## **How much total carbohydrate and added sugar should you eat?**

Proponents of low-carbohydrate diets claim that eating carbohydrates makes you gain weight. However, anyone who consumes more Calories than he or she expends will gain weight, whether those Calories are in the form of simple or complex carbohydrates, protein, or fat. Moreover, fat is twice as "fattening" as carbohydrate: it contains 9 kcal per gram, whereas carbohydrate contains only 4 kcal per gram. In fact, as we noted earlier, eating fiber-rich carbohydrates has been shown to reduce the overall risk for obesity, cardiovascular disease, and diabetes. Thus, all carbohydrates are not bad, and even foods with added sugars--in limited amounts--can be included in a healthful diet.

**The Recommended Dietary Allowance for Total Carbohydrate Reflects Glucose Use by the Brain**

The Recommended Dietary Allowance (RDA) for carbohydrate is based on the amount of glucose the brain uses.2 The current RDA for adults 19 years of age and older is 130 g of carbohydrate per day. It is important to emphasize that this RDA does not cover the amount of carbohydrate needed to support daily activities; it covers only the amount of carbohydrate needed to supply adequate glucose to the brain.

Recall from Chapter 1 that carbohydrates have been assigned an Acceptable Macronutrient Distribution Range (AMDR) of 45% to 65% of total energy intake. This is the range of intake associated with a decreased risk for chronic diseases. **TABLE 4.1** compares the RDA and AMDR recommendations from the Health and Medicine Division of the National Academies of Science with the *2015-2020 Dietary Guidelines for Americans* related to carbohydrate-containing foods.2,3 As you can see, the Health and Medicine Division of the National Academies of Science provides specific numeric recommendations, whereas the Dietary Guidelines focus on consumption of a healthful eating pattern. Most health agencies agree that most of the carbohydrates you eat each day should be high in fiber, whole-grain, and unprocessed. As recommended in the USDA Food Guide, eating at least half your grains as whole grains and eating the suggested amounts of fruits and vegetables each day will ensure that you get enough fiber-rich carbohydrates in your diet. Although fruits are predominantly composed of simple sugars, they are good sources of vitamins, some minerals, and fiber.

**Most Americans Eat Too Much Added Sugar**

The average carbohydrate intake per person in the United States is approximately 50% of total energy intake. For some people, almost half of this amount consists of sugars. Where does all this sugar come from? Some sugar comes from healthful food sources, such as fruit and milk. Some comes from foods made with refined grains, such as soft white breads, saltine crackers, and pastries. Much of the rest comes from **added sugars**--that is, sugars and syrups that are added to foods during processing or preparation. For example, many processed foods include high-fructose corn syrup (HFCS), an added sugar.

[Image: The RDA for carbohydrate is based on the amount the brain uses. Exercise, or even routine activity, increases our need for carbohydrate beyond the RDA.]

[Sidebar: **added sugars** Sugars and syrups that are added to food during processing or preparation.]

**TABLE 4**.**1** **Dietary Recommendations for Carbohydrates**

|  |  |
| --- | --- |
| **Health and Medicine Division of the National Academies of Science Recommendations\*** | **2015-2020 Dietary Guidelines for Americans**† |
| Recommended Dietary Allowance (RDA) for adults 19 years of age and older is 130 g of carbohydrate per day.  The Acceptable Macronutrient Distribution Range (AMDR) for carbohydrate is 45-65% of total daily energy intake.  Added sugar intake should be 25% or less of total energy intake each day. | Consume a healthful eating pattern that accounts for all foods and beverage within an appropriate Calorie level. A healthful eating pattern includes: a variety of vegetables from all subgroups (dark green, red and orange, legumes, starch and other); fruits (especially whole fruits); grains (at least half of which are whole grains); fat-free or low-fat dairy; a variety of protein foods; and oils.  Consume less than 10% of Calories per day from added sugars. |

\*Data from: Health and Medicine Division of the National Academies of Science, Food and Nutrition Board, 2005. *Dietary Reference Intakes for Energy, Carbohydrates, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients).* Washington, DC: The National Academy of Sciences. Reprinted with permission.

†Data from: U.S. Department of Health and Human Services and U.S. Department of Agriculture. *2015-2020 Dietary Guidelines for Americans,* 8th edn.

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Note in Table 4.1 that the *2015-2020 Dietary Guidelines for Americans* recommend consuming less than 10% of our total energy from added sugars. As discussed in Chapter 2, the Nutrition Facts panel being revised by the FDA will include the % Daily Values for added sugars, which will be an additional tool to help consumers identify foods that are high in added sugars.

The most common source of added sugars in the U.S. diet is sweetened soft drinks; we drink an average of 40 gallons per person each year. Consider that one 12-oz cola contains 38.5 g of sugar, or almost 10 teaspoons. The average American consumes more than 16,420 g of sugar (about 267 cups) in sweetened soft drinks each year. Other common sources of added sugars include cookies, cakes, pies, fruit drinks, fruit punches, and candy. Even many nondessert items, such as peanut butter, yogurt, flavored rice mixes, and even salad dressing, contain added sugars.

If you want a quick way to figure out the amount of sugar in a processed food, check the Nutrition Facts panel for the line that identifies "Sugars." You'll notice that the amount of total and added sugars in a serving is identified in grams. Divide the total grams by 4 to get teaspoons. For instance, one national brand of yogurt contains 21 grams of sugar in a half-cup serving. That's more than 5 teaspoons of sugar! Doing this simple math before you buy may help you choose among different, more healthful versions of the same food.

There is also confusion about whether some types of sweeteners are more healthful than others, with claims that sweeteners such as honey, molasses, or raw sugar are more natural and nutritious than table sugar. Is there any evidence to back these claims?

Remember that sucrose consists of one glucose molecule and one fructose molecule joined together. From a chemical perspective, honey is almost identical to sucrose because honey also contains glucose and fructose molecules in almost equal amounts. However, enzymes in bees' "honey stomachs" separate some of the glucose and fructose molecules, and bees fan honey with their wings to reduce its moisture content; as a result, honey looks and tastes slightly different.

Honey does not contain any more nutrients than sucrose, so it is not a more healthful choice. In fact, per tablespoon, honey has more Calories (energy) than table sugar. This is because the crystals in table sugar take up more space on a spoon than the liquid form of honey, so a tablespoon contains less sugar. However, some people argue that honey is sweeter, so you use less.

Is raw sugar more healthful than table sugar? Actually, the "raw sugar" available in the United States has gone through more than half of the same steps in the refining process used to make table sugar. Raw sugar has a coarser texture than white sugar and is unbleached; in most markets, it is also significantly more expensive. Nevertheless, it's still sugar. What about molasses? The syrup that remains when sucrose is made from sugarcane, molasses has a distinctive taste that is less sweet than table sugar. It does contain some iron, but this iron does not occur naturally. It is a contaminant from the machines that process the sugarcane!

As you can see, all added sugars are chemically similar, and foods and beverages with added sugars have lower levels of vitamins, minerals, and fiber than foods that naturally contain simple sugars. Moreover, increasing concerns about the contribution of added sugars to obesity and chronic disease have led many public health agencies to recommend that we limit our consumption of added sugars. In addition to checking the Nutrition Facts panel for information on added sugars, you should also read the ingredients list to help you distinguish between added sugars and naturally occurring sugars. Refer to **TABLE 4.2** on page 116 for a list of terms indicating added sugars. To maintain a diet low in added sugars, limit foods in which a form of added sugar is listed as one of the first few ingredients on the label.

**Sugars Are Blamed for Many Health Problems**

Why do added sugars have such a bad reputation? First, they are known to contribute to tooth decay. Second, eating a lot of sugar could increase the levels of unhealthful lipids in our blood, increasing our risk for cardiovascular disease. High intakes of added sugars have also been blamed for diabetes and obesity. Let's learn the truth about these accusations.

[Image: Honey is no more nutritious than table sugar.]

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**TABLE 4.2 Forms of Sugar Commonly Added to Foods**

|  |  |
| --- | --- |
| **Name of Sugar** | **Definition** |
| Brown sugar | A highly refined sweetener made up of approximately 99% sucrose and produced by adding to white table sugar either molasses or burnt table sugar for coloring and flavor. |
| Cane sugar | Sucrose that has been extracted from sugarcane, a tropical plant naturally rich in sugar. |
| Concentrated fruit juice sweetener | A form of sweetener made with concentrated fruit juice, commonly pear juice. |
| Confectioner's sugar | A highly refined, finely ground white sugar; also referred to as powdered sugar. |
| Corn sweeteners | A general term for any sweetener made with corn starch. |
| Corn syrup | A syrup produced by the partial hydrolysis of corn starch. |
| Dextrose | An alternative term for glucose. |
| Fructose | A monosaccharide that occurs in fruits and vegetables; also called levulose, or fruit sugar. |
| Galactose | A monosaccharide that joins with glucose to create lactose. |
| Granulated sugar | Another term for white sugar, or table sugar. |
| High-fructose corn syrup | A type of corn syrup in which part of the sucrose is converted to fructose, making it sweeter than sucrose or regular corn syrup; most high-fructose corn syrup contains 42% to 55% fructose. |
| Honey | A sweet, sticky liquid sweetener made by bees from the nectar of flowers; contains glucose and fructose. |
| Invert sugar | A sugar created by heating a sucrose syrup with a small amount of acid; inverting sucrose results in its breakdown into glucose and fructose, which reduces the size of the sugar crystals; because of its smooth texture, it is used in making candies and some syrups. |
| Levulose | Another term for fructose, or fruit sugar. |
| Mannitol | A type of sugar alcohol. |
| Maple sugar | A sugar made by boiling maple syrup. |
| Molasses | A thick, brown syrup that is separated from raw sugar during manufacturing; it is considered the least refined form of sucrose. |
| Natural sweeteners | A general term used for any naturally occurring sweeteners, such as fructose, honey, and raw sugar. |
| Raw sugar | The sugar that results from the processing of sugar beets or sugarcane; it is approximately 96% to 98% sucrose; true raw sugar contains impurities and is not stable in storage; the raw sugar available to consumers has been purified to yield an edible sugar. |
| Sorbitol | A type of sugar alcohol. |
| Turbinado sugar | The form of raw sugar that is purified and safe for human consumption; sold as "Sugar in the Raw" in the United States. |
| White sugar | Another name for sucrose, or table sugar. |
| Xylitol | A type of sugar alcohol. |

**Sugar and Tooth Decay**

Sugars do play a role in dental problems, because the bacteria that cause tooth decay thrive on sugar. These bacteria produce acids, which eat away at tooth enamel and can eventually cause cavities and gum disease **(FIGURE 4.12).** Eating sticky foods that adhere to teeth--such as caramels, crackers, sugary cereals, and licorice--and slowly sipping sweetened beverages over time are two behaviors that should be avoided because they increase the risk for tooth decay. People also shouldn't put babies to bed with a bottle unless it contains water. As we have seen, even breast milk contains sugar, which can slowly drip onto the baby's gums. As a result, infants should not routinely be allowed to fall asleep at the breast.

To reduce your risk for tooth decay, brush your teeth after each meal, after drinking sugary drinks, and after snacking on sweets. Drinking fluoridated water and using a fluoride toothpaste will also help protect your teeth.

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**Sugar and Blood Lipids**

Research evidence does suggest that consuming a diet high in added sugars is associated with unhealthful changes in blood lipids. For example, higher intakes of added sugars are associated with changes in lipoproteins that are risk factors for cardiovascular disease. Two recent studies have shown that people who consume sugar-sweetened beverages have an increased risk of and premature mortality from cardiovascular disease.9,10 Although the Health and Medicine Division of the National Academies of Science has yet to set a UL for added sugars, the growing body of evidence suggests that eating high amounts may be harmful. Again, the *2015-2020 Dietary Guidelines for Americans* recommends we should consume less than 10 % of our total Calories as added sugars. Because added sugars are a component of many processed foods and beverages, careful label reading is advised.

**Sugar and Diabetes**

Recent studies suggest that eating a diet high in added sugars is associated with a higher risk for diabetes; the relationship is particularly strong between higher intakes of sugar-sweetened beverages and diabetes. An observational study examined the relationship between diabetes and sugar intake across 175 countries and found that for every 150 kcal per person per day increase in availability of sugar (equivalent to about one can of soft drink per day), the prevalence of diabetes increased by 1.1%.11 Although the exact mechanisms explaining this relationship are not clear, experts have speculated that the surges in glucose and insulin levels that occur when we consume high amounts of rapidly absorbable carbohydrates (which includes any forms of sugar, including fructose as discussed earlier) may stimulate appetite, increase food intake, and promote weight gain, which increases our risk for diabetes. High-fructose corn syrup in particular has negative effects on how we metabolize and store body fat; this can lead to us being more resistant to the normal actions of insulin and increase our risk for diabetes.

