production from the complete

Lipolysis: The breakdown of a triglyceride (triacylglycerol) releasing a glycerol molecule and three fatty acids.

Hormone-sensitive lipase: An enzyme found in fat cells that helps to mobilize the fat stored there.

Gluconeogenesis: The manufacture of glucose by the liver from other compounds such as lactate, protein, and fat. Gluco = glucose, neo = new, genesis = beginning.

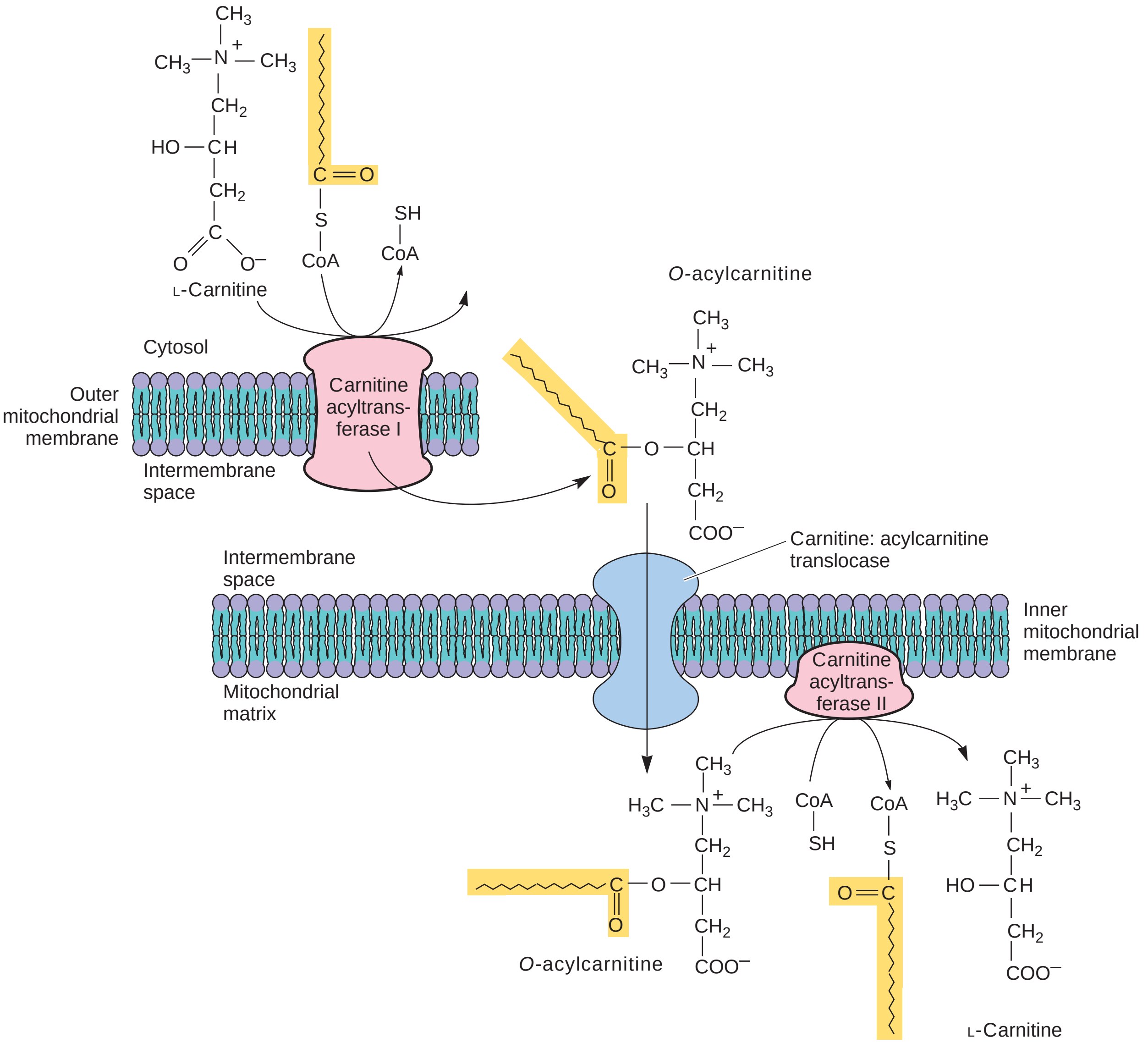


Figure 6.9 Mitochondrial Transfer of Fatty Acyl-CoA

In the outer mitochondrial membrane, the CoA of fatty acyl-CoA is removed and joined to carnitine via carnitine acyltransferase. The acylcarnitine is then translocated into the mitochondria where the fatty acid is separated from the carnitine and is rejoined with a CoA.

metabolism of palmitate is 129 ATP. When compared to the two ATP obtained from glucose by anaerobic glycolysis or even the 36 ATP from glucose by aerobic metabolism, fat metabolism has a substantial advantage in the provision of energy. The major disadvantages of fat metabolism are the numerous steps involved and the necessity to consume additional oxygen.

Ketosis. Fat is primarily metabolized as described above, but acetyl CoA may also be catabolized to produce ketone bodies—acetoacetate, β-hydroxybutyrate, and acetone. This is a normal metabolic pathway that is sometimes referred to as an "overflow" pathway. It is estimated that the liver can produce as much as 185 g of ketones daily and that after an overnight fast ketones supply ~2 to 6 percent of the body's total energy needs. The normal blood ketone concentration is less than 0.05 mmol/L, with the highest concentration being present after an overnight fast. The normal urine ketone concentration is typically zero (VanItallie and Nufert, 2003).

Ketone production is increased when fatty acid oxidation is accelerated. This can occur when carbohydrate intake is low due to self-restriction or involuntary starvation. It can also occur when carbohydrate metabolism is impaired, which is the case for those with diabetes mellitus. For medical purposes, ketosis is defined as an abnormal increase in ketone bodies or a blood ketone concentration > 0.06 mmol/L. In someone with diabetes, ketosis is a potentially dangerous complication because it can result in ketoacidosis, a condition in which the pH of the blood is more acidic than the body tissues. Ketoacidosis can result in diabetic coma and death. However, ketosis in those without diabetes rarely leads to ketoacidosis. In discussions of ketosis it is very important to distinguish between individuals that have diabetes and those that do not have diabetes.

To understand how ketones are formed, a brief review of carbohydrate metabolism is needed (see Chapter 4 for details). Glycolysis is the process that converts glucose to pyruvate. Pyruvate is transported into the mitochondria where it is metabolized to acetyl CoA. Acetyl CoA joins with oxaloacetate, the first step in the Krebs Cycle. With a low carbohydrate intake, the body must find other sources of acetyl CoA, namely fatty acids and some amino acids. As more fatty acids are broken down to provide acetyl CoA, it begins to accumulate because of a low supply of oxaloacetate. In response to the accumulating acetyl CoA, ketone bodies are produced. The ketones become especially important as a source of energy for the brain because its usual energy source, glucose, is declining and fatty acids cannot cross the blood-brain barrier.

In the first two to three days of carbohydrate and energy restriction, the body produces glucose from alternative sources, such as lactate and amino acids provided by muscle. At this point, approximately two-thirds of the fuel used by the brain is glucose with the remaining one-third provided by ketones. Sustaining this alternative metabolic pathway would be untenable because too much muscle protein would need to be degraded to provide fuel for the central nervous system. As carbohydrate and energy restriction continues past a few days (referred to as starvation), more metabolic adaptations take place. Glucose will be primarily manufactured from glycerol (obtained from the breakdown of fatty acids) and ketones will become the primary source of fuel for the brain. After six weeks of starvation, about 70 percent of the brain's energy sources will be ketones, with less than 30 percent provided by glucose (Gropper et al., 2005).

Starvation also produces changes in skeletal muscle. Restricted carbohydrate intake results in the muscle cells using a fuel source other than glucose, which is now in short supply since muscle glycogen has been depleted and dietary carbohydrate is not providing glucose for glycogen resynthesis.

A low-carbohydrate, calorie-restricted diet that results in ketosis is one popular method for weight loss used by overweight and obese individuals (see Chapter 12). Athletes may wonder if such a diet plan is appropriate for them. Ketosis is a result of both restricted energy (caloric) and carbohydrate intakes, dietary manipulations that would likely have a negative effect on an athlete's training. Some loss of muscle protein would occur, although a high dietary protein intake may help to **attenuate** muscle degradation. While ketosis in a nondiabetic athlete will not likely result in ketoacidosis, the disadvantages (e.g., low glycogen stores, inability to sustain training and/or train at higher intensities) seem to outweigh the advantages (e.g., loss of weight as fat) when viewed from the perspective of optimal performance.

What's the point? Fats are complicated to absorb, transport, and metabolize. When compared to carbohydrates, fats yield a large amount of ATP via aerobic metabolism, but additional oxygen is needed.

Fats as a Source of Energy During Exercise

Fat is an important fuel source for energy production at rest and during exercise. As mentioned in previous chapters, carbohydrate and fat are the two major fuel sources, with protein playing a much smaller role. The degree to which either of these fuel sources may contribute to the body's energy needs is dependent upon a variety of factors that will be discussed in this section, with an emphasis on the factors that influence fat oxidation (Jeukendrup, Saris, and Wagenmakers, 1998a,b).

The use of fat as a fuel has a number of important advantages: Fat is abundant in the food supply, energy dense (high caloric content on a per unit weight basis), stored in substantial amounts in adipose tissue, and when metabolized, provides a large number of ATP. Disadvantages, however, include the many steps and the time involved in metabolizing fat. In addition, it should be recalled that fat can only be used in aerobic metabolism. Its use as a fuel is therefore limited to activities and exercise that can be supported by oxidative phosphorylation (e.g., low to moderate intensity). This is in contrast to carbohydrate metabolism—glucose and glycogen can either be metabolized via oxidative phosphorylation or used anaerobically through anaerobic glycolysis to support higher-intensity activities. As shown in the example with palmitate, the complete metabolism of one molecule of a fatty acid results in the rephosphorylation of a large number of ATP compared to the metabolism of glucose. The metabolism of fatty acids requires significantly more oxygen, however. When the ATP yield is analyzed relative to the amount of oxygen consumed, fat metabolism is less efficient than carbohydrate because it requires more oxygen for each ATP replenished.

RELATIVE AND ABSOLUTE FAT OXIDATION

To understand the use of fat as a fuel at rest and during exercise, it is important to understand how the utilization of this fuel is determined and expressed. Recall

Attenuate: To reduce the size or strength of.

Table 6.1 Energy Expenditure and Fuel Utilization

Run Pace (min/mile)	Heart Rate (bpm)	RER	Percent Energy from Fat	Percent Energy from CHO	Total Energy Expenditure (kcal/min)	Fat (kcal/min)	CHO (kcal/min)
Rest	72	0.77	78.2	21.8	1.4	1.1	0.3
9:30	127	0.88	40.8	59.2	11.5	4.7	6.8
9:00	138	0.89	37.4	62.6	13.4	5.0	8.4
8:30	144	0.91	30.6	69.4	14.2	4.4	9.8
8:00	153	0.92	27.2	72.8	15.3	4.2	11.1

Heart rate, RER, and relative and absolute energy expenditure from fat and carbohydrate at rest and at four different running paces for a 49-year-old male marathon runner.

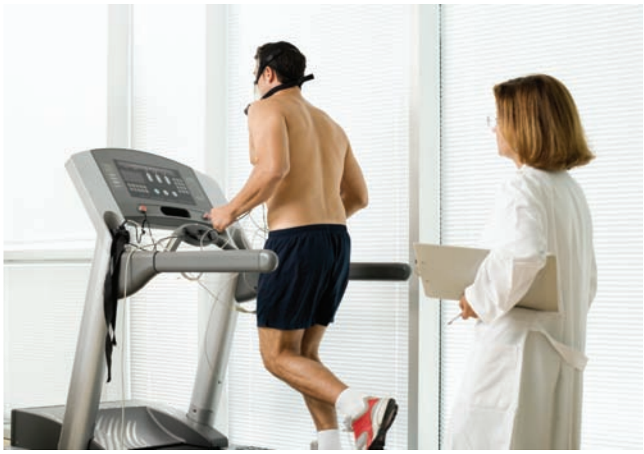
Legend: min = minutes; bpm = beats per minute; RER = respiratory exchange ratio; CHO = carbohydrate; kcal = kilocalories

from Chapter 3 that the most common way of determining fuel utilization during aerobic exercise or activity is through indirect calorimetry and the use of the respiratory exchange ratio (RER). The RER is the ratio of carbon dioxide produced to the amount of oxygen consumed. Metabolism of carbohydrate requires the utilization of an amount of oxygen equal to the amount of carbon dioxide produced to give a higher RER, approaching or equal to 1.0. Because oxidation of fat requires a larger consumption of oxygen than the carbon dioxide produced, the RER during fat metabolism is lower, approaching 0.70.