**Sugar and Obesity**

There is also evidence linking added sugar intake with obesity. For example, a recent systematic review of randomized controlled trials and observational studies found that reducing intake of added sugars in adults results in weight loss and increasing intake of added sugars results in weight gain.12 This increase in weight is due to the excess Calorie intake and not due to the sugars per se. This same review found that children who consume one or more servings of sugar-sweetened beverages per day had a 1.55 times higher risk of being overweight than those children consuming none or very little.

It is important to emphasize that if you consume more energy than you expend, you will gain weight. It makes intuitive sense that people who consume extra energy from high-sugar foods are at risk for obesity, just like people who consume extra energy from fat or protein. However, more evidence is accumulating to indicate that the type of carbohydrates consumed may play a role in increasing one's risk for obesity. The precise relationship between added sugars and obesity is discussed in more detail in the **Nutrition Debate** (page 127).

If you're concerned about the amount of added sugars you consume, what can you do to cut down? See the **Quick Tips** feature on page 118 for answers.

**[recap**

The RDA for carbohydrate is 130 g per day; this amount is only sufficient to supply adequate glucose to the brain. The AMDR for carbohydrate is 45% to 65% of total energy intake. The *2015-2020 Dietary Guidelines for Americans* recommend consuming less than 10% of Calories per day as added sugars; that is, sugars and syrups added to foods during processing or preparation. The most common source of added sugars in the U.S. diet is sweetened soft drinks. Sugar causes tooth decay. High intakes of added sugars are associated with increases in unhealthful blood lipids and increased risks for cardiovascular disease, diabetes, and obesity.]

**[FIGURE 4.12** Eating sugars can cause an increase in cavities and gum disease. This is because bacteria in the mouth consume sugars present on the teeth and gums and produce acids, which eat away at these tissues.]

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**[Slashing Your Sugar Intake**

Switch from sugary drinks to diet drinks, milk or soymilk, unsweetened tea or coffee, fruit juice highly diluted with sparkling water, or plain water.

Limit the number of specialty coffees flavored with syrup that you drink--have these as an occasional treat.

Reduce the amount of sugar you put into your coffee, tea, and cereal--try cutting the amount to half, then a quarter. Or consider using an alternative sweetener instead of sugar.

When buying fruit, go for fresh, frozen, dried, or canned options packed in water or their own juice. Avoid fruits packed in syrup.

Switch from fruit-flavored yogurts, ice cream, or sherbet to plain yogurt topped with fresh fruit.

Choose desserts such as cookies, candies, and cakes less often, replacing them with fresh or dried fruit, nuts and seeds, or a small piece of dark chocolate.

Read food labels to increase your awareness of the sugar content of the foods you normally buy.]

**LO 6** Identify the Adequate Intake for fiber and list several foods that are good sources of fiber-rich carbohydrates.

## **How much fiber do you need, and what are the best sources?**

Do you get enough dietary fiber each day? Most Americans don't.13 The Adequate Intake (AI) for fiber is 25 g per day for women and 38 g per day for men, or 14 g of fiber for every 1,000 kcal per day that a person eats.2 Most people in the United States eat only 15 g (females) and 18 g (males) of fiber each day, which is only about half of the fiber they need.13 Although fiber supplements are available, it is best to get fiber from your diet because foods rich in fiber also provide vitamins, minerals, and phytochemicals. So what foods qualify?

**Whole Grains Are Excellent Sources of Fiber**

Whole-grain foods have many benefits. In addition to being excellent sources of fiber, they're rich in micronutrients and phytochemicals. They also have a lower glycemic index than refined carbohydrates; thus, they prompt a more gradual release of insulin and result in less severe fluctuations in both insulin and glucose.

**TABLE 4.3** lists the terms commonly used on nutrition labels to identify the type of grains in breads and cereals. Read the label for the bread you eat--does it list *whole-wheat flour* or just *wheat flour?* The term *wheat flour* actually refers to refined white flour. So make sure to choose products with the word *whole* in the first ingredient listed. To appreciate exactly what you'll be buying, let's look at what makes a whole grain whole.

Grains are grasses that produce edible kernels. A kernel of grain is the seed of the grass. If you were to plant a kernel of barley, a blade of grass would soon shoot up. Kernels of different grains all share a similar design. As shown in **FIGURE 4.13,** they consist of three parts:

- The outermost covering, called the *bran,* is very high in fiber and contains most of the grain's vitamins and minerals.

- The *endosperm* is the grain's midsection and contains most of the grain's carbohydrates and protein.

- The *germ* sits deep in the base of the kernel, surrounded by the endosperm, and is rich in healthful fats and some vitamins.

**[FIGURE 4.13** A whole grain includes the bran, endosperm, and germ.]

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**TABLE 4.3 Terms Used to Describe Grains and Cereals on Nutrition Labels**

|  |  |
| --- | --- |
| **Term** | **Definition** |
| Brown bread | Bread that may or may not be made using whole-grain flour. Many brown breads are made with white flour with brown (caramel) coloring added. |
| Enriched (or fortified) | Enriching or fortifying involves adding nutrients back to refined foods. In order to use this term in grain products in the United States, a minimum amount of iron, folate, niacin, thiamin, and riboflavin must be added. Other nutrients can also be added. |
| Refined | Refining involves removing the coarse parts of food products; refined wheat flour is flour in which all but the internal part of the kernel has been removed. |
| Stone ground | This term refers to a milling process in which limestone is used to grind any grain. Stone ground does not mean that bread is made with whole grain because refined flour can be stone ground. |
| Unbleached flour | Unbleached flour has been refined but not bleached; it is very similar to refined white flour in texture and nutritional value. |
| Wheat flour | This term refers to any flour made from wheat; it includes white flour, unbleached flour, and whole-wheat flour. |
| White flour | White flour has been bleached and refined. All-purpose flour, cake flour, and enriched baking flour are all types of white flour. |
| Whole-grain flour | This flour is made from grain that is not refined; whole grains are milled in their complete form with only the husk removed. |
| Whole-wheat flour | Whole-wheat flour is an unrefined, whole-grain flour made from whole-wheat kernels. |

*Whole grains* are kernels that retain all three of these parts. The kernels of some grains also have a *husk* (hull): a thin, dry coat that is inedible. Removing the husk is always the first step in milling (grinding) these grains for human consumption.

People worldwide have milled grains for centuries, usually using heavy stones. A little milling removes only a small amount of the bran, leaving a crunchy grain suitable for cooked cereals. For example, cracked wheat and hulled barley retain much of the kernel's bran. Whole-grain flours are produced when whole grains are ground and then recombined. Because these hearty flours retain a portion of the bran, endosperm, and germ, foods such as breads made with them are rich in fiber and a wide array of vitamins and minerals.

With the advent of modern technology, processes for milling grains became more sophisticated, with seeds being repeatedly ground and sifted into increasingly finer flours, retaining little or no bran and therefore little fiber and few vitamins and minerals. For instance, white wheat flour, which consists almost entirely of endosperm, is high in carbohydrate but retains only about 25% of the wheat's fiber, vitamins, and minerals.

In the United States, manufacturers of breads and other baked goods made with white flour are required by law to enrich their products with vitamins and minerals to replace some of those lost in processing. **Enriched foods** are foods in which nutrients that were lost during processing have been added back, so the food meets a specified standard. However, enrichment replaces only a handful of nutrients and leaves the product low in fiber. Notice that the terms *enriched* and *fortified* are not synonymous: **fortified foods** have nutrients added that did not originally exist in the food (or existed in insignificant amounts). For example, some breakfast cereals have been fortified with iron, a mineral that is not naturally present in cereals.

Again, when choosing cereals, breads, and crackers and other baked goods, look for whole wheat, whole oats, or similar whole grains on the ingredient list. This ensures that the product contains the fiber and micronutrients that nature packed into the plant's seed. Try the **Nutrition Label Activity** on page 120 to learn how to recognize various carbohydrates on food labels.

**Other Good Sources of Fiber Are Vegetables, Fruits, Nuts, and Seeds**

Most people in the United States eat less than three servings of fruits or vegetables each day.14 This is true of college students as well: fewer than 6% eat the recommended five or more servings of fruits and vegetables each day.15

Whole-grain breads provide more nutrients and fiber than breads made with enriched flour.]

[Sidebar: **enriched** foods Foods in which nutrients that were lost during processing have been added back, so that the food meets a specified standard.]

[Sidebar: **fortified** foods Foods in which nutrients are added that did not originally exist in the food, or which existed in insignificant amounts.]

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## [**nutrition label activity Recognizing Carbohydrates on the Label**

**FIGURE 4.14** shows labels for two breakfast cereals. The cereal on the left (a) is processed and sweetened, whereas the one on the right (b) is a whole-grain product with no added sugar. Which is the better breakfast choice? Fill in the label data below to find out!

- Check the center of each label to locate the amount of total carbohydrate.

**1.** For the sweetened cereal, the total carbohydrate is \_\_\_\_\_\_\_ g.

**2.** For the whole-grain cereal, the total carbohydrate is \_\_\_\_\_\_\_ g for a smaller serving size.

- Look at the information listed as subgroups under Total Carbohydrate. The label for the sweetened cereal lists all types of carbohydrates in the cereal: dietary fiber, sugars, and other carbohydrate (which refers to starches). Notice that this cereal contains 13 g of sugar--half of its total carbohydrates.

**3.** How many grams of dietary fiber does the sweetened cereal contain? \_\_\_\_\_\_\_

- The label for the whole-grain cereal lists only 1 g of sugar, which is 4% of its total carbohydrates.

**4.** How many grams of dietary fiber does the whole-grain cereal contain?

- To calculate the percentage of Calories that comes from carbohydrate, do the following:

a. Calculate the *Calories* in the cereal that come from carbohydrate. Multiply the total grams of carbohydrate per serving by the energy value of carbohydrate:

26 g of carbohydrate × 4 kcal/g = 104 kcal from carbohydrate

b. Calculate the *percentage of Calories* in the cereal that comes from carbohydrate. Divide the Calories from carbohydrate by the total Calories for each serving:

(104 kcal ÷ 120 kcal) × 100 = 87% Calories from carbohydrate

Which cereal should you choose to increase your fiber intake? Check the ingredients for the sweetened cereal. Remember that they are listed in order from highest to lowest amount. The second and third ingredients listed are sugar and brown sugar, and the corn and oat flours are not whole grain. Now look at the ingredients for the other cereal--it contains whole-grain oats. Although the sweetened product is enriched with more B-vitamins, iron, and zinc, the whole-grain cereal packs 4 g of fiber per serving, not to mention 5 g of protein, and it contains no added sugars. Overall, it is a more healthful choice.

**[FIGURE 4.14** Labels for two breakfast cereals: **(a)** processed and sweetened cereal; **(b)** whole-grain cereal with no sugar added.]]

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That's unfortunate, because fruits and vegetables are excellent sources of dietary fiber. **FIGURE 4.15** shows the fiber content of some common legumes, other vegetables, fruits, and whole grains. Eating a variety of these foods will help ensure that you eat enough fiber.

Notice that, among vegetables, legumes are particularly high in fiber. Add them to soups and salads, chili, tacos and burritos, or eat them on their own as a side dish. Leafy or crunchy greens like spinach, kale, and cabbage are also rich in fiber, as are baked potatoes with the skin on. For fruits, all berries are particularly high in fiber, as are apples and pears--as with potatoes, eat the skin.

Although not shown in Figure 4.15, nuts and seeds can be excellent sources of fiber. An ounce of almonds provides 4 g, and pistachio nuts, pumpkin seeds, and sunflower seeds all provide 3 g per ounce. Quinoa (pronounced keen-wah), a seed that is cooked and served as a grain, is very high in fiber--about 5 grams per serving. For more suggestions on selecting healthful carbohydrate sources rich in fiber, see the **Quick Tips** feature (page 123).

**MEAL FOCUS FIGURE 4.16** on page 122 compares the food and fiber content of two diets, one high in fiber-rich carbohydrates and one high in refined carbohydrates. Notice that the meals on the right provide more than double the fiber.

It's important to drink plenty of fluid as you increase your fiber intake because fiber binds with water to soften stools. Inadequate fluid intake with a high-fiber diet can actually result in hard, dry stools that are difficult to pass through the colon. At least eight 8-oz glasses of fluid each day are commonly recommended.

Also, be aware that it's possible to eat too much fiber. Excessive fiber consumption can lead to intestinal gas, bloating, and constipation, and because fiber causes

[To see a vast menu of high-fiber choices and find out how much fiber various foods provide, visit the Fiber-o-Meter at **www.webmd.com.** Type "fiber-o-meter" in the search bar, then click on the link.]

**[FIGURE 4.15** Fiber content of common foods. *Note:* The Adequate Intake for fiber is 25 g per day for women and 38 g per day for men.

Data from: U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. 2015. USDA National Nutrient Database for Standard Reference, Release 28. http://www.ars.usda.gov/nea/bhnrc/ndl.]

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**meal focus figure 4.16 Maximizing Fiber Intake**

**a day of meals**

**about 15.6 grams of** dietary fiber

**about 32** **grams of dietary fiber**

**BREAKFAST**

*1 cup Froot Loops Cereal*

*1 cup skim milk*

*2 slices of white bread with*

*1 tbsp of butter*

*8 fl. oz orange juice*

*1 cup Cheerios*

*1 cup skim milk*

*1 medium banana*

*2 slices whole-wheat toast with*

*1 tbsp light margarine*

*8 fl. oz orange juice*

**LUNCH**

*McDonald's Quarter Pounder*

*1 small French Fries*

*1 packet ketchup*

*16 fl oz cola beverage*

*15 jelly beans*

**Tuna Sandwich with:**

*2 slices of whole wheat bread*

*3 oz tuna packed in water, drained*

*1 tsp Dijon mustard*

*1 tbsp reduced-calorie mayonnaise*

*1* *large carrot, sliced*

*1 cup raw cauliflower*

*2 tbsp fat-free ranch dressing*

*8 fl oz non-fat fruit yogurt*

**DINNER**

*½* chicken breast, roasted

*1 cup mashed potatoes*

*½* cup sliced cooked carrots

*12 fl oz cola beverage*

*Apple pie (1/8 of 9-inch pie)*

*1/2 chicken breast, roasted*

*1 cup brown rice*

*1 cup steamed broccoli*

**Spinach salad:**

*1 cup chopped spinach*

*1 boiled egg*

*2 slices turkey bacon*

*3 cherry tomatoes*

*2 tbsp cream poppyseed dressing*

*1 cup fresh blueberries with*

*½* cup whipped cream

*8 fl oz cranberry juice*

**nutrient analysis**

**2,410** kcal

**58.3%** of energy from carbohydrates

**29.2%** of energy from fat

**12.5%** of energy from protein

**15.6** grams of dietary fiber

**nutrient analysis**

**2,181** kcal

**58.5%** of energy from carbohydrates

**22.3%** of energy from fat

**19.2%** of energy from protein

**32** grams of dietary fiber

**[Double** the fiber intake!]

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**[Hunting for Fiber**

Select breads made with *whole* grains, such as wheat, oats, barley, and rye. Two slices of whole-grain bread provide 4-6 grams of fiber.

Switch from a low-fiber breakfast cereal to one that has at least 4 grams of fiber per serving.

For a mid-morning snack, stir ground flaxseed meal, chia seeds, or chopped almonds (about 4 grams of fiber) into a cup of plain yogurt. Or choose an apple or a pear, with the skin left on (about 5 grams of fiber).

Instead of potato chips with your lunchtime sandwich, have a side of carrot or celery sticks (about 2 grams of fiber).

Eat legumes every day, if possible (about 5 to 6 grams of fiber per serving). Have them as your main dish, as a side, or in soups and other dishes.

Choose brown rice instead of white rice, and whole-wheat or quinoa pasta instead of regular pasta.

Don't forget the greens! A cup of cooked leafy greens provides about 4 grams of fiber, and a salad is rich in fiber.

Snack on a mixture of nuts and dried fruit.

For dessert, try a baked apple or pear or a high-fiber granola with soymilk.

When shopping, choose fresh, frozen, and canned fruits and vegetables. Check the labels of frozen and canned selections to make sure there is no sugar or salt added, or rinse before serving.]

the body to eliminate more water in the feces, a very-high-fiber diet could result in dehydration. Fiber also binds many vitamins and minerals; thus, a diet with too much fiber could reduce absorption of iron, zinc, calcium, and vitamin D. In children, some elderly, the chronically ill, and other at-risk populations, extreme fiber intake can even lead to malnutrition--they feel full before they have eaten enough to provide adequate energy and nutrients. Although there is no UL for fiber, most Americans find it difficult to tolerate more than about 50 g of fiber per day.

**[recap**

The Adequate Intake for fiber is 25 g per day for women and 38 g per day for men. Most Americans eat only about half of the fiber they need each day. A whole grain retains the bran, which is rich in fiber and micronutrients, the endosperm, and the germ. Foods high in fiber and nutrient density include whole grains and products made with whole grains; legumes and other vegetables; fruits; and nuts and seeds. The more processed the food, the fewer fiber-rich carbohydrates it contains. It's important to drink plenty of fluid as you increase your fiber intake, and to avoid consuming more than about 50 g of fiber a day.]

**LO 7** Compare and contrast a variety of alternative sweeteners.

## **What's the story on alternative sweeteners?**

Most of us love sweets but want to avoid the extra Calories and tooth decay that go along with them. Remember that all carbohydrates, whether simple or complex, contain 4 kcal of energy per gram. Because sweeteners such as sucrose, fructose, honey, and brown sugar contribute energy, they are called **nutritive sweeteners.**

[Image: Eating five or more servings of vegetables and fruits, such as apricots, will help you get enough fiber in your diet.]

[Sidebar: **nutritive sweeteners** Sweeteners, such as sucrose, fructose, honey, and brown sugar, that contribute Calories (energy).]

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Other nutritive sweeteners include the *sugar alcohols* such as mannitol, sorbitol, isomalt, and xylitol. Popular in sugar-free gums, mints, and diabetic candies, sugar alcohols are less sweet than sucrose. Foods with sugar alcohols have health benefits that foods made with sugars do not have, such as a reduced glycemic response and decreased risk of dental caries. Also, because sugar alcohols are absorbed slowly and incompletely from the intestine, they provide less energy than sugar, usually 2 to 3 kcal of energy per gram. However, because they are not completely absorbed from the intestine, they can attract water into the large intestine and cause diarrhea.

A number of other products have been developed to sweeten foods without promoting tooth decay and weight gain. Because these products provide little or no energy, they are called **nonnutritive,** or *alternative,* **sweeteners.**

**Limited Use of Alternative Sweeteners Is Not Harmful**

Research has shown alternative sweeteners to be safe for adults, children, and individuals with diabetes. Women who are pregnant should discuss the use of alternative sweeteners with their healthcare provider. In general, it appears safe for pregnant women to consume alternative sweeteners in amounts within the Food and Drug Administration (FDA) guidelines.16 These amounts, known as the **Acceptable Daily Intake (ADI),** are estimates of the amount of a sweetener that someone can consume each day over a lifetime without adverse effects. The estimates are based on studies conducted on laboratory animals, and they include a 100-fold safety factor. It is important to emphasize that actual intake by humans is typically well below the ADI.

**Saccharin**

Discovered in the late 1800s, *saccharin* is about 300 times sweeter than sucrose. Concerns arose in the 1970s that saccharin could cause cancer; however, more than 20 years of subsequent research failed to link saccharin to cancer in humans, and in 2000, the National Toxicology Program of the U.S. government removed saccharin from its list of products that may cause cancer. No ADI has been set for saccharin, and it is used in foods and beverages and as a tabletop sweetener. It is sold as Sweet n' Low (also known as "the pink packet") in the United States.

**Acesulfame-K**

*Acesulfame-K* (acesulfame potassium) is marketed under the names Sunette and Sweet One. It is a Calorie-free sweetener that is 200 times sweeter than sugar. It is used to sweeten gums, candies, beverages, instant tea, coffee, gelatins, and puddings. The taste of acesulfame-K does not change when it is heated, so it can be used in cooking. The body does not metabolize acesulfame-K, so it is excreted unchanged by the kidneys. The ADI for acesulfame-K is 15 mg per kg body weight per day. For example, the ADI in an adult weighing 150 pounds (or 68 kg) would be 1,020 mg.

**Aspartame**

*Aspartame,* also called Equal ("the blue packet") and NutraSweet, is one of the most popular alternative sweeteners currently in use. Aspartame is composed of two amino acids: phenylalanine and aspartic acid. When these amino acids are separate, one is bitter and the other has no flavor--but joined together, they make a substance that is 180 times sweeter than sucrose. Although aspartame contains 4 kcal of energy per gram, it is so sweet that only small amounts are used, thus it ends up contributing little or no energy. Heat destroys the bonds that bind the two amino acids in aspartame. Therefore, it cannot be used in cooking because it loses its sweetness.

Although there are numerous claims that aspartame causes headaches and dizziness, and can increase a person's risk for cancer and nerve disorders, studies do not support these claims.17 A significant amount of research has been done to test the safety of aspartame.

The ADI for aspartame is 50 mg per kg body weight per day. For an adult weighing 150 pounds (or 68 kg), the ADI would be 3,400 mg. **TABLE 4.4** shows how many servings of aspartame-sweetened foods would have to be consumed to exceed the ADI. Because the ADI is a very conservative estimate, it would be difficult for adults or children to exceed this amount of aspartame intake.

[Image: Contrary to media reports claiming severe health consequences related to the consumption of alternative sweeteners, major health agencies have determined that these products are safe for us to consume.]

[Sidebar: **nonnutritive sweeteners** Manufactured sweeteners that provide little or no energy; also called *alternative sweeteners.*]

[Sidebar: **Acceptable Daily Intake (ADI)** An FDA estimate of the amount of a nonnutritive sweetener that someone can consume each day over a lifetime without adverse effects.]

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**TABLE 4.4 Foods and Beverages That a Child and an Adult Would Have to Consume Daily to Exceed the ADI for Aspartame**

|  |  |  |
| --- | --- | --- |
| **Foods and Beverages** | **50-lb Child** | **150-lb Adult** |
| 12 fl. oz carbonated diet soft drink *or* | 5.6 | 17 |
| 8 fl. oz powdered soft drink or | 11 | 34 |
| 4 fl. oz gelatin dessert *or* | 14 | 42 |
| Packets of tabletop sweetener | 32 | 97 |

Data from: Academy of Nutrition and Dietetics. 2015. "Sugar Substitutes: How Much Is Too Much?" http://www.eatright.org/resource/food/nutrition/dietary-guidelines-and-myplate/sugar-substitutes-how-much-is-too-much.

However, drinks sweetened with aspartame, which are extremely popular among children and teenagers, are very low in nutritional value. They should not replace more healthful beverages such as milk, water, and 100 % fruit juice.

There are some people who should not consume aspartame at all: those with the disease *phenylketonuria (PKU).* This is a genetic disorder that prevents the breakdown of the amino acid phenylalanine. Because the person with PKU cannot metabolize phenylalanine, it builds up to toxic levels in the tissues of the body and causes irreversible brain damage. In the United States, all newborn babies are tested for PKU; those who have it are placed on a phenylalanine-limited diet. Some foods that are common sources of protein and other nutrients for many growing children, such as meats and milk, contain phenylalanine. Thus, it is critical that children with PKU not waste what little phenylalanine they can consume on nutrient-poor products sweetened with aspartame.

**Sucralose**

Sucralose is marketed under the brand name Splenda and is known as "the yellow packet." It is made from sucrose, but chlorine atoms are substituted for the hydrogen and oxygen normally found in sucrose, and it passes through the gastrointestinal tract unchanged, without contributing any energy. It is 600 times sweeter than sucrose and is stable when heated, so it can be used in cooking. It has been approved for use in many foods, including chewing gum, salad dressings, beverages, gelatin and pudding products, canned fruits, frozen dairy desserts, and baked goods. Studies have shown sucralose to be safe. The ADI for sucralose is 5 mg per kg body weight per day. For example, the ADI of sucralose in an adult weighing 150 pounds (or 68 kg) would be 340 mg.

**Neotame, Stevia, and Advantame**

*Neotame* is an alternative sweetener that is 7,000 times sweeter than sugar. Manufacturers use it to sweeten a variety of products, such as beverages, dairy products, frozen desserts, and chewing gums.

*Stevia* was approved as an alternative sweetener by the FDA in 2008. It is produced from a purified extract of the stevia plant, native to South America. Stevia is 200 times sweeter than sugar. It is currently used commercially to sweeten beverages and is available in powder and liquid for tabletop use. Stevia is also called Rebiana, Reb-A, Truvia, and Purevia.

*Advantame* was approved as an alternative sweetener in 2014. It is Calorie-free and 20,000 times sweeter than sugar. Although derived from aspartame, it is so much sweeter that very little is used; therefore, it is considered safe for people with phenylketonuria to consume. Advantame is used to sweeten foods such as frozen desserts, beverages, and chewing gum.

**The Effect of Alternative Sweeteners on Body Weight Is Unclear**

Although alternative sweeteners are used to reduce the energy content of various foods, their role in weight loss and weight maintenance is unclear.

[Image: A purified extract of the stevia plant, native to South America, is the source of the alternative sweetener stevia.]

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Although the popular media have recently linked drinking diet soft drinks with weight gain, a recent review concluded that there is no evidence that alternative sweeteners cause weight gain, and they may help people to lose weight.18 In addition, a recent randomized controlled trial found that participants in a behavioral weight loss program who consumed at least 24 fluid ounces per day of an artificially sweetened beverage lost more weight after 12 weeks than participants who drank only water, suggesting that alternative sweeteners can be an effective part of a weight loss program.19

However, this doesn't mean that consuming alternative sweeteners will necessarily help you maintain a healthful body weight. To prevent weight gain, you need to balance the total number of kcal you consume against the number you expend. If you're expending an average of 2,000 kcal a day and you consume about 2,000 kcal per day, then you'll neither gain nor lose weight. But if, in addition to your normal diet, you regularly indulge in "treats," you're bound to gain weight, whether they are sugar free or not. Consider the Calorie count of these artificially sweetened foods:

- One cup of nonfat chocolate frozen yogurt with artificial sweetener = 199 Calories

- One sugar-free chocolate cookie = 100 Calories

- One serving of no-sugar-added hot cocoa = 55 Calories

Does the number of Calories in these foods surprise you? *Remember, sugar free doesn't mean Calorie free.* Make it a habit to check the Nutrition Facts panel to find out how much energy is really in your food!