The respiratory exchange ratio that is determined during a steady-state aerobic activity gives an indication of the percentage of the energy expenditure that is derived from fat oxidation relative to the percentage derived from carbohydrate oxidation. This is an expression of the fuel sources in a relative fashion, as a percentage of the total energy expenditure. Because only nonprotein sources of fuel are typically considered, fat and carbohydrate can be expressed as a percentage relative to the other. Sometimes it is important to know the percentage of energy expenditure provided by fat and carbohydrate oxidation (see case study below).

The expression of fuel utilization in a relative fashion is useful, but does not provide any information about the actual amount of energy being expended; in other words, the total amount of energy that is being provided by fat and carbohydrate. An expression of the total amount of energy expenditure is termed absolute. A common way of expressing energy expenditure is the use of rate, the number of kilocalories (kcal) expended each minute (min).

If one knows both the absolute energy expenditure (kcal/min) and the relative contribution of each fuel (percentage from fat and carbohydrate), the absolute caloric expenditure (kcal/min) from fat and carbohydrate can be determined. The case study presented here will illustrate a number of important concepts about fat metabolism during exercise and the relationship of fat and carbohydrate as fuel sources.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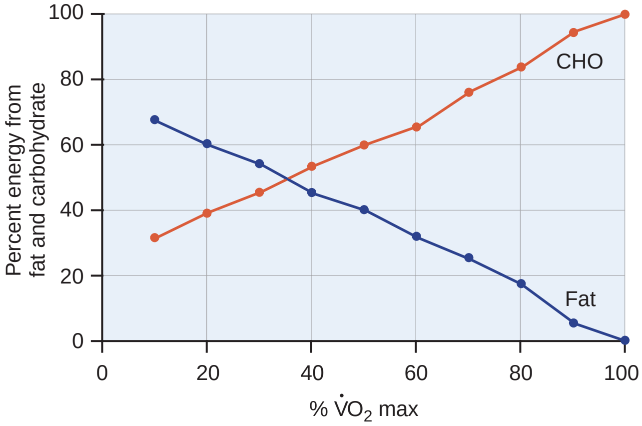
Energy expenditure and fuel utilization during running can be measured.

Consider the case of a 49-year-old male who is in the process of training for his first marathon to celebrate his 50th birthday. He had some previous recreational running experience and had run several 10-kilometer races and two half-marathons. At 5′6″ (168 cm) and 182 lb (82.5 kg), he realizes that losing weight and body fat will help him accomplish his goal of running a marathon. He participated in an indirect calorimetry study at rest and while running on a treadmill to learn more about his energy expenditure and fuel utilization at different running paces (see Table 6.1).

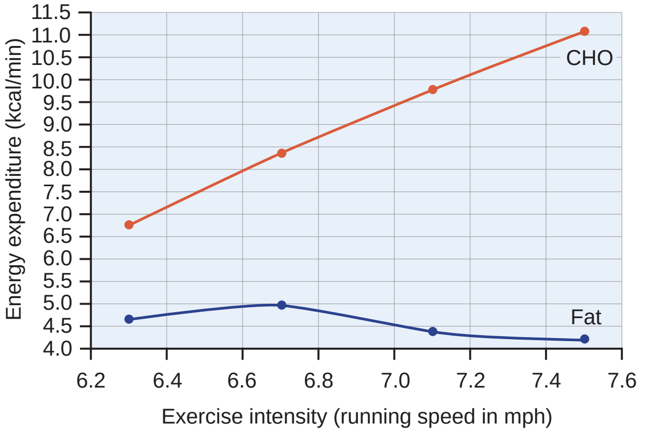
First, observe the results from the metabolic study at rest. Heart rate is low (72 bpm), RER is low (0.77), and total energy expenditure is low (1.4 kcal/min). The low RER indicates that a large proportion (78.2 percent) of energy at rest is provided by fat oxidation, and a relatively small percentage (21.8 percent) is provided by metabolizing carbohydrate. Of the total energy



CHO = carbohydrate
$\dot{V}O_2max$ = maximum oxygen consumption

Figure 6.10 Percentage of Fat and Carbohydrate Used as Exercise Intensity Increases

As exercise intensity increases (as a percentage of $\dot{V}O_{2max}$), the percentage of energy provided by fat metabolism decreases and the percentage of energy from carbohydrate metabolism increases.



CHO = carbohydrate
kcal/min = kilocalories per minute
mph = miles per hour

Figure 6.11 Absolute Fat and Carbohydrate Oxidation

Absolute energy expenditure from carbohydrate oxidation increases as exercise intensity increases and is higher than fat oxidation at all running paces. Absolute fat oxidation increases as the exercise intensity increases from a running speed of 6.3 to 6.7 mph, but then declines as the exercise intensity continues to increase.

expenditure of 1.4 kcal/min, 1.1 kcal/min is provided by fat. This is a typical metabolic response at rest, particularly if it has been several hours since the last meal—long enough for any food to be completely digested and absorbed (i.e., postabsorptive state).

Fat Oxidation During Exercise. Next, observe the metabolic response when he begins running at a steady pace of 9 minutes and 30 seconds (9:30) per mile, a modest exercise intensity for this athlete. As one would expect, heart rate increases above resting (127 bpm) and total energy expenditure increases substantially to 11.5 kcal/min. In other words, he burns 11.5 kcal every minute he runs at this pace. The RER rises to 0.88, indicating the percentage of energy derived from fat has dropped to 40.8 percent while that provided by carbohydrate has increased to 59.2 percent. Even at this fairly modest exercise intensity, fat is no longer the predominate source of energy for running. However, even though the percentage of energy from fat has declined, the absolute number of kcal from fat metabolism has increased dramatically over what was seen at rest. This makes perfect sense—although the percentage is less (40.8 percent compared to 78.2 percent at rest), it is a smaller percentage of a much larger number—the total energy expenditure has increased 10-fold, from 1.1 kcal/min at rest to 11.5 kcal/min during exercise.

Finally, observe the metabolic response as exercise intensity continues to increase as the running pace gets faster, to 9:00, 8:30, and finally 8:00 minutes per mile. Again as expected with increasing exercise intensity, the heart rate increases and the total energy expenditure increases. The RER also increases with each successive increase in exercise intensity, indicating a continuing decline in the percentage of energy that is supplied by fat metabolism and a continuing increase in that provided by carbohydrate metabolism. The pattern of response is also illustrated in Figure 6.10. There is a point in exercise intensity when carbohydrate increases and becomes the predominant source of energy and the utilization of fat declines to a lesser percentage. This point has been described as the "crossover concept" by Brooks, Fahey, and Baldwin (2005).

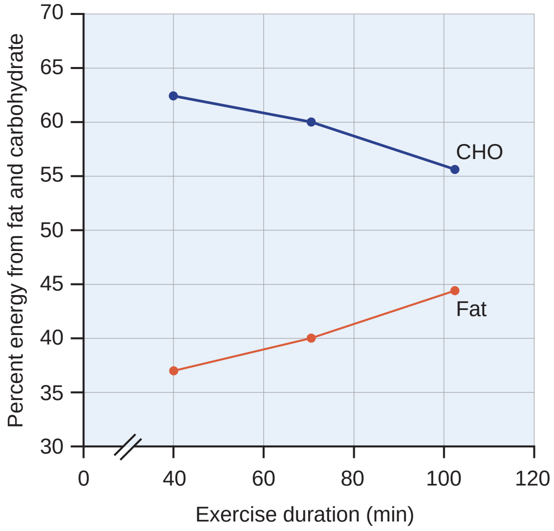
The *relative* expression of fuel utilization only provides a portion of the true picture, however. To complete the story, one must examine the *absolute* energy expenditure from fat and carbohydrate. As the running pace increases from 9:30 to 9:00 minutes per mile, there is an increase in absolute fat oxidation, from 4.7 to 5.0 kcal/min (see Table 6.1). Even though the percentage of energy from fat has declined, the larger total energy expenditure indicates that the total absolute amount of fat being metabolized each minute has actually increased. There is a maximum point of absolute fat oxidation, however, and as speed continues to increase beyond this point the absolute amount of fat metabolism goes down (in this case, from 5.0 to 4.4 then 4.2 kcal/min) along with a consistent decline in the percentage of energy derived from fat. The patterns of response of absolute fat and carbohydrate oxidation by the marathon runner to increasing exercise intensity are shown in Figure 6.11.

If fat is such a good energy source, why does fat metabolism decline as exercise intensity increases?

Again, understand that there is an initial increase in absolute fat oxidation with lower-intensity exercise. The body responds to the exercise by stimulating lipolysis through sympathetic nervous system stimulation of hormones such as epinephrine, norepinephrine, and growth hormone. The free fatty acids that are mobilized are delivered to exercising muscle fibers by the increase in blood flow that occurs with exercise activity. Increases in oxygen consumption by muscle are made possible by increases in breathing and circulation of oxygen-laden blood to the exercising muscle, so aerobic metabolism increases, including an increase in fat oxidation.

As exercise intensity continues to increase, however, a number of changes occur that may reduce the body's ability to metabolize fat. Increased exercise intensity means an increased reliance on fast-twitch muscle fibers. These fibers rely more on anaerobic energy systems, particularly anaerobic glycolysis, and have a relatively poor ability to oxidize fat. As these fibers use anaerobic glycolysis, they produce lactate. Lactate in the blood is known to inhibit the ability of the plasma protein albumin to bind and carry free fatty acids in the blood. Without this carrier mechanism available to transport the fatty acids, they essentially become "stuck" in the fat cells, unable to be transported anywhere else in the body. In addition, when the exercise intensity is higher, a successively larger proportion of the body's blood flow is diverted to exercising muscle, and may not be as available to circulate through adipose tissue to pick up fatty acids. Because fat oxidation requires greater oxygen consumption than carbohydrate oxidation to produce the same number of ATP, it is more energetically efficient to oxidize carbohydrate under conditions when oxygen consumption is very high, that is, during higher-intensity exercise.

Fat Oxidation During Prolonged Steady-State Exercise. The subject in this case study had a goal to run a marathon, a prolonged distance run of 26.2 miles. The data from the metabolic study show what happens to energy expenditure and fuel utilization if the athlete runs at different intensities, but what metabolic response occurs when he runs at a steady pace for several hours? This runner did indeed complete a marathon in celebration of his 50th birthday. His final time for the marathon was 3 h, 55 min, 48 seconds, an average pace of 9:00 minutes per mile. Reviewing the metabolic study data, at a pace of 9:00 minutes per mile this runner was obtaining approximately 37.4 percent of his energy from fat metabolism and 62.6 percent from carbohydrates. As a runner continues to exercise for a prolonged period of time, however, carbohydrate stores are reduced significantly, eventually leading to muscle glycogen depletion. As the available carbohydrate stores are diminished, the body has no choice but to rely more on fat oxidation. Therefore, a very common metabolic response to prolonged exercise is a slight, gradual rise in the RER, indicating a reduced reliance on carbohydrate and an increased dependence on fat oxidation. This metabolic response to exercise duration is illustrated in Figure 6.12.



CHO = carbohydrate
min = minutes

Figure 6.12 Percentage of Fat and Carbohydrate Used as Exercise Duration Increases

As steady-state exercise continues for a prolonged period of time, the percentage of energy derived from fat may increase slightly as the percentage of energy derived from carbohydrate oxidation declines.

Do You Have to Burn Fat to Lose Fat? Like many people, the subject of this case study wanted to lose body fat by exercising. Because fat can be used as a fuel source during exercise, it seems logical to focus on fat "burning" as a primary way to reduce the body's fat stores. This idea has unfortunately led to erroneous recommendations by some people in the fitness industry. A common recommendation is to exercise at a "fat-burning" intensity. Commercial exercise equipment such as treadmills even come programmed with "fat-burning zones." This recommendation to "burn fat to lose fat" is faulty on at least two levels.