**[recap**

Alternative sweeteners can be used in place of sugar to sweeten foods. Most of these products do not promote tooth decay and contribute little or no energy. The alternative sweeteners approved for use in the United States are considered safe when consumed in amounts less than the Acceptable Daily Intake, an estimate of the amount of a sweetener that someone can consume each day over a lifetime without adverse effects. People with phenylketonuria should avoid foods and beverages sweetened with aspartame. Other approved sweeteners commonly used are saccharin, acesulfame-K, sucralose, neotame, stevia, and advantame. Products that are sugar free are not necessarily low in Calories; thus, consuming foods and beverages made with alternative sweeteners will not necessarily help you maintain a healthful body weight.]

## **nutri-case HANNAH**

"Last night, my mom called and said she'd be late getting home from work, so I made dinner. I made vegetarian quesadillas with flour tortillas, canned green chilies, cheese, and sour cream, plus a few baby carrots on the side. Later on while I was studying, I got really hungry, so I had some sugar-free cookies. They're sweetened with sorbitol and taste just like regular cookies! I ate maybe three or four, but I didn't think it was a big deal because they're sugar free. When I checked the package label this morning, I found out that each cookie has 90 Calories! I'm so mad at myself for blowing my diet!"

Without knowing the exact ingredients in Hannah's dinner and snack, would you agree that, prior to the cookies, she'd been making healthy choices? Why or why not? How might she have changed the ingredients in her quesadillas to increase their fiber content? And, if the cookies were sugar free, how can you explain the fact that each cookie still contained 90 Calories?

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**nutrition debate Are Added Sugars the Cause of the Obesity Epidemic?**

[Over the past 40 years, obesity rates in the United States have increased dramatically for both adults and children. At the same time, the risk for many chronic diseases, such as type 2 diabetes, cardiovascular disease, and arthritis, has also increased. We cannot blame genetics for America's rapid rise in obesity rates. Our genes have evolved over thousands of years; humans who lived even 100 years ago had a similar genetic makeup to humans today. Instead, we need to look at the effect of our lifestyle changes over the last four decades.

One lifestyle factor that has come to the forefront of obesity research is our increased consumption of added sugars.20 The *2015-2020 Dietary Guidelines for Americans* recommend limiting added sugars to less than 10% of total Calories; however, Americans currently consume about 16% of their total energy from added sugars.21 The primary source of the added sugars in our diet is sugary drinks--soft drinks, fruit drinks, energy drinks, bottled coffees and teas, and vitamin waters. It is estimated that children's intake of sugary drinks has increased threefold since the late 1970s, with approximately 10% of children's energy intake coming from these beverages.22

High-fructose corn syrup (HFCS), in particular, has garnered a great deal of attention because until recently it was the sole caloric sweetener used in sugary drinks, and was also added to many other foods and beverages in the United States. More than a decade ago, researchers linked the increased use and consumption of HFCS with the rising rates of obesity since the 1970s, when HFCS first appeared.23 HFCS is made by converting the starch in corn to glucose and then converting some of the glucose to fructose, which is sweeter. As described earlier in this chapter, fructose is metabolized differently from glucose, and these differences could affect appetite control, decrease feelings of satiety, and increase storage of body fat. The "fructose hypothesis" now dominating both the scientific and popular media proposes that fructose is associated with, and may even cause, obesity, cardiovascular disease, type 2 diabetes, and nonalcoholic fatty liver disease.24-26

The growing evidence linking the consumption of added sugars with overweight and obesity in children has led to a decline in consumption in schools and at school-sponsored events. In 2006, the beverage industry agreed to a voluntary ban on sales of all sweetened soft drinks in U.S. schools. Then, the Healthy, Hunger-Free Kids Act of 2010 required the U.S. Department of Agriculture to issue new nutrition standards for competitive foods and beverages--those sold outside of the school meals program. The new standards limited the amount of energy, salt, fat, and sugar in these products. Unfortunately, state policies regulating the availability and content of competitive foods vary. Thus, despite these positive changes, foods and beverages containing added sugars are still widely available in America's schools.

Although the evidence pinpointing added sugars and HFCS as major contributors to the obesity epidemic may appear strong, some nutrition professionals disagree. It has been proposed that soft drinks and other foods high in added sugars would have contributed to the obesity epidemic whether the sweetener was sucrose or fructose, and that their contribution to obesity is due to increased consumption as a result of advertising, increases in serving sizes, and virtually unlimited access. It is also possible that the obesity epidemic has resulted from increased consumption of energy from all sources, along with a reduction in physical activity levels, and that added sugars themselves are not to blame.

This issue is extremely complex, and more research needs to be done before we can fully understand how added sugars contribute to our diet, our weight, and our health.

**CRITICAL THINKING QUESTIONS**

1. After reading this debate, do you think added sugars in foods and beverages should be tightly regulated, or even banned? Why or why not?

2. Should reducing consumption of sugary drinks be up to individuals, or should it be encouraged via sales taxes and/or bans on promotions such as coupons, two-for-one pricing, and free refills in restaurants that would make these drinks more expensive overall? Defend your answer.

3. Make a list of your five favorite "sweet" snack foods. Using the USDA National Nutrient Database for Standard Reference (https://ndb.nal.usda.gov/), search for each of these foods and determine how much total sugar is in the amount of each snack food you would normally consume. After considering this information, do you feel you should identify alternative snack foods that are more healthful? Why or why not?

[Image: It is estimated that the rate of overweight in children has doubled since the mid-1970s.]

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**[TEST YOU**RSELF *ANSWERS*

**1 F** At 4 kcal/g, carbohydrates have less than half the energy of a gram of fat. Although eating a diet high in added sugars is associated with an increased risk for obesity, eating a diet high in complex, fiber-rich carbohydrates is associated with a decreased risk for obesity.

**2 F** Honey is nearly identical, chemically, to table sugar.

**3** **T** Contrary to recent reports claiming harmful consequences related to the consumption of alternative sweeteners, major health agencies have determined that these products are safe for most of us to consume in limited quantities.]

**review questions**

**LO 1** 1. Glucose, fructose, and galactose are

a. monosaccharides.

b. disaccharides.

c. polysaccharides.

d. complex carbohydrates.

**LO 2** **2.** Which of the following statements about carbohydrates is true?

a. Carbohydrates are our main energy source during light activity and while we are at rest.

b. Simple carbohydrates are higher in energy (kcals per gram) than complex carbohydrates.

c. Excessive intake of carbohydrates can lead to ketoacidosis.

d. Consuming a diet high in fiber-rich carbohydrates may reduce the level of cholesterol in the blood.

**LO 3 3.** Glucose not immediately needed by the body

a. is converted to cholesterol and stored in abdominal fat.

b. is converted to glycogen and stored in the liver and muscles.

c. passes into the large intestine and is fermented by bacteria.

d. All of the above are possible fates of excess glucose.

**LO 4** **4.** The glycemic index rates

a. the acceptable amount of alternative sweeteners to consume in 1 day.

b. the potential of foods to raise blood glucose and insulin levels.

c. the risk of a given food for causing diabetes.

d. the ratio of soluble to insoluble fiber in a complex carbohydrate.

**LO 5 5.** The Health and Medicine Division of the National Academies of Science recommends that adults consume

a. up to 14 grams of carbohydrate a day.

b. at least 25% of our daily energy intake as added sugars.

c. up to 65 % of our daily energy intake as carbohydrate.

d. all grains as whole grains.

**LO 5 6.** The most common source of added sugars in the American diet is

a. table sugar.

b. white flour.

c. alcohol.

d. sweetened soft drinks.

**LO 6 7.** Which of the following is a reliable source of fiber-rich carbohydrate?

a. gluten-free pasta

b. unbleached flour

c. whole-oat cereal

d. enriched 9-grain bread

**LO 7** **8.** Aspartame should not be consumed by people who have

a. phenylketonuria.

b. hypoglycemia.

c. lactose intolerance.

d. diverticulosis.

**LO 1** **9.** **True or false?** In the process of photosynthesis, plants produce glucose and store it as fiber.

**LO 4** **10.** **True or false?** Both glucagon and cortisol cause an increase in blood glucose.

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**LO 5 11.** Simon is trying to determine the minimum amount of carbohydrate he should consume in his diet to meet the AMDR for health. The total energy intake needed to maintain his current weight is 3,500 kcal per day. How many (a) kcal and (b) grams of carbohydrate should Simon consume each day?

*Answers to Review Questions and Math Review are located at the back of this text and in the MasteringNutrition Study Area.*

**web links**

**www.foodinsight.org**

Food Insight--International Food Information Council Foundation

*Search this site to find out more about sugars and low-Calorie sweeteners.*

**www.ada.org/en/**

American Dental Association

*Go to this site to learn more about tooth decay as well as other oral health topics.*

**www.choosemyplate.gov**

The USDA's MyPlate Home Page

*Click on the various food groups in MyPlate on this website to learn more about foods that are high in fiber.*

**caloriecontrol.org**

Calorie Control Council

*This site provides information about reducing energy and fat in the diet, achieving and maintaining a healthy weight, and eating various low-Calorie, reduced-fat foods and beverages.*

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# **in** **depth 4.5** **Diabetes**

***After studying this In Depth, you should be able to:***

**1** Define diabetes and explain how it damages cells and tissues, p. 131.

**2** Distinguish between type 1 diabetes, type 2 diabetes, and prediabetes, pp. 132-134.

**3** Identify the risk factors for type 2 diabetes and the lifestyle choices that can help you reduce that risk, pp. 134-137.]

**In 2012, the most recent year for which statistics are available, about 1.7 million Americans were newly diagnosed with diabetes.**1 Despite the image of diabetes as a disease of aging, these diagnoses weren't limited to the elderly: an estimated 24,000 were in children and adolescents, and another 371,000 were in adults younger than age 45.

Patients with diabetes have two to four times the risk for heart disease and stroke seen in people without the disease. Moreover, nearly half the cases of kidney failure as well as the majority of amputations and new cases of blindness occur among people with diabetes.1 These complications typically develop about 10 to 15 years after the onset of the disease, and until recently, were almost exclusively seen in people over age 60. Now, as more and more children and adolescents are being diagnosed with diabetes, these complications are increasingly affecting young adults.1

What is diabetes, and how does it lead to kidney failure, blindness, and death? Why are diagnoses soaring, especially among young people? Can you reduce your risk? In this **In Depth** essay, we explore these questions.

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## **What is diabetes?**

**LO 1** Define diabetes and explain how it damages cells and tissues.

Diabetes is a chronic disease in which the body can no longer regulate glucose within normal limits. As a result, **hyperglycemia**--a condition in which the level of glucose in the blood is abnormally high--becomes chronic. It is imperative to detect and treat the disease as soon as possible because, as we explain shortly, hyperglycemia injures tissues throughout the body.

Approximately 29.1 million people in the United States--9.3% of the total population, including adults and children--live with diabetes. Of these, 21 million have been diagnosed, and it is speculated that another 8.1 million have diabetes but do not know it.1 **FIGURE 1** shows the percentage of adults with diabetes from various ethnic groups in the United States. As you can see, diabetes is much more common in American Indians/Alaska Natives than in members of other ethnic and racial groups.2

Diabetes causes disease when chronic exposure to elevated blood glucose levels damages the body's blood vessels, and this in turn damages other body tissues. As the concentration of glucose in the blood increases, a shift in the body's chemical balance allows glucose to attach to certain body proteins, including ones that make up blood vessels. Glucose coats these proteins like a sticky glaze, causing damage and dysfunction.

**[FIGURE 1** The percentage of adults from various ethnic and racial groups with type 2 diabetes.

Data from: Blackwell, D. L, *I.* W. Lucas, and T. C. Clarke. 2014. Summary Health Statistics for U.S. Adults: National Health Interview Survey, 2012. National Center for Health Statistics. *Vital and Health Stat.* 10(260).]

**[FIGURE 2** Amputations are a common complication of uncontrolled diabetes.]

Damage to large blood vessels results in problems referred to as *macrovascular complications.* These include cardiovascular disease, which occurs because damage to artery walls allows fatty plaque to accumulate and narrow or block the vessels.

Damage to small blood vessels results in *microvascular complications.* For example, the kidneys' microscopic blood vessels, which filter blood and produce urine, become thickened. This impairs their function and can lead to kidney failure. Blood vessels that serve the eyes can swell and leak, leading to blindness.

When blood vessels that supply nutrients and oxygen to nerves are affected, *neuropathy,* damage to the nerves, can also occur. This condition leads to a loss of sensation, most commonly in the hands and feet. At the same time, circulation to the limbs is reduced overall. Together, these changes increase the risk of injury, infection, and tissue death (necrosis), leading to a greatly increased number of toe, foot, and lower leg amputations in people with diabetes **(FIGURE 2).**

Because uncontrolled diabetes impairs carbohydrate metabolism, the body begins to break down stored fat, producing ketones for fuel. A buildup of excessive ketones can lead to ketoacidosis, a condition in which the brain cells do not get enough glucose to function properly. The person will become confused and lethargic and have trouble breathing. If left unchecked, ketoacidosis may result in coma and death. Indeed, as a result of cardiovascular disease, kidney failure, ketoacidosis, and other complications, diabetes is the seventh leading cause of death in the United States.3

[Watch any of several videos on diabetic eye diseases at **https://nei.nih.gov/youtube/ded/.]**

[Sidebar: **diabetes** A chronic disease in which the body can no longer regulate glucose normally.]

[Sidebar: **hyperglycemia** A condition in which blood glucose levels are higher than normal.]

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## **How is diabetes classified?**

**LO 2** Distinguish between type 1 diabetes, type 2 diabetes, and prediabetes.

The two main forms of diabetes are type 1 and type 2. Some women develop a third form, *gestational diabetes,* during pregnancy (see Chapter 14). See **FOCUS FIGURE 3** for an overview of the processes involved in type 1 and type 2 diabetes.

**In Type 1 Diabetes, the Body Does Not Produce Enough Insulin**

Approximately 5 % of people with diabetes have **type 1 diabetes,** in which the body cannot produce enough insulin.1 Most cases are diagnosed in adolescents around 10 to 14 years of age, although the disease can appear in infants, young children, and adults. It has a genetic link, so siblings and children of those with type 1 diabetes are at greater risk.4

When people with type 1 diabetes eat a meal and their blood glucose rises, the pancreas is unable to secrete insulin in response. Glucose therefore cannot move into body cells and remains in the bloodstream. The kidneys try to expel the excess blood glucose by excreting it in the urine. In fact, the medical term for the disease is *diabetes mellitus* (from the Greek *diabainein,* "to pass through," and Latin *mellitus,* "sweetened with honey"), and frequent urination is one of its warning signs (see TABLE 1 for other symptoms). If blood glucose levels are not controlled, a person with type 1 diabetes can develop potentially fatal ketoacidosis.

Type 1 diabetes is classified as an *autoimmune disease.* This means that the body's immune system attacks and destroys its own tissues--in this case, the insulin-producing beta cells of the pancreas.4

**TABLE 1 Symptoms of Type 1 and Type 2 Diabetes**

|  |  |
| --- | --- |
| **Type 1 Diabetes** | **Type 2 Diabetes\*** |
| Increased or frequent urination | Any of the type 1 signs and symptoms |
| Excessive thirst | Greater frequency of infections |
| Constant hunger | Sudden vision changes |
| Unexplained weight loss | Slow healing of wounds or sores |
| Extreme fatigue | Tingling or numbness in the hands or feet |
| Blurred vision | Very dry skin |

\*Some people with type 2 diabetes experience no symptoms.

Data adapted from: U.S. Dept. of Health and Human Services, National Diabetes Information Clearinghouse (NDIC). Available at http://www.niddk. nih.gov/health-information/health-topics/Diabetes/your-guide-diabetes/Pages/index.aspx#signs and from the Centers for Disease Control and Prevention, Basics about Diabetes, available at http://www.cdc.gov/diabetes/ basics/diabetes.html.

By the late 19th century, scientists had discovered that some type of abnormality of the pancreas triggered diabetes. Experiments had shown that, without a pancreas, an otherwise healthy animal would develop the disease quickly. Still, no one knew how to treat diabetes: nutritional therapies ranged from low-carbohydrate diets to starvation. For children, a diagnosis of diabetes was essentially a death sentence.

Then, in 1921, Canadian surgeon Frederick Banting had an idea. He and his medical assistant removed the pancreas from a dog, thereby inducing diabetes. They then injected the diabetic dog with secretions extracted from the pancreatic islets (or *islets of Langerhans),* which are clusters of hormone-secreting cells, including beta cells, in the pancreas. They called their extraction *isletin.* A few injections of isletin a day cured the dog of diabetes. They then purified the substance--which we now call insulin--and repeated their experiment several times before trying it on a 14-year-old boy dying of diabetes. The injections reversed all signs of the disease in the boy. Banting published a paper on his research in 1922 and received a Nobel Prize the following year.

To this day, the only treatment for type 1 diabetes is the administration of insulin by injection or pump several times daily. Insulin is a hormone composed of protein, so it would be digested in the intestine if taken as a pill. Individuals with type 1 diabetes must also monitor their blood glucose levels closely to ensure that they remain within a healthful range **(FIGURE 4** on page 134).

**In Type 2 Diabetes, Cells Become Less Responsive to Insulin**

In **type 2 diabetes,** body cells become resistant (less responsive) to insulin. This type of diabetes develops progressively, meaning that the biological changes resulting in the disease occur over a long period. Approximately 90% to 95% of all cases of diabetes are classified as type 2.1

Obesity is the most common trigger for a cascade of changes that eventually results in this disorder. It is estimated that 80% to 90% of people with type 2 diabetes are overweight or obese. One factor linking obesity to diabetes is the inappropriate accumulation of lipids in muscle cells, liver cells, and the beta cells of the pancreas, which reduces the ability of these cells to respond to insulin. That is, in many obese people, the muscle, liver, and pancreatic cells begin to exhibit **insulin insensitivity** (also called *insulin resistance).*

[Sidebar: **type** **1 diabetes** A disorder in which the body cannot produce enough insulin.]

[Sidebar: **type 2 diabetes** A progressive disorder in which body cells become less responsive to insulin.]

[Sidebar: **insulin insensitivity** *(insulin resistance)* A condition in which the body becomes less sensitive (or more resistant) to a given amount of insulin, resulting in insulin having a biological effect that is less than expected.]

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**focus figure 3 Diabetes**

Diabetes is a chronic disease in which the body can no longer regulate glucose within normal limits, and blood glucose becomes dangerously high.

**NORMAL**

**1** Liver releases glucose into bloodstream.

**2** Beta cells of pancreas release insulin into bloodstream.

**3** Insulin stimulates glucose transporters within cells to travel to the cell membrane and prompt the uptake of glucose into cells.

**4** As glucose is taken into interior of cells, less glucose remains in bloodstream.

[Image Removed]

**TYPE 1 DIABETES**

**1** Liver releases glucose into bloodstream.

**2** Beta cells of pancreas are damaged or destroyed. Little or no insulin is released into bloodstream.

**3** In the absence of insulin, glucose is not taken up by cells.

**4** High levels of glucose remain in the bloodstream.

[Image Removed]

**TYPE 2 DIABETES**

**1** Liver releases glucose into bloodstream.

**2** Beta cells of pancreas release insulin into bloodstream.

**3** Insulin is present, but cells fail to respond adequately. Progressively higher amounts of insulin must be produced by the pancreas to stimulate cells to uptake glucose.

**4** High levels of glucose remain in the bloodstream.

[Image Removed]

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**[FIGURE 4** Monitoring blood glucose usually requires pricking the fingers and measuring the blood using a glucometer multiple times each day.]

The pancreas attempts to compensate for this insensitivity by secreting more insulin. At first, the increased secretion is sufficient to maintain normal blood glucose levels. However, over time, a person who is insulin insensitive will have to circulate very high levels of insulin to use glucose for energy. Eventually, this excessive production becomes insufficient for preventing a persistently high level of blood glucose, even when the individual has not recently consumed carbohydrate. The resulting condition is referred to as **impaired fasting glucose**, meaning glucose levels are persistently higher than normal but not high enough to indicate a diagnosis of type 2 diabetes. Health care providers typically refer to this condition as **prediabetes**, because people with impaired fasting glucose are more likely to develop type 2 diabetes than people with normal fasting blood glucose levels. Ultimately, the pancreas becomes incapable of secreting these excessive amounts of insulin and stops producing the hormone altogether.

In short, in type 2 diabetes, blood glucose levels may be elevated because (1) the person has developed insulin insensitivity, (2) the pancreas can no longer secrete enough insulin, or (3) the pancreas has entirely stopped insulin production.

**Three Blood Tests Are Used to Diagnose Diabetes**

Diabetes is diagnosed when two or more tests of a person's blood glucose indicate values in the clinically defined range. Three tests currently used to diagnose diabetes and prediabetes include the following **(FIGURE 5):**

- The fasting plasma glucose (FPG) test measures blood glucose in a person who has been fasting for at least

8 hours. It is a common and inexpensive test.

- The oral glucose tolerance (OGT) test is more reliable than the FPG test, but less convenient. It requires the person to fast for at least 8 hours, and then to drink a glucose solution. After two hours, blood is drawn and the glucose level measured.

- The glycosylated hemoglobin test (abbreviated HbA1c, or simply A1c) provides information about a person's average blood glucose levels over the previous three months.

## **How can you reduce your risk for type 2 diabetes?**

**LO 3** Identify the risk factors for type 2 diabetes and the lifestyle choices that can help you reduce that risk.

Certain factors significantly increase your risk for diabetes. Some of these are not modifiable, but others are within your power to change. Let's have a look.

[Sidebar: **impaired fasting glucose** Fasting blood glucose levels that are higher than normal but not high enough to lead to a diagnosis of type 2 diabetes.]

[Sidebar: **prediabetes** A term used synonymously with *impaired fasting glucose;* it is a condition considered to be a major risk factor for both type 2 diabetes and heart disease.]

|  |  |  |  |
| --- | --- | --- | --- |
| **Diagnosis** | **Fasting Plasma**  **Glucose**  **(mg/dL)** | **Oral Glucose Tolerance Test (mg/dL)** | **A1C**  **(percent)** |
| **Diabetes** | 126 or above | 200 or above | 6.5 or above |
| **Prediabetes** | 100 to 125 | 140 to 199 | 5.7 to 6.4 |
| **Normal** | 99 or below | 139 or below | About 5 |

Definitions: mg = milligram, dL = deciliter

For all three tests, within the prediabetes range, the higher the test result, the greater the risk of diabetes.

**[FIGURE 5** Blood test levels for diagnosing diabetes and prediabetes according to the fasting plasma glucose, oral glucose tolerance, and HbA1c tests.]

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**Some Diabetes Risk Factors Are Modifiable**

Increased age is a significant risk factor for type 2 diabetes: most cases develop after age 45, and 26% of Americans 65 years and older have diabetes.1 In fact, type 2 diabetes used to be referred to as *adult-onset diabetes* because it was virtually unheard of in children and adolescents until about 20 years ago. Unfortunately, the prevalence of the disease in young people has been increasing dramatically. In the United States, about 208,000 people younger than 20 years of age are estimated to have diagnosed diabetes, which is about 0.25% of that population group.1

A family history of type 2 diabetes increases your own risk. Your race/ethnicity is another significant influence: Among Native Americans age 20 or older, the prevalence of diabetes is more than double that of Caucasian Americans (see Figure 1). African Americans, Hispanic Americans, and Asian Americans also have an increased prevalence of diabetes as compared to Caucasian Americans.

In addition, a cluster of potentially modifiable risk factors referred to as the *metabolic syndrome* is known to increase the risk for type 2 diabetes. The criteria for metabolic syndrome include:

- Abdominal obesity; that is, a waist circumference greater than 88 cm (35 in.) for women and 102 cm (40 in.) for men

- Elevated blood pressure

- Elevated blood glucose (FPG 110 mg/dL or higher)

- Unhealthful levels of certain blood lipids (identified in the In Depth essay following Chapter 5).

[Image: Actor Tom Hanks has type 2 diabetes.]

Because these criteria for metabolic syndrome can be reduced significantly by following a healthful eating pattern and engaging in regular physical activity, they are modifiable.

**Lifestyle Changes Can Reduce Your Risk**

Type 2 diabetes is thought to have become an epidemic in the United States because of a combination of an aging population and our increased rates of obesity. We can't control our age, but we can and do control how much and what types of foods we eat and how much physical activity we engage in--and that, in turn, influences our risk for obesity. Currently, about 35% of American college students are either overweight or obese.5

Dietary changes specifically recommended to reduce your risk for type 2 diabetes include the following:

- Limit your intake of added sugars. A recent study examining the influence of availability of sugar on type 2 diabetes risk in 175 countries found that for every 150 kcal per person per day of sugar availability (which is equivalent to approximately one 12-ounce soft drink), the prevalence of type 2 diabetes increased by 1.1%.6 This increase was independent of levels of overweight and obesity.