The recommended "fat-burning zone" is typically lower-intensity aerobic exercise, with the rationale that people burn more fat at lower exercise intensities. It is true that RER is typically lower during lower-intensity exercise (see Table 6.1), but this only indicates that fat burning is higher *as a percentage of the total energy expenditure*. If having the highest possible *percentage* of fat burning were the key factor in losing body fat, the best strategy would be to lie on the couch all day! A person typically has the lowest RER and highest *percentage* of fat utilization when they are at rest. The marathon runner in the case study was getting nearly 80 percent of his energy from fat metabolism while resting, but total energy expenditure (1.4 kcal/min) and the absolute number of fat calories (1.1 kcal/min) being burned were very low.

To find the exercise intensity that results in the highest *amount* of fat being burned, look again at the metabolic study of the marathon runner. The highest rate of absolute fat oxidation (5 kcal/min) was reached at a running pace of 9:00 min/mile, even though as a percentage, the relative contribution of fat had dropped to approximately 37 percent. If this subject runs for an hour at this pace, he would burn 804 kcal, 300 kcal of which are from fat. If he runs for an hour at a lower intensity (e.g., slows down to 9:30 minutes per mile) he would burn only 690 kcal, 282 kcal of which are from fat. It is clear that a low exercise intensity does not necessarily result in a greater amount of "fat burning."

The second level of faulty reasoning behind these recommendations is based on the incorrect assumption that in order to lose body fat, a person must burn fat *during* exercise. Casual observation of athletes such as sprinters, weight lifters, and bodybuilders reveals that these athletes can be very lean with low levels of body fat, yet their exercise activities are very high intensity, relying mostly on anaerobic energy systems during which very little fat is utilized. Research studies, such as that by Grediagin et al. (1995), demonstrate the most important factor in weight and fat loss is total caloric expenditure, not exercise intensity or the source of the fuel used during exercise. In this study half of the subjects exercised at a lower intensity, but the duration of the exercise was increased to equal the total amount of kcal expended by the other half of the subjects that exercised at a higher intensity. Both groups lost weight and both lost an identical amount of body fat. If exercise time (duration) is limited, the most appropriate strategy for weight/fat loss is to not worry about the source of the fuel, but to exercise in a way that maximizes caloric expenditure during the allotted time.

Returning to the example of the marathon runner, if he were to increase his running pace from 9:00 to 8:00 min/mile for his one-hour run, he would expend 918 kcal instead of 804 kcal. The number of kcal expended from fat would decline from 300 to 250, but the total energy expenditure during the same amount of time is over 100 kcal greater. To summarize and answer the question—Do you have to burn fat to lose fat?—no, you do not need to burn fat during a short-term exercise session to accomplish long-term body fat loss.

EFFECTS OF TRAINING ON FAT USAGE

Endurance exercise training results in an enhanced ability to oxidize fat. This is potentially advantageous to endurance athletes—if they can rely more on fat metabolism during an endurance event they may be able to "spare" the body's limited carbohydrate stores (i.e., muscle glycogen) for use later in the event and improve their performance.

The regular stimulus of chronic exercise training taxes the oxidative phosphorylation energy system and the oxidative pathways of fat and carbohydrate metabolism. Over time a number of physiological adaptations occur that enhance the body's fat oxidation capability. Fatty acids are mobilized from adipocytes more easily and are taken up into muscle cells more readily. Cardiovascular adaptations include an increase in the capillary network in muscle, which allows for an enhanced delivery of fatty acids. One of the most important adaptations to endurance training that aids fat oxidation is an increase in mitochondrial mass in the muscle due to an increase in both the number and size of these important oxidative organelles. Mitochondrial mass can double in response to endurance training and results in an overall increase in activity of oxidative enzymes, once again enhancing the body's ability to metabolize fat.

The enhanced ability to metabolize fat during exercise can be seen at the same absolute exercise intensity and to a lesser degree at the same exercise intensity relative to the athlete's maximum. In other words, an athlete running at the exact same pace after months of training will be able to oxidize more fat due to the increase in fat oxidation capability. This is the same absolute exercise intensity, but because the athlete's maximal exercise capacity has increased, it now represents a lower percentage of his or her maximum. For example, if a 9:00 min/mile running pace was 75 percent of the runner's $\dot{V}O_{2max}$ before training, it may now be only 65 percent of the new, higher $\dot{V}O_{2max}$. To a certain degree, the ability to oxidize fat increases at the same relative exercise intensity in response to endurance training. If this runner increases the running pace to the point that it represents 75 percent of the new, higher $\dot{V}O_{2max}$, fat oxidation will be slightly higher after training than at the same percentage of maximum before training. This increased ability to metabolize fat during exercise may be beneficial to the endurance athlete during training and during some periods of lesser effort during competition; however, during a competitive event the intensity of exercise at "race pace" means that the predominant fuel source will be carbohydrate.

High-Fat Diets/Fat Loading. Long-term consumption of a diet that is high in fat will result in a metabolic adaptation to favor fat oxidation at rest and during exercise of certain intensities. As a strategy to increase fat metabolism and potentially spare carbohydrate usage, the use of high-fat diets has been studied to determine if endurance performance can be improved.

The study of Phinney et al. (1983) is often referenced in support of this strategy. In this study a group of cyclists were fed a high-fat ketogenic diet for four weeks that provided less than 20 g of carbohydrate each day. Endurance ability was tested before and after the high-fat diet period by having the cyclists ride as long as they could on a cycle ergometer in the lab at an intensity of approximately 60 percent of $\dot{V}O_{2max}$. The RER was significantly lower, indicating an enhancement in fat oxidation, and the "ride-to-exhaustion" time was four minutes longer on average after a month on the high-fat diet. The results of this study are sometimes used erroneously to suggest high-fat diets improve performance, although the four-minute difference was not statistically significant. This study is also sometimes used to suggest that adaptation to a high-fat diet at least does not hurt endurance performance. However, this study used a small sample size, only five cyclists, and in the post-test of endurance only three of the subjects increased their endurance time while two decreased their time. Most relevant to the question of performance for the endurance athlete was the intensity of the performance task. The cyclists were asked to ride at a relatively low percentage of their maximum for as long as they could—a measure of endurance time that fails to mimic the demands of an endurance event. The exercise intensity was also one that was far below that of an athlete actually competing in an endurance race event.

Subsequent research studies (Carey et al., 2001) and reviews (Helge, 2000) show that consumption of a high-fat diet can indeed alter the metabolic response at rest and during light- to moderate-intensity exercise in favor of fat oxidation. However, there does not appear to be any practical benefit when it comes to endurance performance.

Effect of Caffeine on Fat Usage. Some endurance athletes use caffeine to enhance performance. The rationale for its use is based on the fact that caffeine enhances free fatty acid utilization during endurance exercise and therefore theoretically reduces muscle glycogen usage. In other words, caffeine is purported to have a glycogen-sparing effect. In long endurance events, such as marathons or triathlons, low muscle glycogen levels are associated with fatigue and negatively affect performance; it would be advantageous to spare glycogen and prevent muscle glycogen levels from dropping too low.

To achieve the desired effect of elevating plasma free fatty acid levels, users must have a large amount of caffeine in their blood. The dose at which caffeine is effective is estimated to be 5 to 6 mg/kg body weight. For a 110-lb (50-kg) person, the recommended dose would be 250 to 300 mg of caffeine, equivalent to about 3 cups of strongly brewed coffee. This amount of caffeine could be consumed in a variety of ways, including the consumption of strongly brewed coffee, other caffeine-containing beverages, or caffeine-containing pills. The latter are widely used because they contain a known concentrated dose.

A review of the considerable research literature on the effects of caffeine ingestion on endurance performance reveals a consensus view that caffeine may be an effective ergogenic aid, but not for the metabolic rationale outlined above (Spriet, 1995). While caffeine may enhance free fatty acid mobilization above normal levels during endurance exercise, fat oxidation is not significantly increased, nor is muscle glycogen "spared."

The major ergogenic benefit of caffeine use may be more closely related to its role as a central nervous system stimulant. Caffeine's role in improvement in endurance athletic performance is associated with a heightened sense of awareness and a decreased perception of effort. People who are not habituated to using caffeine on a regular basis experience these benefits more readily.

The use of caffeine to improve performance is not limited to endurance athletes, as caffeine's stimulatory effects may also enhance strength performance. Some strength athletes use caffeine for the purpose of activating muscle fibers. Caffeine may have an effect on recruitment of muscle for exercise by reducing the motor unit recruitment threshold and enhancing nerve conduction velocity. It may also have direct effect on muscle by altering calcium release kinetics by the sarcoplasmic reticulum (Graham, 2001).

Caffeine is legal and socially acceptable throughout the world as a compound found in many beverages. At certain concentrations caffeine is a banned substance by some sports-governing bodies (e.g., National Collegiate Athletic Association [NCAA]). For example, in a postcompetition urine analysis, urinary caffeine levels exceeding 15 mcg/ml would subject an NCAA athlete to disqualification. However, such levels would be very difficult to reach via food or beverage intake (i.e., the equivalent of 6 to 8 cups of caffeinated coffee two to three hours prior to competition), and the equivalent amount of caffeine-containing tablets would likely impair performance in other ways (e.g., shaking, rapid heartbeat, nausea).

Caffeine is considered safe for use by most adults, although it has several known side effects. Blood pressure is increased both at rest and during exercise, heart rate is increased, gastrointestinal distress can occur, and insomnia may result. The side effects are more likely to occur in those people who are caffeine naïve (i.e., don't routinely consume caffeine). For routine users, caffeine is addictive and sudden withdrawal can result in severe headaches. To summarize, caffeine does elevate free fatty acid levels but caffeine's influence on endurance performance is due to its stimulatory effects and not its

What's the point? Fats are the predominant fuel source at rest and during lower-intensity exercise. As exercise intensity increases, the *absolute* amount of fat used increases then declines, but the *relative* amount decreases, because more carbohydrate is used than fat. Endurance training enhances the body's ability to use fat but caffeine does not. Caffeine's positive effect on endurance performance is due to central nervous system stimulation.

The Internet Café

Where do I find reliable information about fat metabolism and exercise?

Athletes who search for information about fat metabolism on the Internet will often be directed to commercial sites that are selling “fat-burning” supplements or weight loss diets. For those who wish to read research articles about fat metabolism, one of the most comprehensive resources is to search the biomedical journals indexed in Medline at **www.pubmed.gov.** Sports-governing bodies and sites directed towards coaches and athletes in particular sports may include information on fat metabolism that is written by experts. Some of these articles are well referenced. Consumers should check the scientific credentials of the authors of articles about the metabolism of fat.

effect on fat metabolism or usage. More information on caffeine is found in Chapters 7, 10 and 11.

FAT-RELATED DIETARY SUPPLEMENTS

Supplements that are involved in “fat burning” are marketed to both athletes and nonathletes. Some, such as carnitine, are associated with the oxidation of fatty acids, and are often marketed as ways to enhance the metabolism of fat. Others are specific types of fat, such as conjugated linoleic acid (CLA) and medium-chain triglycerides (MCT). Supplements sold as an adjunct to weight loss (e.g., advertised as “fat burning”) typically contain stimulants, such as caffeine, guarana, and ephedrine. The supplements reviewed in this chapter, carnitine and MCT, are those that affect fat metabolism and performance; those that affect body fat loss are discussed in Chapter 11.

Carnitine. Carnitine is essential to transport fatty acids into the mitochondria where they can be broken down for energy. Whenever a substance is known to have a direct role in metabolism, an intriguing question is raised: Would a concentrated amount, such as that found in a supplement, enhance the normal metabolic process?

Carnitine is found in food and can be synthesized in the body from the amino acid lysine. Deficiencies have been reported in humans but they are rare. As would be expected, in carnitine-deficient individuals supplementation normalizes long-chain fatty acid metabolism. Healthy adults are not carnitine deficient and exercise does not result in the loss of carnitine in the muscle. Studies have shown that carnitine supplements do not increase the carnitine content of muscles, probably because the transport of carnitine into the muscle is well controlled and only very small amounts are needed for proper fatty acid metabolism (Brass, 2004; Muller et al., 2002).