- Choose fiber-rich whole grains and whole-grain products in place of refined and processed carbohydrate foods. The evidence is strong that consuming a dietary pattern rich in fiber and whole grains is protective against type 2 diabetes, while a dietary pattern high in refined grains and processed carbohydrates increases type 2 diabetes risk.7,8

- Limit your consumption of red meats and processed meats. Overall, an increased intake of red and processed meats is associated with an elevated risk for type 2 diabetes.9 Moreover, a study examining changes in intake of red meat over a 4-year period found that increasing red meat consumption by more than half a serving size was associated with a 48% elevated risk for type 2 diabetes.10 Correspondingly, the study found that a reduction of at least half a serving size of red meat was associated with a 14% decreased risk for type 2 diabetes.

Although adopting a healthful diet is important, moderate daily exercise may prevent the onset of type 2 diabetes more effectively than dietary changes alone.

[To calculate your current level of risk for type 2 diabetes, go to **www.diabetes.org.** Enter "diabetes risk test" into the search bar, then click on the link to the test.]

[To download a family history tree that you can fill out to determine your family history of diabetes, visit **www.heart.org.** Enter "my family health tree" into the search box, and then click on the link that appears.]

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In a recent study, researchers followed more than 1.5 million young men over 26 years and found that those who were defined as unfit (according to their muscle strength and aerobic capacity) at 18 years of age were three times more likely to develop type 2 diabetes by 44 years of age as compared to men who were defined as fit at 18 years of age.11 This higher risk was observed regardless of the person's body weight and family history of type 2 diabetes. Exercise will also assist in weight loss, and studies show that losing only 10 to 30 pounds can reduce or eliminate the symptoms of type 2 diabetes.12 (See Chapter 11 for examples of moderate exercise programs.)

Avoiding or stopping smoking can also reduce a person's risk for type 2 diabetes. Evidence indicates that smokers are 30% to 40% more likely to develop type 2 diabetes than nonsmokers, and people with type 2 diabetes who smoke have greater difficulty controlling their disease than nonsmokers with type 2 diabetes.13

In summary, by eating a healthy diet, staying active, maintaining a healthful body weight, and avoiding smoking, you should be able to keep your risk for type 2 diabetes low.

**Dietary Counseling Can Help People Living with Diabetes**

What if you've already been diagnosed with type 2 diabetes? The Academy of Nutrition and Dietetics emphasizes that there is no *single* diet or eating plan for people with diabetes. You should follow a healthful eating pattern just as you would to reduce your risk for heart disease, cancer, and obesity. One difference is that you may need to eat fewer carbohydrates and slightly more fat or protein to help regulate your blood glucose levels. Carbohydrates are still an important part of the diet, so, if you're eating less, make sure your choices are rich in micronutrients and fiber. Because precise nutritional recommendations vary according to each individual's responses to foods, consulting with a registered dietitian/ nutritionist is essential.

The Academy of Nutrition and Dietetics identifies the following basic strategies for eating more healthfully while living with diabetes:14

- Eat meals and snacks regularly and at planned times throughout the day.

- Try to eat about the same amount and types of food at each meal or snack.

- Follow the Dietary Guidelines for Americans or the USDA Food Patterns to guide your food choices (see Chapter 2).

- Seek the expert advice of a registered dietitian/nutritionist to assist you with carbohydrate counting and using the exchange system.

## **nutri-case JUDY**

"My daughter, Hannah, has been pestering me about changing how we eat and getting more exercise. She says she's just trying to lose weight, but ever since we found out I have type 2 diabetes I know she's been worried about me. What I didn't get until last night is that she's worried about herself, too. All through dinner she was real quiet; then all of a sudden she says, 'Mom, I had my blood sugar tested at the health center, and guess what? They said I have prediabetes.' She said that's kind of like the first step toward diabetes and that, if she doesn't make some serious changes, she'll end up just like me. So I guess we both need to change some things. Trouble is, I don't really know where to start."

Are you surprised to learn that Hannah has prediabetes? What are her risk factors? Given what you know about Judy's and Hannah's lifestyle, what kind of small changes could both mother and daughter make immediately to start addressing their high blood glucose levels?

In addition, people with diabetes should avoid alcoholic beverages, which can cause hypoglycemia, a drop in blood glucose that can cause confusion, clumsiness, and fainting. If left untreated, this can lead to seizures, coma, and death. The symptoms of alcohol intoxication and hypoglycemia are very similar. People with diabetes, their companions, and even healthcare providers may confuse these conditions; this can result in a potentially life-threatening situation.

**Prescription Medications or Surgery May Be Advised**

When blood glucose levels can't be adequately controlled with lifestyle changes, oral medications may be required. The prescription medication most commonly prescribed is metformin. It works both by increasing body cells' sensitivity to insulin and by reducing the amount of glucose the liver produces. Possible side effects include nausea and diarrhea, but these typically resolve as the body adapts to the drug. Two other classes of medications (sulfonylureas and meglitinides) work by stimulating the pancreas to increase its secretion of insulin. These medications are less often prescribed because blood glucose can drop too low, and weight gain is a possible side effect.

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Another group of medications (GLP-1 receptor agonists) work by slowing digestion, and can actually contribute to weight loss. Finally, a new class of medications (SGLT2 inhibitors) works by increasing the body's excretion of glucose in the urine. If both lifestyle changes and prescription medications cannot adequately control blood glucose, then people with type 2 diabetes must have daily insulin injections, just like people with type 1 diabetes.

**web links**

**www.eatright.org**

Academy of Nutrition and Dietetics

*Visit this website to learn more about diabetes, low- and high-carbohydrate diets, and healthy eating guidance for people with diabetes.*

**www.diabetes.org**

American Diabetes Association

*Find out more about the nutritional needs of people living with diabetes.*

**www.niddk.nih.gov**

National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)

*Learn more about diabetes, including treatment, complications, U.S. statistics, clinical trials, recent research, and the National Diabetes Education Program.*

**www.cdc.gov/diabetes/home/**

Centers for Disease Control and Prevention (CDC)

*Explore the latest research and statistics about diabetes, find out if you are at risk, and learn about the National Diabetes Prevention Program.*

**www.joslin.org/**

Joslin Diabetes Center

*Learn more about type 1 diabetes and the latest research regarding treatments and a potential cure.*

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**[test yourself**

**1.** **T F** Some fats are essential for good health.

**2.** **T F** Fat is a primary source of energy during exercise.

**3.** **T F** Fried foods are relatively nutritious as long as vegetable shortening is used to fry the foods.

*Test Yourself answers are located in the Study Plan at the end of this chapter.*]

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# **CHAPTER 5** **Fats Essential energy-supplying nutrients**

***After studying this chapter you should be able to:***

**1** Distinguish between triglycerides, phospholipids, and sterols, pp. 140-142.

**2** Compare and contrast types of triglycerides, explaining why some are more healthful than others, pp. 142-147.

**3** Identify five functions of fat, pp. 147-150.

**4** Describe the steps involved in fat digestion, absorption, and transport, pp. 150-154.

**5** Identify the DRIs for fats and common food sources of unhealthful and beneficial fats, pp. 154-163.]

**Wyatt and John are sharing an apartment off-campus this year and often shop for groceries together.** They don't always agree on what to buy, however: Wyatt describes himself as a "health freak," whereas John is a "meat and potatoes" guy. At the market this evening, John said he was too tired to fix a meal from scratch, and suggested picking up some prepared ribs and potato salad from the deli. Wyatt said no way--ribs were loaded with saturated fat! He'd compromise on the potato salad if John would agree to have it with chicken or fish--and a green vegetable on the side. "Fine with me," John laughed, "but you're cooking it!"

Is saturated fat really such a menace? If so, why? What is saturated fat, anyway? And are other types of fat--*trans* fats, for instance--just as bad?

Although some people think that all dietary fat should be avoided, a certain amount of fat is essential for life and health. In fact, consuming adequate amounts of certain healthful fats can reduce your risk for cardiovascular disease. In this chapter, we'll explore several types of dietary fat and discuss their critical functions in the human body. We'll also identify changes you can make to shift your diet toward more healthful fats. The role of dietary fats in cardiovascular disease is discussed in the **In Depth** essay following this chapter.

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**LO 1** Distinguish between triglycerides, phospholipids, and sterols.

## **What are fats?**

Fats are just one form of a much larger and more diverse group of organic substances called **lipids,** which are distinguished by the fact that they are insoluble in water. Think of a salad dressing made with vinegar, which is mostly water, and olive oil, which is a lipid. Shaking the bottle *disperses* the oil but doesn't *dissolve* it: that's why it separates back out again so quickly. Lipids are found in all sorts of living things, from bacteria to plants to human beings. In fact, their presence on your skin explains why you can't clean your face with water alone: you need some type of soap to break down the insoluble lipids before you can wash them away. In this chapter, we focus on the small group of lipids that are found in foods.

We can distinguish two different types of food lipids according to their state at room temperature: Fats, such as butter, are solid at room temperature, whereas oils, such as olive oil, are liquid. Because most people are familiar with the term *fats,* we will use that term generically throughout this book, including when referring to oils. We can also distinguish three types of food lipids according to their chemical structure. These are triglycerides, phospholipids, and sterols. Let's take a look at each.

**Triglycerides Are the Most Common Food-Based Fat**

About 95% of the fat we eat is in the form of triglycerides (also called *triacylglycerols).* As reflected in the prefix *tri-,* a **triglyceride** is a molecule consisting of *three* fatty acids attached to a *three*-carbon glycerol backbone. **Fatty acids** are long chains of carbon atoms bound to each other as well as to hydrogen atoms. They are acids because they contain an acid group (carboxyl group) at one end of their chain. **Glycerol,** the backbone of a triglyceride molecule, is an alcohol composed of three carbon atoms. One fatty acid attaches to each of these three carbons to make the triglyceride **(FIGURE 5.1).**

Triglycerides are not only the most common form of fat in our diet, but also the form in which most of our body fat is stored. Body fat, clinically referred to as *adipose tissue* from the Latin root *adip-* meaning fat, is not inert. Rather, it is a metabolically active tissue that can contribute to or reduce our health. (We discuss the influence of body fat on health later in this chapter.)

**[FIGURE 5.1** A triglyceride consists of three fatty acids attached to a three-carbon glycerol backbone.]

[Image: Some fats, such as olive oil, are liquid at room temperature.]

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**Phospholipids Combine Lipids with Phosphate**

**Phospholipids** are found in a limited number of foods, including egg yolks, liver, peanuts, soybeans, and some processed foods. They consist of two fatty acids and a glycerol backbone bound to another compound that contains phosphate **(FIGURE 5.2).** This addition of a phosphate compound makes phospholipids soluble in water, a property that enables phospholipids to assist in transporting fats in our bloodstream. Also, phospholipids in our cell membranes regulate the transport of substances into and out of the cell. Phospholipids also help with the digestion of dietary fats: the liver uses phospholipids called *lecithins* to make bile. The body manufactures phospholipids, so they are not essential nutrients. What *is* essential is phosphorus, a mineral that combines with oxygen to make phosphate.

**Sterols Have a Ring Structure**

**Sterols** are lipids with a multiple-ring structure **(FIGURE 5.3a).** They are found in both animal and plant foods and are produced in the body.

Cholesterol is the most commonly occurring sterol in the diet (see Figure 5.3b). It is found only in the fatty part of animal products such as butter, egg yolks, whole milk, meats, and poultry. Low- or reduced-fat animal products, such as lean meats and skim milk, have little cholesterol.

We don't need to consume cholesterol in our diet because our body continually synthesizes it, mostly in the liver and intestines. This continuous production is essential because cholesterol is part of every cell membrane, where it works in conjunction with fatty acids to help maintain cell membrane integrity. It is particularly plentiful in the neural cells that make up our brain, spinal cord, and nerves. The body also uses cholesterol to synthesize several important compounds, including sex hormones (estrogen, androgen, and progesterone), bile, adrenal hormones, and vitamin D. Given these important functions of cholesterol, you might be wondering why it has such a bad reputation. The answer is that a high level of cholesterol circulating in the blood is associated with cardiovascular disease, the subject of the **In Depth** essay following this chapter.

As just noted, plants also contain some sterols. Plant sterols are not very well absorbed; nevertheless, they may confer a health benefit because they appear to block the absorption of dietary cholesterol. Nuts are especially rich in plant sterols.

**[recap**

Fats and oils are two forms of lipids, compounds that are insoluble in water. Three types of lipids are found in foods and in the body. These are triglycerides, phospholipids, and sterols. Triglycerides are the most common. A triglyceride is made up of a glycerol backbone and three fatty acids. Phospholipids combine two fatty acids and a glycerol backbone with a phosphate-containing compound, making them soluble in water.]

**[FIGURE 5.2** Structure of a phospholipid. Phospholipids consist of a glycerol backbone with two fatty acids and a compound that contains phosphate.]

**[FIGURE 5.3** Sterol structure. **(a)** Sterols are lipids that contain multiple-ring structures. **(b)** Cholesterol is the most commonly occurring sterol in our diets.]

[Sidebar: **lipids** A diverse group of organic substances that are insoluble in water; lipids include triglycerides, phospholipids, and sterols.]

[Sidebar: **triglyceride** A molecule consisting of three fatty acids attached to a three-carbon glycerol backbone.]