Two small studies, one in healthy adults and one in athletes, concluded that fat oxidation was increased with carnitine supplementation (Muller et al., 2002; Cha et al., 2001). In the study of athletes, the supplement was ingested with caffeine so it is impossible to draw conclusions about a carnitine supplement without caffeine. A study of 36 moderately obese women who combined carnitine supplements with regular exercise showed no difference in weight loss or endurance (Villani et al., 2000). Volek et al. (2002) studied 10 healthy active men who supplemented carnitine for three weeks. This study reported statistically significant improvement in recovery from high-repetition squat exercises. At the present time, there is not enough evidence to suggest that carnitine supplementation is effective for increasing fat oxidation, improving performance, or inducing body fat loss. On the other hand, carnitine supplementation has not been shown to be detrimental to performance (Brass, 2004).

Carnitine supplements are sold in pill or liquid form. Supplement manufacturers recommend a dose of 2 to 4 g/day, which is the dose used in most scientific studies. Carnitine supplementation appears to be safe at these doses. As with most supplements, purity and potency is not assured.

Medium-Chain Triglycerides. As described earlier in the chapter, medium-chain triglycerides contain six to 10 carbon atoms. They are rapidly absorbed via the portal vein and are easily transported into the mitochondria. For these reasons, MCT are sometimes advertised as being an energy source that is as readily available as carbohydrate. It is important to know if the use of MCT by endurance athletes could increase fat oxidation during moderate- to high-intensity exercise, reduce reliance on muscle glycogen stores, or enhance performance (Hawley, 2002; Horowitz and Klein, 2000).

Several studies of well-trained endurance athletes have found that MCT ingestion does not alter fat metabolism, spare muscle glycogen, or improve performance (Goedecke et al., 2005; Misell et al., 2001; Horowitz et al., 2000; Angus et al., 2000). In fact, Goedecke et al. (2005) found that ingestion of MCT by ultraendurance cyclists compromised sprint performance—high-intensity, short-duration cycling bouts required as part of some ultraendurance competitions. The negative effect on sprint performance may have been due to gastrointestinal upset from the MCT solution. This is an example of a supplement that not only fails to improve performance but also may actually impair it.

Fat Recommendations for Athletes

The appropriate amount of dietary fat for the athlete will depend on two factors—overall energy (caloric) need and macronutrient balance. Recall that the four energy-containing nutrients are carbohydrate, fat, protein, and alcohol. While each nutrient can be considered separately, the relationships among them are also important. Typically only carbohydrate, fat, and protein are included in macronutrient balance discussions. Alcohol is usually not included in general recommendations for athletes because it contains no essential nutrients and many athletes cannot legally consume alcohol due to age restrictions.

RECOMMENDED TOTAL DAILY FAT INTAKE FOR ATHLETES IN TRAINING

To determine the amount of dietary fat required, one must also know how much carbohydrate, protein, and total energy (kcal) the athlete needs. This discussion assumes that the athlete is in energy balance. In other words, the athlete does not want to change body weight or composition and energy intake is equal to energy output. How much dietary fat does such an athlete need to consume?

In some respects this is a mathematical problem. Since the athlete wishes to remain in energy balance, the daily number of kcal needed to match energy expenditure must be determined. The amount of carbohydrate necessary to support the demands of the sport and the goals of the training cycle must be established. The daily protein goal is also important information. Once those figures are obtained, the amount of fat can be calculated. The recommended fat intake will be determined within the context of energy and macronutrient balance.

Emily, a 140-lb (~64 kg) elite 800-m runner, needs approximately 2,700 kcal (~42 kcal/kg) daily to maintain energy balance. To restore the glycogen used during her most demanding training mesocycle, she needs a carbohydrate intake of 7 g/kg (~445 g daily). Her goal for protein intake is 1.4 g/kg (~89 g daily). Together, carbohydrate and protein provide approximately 2,136 kcal. With an estimated total energy need of 2,700 kcal, fat needs to provide about 564 kcal or approximately 63 grams of fat daily.

The carbohydrate and protein recommendations are expressed on a gram per kilogram body weight basis (g/kg). In other words, carbohydrate and protein recommendations are stated as an absolute amount. They are not stated as a relative amount, such as a percent of total energy intake (e.g., 60 percent of total calories as carbohydrate). Although carbohydrate and protein recommendations are commonly expressed on an absolute basis in the planning of athletes' diets, fat recommendations have not usually been expressed this way. It is common to express fat as a percentage of total energy intake, even though this method is inconsistent with carbohydrate and protein recommendations. However, that is changing as some sports dietitians are beginning to state fat recommendations on a g/kg basis.

A very general guideline for daily fat intake by athletes is approximately 1.0 g/kg. This figure is also consistent with the range recommended by the Dietary Reference Intakes (DRI) and the Dietary Guidelines (20 to 35 percent of total caloric intake). Endurance athletes may need up to 2.0 g/kg to adequate replace intramuscular triglycerides (Horvath, Eagen, Fisher et al., 2000). When energy needs are exceptionally high, as is the case with ultraendurance athletes, the amount of fat in the diet may be as high as 3.0 g/kg (Seebohar, 2005). These g/kg guidelines are based on observations of the amount of fat trained athletes consume when they are in energy and macronutrient balance, not on research studies that have examined optimal dietary fat intake. In the example above, Emily's fat intake was approximately 1.0 g/kg or 21 percent of total energy intake.

Many athletes wonder if their diet must be "low fat." For most well-trained athletes, the diet is relatively low in fat because the intake of carbohydrate and protein is relatively high. However, fat intake typically falls within the DRI and the Dietary Guidelines. Although fat may be limited to accommodate higher carbohydrate and protein needs, athletes' diets do not need to be overly restrictive or devoid of fat. One study has shown that male and female distance runners (minimum 35 miles/wk) who consumed low-fat diets (16% of total energy intake as fat) for four weeks also consumed significantly fewer kilocalories when compared to medium to high-fat diets of 31 percent and 44 percent of total energy, respectively. Interestingly, the low-fat diet that resulted in the consumption of 19 percent fewer kilocalories was also associated with a statistically significant decrease in endurance performance (Horvath, Eagen, Fisher et al., 2000).

In general, people believe that a high intake of dietary fat results in increases in body fat. Because of this belief, fat is perceived negatively and fat intake is often restricted (Wenk, 2004). However, increases in body fat are due to the excess consumption of total energy (kcal). The overconsumption of any of the energy-containing compounds—carbohydrate, fat, protein, and/or alcohol—can result in increased body fat. Dietary fat intake is not the sole determinant of the extent of body fat stores. Athletes should not consider fat a forbidden nutrient or be misled by the erroneous belief that all fat is unhealthy (see Spotlight on Enrichment: Must an Athlete's Diet Be a "Low-Fat" Diet?).

ADJUSTING FAT INTAKE TO ACHIEVE ENERGY DEFICITS

Many athletes do not wish to be in energy balance; instead they wish to maintain an energy deficit for some period of time. The reason for the deficit is to force the body to use stored body fat for energy. The athlete's goal is to attain a lower percentage of body fat, which presumably will translate to a performance advantage. A low percentage of body fat may be advantageous to performance depending on the sport. For example, there is a potential performance advantage for a 10,000-m (6.2-mile) runner to attain a low percentage of body fat because there is less body mass (weight) to be moved. Extra body fat is "dead weight"—it does not produce any force to help with the exercise task and is extra weight that must be carried. However, performance and health can be negatively affected when body fat stores are too low or when dietary fat intake is severely limited. Given that a loss of body fat would be advantageous, how does the athlete best achieve an energy deficit?

Again, the athlete must consider the four energy-containing nutrients—carbohydrate, fat, protein, and alcohol. If the athlete is consuming all four of these nutrients, then the obvious nutrient to reduce is alcohol because its intake is not essential and may be counterproductive. If alcohol is not a part of the athlete's diet, then only the three remaining energy-containing nutrients could be adjusted. Sufficient carbohydrate is needed to adequately replenish glycogen stores and sufficient protein is needed to maintain muscle mass. Since both of these nutrients are directly or indirectly related to performance, fat often becomes the nutrient to reduce by default.

Although athletes in many different sports may want to maintain an energy deficit to produce a change in body fat, the sport of bodybuilding provides an excellent illustration. Six to 12 weeks prior to a contest, bodybuilders change their diets so they are deficient in energy on a daily basis. Protein intake is kept at a relatively high level, since they want to maintain the maximum amount of muscle mass, and weeks of low energy intake will result in some protein being used as an energy source. Carbohydrate intake must be adequate to replenish glycogen used during weight lifting and for aerobic activities. By design, precontest diets are low in fat, which results in an energy deficit when compared to energy intake in previous months. Adding or increasing aerobic exercise achieves a further energy deficit (Lambert, Frank, and Evans, 2004).


Kevin Dodge/Masterfile

The fat intake of a bodybuilder will vary depending on the training cycle.

Consider the case of Kevin, a 220-lb (100-kg) body builder who routinely consumes about 5,500 kcal (55 kcal/kg). His usual fat intake is about 1.5 g/kg or 150 g daily (~25 percent of total energy intake). Two to three months before a big contest he will reduce his energy

SPOTLIGHT ON ENRICHMENT

Must an Athlete's Diet Be a "Low-Fat" Diet?

Many athletes wonder if they must routinely consume a low-fat diet. Before answering this question, the term *low-fat* must be clarified. For the general population, a low-fat diet has been defined historically as one that contains less than 30 percent of total calories as fat. This definition was developed in the mid-1960s when the average fat intake in the U.S. diet was 40 to 42 percent of total calories, a level associated with health risks (Chanmugam et al., 2003). Using this typical definition, athletes usually consume a "low-fat" diet because fat intake is often less than 30 percent of total calories.

Because Americans are normally very sedentary, the typical diet consumed in the United States is too high in fat and calories. Today people eat more grams of fat, on average 76 g daily, and more calories than they did in the 1960s. The public health message is still the same—reduce intake of dietary (saturated and *trans*) fat. However, this message does not automatically apply to athletes because of their high level of activity.

Although a low-fat diet can be appropriate for athletes, they should be aware that a very-low-fat diet can be detrimental to training, performance, and health. A very-low-fat diet is typically defined as less than 15 to 20 percent of total calories as fat. In most cases, such diets are also too low in energy over the long term to support training and can result in impaired performance. A low-fat diet can result in a lower caloric intake that can lead to a lower intake of other nutrients (Horvath, Eagen, Ryder-Calvin et al., 2000).

The reality for athletes is that their diets are usually lower in fat than those of the general population who are not attempting to lose weight, but they do not need to be exceptionally low in fat. In fact, very-low-fat diets may be detrimental for athletes.

intake to approximately 3,500 kcal. In addition to reducing caloric intake, he will slightly increase protein intake, slightly reduce carbohydrate intake, and substantially reduce fat intake. His precontest fat intake will likely be about 65 g daily or 0.65 g/kg, less than half of his usual fat consumption. During the seven days before the contest he will reduce fat intake even more in an effort to lose as much body fat as possible without sacrificing muscle mass or the ability to maintain training. After the contest he will return to his usual intake of 5,500 kcal, which includes a routine fat intake of about 1.5 g/kg daily.

ACUTE AND CHRONIC FAT AND ENERGY DEFICITS

Reductions in fat and energy intake can be either **acute** (short term) or chronic (long term). Acute deficits are usually made to reduce body fat or body weight to meet an immediate or short-term goal. Examples include a wrestler trying to "make weight" (i.e., not exceed the maximum weight in a given weight classification) or a bodybuilder preparing for a contest. Acute reductions in dietary fat and energy usually last several days to two or three months. At the end of this period, fat and energy intakes are restored to usual levels.

Chronic fat and energy deficits are those that last several months or years. Male and female distance runners and jockeys and female figure skaters, gymnasts, and dancers are examples of athletes who often exhibit chronic fat and energy deficits. Severe fat restriction can be a routine part of an energy-restricted diet adopted by an athlete to attain or maintain a low percentage of body fat. This is particularly true for the athlete who struggles to maintain a low percentage of body fat. The ultimate degree of leanness possible is largely determined by genetics, and forcing the body to maintain a very low percentage of body fat may only be achievable with long-term energy deficits (i.e., semistarvation state). In some cases chronic, severe fat restriction is a result of a fat phobia—an irrational fear that dietary fat will become body fat. Any time that fat and kilocalories are severely restricted, athletes need to ask important questions about the effect on training, performance, and health. Dietary and psychological counseling can be beneficial.