[Sidebar: **fatty acids** Long chains of carbon atoms bound to each other as well as to hydrogen atoms.]

[Sidebar: **glycerol** An alcohol composed of three carbon atoms; it is the backbone of a triglyceride molecule.]

[Sidebar: **phospholipid** A type of lipid in which a fatty acid is combined with another compound that contains phosphate; unlike other lipids, phospholipids are soluble in water.]

[Sidebar: **sterol** A type of lipid found in foods and the body that has a ring structure; cholesterol is the most common sterol in our diets.]

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[Sterols have a multiple-ring structure. Cholesterol is the most commonly occurring sterol in our diet, and is used by the body to build many essential compounds. Cholesterol is found only in animal-based foods. Plant foods provide plant sterols.]

**LO 2** Compare and contrast types of triglycerides, explaining why some are more healthful than others.

## **Why are some triglycerides better than others?**

Now that you know how triglycerides differ from phospholipids and sterols, let's compare the various types of triglycerides to find out why some are better than others. In general, triglycerides can be classified by:

- their chain length, which is the number of carbons in each fatty acid.

- their level of saturation; that is, how much hydrogen, H, is attached to each carbon atom in the fatty acid chain.

- their shape, which is determined in some cases by how they are commercially processed.

All of these factors influence how the body uses triglycerides.

**Fatty Acid Chain Length Affects Digestion and Absorption**

The fatty acids attached to the glycerol backbone can vary in the number of carbons they contain, referred to as their *chain length.*

- Short-chain fatty acids are usually fewer than 6 carbon atoms in length.

- Medium-chain fatty acids are 6 to 12 carbons in length.

- Long-chain fatty acids are 14 or more carbons in length.

Fatty acid chain length determines how the fat is digested, absorbed, and transported in the body. For example, short- and medium-chain fatty acids are digested and absorbed more quickly than long-chain fatty acids. We discuss the digestion, absorption, and transport of fats in more detail later in this chapter.

**Level of Hydrogen Saturation Influences Health Effects**

Triglycerides can also vary by their level of saturation, which is determined by the types of bonds found in the fatty acid chains. **FIGURE 5.4** shows two types of carbon bonds found in fatty acid chains. Notice that the central carbon can bond with single bonds to two hydrogens and two other carbons (Figure 5.4a). Alternatively, the central carbon can bond with single bonds to one hydrogen and a second carbon, and with a double bond to a third carbon (Figure 5.4b).

If a fatty acid chain has no carbons bonded together with a double bond, it is referred to as a **saturated fatty acid (SFA).** This is because every carbon atom in the chain is *saturated* with hydrogen: each has the maximum amount of hydrogen bound to it. The fatty acid chain in Figure 5.1 is saturated, as is the one in the top row of **FIGURE 5.5a,** which looks a bit different because it's represented with a more succinct chemical formula. Some foods that are high in saturated fatty acids are coconut oil, palm oil, palm kernel oil, butter, cream, whole milk, lard, and beef.

If, within the chain of carbon atoms, two carbons are bound to each other with a double bond, then this double carbon bond excludes hydrogen. This lack of hydrogen at *one* part of the molecule results in a fat that is referred to as *monounsaturated* (recall from Chapter 4 that the prefix *mono-* means "one"). A **monounsaturated fatty acid (MUFA)** is usually liquid at room temperature (see the middle row of Figure 5.5a).

[Learn more about plant sterols and how to incorporate them into your diet at **www.webmd.com.** Type "plant sterols" in the search bar to get underway.]

**[FIGURE 5.4** An atom of carbon has four attachment sites. In fatty acid chains, two of these sites are filled by adjacent carbon atoms. **(a)** In saturated fatty acids, the other two sites are always filled by two hydrogen atoms. **(b)** In unsaturated fatty acids, at one or more points along the chain, a double bond to an adjacent carbon atom takes up one of the attachment sites that would otherwise be filled by hydrogen.]

[Sidebar: **saturated fatty acid (SFA)** A fatty acid that has no carbons joined together with a double bond; SFAs are generally solid at room temperature.]

[Sidebar: **monounsaturated fatty acid (MUFA)** A fatty acid that has two carbons in the chain bound to each other with one double bond; MUFAs are generally liquid at room temperature.]

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[**FIGURE 5.5** Examples of levels of saturation among fatty acids and how these levels of saturation affect the shape of fatty acids. **(a)** Saturated fatty acids are saturated with hydrogen, meaning they have no carbons bonded together with a double bond. Monounsaturated fatty acids contain two carbons bound by one double bond. Polyunsaturated fatty acids have more than one double bond linking carbon atoms. **(b)** Saturated fats have straight fatty acids packed tightly together and are solid at room temperature. **(c)** Unsaturated fats have "kinked" fatty acids at the area of the double bond, preventing them from packing tightly together; they are liquid at room temperature.]

Foods that are high in MUFAs are olive oil, canola oil, and cashew nuts.

If the fat molecule has *more than one* double bond, it contains even less hydrogen and is referred to as a **polyunsaturated fatty acid (PUFA)** (see the bottom row of Figure 5.5a). Polyunsaturated fatty acids are also liquid at room temperature. Canola, com, and safflower oils are rich in PUFAs.

Although foods vary in the types of fatty acids they contain, in general we can say that animal-based foods tend to be high in saturated fats and plant foods tend to be high in unsaturated fats. Specifically, animal fats provide approximately 40-60 % of their energy from saturated fats, whereas plant fats provide 80-90% of their energy from monounsaturated and polyunsaturated fats. Most oils are a good source of both MUFAs and PUFAs. **FIGURE 5.6** on page 144 compares the percentages of the different types of fats in a variety of foods.

In general, saturated fats have a detrimental effect on our health, whereas unsaturated fats are protective. It makes sense, therefore, that diets high in plant foods--because they're low in saturated fats--are more healthful than diets high in animal products. We discuss the influence of various types of fatty acids on your risk for cardiovascular disease in the **In Depth** essay immediately following this chapter.

**Carbon Bonding Influences Shape**

Have you ever noticed how many toothpicks are packed into a small box? A hundred or more! But if you were to break a bunch of toothpicks into V shapes anywhere along their length, how many could you then fit into the same box? It would be very few because the bent toothpicks would jumble together, taking up much more space.

[Sidebar: **polyunsaturated fatty acid (PUFA)** A fatty acid that has more than one double bond in the chain; PUFAs are generally liquid at room temperature.]

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[**FIGURE 5.6** Major sources of dietary fat.]

Molecules of saturated fat are like straight toothpicks: they have no double carbon bonds and always form straight, rigid chains. Because they have no kinks, these chains can pack together tightly (see Figure 5.5b). That is why saturated fats, such as the fat in meats, are solid at room temperature.

In contrast, each double carbon bond of unsaturated fats gives them a kink along their length (see Figure 5.5c). This means that they're unable to pack together tightly--for example, to form a stick of butter--and instead are liquid at room temperature.

Unsaturated fatty acids are kinked when they occur naturally, but they can be manipulated by food manufacturers to create a straight fatty acid called a *trans* fat. Let's take a look at this process.

***Trans*** Fatty Acids Are Especially Harmful

Unsaturated fatty acids can occur in either a *cis* or a *trans* shape. The prefix *cis-*means things are located on the same side or near each other, whereas *trans-* is a prefix that denotes across or opposite. These terms describe the positioning of the hydrogen atoms around the double carbon bond as follows:

- A *cis fatty acid* has both hydrogen atoms located on the same side of the double bond **(FIGURE 5.7a).** This positioning gives the *cis* molecule a pronounced kink at the double carbon bond. We typically find the *cis* fatty acids in nature and, thus, in whole foods.

- In a *trans* *fatty acid,* the hydrogen atoms are attached on diagonally opposite sides of the double carbon bond (see Figure 5.7b). This positioning makes the fatty acid straighter and more rigid, just like saturated fats. Thus, *"trans* fats" is a collective term used to define fats with *trans* double bonds. Although *trans* fatty acids occur in limited amounts in cow's milk and meat, the majority of *trans* fatty acids in foods are produced by manipulating the fatty acids during food processing.

This process, called **hydrogenation**, was developed in the early 1900s to produce a type of cheap fat that could be stored in a solid form and would resist rancidity.

[Sidebar: **hydrogenation** The process of adding hydrogen to unsaturated fatty acids, making them more saturated and thereby more solid at room temperature.]

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[**FIGURE 5.7** Structure of **(a)** a cis and **(b)** a *trans* polyunsaturated fatty acid. Notice that cis fatty acids have both hydrogen atoms located on the same side of the double bond. This positioning makes the molecule kinked. In the *trans* fatty acids, the hydrogen atoms are attached on diagonally opposite sides of the double carbon bond. This positioning makes them straighter and more rigid.]

During hydrogenation, pressurized hydrogen is added directly to unsaturated fatty acids, such as those found in corn and safflower oils. This alters the arrangement of their double bonds and thereby straightens the fatty acid chains. The degree of hydrogenation can make an oil more or less saturated, resulting in a *partially hydrogenated oil (PHO).*

The *Dietary Guidelines for Americans* suggest that you keep your *trans* fat intake as low as possible. This recommendation is grounded in an overwhelming body of evidence associating *trans* fats with an increased risk for cardiovascular disease. In fact, *trans* fats are considered the most harmful fat for your health.

Be aware that products labeled as having "zero" *trans* fats can still contain *trans fatty* acids! That's because the U.S. Food and Drug Administration (FDA) allows products that have less than 1 g of *trans* fat per serving to claim that they are *trans* fat free. So, even if the Nutrition Facts panel states 0 g *trans* fats, the product can still have 1/2 g of *trans* fat per serving.

How can you tell if a food contains *trans* fats? Check the ingredients list. If it states that the product contains PHOs, it contains *trans* fats. However, new regulations from the FDA mean that you'll rarely need to take this precaution in coming years. Because of the negative effect *trans* fatty acids have on health, especially cardiovascular health, in 2015 the FDA removed PHOs from a list of food components "generally recognized as safe."1 Thus, all food manufacturers must remove PHOs from their products by the middle of 2018. Even after this date, you might still consume some *trans* fatty acids since they occur naturally in meat and dairy.

**Essential Fatty Acids Have Unique Health Benefits**

There has been a lot of press lately about "omega" fatty acids, so you might be wondering what they are and why they're so important. First, let's explain the Greek name. As illustrated in **FIGURE 5.8** on page 146, one end of a fatty acid chain (where it attaches to glycerol in a triglyceride) is designated the a (alpha) end (a is the first letter in the Greek alphabet). The other end of a fatty acid chain is called the ω (omega) end (ω is the last letter in the Greek alphabet).

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[**FIGURE 5.8** Two essential fatty acids: linoleic acid (an omega-6 fatty acid) and alpha-linolenic acid (an omega-3 fatty acid).]

When synthesizing fatty acids, the body has no mechanism for inserting double bonds before the ninth carbon from the omega end. This means that, when our body needs types of fatty acids having a double bond close to the omega end, it has to obtain them from the foods we eat. These are considered **essential fatty acids (EFAs)** because the body cannot make them, yet it requires them for healthy functioning. The EFAs are classified into two groups: omega-6 fatty acids and omega-3 fatty acids.

**Omega-6 Fatty Acids**

Fatty acids that have a double bond six carbons from the omega end (at ω-6) are known as *omega-6 fatty acids.* One omega-6 fatty acid, **linoleic acid,** is essential to human health. It is found in vegetable and nut oils, such as sunflower, safflower, corn, soy, and peanut oil. If you eat lots of vegetables or use vegetable-oil-based margarines or vegetable oils, you are probably getting adequate amounts of this EFA in your diet.

**Omega**-**3** **Fatty Acids**

Fatty acids with a double bond three carbons from the omega end (at ω-3) are known as *omega-3 fatty acids.* The most common omega-3 fatty acid in our diet is **alpha-linolenic acid (ALA).** It is derived primarily from plants, especially dark green, leafy vegetables, flaxseeds and flaxseed oil, soybeans and soybean oil, walnuts and walnut oil, and canola oil.

You may also have read news reports of the health benefits of the two omega-3 fatty acids found in many fish. These are **eicosapentaenoic acid (EPA)** and **docosahexaenoic acid (DHA).** Although our body can use ALA to assemble the chains of EPA and DHA, the amount that can be converted is limited;2 therefore, it is important to consume them directly from marine sources. They are found in fish, shellfish, and fish oils. Fish that naturally contain more oil, such as salmon and tuna, are higher in EPA and DHA than lean fish, such as cod or flounder.

[Image: Salmon is high in omega-3 fatty acid content.]

[Sidebar: **essential fatty acids (EFAs)** Fatty acids that must be consumed in the diet because they cannot be made by our body.]

[Sidebar: **linoleic acid** An essential fatty acid found in vegetable and nut oils; one of the omega-6 fatty acids.]

[Sidebar: **alpha-linolenic acid (ALA)** An essential fatty acid found in leafy green vegetables, flaxseed oil, soy oil, and other plant foods; an omega-3 fatty acid.]