EFFECTS OF AN INADEQUATE FAT INTAKE ON TRAINING, PERFORMANCE, AND HEALTH

Inadequate fat intake, and the energy restriction that usually accompanies it, has the potential to negatively affect training, performance, and health. These effects may include: 1) inadequate replenishment of intramuscular fat stores, 2) inability to manufacture sex-related hormones, 3) alterations in the ratio of high- and low-density lipoproteins (HDL:LDL), and 4) inadequate fat-soluble vitamin intakes.

Intramuscular fat stores, such as muscle triglycerides, are reduced after endurance exercise and even more so after ultraendurance exercise. These muscular fat stores must be replenished. A routine very-low-fat diet may not be sufficient for the resynthesis of muscle triglycerides, just as a routine low-carbohydrate diet does not provide enough carbohydrates for the resynthesis of muscle glycogen (Pendergast, Leddy, and Venkatraman, 2000).

Chronic fat restriction may negatively impact the manufacture of sex-related hormones such as **testosterone.** Some studies of healthy men have shown that a low-fat diet (between 18 and 25 percent of total calories) with a high ratio of polyunsaturated to saturated fat lowered testosterone concentration (Dorgan et al., 1996; Hamalainen et al., 1984). There have also been reports of lowered testosterone concentration in wrestlers who consumed fat- and energy-restricted diets (Strauss, Lanese, and Malarkey, 1985). These studies did not examine the effect that low testosterone concentration may have on muscle mass, but they have been interpreted to mean that chronic and severe fat restriction is not desirable for male athletes because of the potential effect on testosterone production (Lambert, Frank, and Evans, 2004).

The effect of chronic fat restriction by females on the manufacture of sex-related hormones such as estrogen has been hard to ascertain. Female athletes with exercise-related menstrual irregularities tend to have both low-fat and low-energy intakes (De Cree, 1998). For some, their fat and energy restriction is one aspect of an eating disorder, **anorexia athletica** (Sudi et al., 2004). Because there are several interrelated factors, it is not known if and how one factor, the chronic low intake of dietary fat, influences the low estrogen concentrations that are observed. However, increasing both dietary fat and caloric intake is one facet of the treatment for those with anorexia athletica.

As part of the Dietary Reference Intakes for fat intake, it is recommended that daily dietary fat intake not be below 20 percent of total energy intake. Studies have shown that very-low-fat diets in healthy individuals can result in declines in high-density lipoprotein (HDL) concentrations. HDL is a lipid carrier that tends to remove cholesterol from the surface of arteries and transports it back to the liver where the cholesterol can be metabolized. Low HDL concentrations are a risk factor for cardiovascular disease as explained in Chapter 12 (Institute of Medicine, 2002).

Inadequate fat-soluble vitamin intake is a concern when dietary fat intake is low (i.e., <0.75 g/kg). Four vitamins are fat-soluble: Vitamins A, D, E, and K. These vitamins are found in foods that contain fat and a small amount of fat must be present for their proper absorption. Surveys of athletes with low fat and energy intakes suggest that vitamin E is consumed in low amounts, often less than one-third of the recommended intake

(Ziegler, Nelson, and Jonnalagadda, 1999; Leydon and Wall, 2002).

Linoleic and alpha-linolenic are essential fatty acids that cannot be manufactured by the body. Essential fatty acid deficiencies have been reported in humans that have diseases that result in fat malabsorption. However, in healthy adults essential fatty acid deficiencies are unlikely even among people who chronically consume low-fat diets. The reason is that about 10 percent of the fat stored in adipose cells is linoleic acid. This protects the adult body against essential fatty acid deficiencies that are a result of long-term fat and energy deficits (Institute of Medicine, 2002). Although essential fatty acid deficiencies are not likely, for the other reasons stated above, chronically low fat intake can be detrimental to performance and health.

Translating Daily Fat Recommendations to Food Choices

Many athletes fail to consume an appropriate amount of fat. For some, fat intake is too high and for others fat consumption is too low. In addition to the total amount of fat needed, athletes should also be aware of the kinds of fatty acids that are associated with good health. Unsaturated fatty acids may help to reduce heart disease risk, while excess saturated fatty acids are associated with an increased risk for cardiovascular disease.

A frequent recommendation for both athletes and the general population is the inclusion of "heart-healthy" fats—oils such as olive, canola, or flaxseed, nuts, and fatty fish or fish oils. These are often referred to as "good" fats, although this may not be the best terminology. A better way of communicating the point is that these foods should be emphasized in the diet. Foods that have large amounts of saturated fatty acids or cholesterol are not inherently "bad," but they should not represent the predominant types of fat consumed. *Trans* fatty acids have no known health benefits and their consumption should be limited. This can be achieved by primarily eating foods that contain naturally occurring fats, since naturally occurring fats are in the *cis* formation. Foods that contain **hydrogenated** vegetable oils (e.g., snack foods such as crackers, chips, and cookies or stick margarine) are usually sources of *trans* fatty acids.

AMOUNT AND TYPES OF FATS IN FOOD

When planning a diet from scratch, athletes generally begin by determining the amount of carbohydrate and protein needed followed by the need for fat. Similarly, when translating recommendations to food choices, athletes often choose carbohydrate and protein foods first. If this is the case, the amount of fat contained in these foods must be accounted for. The remaining fat needed to meet total energy needs then tends to come from fats that are added to foods (e.g., butter, margarine, or salad dressings). Athletes may also analyze their current food intake and make adjustments to their present diet instead of planning a diet from scratch. In either case, athletes should be aware of the amount and types of fats found in food.

Table 6.2 lists foods that are 100 percent fat or nearly 100 percent fat, such as oils and margarine, and the amount of fat in one serving. The predominant fat contained (e.g., monounsaturated, polyunsaturated, or saturated) is noted. Most of these fats are added to foods or used for food preparation. Table 6.3 lists fat-containing foods that also have some carbohydrate and/or protein, such as nuts and seeds. The amount of energy, fat, carbohydrate, and protein are listed. The predominant type of fat is also noted. Notice that there are substantial differences in the foods collectively called fats and oils. For example, some oils contain a high percentage of monounsaturated fatty acids (olive oil has the highest concentration), while others are predominantly polyunsaturated. The fatty acid content of margarines differs, depending on whether the margarine is liquid, soft, or hard. Although it won't affect athletic performance, the type of fat may affect long-term health.

The amounts of carbohydrate and protein required by athletes are substantial; thus, fat intake is comparatively low, especially if an energy (caloric) deficit is desirable. Low-fat or nonfat versions of foods may better fit into an athlete's diet plan. In particular, lean meat, fish, and poultry and modified-fat dairy products are often chosen. Table 6.4 compares high-, medium-, and low-fat versions of similar foods.

What may not be readily apparent is the amount or type of fat that is in a processed food. This is sometimes referred to as "hidden fat." Reading food labels is necessary if athletes want to discover a processed food's nutrient composition. The Nutrition Facts label is required to show the amount of total fat, saturated fat, *trans* fat, and cholesterol, and the percentage of total calories from fat. The amount of monounsaturated or polyunsaturated fat may be included, but listing these values is voluntary. Table 6.5 lists the amount of total and saturated fat found in some snack foods.

Acute: Brief or quick. Opposite of chronic.

Testosterone: A steroid hormone associated with the development of male sex characteristics.

Anorexia athletica: An eating disorder unique to athletes. May include some elements of anorexia nervosa and bulimia and excessive exercise.

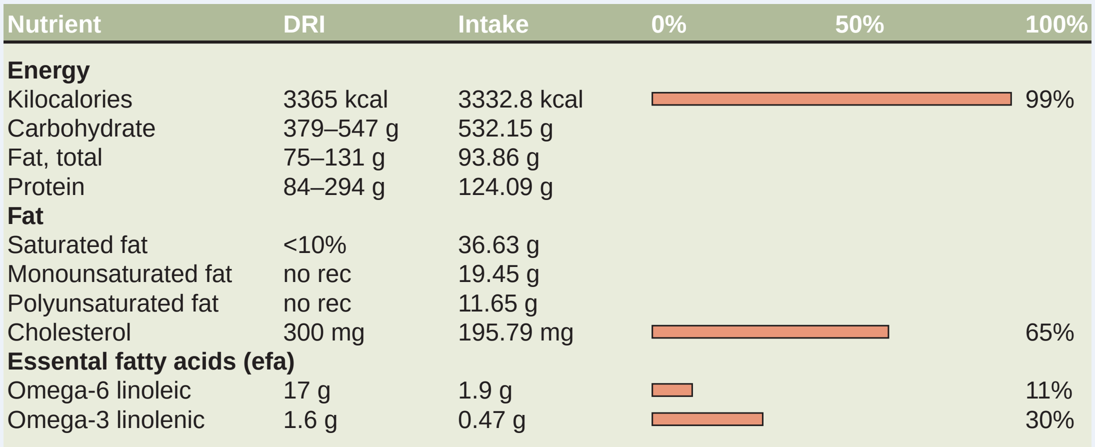
SPOTLIGHT ON A REAL ATHLETE

Lucas, a Cross Country Runner

As in previous chapters, a one-day dietary intake of Lucas, a collegiate cross country runner, is analyzed. Recall that the appropriate amount of dietary fat for an athlete depends on two factors—overall energy (caloric) need and macronutrient balance. Lucas' need for energy is approximately 3,400 kcal (~ 54 kcal/kg) daily. Due to the demands of his training (running 75 to 80 miles per week), his daily goal for carbohydrate is 8 g/kg. His daily protein goal is 1.5 g/kg. It is in this context that his fat intake should be evaluated. An analysis of the one-day diet that Lucas consumed is shown in Figure 6.13.

According to the dietary analysis, Lucas consumed approximately 3,333 kcal, 532 g of carbohydrate (~ 8.5 g/kg), and 124 g of protein (~ 2 g/kg). His fat intake was 94 g or 1.5 g/kg (~ 25 percent of total energy intake). His total energy intake was neither too high nor too low. He exceeded his goals for carbohydrate and protein intake. His fat intake allowed him to achieve macronutrient and energy balance. From a performance perspective, Lucas' fat intake was appropriate. An evaluation of Lucas' diet from a health perspective is included in Chapter 12.

It should be pointed out that Lucas included a number of nonfat and low-fat foods in his diet. For example, the smoothie that he had for breakfast was made from nonfat milk and low-fat yogurt. The lunchtime burritos were made from low-fat tortillas and low-fat refried black beans. For dinner he drank nonfat milk and chose white meat turkey for his sandwich. Because Lucas began running cross country in high school, he had already made adjustments to his diet. Had he eaten full-fat versions of these foods he would have exceeded his fat and energy goals.



Nutrient	DRI	Intake	0% 50% 100%
Energy			
Kilocalories	3365 kcal	3332.8 kcal	99%
Carbohydrate	379–547 g	532.15 g	
Fat, total	75–131 g	93.86 g	
Protein	84–294 g	124.09 g	
Fat			
Saturated fat	<10%	36.63 g	
Monounsaturated fat	no rec	19.45 g	
Polyunsaturated fat	no rec	11.65 g	
Cholesterol	300 mg	195.79 mg	65%
Essental fatty acids (efa)			
Omega-6 linoleic	17 g	1.9 g	11%
Omega-3 linolenic	1.6 g	0.47 g	30%

MyPyramid.gov
STEPS TO A HEALTHIER YOU

	Goal*	Actual	% Goal
Grains	10 oz. eq.	11.8 oz. eq.	118%
Vegetables	4 cup eq.	1.2 cup eq.	30%
Fruits	2.5 cup eq.	1.7 cup eq.	68%
Milk	3 cup eq.	5.4 cup eq.	180%
Meat & Beans	7 oz. eq.	8.8 oz. eq.	126%
Discretionary	648	1152	178%

*Your results are based on a 3200 calorie pattern, the maximum caloric intake used by MyPyramid.

Figure 6.13 Dietary Analysis of 24-Hour Diet of a Male Collegiate Cross Country Runner

Table 6.2 Fats and Oils

Food*	Amount	Energy (kcal)	Fat (g)	Predominant Type of Fat**
Olives, black	6 medium	30	3	Monounsaturated
Olives, green	4 medium, stuffed	40	3	Monounsaturated
Olive oil	1 T	120	13.5	Monounsaturated
Canola oil	1 T	120	13.5	Monounsaturated
Peanut oil	1 T	120	13.5	Monounsaturated
Safflower oil, >70% oleic	1 T	120	13.5	Monounsaturated
Safflower oil, >70% linoleic	1 T	120	13.5	Polyunsaturated
Corn oil	1 T	120	13.5	Polyunsaturated
Soybean oil	1 T	120	13.5	Polyunsaturated
Flaxseed oil	1 T	115	13	Polyunsaturated
Margarine, liquid (squeezable)	1 T	100	11	Polyunsaturated
Margarine, soft (tub)	1 T	100	11	Polyunsaturated/ Monounsaturated
Margarine, hard (stick)	1 T	100	11	Saturated
Mayonnaise	1 T	100	11	Polyunsaturated
Salad dressing, oil and vinegar	1 T	85	8	Depends on the type of oil used
Salad dressing, Ranch type	1 T	73	8	Polyunsaturated
Coconut oil	1 T	117	13.5	Saturated
Bacon grease	1 T	112	12	Saturated/ Monounsaturated
Butter, stick	1 T	108	12	Saturated
Butter, whipped	1 T	82	9	Saturated
Coconut oil	1 T	120	13.5	Saturated
Cream, half and half	1 T	20	1.5	Saturated
Lard	1 T	114	12.5	Monounsaturated/ Saturated
Shortening	1 T	110	12	No one type is predominant

Examples of foods that are 100 percent, or nearly 100 percent fat and the predominant type of fat they contain.

Legend: kcal = kilocalorie; g = gram; T = Tablespoon; oz = ounce

*All foods listed are either 100% fat or nearly 100% (contain <1 g of protein and carbohydrate).

**When two fats are listed, both are found in approximately equal amounts.

Table 6.3 High-Fat Foods That Also Contain Carbohydrate and Protein

Food	Amount	Energy (kcal)	Fat (g)	Predominant Type of Fat*	CHO (g)	Protein (g)
Avocado	One (173 g)	306	30	Monounsaturated	12	3.5
Peanuts	¼ c, oil roasted	213	18	Monounsaturated	6	10
Almonds	¼ c, dry roasted	206	18	Monounsaturated	7	8
Hazelnuts (filberts)	¼ c, dry roasted	183	18	Monounsaturated	5	4
Pecans	¼ c, dry roasted	187	19	Monounsaturated	4	2.5
Pistachios	¼ c, dry roasted	183	15	Monounsaturated	9	7
Walnuts	¼ c	196	19.5	Polyunsaturated	4	4.5
Sesame seeds	1 T	51	4	Polyunsaturated/ Monounsaturated	2	1.5
Tahini (sesame seed paste)	1 T	89	8	Polyunsaturated/ Monounsaturated	3	2.5
Sunflower seeds	¼ c, oil roasted	208	19	Polyunsaturated	5	7
Pumpkin seeds	¼ c, oil roasted	296	24	Polyunsaturated	8	19
Flax seeds	1 T	59	4	Polyunsaturated	4	2
Bacon	2 slices	70	6	Monounsaturated/ Saturated	0	4
Canadian-style bacon (pork sirloin)	2 slices	50	1.5	Saturated	0	8
Coconut, sweetened, shredded	2 T	58	4	Saturated	5.5	0
Coconut milk	¼ c	138	14	Saturated	3	1

Legend: kcal = kilocalorie; g = gram; CHO = carbohydrate; c = cup; T = Tablespoon

*When two fats are listed, both are found in approximately equal amounts.

FAT AND THE TYPICAL AMERICAN DIET

The typical American diet is characterized by a high intake of red meat, processed meat, high-fat dairy products, French fries, refined grains, sweets, and desserts. Large portions of these foods are frequently served in restaurants and at home. With the exception of sweets that are pure sugar, all of these foods can contribute substantial amounts of fat and kilocalories to the diet. This dietary pattern has been shown to contribute to chronic diseases such as cardiovascular disease, type 2 diabetes, and metabolic syndrome (see Chapter 12) (Hu et al., 2000).

Traditional Mediterranean, Asian, and Latin American diets differ from the typical American diet in that meats, sweets, and eggs are used sparingly (often on a monthly or weekly basis) and fruits, vegetables, fish, beans, whole grains, and oils are eaten daily. Portion sizes are also smaller. However, traditional Mediterranean, Asian, and Latin American meal patterns are being replaced by the typical American diet pattern in many parts of the world.

The typical American diet is too high in fat for most athletes, so they look for alternatives for both performance and health reasons. Athletes may gravitate to traditional dietary patterns, often referred to as ethnic diets, which are plant- and fish-based and relatively low in fat. Some athletes adopt a nonmeat, nonanimal-product (vegan) diet and in doing so lower their intake of fat, particularly saturated fats. However, meat and animal products do not have to be excluded. Hu (2003) noted that a dietary pattern that includes poultry and low-fat dairy products is also consistent with a reduced risk for cardiovascular disease. In other words, an athlete does not have to become a vegetarian or vegan to lower the risk for chronic diseases. There are various ways to modify the typical American diet to one that supports training, performance, and long-term health.

Table 6.4 High-, Medium-, and Low-Fat Meat, Fish, Poultry, and Dairy Products

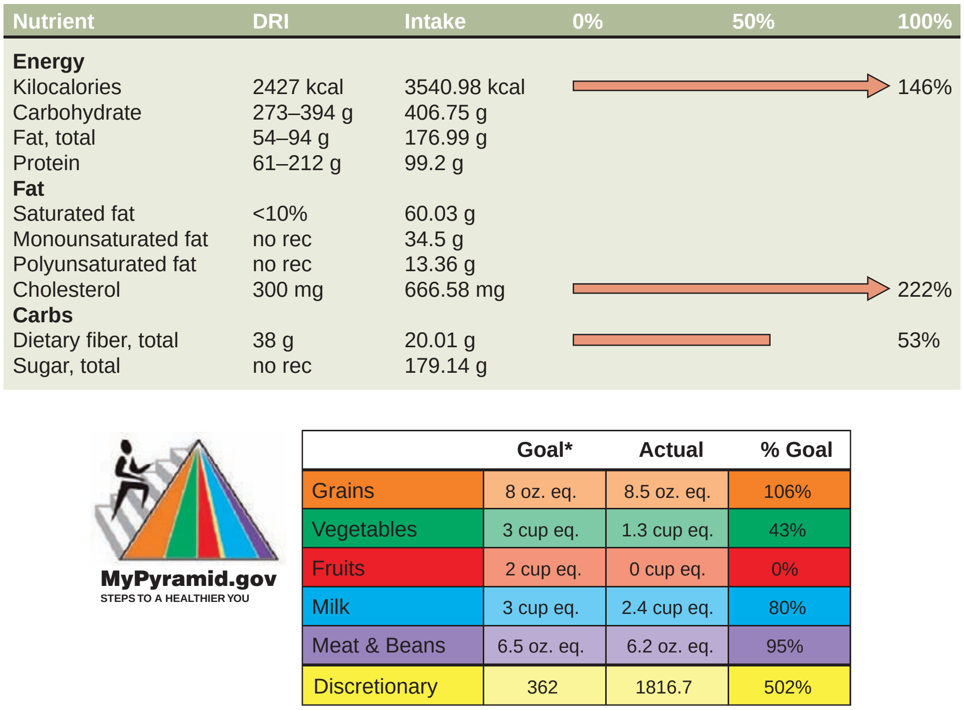
Food	Preparation Method	Amount	Fat (g)
Ground beef, regular	Broiled	3 oz	17.5
Ground beef, lean	Broiled	3 oz	16
Ground beef, extra lean	Broiled	3 oz	14
Tuna salad	Mayonnaise added to tuna	¾ c	20
Light tuna, canned in oil	Drained	2 oz	7
Light tuna, canned in water	Drained	2 oz	0.5
Chicken wing (meat and skin), flour coated	Fried	3 oz	19
Chicken wing (meat and skin)	Roasted	3 oz	16.5
Chicken leg (dark meat)	Roasted	3 oz	7
Chicken breast (white meat)	Roasted	3 oz	3
Whole milk (3.3% butterfat)		8 oz	8
Reduced fat milk (2% butterfat)		8 oz	5
Low-fat milk (1% butterfat)		8 oz	2
Nonfat (skim) milk		8 oz	0.2
Creamed cottage cheese (4% butterfat)		½ c	5
Low-fat cottage cheese (2% butterfat)		½ c	2
Low-fat cottage cheese (1% butterfat)		½ c	1
Dry curd cottage cheese (0.4% or less butterfat)		½ c	~0.5

Legend: g = gram; oz = ounce, c = cup

Table 6.5 Amount of Total and Saturated Fat in Selected Snack Foods

Food	Amount	Energy (kcal)	Total fat (g)	Saturated fat (g)
Oreo cookie ice cream	5 oz	355	20.5	12
Glazed donut	1	350	19	5
Reese's peanut butter cups	2 pieces	250	14	5
Oreo cookies	6 cookies	318	14	3
Nestle plain milk chocolate candy bar	1 (1.45 oz)	210	13	8
Trail mix	¼ c	173	11	2
Milky Way candy bar	1	270	10	5
Fritos	1 oz	160	10	1.5
Brownie	1 piece (1.5 oz)	170	8	1.5
Cheese whiz	2 T	90	7	5
Wheat thins	16 crackers (1 oz)	140	6	1
Hostess Twinkie	1	150	5	2
Pop-tart (frosted toaster pastry)	1	200	5	1

Legend: kcal = kilocalorie; oz = ounce; c = cup; g = gram



Nutrient	DRI	Intake	0%	50%	100%
Energy					
Kilocalories	2427 kcal	3540.98 kcal			146%
Carbohydrate	273–394 g	406.75 g			
Fat, total	54–94 g	176.99 g			
Protein	61–212 g	99.2 g			
Fat					
Saturated fat	<10%	60.03 g			
Monounsaturated fat	no rec	34.5 g			
Polyunsaturated fat	no rec	13.36 g			
Cholesterol	300 mg	666.58 mg			222%
Carbs					
Dietary fiber, total	38 g	20.01 g			53%
Sugar, total	no rec	179.14 g			

	Goal*	Actual	% Goal
Grains	8 oz. eq.	8.5 oz. eq.	106%
Vegetables	3 cup eq.	1.3 cup eq.	43%
Fruits	2 cup eq.	0 cup eq.	0%
Milk	3 cup eq.	2.4 cup eq.	80%
Meat & Beans	6.5 oz. eq.	6.2 oz. eq.	95%
Discretionary	362	1816.7	502%

*Your results are based on 2427 calorie pattern (sedentary male)

Figure 6.14 Dietary Analysis of a Typical American Diet (See text below for foods included)

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The Americanization of traditional ethnic meals often results in the addition of fat.

To begin to modify their diets, individuals need to analyze their current dietary intake. Figure 6.14 illustrates the macronutrient content of a diet containing many foods that Americans commonly consume—bacon and eggs for breakfast; a ham-and-cheese sandwich, potato chips, and cookies for lunch; a super-sized cheeseburger and fries at a fast-food restaurant for dinner; and chocolate ice cream for dessert. One can easily see how many Americans consume high-fat, high-calorie diets.

Most Americans are sedentary and their energy consumption exceeds their energy expenditure. As shown in Figure 6.14, estimated caloric need for a sedentary male Lucas' age is approximately 2,400 kcal, but the caloric value of the foods analyzed is more than 3,500 kcal. Note that fiber intake is low and that cholesterol and saturated fat intakes are excessive, which can be associated with some chronic diseases (see Chapter 12). The MyPyramid analysis clearly shows the low fruit and vegetable intake that is typical of many Americans.

For illustration purposes, now assume that this dietary analysis represents Lucas' alter ego and former high school teammate, Luke. Luke has never much cared about his diet because he didn't think it was all that important. In high school he ate whatever was convenient, which included fast foods most days, and he was still the best cross country runner in his region. He also figured that his diet was fine as long as he didn't gain any body fat. But a dietary analysis reveals some interesting facts. Luke's diet has an excess of energy by about 140 kcal (3,541 kcal consumed compared to 3,400 kcal needed). His carbohydrate intake is ~6.5 g/kg, 1.5 g/kg lower than his daily goal of ~8 g/kg. His fat intake is 177 g or ~2.8 g/kg. He does not meet recommended goals in three crucial areas: energy, carbohydrates, and macronutrient balance. If this one-day diet reflects his usual intake, over time he could fail to meet his training and performance goals. His carbohydrate intake is insufficient to adequately restore muscle glycogen levels depleted by prolonged endurance training and he could expect to gain 15 lb (~7 kg) of body fat over the course of the year if he consumes an excess of 140 kcal daily. From a health perspective, his intake

Table 6.6 Burger Meals Compared

Meal	Energy (kcal)	Fat (g)
Big Mac®	540	29
Large French Fries (6 oz)	570	30
TOTAL	**1,110**	**59**
Quarter Pounder® (no cheese)	410	19
Medium French Fries (4 oz)	790	78
TOTAL	**890**	**46**
Cheeseburger	300	12
Small French Fries (2.6 oz)	250	13
TOTAL	**550**	**25**

Ordering a smaller-sized meal results in lower total fat and energy intakes.

Legend: kcal = kilocalorie; g = gram; oz = ounce

Used with permission from McDonald's Corporation.

of total fat, saturated fat, and cholesterol exceeds the recommendations made to help reduce cardiovascular disease risk (see Chapter 12).

WAYS TO MODIFY THE TYPICAL AMERICAN DIET

Sports dietitians frequently counsel athletes about ways to modify their current diet to lower fat intake. Strategies include reducing portion sizes, preparing and buying foods with less fat, adding less fat to food, choosing lower fat meat and poultry, consuming low-fat or nonfat dairy products, and substituting high-fat refined grains and desserts with fresh fruits and vegetables. There is no one strategy that must be used. Instead, sports dietitians help athletes create an individualized diet plan utilizing some or all of these strategies.

- **Reduce portion size.** Reducing the portion size of high-fat foods is one obvious way to reduce fat and energy intake. Table 6.6 compares small, medium, and large meals containing a cheeseburger and French fries sold at McDonald's. These meals range from a high of 59 g of fat and 1,110 kcal to a low of 25 g of fat and 550 kcal. When high-fat foods are the only option, one strategy to reduce fat and energy intake is to simply order a smaller size.

- **Prepare foods with less fat.** Much fat can be added to food when it is prepared. Ways to prepare food that minimize the amount of fat used for cooking include grilling, roasting, broiling, baking, steaming, or poaching. Deep fat frying adds substantial amounts of fat to the original food. For example, a 3-oz piece of fish that has been coated with flour and fried has about 11 g of fat. The same fish prepared by steaming or baking has about 1 g of fat.

Anthony Blake Photo Library/Photolibrary

Grilling and steaming are preparation methods that do not require additional fat.

- **Add less fat to foods.** Some people add substantial amounts of fat to food, such as butter or margarine on bread or potatoes. Potatoes naturally contain very little fat so a baked potato contributes less than 1 g of fat when eaten plain. But what about the addition of butter, sour cream, or cheese sauce? All of these can be sources of substantial amounts of fat, depending on how much is added. A baked potato with sour cream and chives, which is available at several fast-food restaurants, has approximately 14 g of fat, all coming from the sour cream. Most baked potatoes with cheese sauce sold at fast-food restaurants have about 28 g of fat. The baked potato prepared at home can be equally fat laden, depending on how much fat is added.

- **Be aware of "hidden fats."** The fat content of some foods is surprising. A Caesar salad served in a restaurant can have 30 to 40 g of fat. A Mrs. Fields peanut butter cookie has 16 g of fat. Beverages as sources of fat should not be overlooked. A Double Chocolate Chip Frappuccino® Blended Crème with whipped cream (16 oz) from Starbucks contains 22 g of fat. Many processed snack-type foods such as crackers and chips and desserts such as pastries contain much more fat than one might realize. Reading nutrition labels and looking up nutrition information on commercial websites are ways of finding out how much fat is in a particular food.

- **Consume lower-fat cuts of meat or poultry and low-fat or nonfat dairy products.** White meat chicken, water-packed tuna, flank steak, skim milk, and low-fat cottage cheese are examples of foods that often become the staples of many athletes' diets because these foods are low in fat. Eating the lower-fat version of a product is a strategy frequently used by athletes because these foods taste good and are widely available.

- **Choose lower-fat versions of high-fat processed foods.** There are at least 5,000 foods on supermarket shelves that are lower-fat versions of full-fat foods. Consumers have tremendous choice when it comes to buying foods with a lower fat content. A word of


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Beverages may be a source of fat.

caution: these lower-fat foods may not be lower in kilocalories (energy) than the full-fat version. This is because the fat content of the food may be replaced with carbohydrate, often in the form of sugar.

- **Substitute fruits and vegetables for fat-containing snack foods.** One strategy that athletes may find helpful is to substitute a food that is naturally low in fat, such as most fruits and vegetables, for a high-fat food. This may also result in a lower energy intake, which is a goal for some athletes.

FAT SUBSTITUTES AND FAT BLOCKERS

Fat imparts some of the most appealing flavors and textures found in foods. It is also the most concentrated source of energy in the diet at 9 kcal/g. Because dietary fat is so desirable, there have been many efforts made to find acceptable **fat substitutes** and compounds that block fat absorption.

Fat Substitutes. During the 1990s, when the rates of overweight and obesity were steadily climbing in the United States, the government encouraged the food industry to create more than 5,000 reduced-fat foods. At one point more than a thousand such products were introduced each year (Wylie-Rosett, 2002). Some of these foods simply had the fat removed (e.g., skim milk), but many of the products involved fat substitutes.

Fat substitutes are most often made from carbohydrate sources, although some are derived from fat and at least one is protein-based. Carbohydrates are used because fibers and starches retain water and they add body and texture to the food when the fat is removed. Such foods have much less fat but often a similar amount of kilocalories when compared to the original product.

Protein-based fat substitutes are egg or milk proteins that have been ultracentrifuged to produce extremely small particles. The microparticles roll over each other in the mouth so the product has the same feel and texture as the full-fat product. Protein-based fat substitutes are used in dairy products, such as ice cream, and baked goods.

Many reduced-fat bakery products contain monoglycerides and diglycerides. These fats are derived from vegetable oils and have been emulsified with water. Although all fats contain 9 kcal/g, a gram of

KEEPING IT IN PERSPECTIVE

Fat Is for Fuel and Fun

Angelina looked solemnly at the piece of cake that she had been served. To the others in the room it was simply a small piece of birthday cake, but to her it was 10 g of fat. Even though she had run 5 miles that morning and had a figure that others said they envied, Angelina couldn't bring herself to eat the cake. She feared that "a minute on the lips" meant "a lifetime on the hips." So she said that she was a bit nauseated and didn't eat it, even though it was her birthday.

Fat is a calorie-dense nutrient and there are problems associated with excessive intake. However, it is very important for athletes to be able to keep their fat intake in perspective. On the fat intake continuum athletes should stay centered and not restrict fat too severely or consume fat excessively. They should view fat as a nutrient, not as something that is inherently "bad." At times they must limit fat intake, such as during a training mesocycle or microcycle when energy and fat is restricted in an effort to lose weight. But they also need to be flexible with fat intake, such as eating and enjoying a piece of cake on their birthday.

Fat is an excellent fuel source. When energy, carbohydrate, protein, and fat intakes are balanced there is no need to fret about fat. Fat also imparts a wonderful flavor and texture to food and there is a joy and satisfaction that comes with eating fat-containing foods. Backpackers often stop at the top of a steep pass and enjoy a chocolate bar. Getting to the top of the mountain gives them perspective because they can look at the world from afar. That same kind of perspective is necessary for athletes to evaluate their fat intake and discover that fat, at least in part, is for fuel and fun.

monoglyceride or diglyceride contains a considerable amount of water, so the total amount of fat is reduced when these compounds replace other fats on a per weight basis.

Caprenin and salatrim are fatty acids that are used in baked goods and dairy products because of their similar textural properties to cocoa butter. These fatty acids essentially contain 5 kcal/g because they are only partially digested and absorbed. Substituting these for traditional fats reduces the fat content by almost half. However, gastrointestinal symptoms, such as nausea and cramps, have been reported, especially as the amount consumed increases.

In a class by itself, both structurally and for regulatory purposes, is **Olestra** (Olean®). Olestra is a nonabsorbable fat substitute composed of sucrose polyester, a compound made up of sucrose with six to eight carbon fatty acids attached. Because of its chemical structure, Olestra is resistant to pancreatic lipase and remains unabsorbed in the gastrointestinal tract. When first approved, all products containing Olestra were required to carry a warning label: "This Product Contains Olestra. Olestra may cause abdominal cramping and loose stools. Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins A, D, E, and K have been added." In 2003, the Food and Drug Administration removed the warning label requirement.

Similar to artificial sweeteners, fat substitutes are not the weight loss panacea that both industry and consumers had hoped they would be. Many "fat-free" products do not have fewer kilocalories than the full-fat product, just more sugar. Controlled randomized trials have shown that individuals who choose foods with fat substitutes consume less total fat and less saturated fat but only to a small degree. In one study of Olestra, total dietary fat intake was reduced by 2.7 percent and saturated fat intake was reduced by 1.1 percent (Wylie-Rosett, 2002).

Fat Blockers. **Fat blockers**, compounds that prevent fat absorption, are appealing because, theoretically, high-fat foods could be eaten and enjoyed but blocked before they are absorbed. One such compound is **chitosan,** which is sold as a dietary supplement and advertised as an aid to weight loss.

Chitosan is derived from chitin, a compound extracted from the exoskeletons of crustaceans (i.e., shellfish such as shrimp and crabs). It is a polysaccharide similar to cellulose and is considered a dietary fiber. Studies conducted in rats found that chitosan can bind to fats in the intestine and block their absorption. The chitosan-fat complex is excreted in the feces.

The initial evidence in rats held promise that chitosan may be an aid to weight loss in humans.

Fat substitute: Compounds that replace the fat that would be found naturally in a food. Most are made from proteins or carbohydrates.

Olestra: A fat substitute that cannot be absorbed by the body.

Fat blocker: A compound that prevents fat found in food from being absorbed.

Chitosan: A dietary supplement derived from shellfish that is advertised as an aid to weight loss.

THE EXPERTS IN. . .

Fat Metabolism and Exercise

Many exercise physiologists study the metabolism of fat during exercise and the interactions between carbohydrate and fat metabolism. This basic knowledge of metabolism can lead to applied research that tests dietary manipulations of carbohydrate and fat intake to determine their effects on metabolism and performance. A natural extension of this information is the application it may have to disease states such as diabetes and obesity. George A. Brooks, Ph.D., is an expert in the area of metabolic adjustments to exercise. One of his research interests is the use of carbohydrate, fat, and protein to fuel endurance exercise and his research has led to the identification and better understanding of the "crossover concept." Asker Jeukendrup, Ph.D., a Registered Sport and Exercise Nutritionist in Europe, has published numerous research articles about the interactions between fat and carbohydrate metabolism during exercise. Having competed in Ironman distance events, Jeukendrup has a special interest in conducting applied research to improve performance and reduce gastrointestinal distress in endurance athletes. Joseph A. Houmard, Ph.D., conducts research on lipid metabolism with a focus on obesity, weight loss, and exercise. This type of work helps health professionals to better understand the metabolic basis of obesity and the impact exercise and diet may have on weight loss.

However, when tested in double-blind, randomized clinical trials, there was no significant difference between the weight of those who received chitosan supplements and those who received the placebo. Some participants who received chitosan experienced gastrointestinal distress such as constipation. Systematic reviews of the clinical trials, the strongest level of scientific evidence, conclude that chitosan supplements are not an effective aid to weight loss (Pittler and Ernst, 2004).

Summary

Fat is the most energy-dense nutrient found in food. The predominant fat in food and in the body is the **triglyceride (triacylglycerol)**, which is made up of three fatty acids attached to a **glycerol** molecule. The fatty acids, which are chains of carbon and hydrogen, vary in length and chemical composition. Fats are large molecules and their digestion, absorption, and transport is complicated because they must be broken down into smaller components.

Once absorbed, triglycerides must be re-formed. The main sites of fat storage are **adipocytes** (fat cells), liver, and muscle cells. After a meal, particularly a meal containing fats and carbohydrates, the hormonal environment is such that triglyceride formation and fat storage are favored. To be used in metabolism, fats must be taken out of storage. An enzyme, **hormone-sensitive lipase,** catalyzes **lipolysis** of triglycerides stored in adipocytes.

Fat is the primary energy source at rest and during low-intensity activity. The advantages of fat include its abundance in food, energy density, ability to be easily stored, and ability to produce a large amount of ATP. However, fat usage is limited to rest and low-intensity activity because of the time it takes to metabolize fatty acids and the oxygen necessary for metabolism.

Because the need for carbohydrate and protein is relatively high, athletes find their diets tend to be relatively low in fat and usually lower than the typical American diet. Heart-healthy fats, oils such as olive, canola, or flaxseed, nuts, and fatty fish or fish oils should be emphasized. Athletes can reduce the amount of fat in their diets by reducing portion sizes, preparing and buying foods with less fat, adding less fat to food, choosing lower fat meat and poultry, consuming low-fat or nonfat dairy products, and substituting high-fat refined grains (e.g., snack foods and desserts) with fresh fruits and vegetables. Caution should be used when restricting fat since athletes can reduce the fat in their diets too much.

Post-Test Reassessing Current Knowledge of Fats

Now that you have more knowledge about fats, read the following statements and decide if each is true or false. The answers can be found in Appendix O.

1. A low-calorie, low-carbohydrate diet that results in ketosis is dangerous for athletes because it leads to the medical condition known as ketoacidosis.
2. At rest, the highest percentage of total energy expenditure is from fat and not carbohydrate.
3. To lose body fat, it is best to perform low-intensity exercise, which keeps one in the fat-burning zone.
4. To improve performance, endurance athletes should ingest caffeine because more free fatty acids are oxidized for energy and muscle glycogen is spared.
5. Athletes typically need to follow a very-low-fat diet.

Review Questions

1. What might people mean when they say “too much fat?”
2. Why is consuming enough dietary fat important for athletes?
3. What are the differences between saturated, monounsaturated, and polyunsaturated fatty acids? Name foods in which each type predominates.
4. What is the chemical difference between *cis*- and *trans* fatty acids? Why might people be advised to eat whole (less processed) foods?
5. What is a triglyceride? Where are triglycerides found in food? In the body?
6. Explain the two major factors that dictate the appropriate amount of dietary fat intake for an athlete.
7. Briefly explain the digestion, intestinal absorption, and transportation of fats.
8. Briefly explain the major steps in the metabolism of fatty acids in the body.
9. What happens to the use of fat as a fuel as exercise intensity increases? What happens to the use of fat as a fuel when steady-state exercise progresses in duration?
10. Explain relative and absolute fat oxidation. Does a person need to burn fat during exercise in order to lose body fat?
11. Why do athletes acutely and chronically restrict fat intake?

12. In what ways may severe, chronic fat and energy restriction affect performance and health?
13. What are the recommended guidelines for fat intake for athletes?
14. Describe some strategies that athletes could use to reduce the fat content of their diets.
15. What are fat substitutes?
16. Is the dietary supplement chitosan effective for blocking fat absorption or for weight loss in humans? Why or why not?

References

Angus, D.J., Hargreaves, M., Dancey, J. & Febbraio, M.A. (2000). Effect of carbohydrate or carbohydrate plus medium-chain triglyceride ingestion on cycling time trial performance. *Journal of Applied Physiology,* 88(1), 113–119.

Brass, E.P. (2004). Carnitine and sports medicine: Use or abuse? *Annals of the New York Academy of Sciences*, 1033, 67–78.

Brooks, G.A., Fahey, T.D. & Baldwin, K.M. (2005). *Exercise Physiology: Human Bioenergetics and Its Applications,* 4th ed. New York: McGraw Hill.

Carey, A.L., Staudacher, H.M., Cummings, N.K., Stepto, N.K., Nikolopoulos, V., Burke, L.M. & Hawley, J.A. (2001). Effects of fat adaptation and carbohydrate restoration on prolonged endurance exercise. *Journal of Applied Physiology,* 91(1), 115–122.

Cha, Y.S., Choi, S.K., Suh, H., Lee, S.N., Cho, D. & Li, K. (2001). Effects of carnitine coingested caffeine on carnitine metabolism and endurance capacity in athletes. *Journal of Nutritional Science and Vitaminology,* 47(6), 378–384.

Chanmugam, P., Guthrie, J.F., Cecilio, S., Morton, J.F., Basiotis, P.P. & Anand, R. (2003). Did fat intake in the United States really decline between 1989–1991 and 1994–1996? *Journal of the American Dietetic Association,* 103(7), 867–872.

De Cree, C. (1998). Sex steroid metabolism and menstrual irregularities in the exercising female. A review. *Sports Medicine*, 25(6), 369–406.

Dorgan, J.F., Judd, J.T., Longcope, C., Brown, C., Schatzkin, A., Clevidence, B.A., Campbell, W.S., Nair, P.P., Franz, C., Kahle, L. & Taylor, P.R. (1996). Effects of dietary fat and fiber on plasma and urine androgens and estrogens in men: A controlled feeding study. *American Journal of Clinical Nutrition,* 64(6), 850–855.

Goedecke, J.H., Clark, V.R., Noakes, T.D. & Lambert E.V. (2005). The effects of medium-chain triacylglycerol and carbohydrate ingestion on ultra-endurance exercise performance. *International Journal of Sport Nutrition and Exercise Metabolism*, 15(1), 15–27.

Graham, T.E. (2001). Caffeine and exercise: Metabolism, endurance and performance. *Sports Medicine*, 31(11), 785–807.

Grediagin, A., Cody, M., Rupp, J., Benardot, D. & Shern, R. (1995). Exercise intensity does not effect body composition change in untrained, moderately overfat women. *Journal of the American Dietetic Association*, 95(6), 661–665.

Gropper, S.S., Smith, J.L. & Groff, J.L. (2005). *Advanced Nutrition and Human Metabolism.* Belmont, CA: Thomson/Wadsworth.

Hamalainen, E., Adlercreutz, H., Puska, P. & Pietinen, P. (1984). Diet and serum sex hormones in healthy men. *Journal of Steroid Biochemistry*, 20(1), 459–464.

Hawley, J.A. (2002). Effect of increased fat availability on metabolism and exercise capacity. *Medicine and Science in Sports and Exercise*, 34(9), 1485–1491.

Helge, J.W. (2000). Adaptation to a fat-rich diet: Effects on endurance performance in humans. *Sports Medicine,* 30(5), 347–357.

Horowitz, J.F. & Klein, S. (2000). Lipid metabolism during endurance exercise. *American Journal of Clinical Nutrition,* 72(2 Suppl), 558S–563S.

Horowitz, J.F., Mora-Rodriguez, R., Byerley, L.O. & Coyle, E.F. (2000). Preexercise medium-chain triglyceride ingestion does not alter muscle glycogen use during exercise. *Journal of Applied Physiology*, 88(1), 219–225.

Horvath, P.J., Eagen, C.K., Fisher, N.M., Leddy, J.J. & Pendergast, D.R. (2000). The effects of varying dietary fat on performance and metabolism in trained male and female runners. *Journal of the American College of Nutrition,* 19(1), 52–60.

Horvath, P.J., Eagen, C.K., Ryer-Calvin, S.D. & Pendergast, D.R. (2000). The effects of varying dietary fat on the nutrient intake in male and female runners. *Journal of the American College of Nutrition*, 19(1), 42–51.

Hu, F.B. (2003). Plant-based foods and prevention of cardiovascular disease: An overview. *American Journal of Clinical Nutrition*, 78(3 Suppl), 544S–551S.

Hu, F.B., Rimm, E.B., Stampfer, M.J., Ascherio, A., Spiegelman, D. & Willett, W.C. (2000). Prospective study of major dietary patterns and risk of coronary heart disease in men. *American Journal of Clinical Nutrition*, 72(4), 912–921.

Institute of Medicine (2002). Dietary Reference Intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. Food and Nutrition Board. Washington, DC: The National Academies Press.

Jeukendrup, A.E., Saris, W.H.M. & Wagenmakers, A.J.M. (1998a). Fat metabolism during exercise: A review. Part I: fatty acid mobilization and muscle metabolism. *International Journal of Sports Medicine,* 19(4), 231–244.

Jeukendrup, A.E., Saris, W.H.M. & Wagenmakers, A.J.M. (1998b). Fat metabolism during exercise: A review. Part II: regulation of metabolism and the effects of training. *International Journal of Sports Medicine,* 19(5), 293–302.

Lambert, C.P., Frank, L.L. & Evans, W.J. (2004). Macronutrient considerations for the sport of bodybuilding. *Sports Medicine*, 34(5), 317–327.

Leydon, M.A. & Wall, C. (2002). New Zealand jockeys' dietary habits and their potential impact on health. *International Journal of Sport Nutrition and Exercise Metabolism,* 12(2), 220–237.

Misell, L.M., Lagomarcino, N.D., Schuster, V. & Kern, M. (2001). Chronic medium-chain triacylglycerol consumption and endurance performance in trained runners. *Journal of Sports Medicine and Physical Fitness*, 41(2), 210–215.

Muller, D.M., Seim, H., Kiess, W., Loster, H. & Richter, T. (2002). Effects of oral L-carnitine supplementation on in vivo long-chain fatty acid oxidation in healthy adults. *Metabolism,* 51(11), 1389–1391.

Pendergast, D.R., Leddy, J.J. & Venkatraman, J.T. (2000). A perspective on fat intake in athletes. *Journal of the American College of Nutrition*, 19(3), 345–350.

Phinney, S.D., Bistrian, B.R., Evans, W.J., Gervino, E. & Blackburn, G.L. (1983). The human metabolic response to chronic ketosis without caloric restriction: Preservation of submaximal exercise capability with reduced carbohydrate oxidation. *Metabolism,* 32(8), 769–776.

Pittler, M.H. & Ernst, E. (2004). Dietary supplements for body-weight reduction: A systematic review. *American Journal of Clinical Nutrition*, 79(4), 529–536.

Seebohar, B. (2005). Nutrition for endurance sports. In Dunford, M. (ed.), *Sports Nutrition: A Practice Manual for Professionals,* 4th ed. Chicago, IL: American Dietetic Association, pp. 445–459.

Spriet, L.L. (1995). Caffeine and performance. *International Journal of Sport Nutrition*, 5(Suppl), S84–S99.

Strauss, R.H., Lanese, R.R. & Malarkey, W.B. (1985). Weight loss in amateur wrestlers and its effect on serum testosterone levels. *Journal of the American Medical Association*, 254(23), 3337–3338.

Sudi, K., Ottl, K., Payerl, D., Baumgartl, P., Tauschmann, K. & Muller, W. (2004). Anorexia athletica. *Nutrition*, 20(7–8), 657–661.

VanItallie, T.B. & Nufert, T.H. (2003). Ketones: Metabolism's ugly duckling. *Nutrition Reviews*, 61(10), 327–341.

Villani, R.G., Gannon, J., Self, M. & Rich, P.A. (2000). L-Carnitine supplementation combined with aerobic training does not promote weight loss in moderately obese women. *International Journal of Sport Nutrition and Exercise Metabolism,* 10(2), 199–207.

Volek, J.S., Kraemer, W.J., Rubin, M.R., Gomez, A.L., Ratamess, N.A. & Gaynor, P. (2002). L-Carnitine L-tartrate supplementation favorably affects markers of recovery from exercise stress. *American Journal of Physiology, Endocrinology and Metabolism,* 282(2), 474–482.

Wenk, C. (2004). Implications of dietary fat for nutrition and energy balance. *Physiology & Behavior,* 83(4), 565–571.

Wylie-Rosett, J. (2002). Fat substitutes and health: An advisory from the nutrition committee of the American Heart Association. *Circulation*, 105(23), 2800–2804.

Ziegler, P.J., Nelson, J.A. & Jonnalagadda, S.S. (1999). Nutritional and physiological status of U.S. national figure skaters. *International Journal of Sport Nutrition and Exercise Metabolism*, 9(4), 345–360.