[Sidebar: **eicosapentaenoic acid (EPA)** An omega-3 fatty acid available from marine foods and as a metabolic derivative of alpha-linolenic acid.]

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**Functions of Essential Fatty Acids**

As a group, EFAs are essential to growth and health because they are precursors to important biological compounds called *eicosanoids,* which are produced in nearly every cell in the body. Eicosanoids get their name from the Greek word *eicosa,* which means "twenty," because they are synthesized from fatty acids with 20 carbon atoms. In the body, eicosanoids are potent regulators of cellular function. For example, they help regulate gastrointestinal tract motility, blood clotting, blood pressure, the permeability of our blood vessels to fluid and large molecules, and the regulation of inflammation and gene expression.3

Each EFA also has one or more unique roles. For example, linoleic acid is metabolized in the body to arachidonic acid, which is a precursor to a number of eicosanoids. Linoleic acid is also needed for cell membrane structure and is required for the lipoproteins--lipid-protein compounds--that transport fats in our blood. In contrast, research indicates that diets high in the omega-3 fatty acids stimulate the production of eicosanoids that reduce inflammation, improve blood lipid profiles, and otherwise reduce an individual's risk for cardiovascular disease and cardiac death.3,4

**[recap**

Triglycerides are made up of a molecule of glycerol bonded to three fatty acid chains, which can be classified based on chain length, level of saturation, and shape. Saturated fatty acids have no double carbon bonds and are straight. Monounsaturated fatty acids have one double carbon bond, and polyunsaturated fatty acids have two or more double bonds. Both are kinked. Most *trans* fatty acids are produced by food manufacturers in a process called hydrogenation, in which the unsaturated fatty acids in a plant oil are straightened by the addition of hydrogen. In 2015, the FDA ruled that partially hydrogenated oils are no longer "generally recognized as safe." The essential fatty acids, linoleic acid (an omega-6 fatty acid) and alpha-linolenic acid (an omega-3 fatty acid), cannot be synthesized by the body and yet are necessary for health; thus, they must be consumed in the diet. Both saturated and *trans* fatty acids increase our risk for cardiovascular disease, whereas unsaturated fatty acids, including the essential fatty acids, are protective.]

**LO 3** Identify five functions of fat.

## **Why do we need fats?**

Although dietary fat has been demonized for decades, fat is critical to body function and survival.

**Fats Provide Energy**

Dietary fat is a primary source of energy because fat has more than twice the energy (9 kcal per gram) of carbohydrate or protein (4 kcal per gram). This means that fat is much more energy dense. For example, 1 tbsp. of butter or oil contains approximately 100 kcal, whereas it takes 2.5 cups of steamed broccoli or 1 slice of whole-wheat bread to provide 100 kcal.

**Fats Sustain Us at Rest**

Just as a candle needs oxygen for the flame to burn the tallow, our cells need oxygen to burn fat for energy. At rest, we are able to deliver plenty of oxygen to our cells, and approximately 30-70% of the energy we use comes from fat. The exact percentage varies, according to how much fat you are eating in your diet, how physically active you are, and whether you are gaining or losing weight. If you are dieting, more fat will be used for energy than if you are gaining weight. During times of weight gain, more of the fat consumed in the diet is stored in the adipose tissue, and the body uses more dietary protein and carbohydrate as fuel sources at rest.

[Want to boost your omega-3 intake but not sure what foods to buy? Download an omega-3 shopping list at **www.webmd .com.** To find it, type "omega**-**3 shopping list" in the search bar.]

[Sidebar: **docosahexaenoic acid** **(DHA)** An omega-3 fatty acid available from marine foods and as a metabolic derivative of alpha-linolenic acid.]

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**Fats Fuel Physical Activity**

Fat is a major energy source during physical activity, and one of the best ways to lose body fat and increase energy expenditure is to exercise. During exercise such as running and cycling, fat can be mobilized from any of the following sources: muscle tissue, adipose tissue, blood lipids, and/or any dietary fat consumed shortly before or during exercise.

A number of hormonal changes signal the body to break down stored energy to fuel the working muscles. The hormonal responses, and the amount and source of the fat used, depend on your level of fitness; the type, intensity, and duration of the exercise; and how well fed you are before you exercise. For example, the hormone adrenaline strongly stimulates the breakdown of stored fat. Blood levels of adrenaline rise dramatically within seconds of beginning exercise. This in turn activates additional hormones within the fat cell to begin breaking down fat.

Adrenaline also signals the pancreas to *decrease* insulin production. This is important because insulin inhibits fat breakdown. Thus, when the need for fat as an energy source is high, blood insulin levels are typically low. As you might guess, blood insulin levels are high after eating, when our need for getting energy from stored fat is low and the need for fat storage is high.

Once fatty acids are released from the adipose cell, they travel in the blood attached to a protein, *albumin,* to the muscles, where they enter the mitochondria and use oxygen to produce ATP, which is the cell's energy source. Becoming more physically fit means you can deliver more oxygen to the muscle to use the fat that is delivered there. In addition, you can exercise longer when you are fit. Since the body has only a limited supply of stored carbohydrate as glycogen in muscle tissue, the longer you exercise, the more fat you use for energy. This point is illustrated in **FIGURE 5.9.** In this example, an individual is running for 4 hours at a moderate intensity. The longer the individual runs, the more depleted the muscle glycogen levels become and the more fat from adipose tissue is used as a fuel source for exercise.

**Body Fat Stores Energy for Later Use**

Our adipose tissue gives us ready access to energy even when we choose not to eat (or are unable to eat), when we are exercising, and while we are sleeping. The body has little stored carbohydrate--only enough to last about 1 to 2 days--and there is no place where our body can store extra protein. We cannot consider our muscles and organs as a place where "extra" protein is stored! For these reasons, although we don't want excessive adipose tissue, a moderate amount is absolutely essential to good health.

[Image: The longer you exercise, the more fat you use for energy. Cyclists in long-distance races use fat stores for energy.]

**[FIGURE 5.9** Various sources of energy used during exercise. As a person exercises for a prolonged period, fatty acids from adipose cells contribute relatively more energy than do carbohydrates stored in the muscle or circulating in our blood.

*Data adapted from:* Substrate utilization during exercise in active people. *Am. J. Clin. Nutr.* 6(suppl):958S-979S.]

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Incidentally, muscle tissue also stores some triglycerides; however, the amount is much less than in body fat. This fat is readily used during exercise to fuel the working muscle.

**Fats Enable the Transport of Fat-Soluble Vitamins**

Dietary fat enables the transport of the fat-soluble vitamins (A, D, E, and K) our body needs for many essential metabolic functions. Vitamin A is essential for vision; vitamin D helps maintain bone health; vitamin E protects cell membranes from potentially harmful by-products of metabolism; and vitamin K is important for proteins involved in blood clotting and bone health. (These vitamins are discussed in detail in Chapters 8 and 9.)

**Fats Help Maintain Cell Function**

Phospholipids, cholesterol, and fatty acids--especially PUFAs--are critical components of every cell membrane. These various lipids help maintain membrane integrity, determine what substances are transported into and out of the cell, and regulate what substances can bind to the cell; thus, they strongly influence the function of the cell.

In addition, fats help maintain cell membrane fluidity and flexibility. For example, wild salmon live in very cold water and have high levels of omega-3 fatty acids in their cell membranes. These fats stay fluid and flexible even in very cold environments, allowing the fish to swim in extremely cold water. In the same way, fats help our membranes stay fluid and flexible. For example, they enable our red blood cells to bend and move through the smallest capillaries in our body, delivering oxygen to all our cells.

Fatty acids, especially PUFAs, are also primary components of the tissues of the brain and spinal cord, where they facilitate the transmission of information from one cell to another. We also need fats for the development, growth, and maintenance of these tissues.

**Body Fat Provides Protection**

Many people think of body fat as "bad," but it helps keep us healthy. Besides being the primary site of stored energy, adipose tissue pads our body and protects our organs, such as the kidneys and liver, when we fall or are bruised. The fat under our skin also acts as insulation to help us retain body heat.

Although some stored fat is essential to life, too much, especially in the abdominal region, is a risk factor for metabolic syndrome, which increases the risk for type 2 diabetes and cardiovascular disease. That's because adipose cells overloaded with triglycerides can malfunction, secreting proteins and other compounds that promote insulin resistance and blood vessel inflammation. (Obesity and metabolic syndrome are discussed in the **In Depth** essay following Chapter 10.)

**Dietary Fats Contribute to the Flavor, Texture, and Satiety of Foods**

Dietary fat helps food taste good because it contributes to texture and flavor. Fat makes salad dressings smooth and ice cream "creamy," and it gives cakes and cookies their moist, tender texture. Frying foods in melted butter, lard, or oils gives them a crisp, flavorful coating; however, eating fried foods regularly is unhealthful because these foods are high in saturated and *trans* fatty acids.

Although protein is the most satiating nutrient, fats are more satiating than carbohydrates, so we stop eating sooner and can go a longer time before we feel hungry again. This is in part due to fat's higher energy density. In addition, fat takes longer to digest because more steps are involved in the digestion process. This may help you feel fuller for a longer period of time as energy is slowly released into your bloodstream.

[Image: Fat adds texture and flavor to foods.]

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Unfortunately, you can eat a lot of fat without feeling overfull because fat is so compact. For example, one medium apple weighs 117 g (approximately 4 oz) and has 70 kcal, but the same number of Calories of butter--two pats--would hardly make you feel full! Looked at another way, an amount of butter weighing the same number of grams as a medium apple would contain 840 kcal.

**[recap**

Dietary fats provide more than twice the energy of protein and carbohydrate, at 9 kcal per gram. They provide the majority of the energy required at rest, and are a major fuel source during exercise, especially endurance exercise. Dietary fats help transport the fat-soluble vitamins into the body and help regulate cell function and maintain membrane integrity. Stored body fat in the adipose tissue helps protect vital organs and pad the body. Fats contribute to the flavor and texture of foods and the satiety we feel after a meal.]

**LO 4** Describe the steps involved in fat digestion, absorption, and transport.

## **How does the body process fats?**

Because fats are not soluble in water, they cannot enter our bloodstream easily from the digestive tract. Thus, fats must be digested, absorbed, and transported within the body differently than carbohydrates and proteins, which are water-soluble substances. The digestion and absorption of fat were discussed in Chapter 3, but we review the process here, and the steps are illustrated in **FOCUS FIGURE 5.10.**

Salivary enzymes released during chewing have a limited role in the breakdown of fats, so most fat reaches the stomach intact. The primary role of the stomach in fat digestion is to mix and break up the fat into small droplets. Because they are not soluble in water, these fat droplets typically float on top of the watery digestive juices in the stomach until they are passed into the small intestine.

**The Gallbladder, Liver, and Pancreas Assist in Fat Digestion**

Because fat is not soluble in water, its digestion requires the help of bile from the gallbladder and digestive enzymes from the pancreas. The gallbladder is a sac attached to the underside of the liver, and the pancreas is an oblong-shaped organ sitting below the stomach. Both have a duct connecting them to the small intestine.

As fat enters the small intestine from the stomach, the gallbladder contracts and releases bile, a compound synthesized in the liver and stored in the gallbladder until needed. Bile contains cholesterol, certain amino acids, and the mineral sodium in compounds referred to as *bile salts.* As shown in **FIGURE 5.11a** (page 152), bile salts act somewhat like soap, emulsifying large fat droplets into smaller and smaller droplets. At the same time, pancreatic lipases--lipid-digesting enzymes produced in the pancreas--travel through the pancreatic duct into the small intestine. By emulsifying the fat into small droplets, bile has exposed more surface area to the action of pancreatic lipases, which now begin digesting the triglycerides. Each triglyceride molecule is broken down into two free fatty acids and one *monoacylglyceride,* a glycerol backbone with one fatty acid still attached.

**Absorption of Fat Occurs Primarily in the Small Intestine**

The majority of fat absorption occurs in the enterocytes with the help of micelles (see Figures 5.10 and 5.11b). A *micelle* is a spherical compound made up of bile and phospholipids that can trap the free fatty acids and monoacylglycerides, as well as cholesterol and phospholipids, and transport these products to the enterocytes for absorption.

[Image: Fats and oils do not dissolve readily in water.]

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The majority of lipid digestion takes place in the small intestine, with the help of bile from the liver and digestive enzymes from the pancreas. Micelles transport the end products of lipid digestion to the enterocytes for absorption and eventual transport via the blood or lymph.

**[ORGANS OF THE GI TRACT**

**MOUTH**

Lingual lipase secreted by tongue cells and mixed with saliva digests some triglycerides.

Little lipid digestion occurs here.

**STOMACH**

Most fat arrives intact at the stomach, where it is mixed and broken into droplets.

Gastric lipase digests some triglycerides.

**SMALL INTESTINE**

Bile from the gallbladder breaks fat into smaller droplets.

Lipid-digesting enzymes from the pancreas break triglycerides into monoacylglycerides and fatty acids.

Lipid-digesting enzymes from the pancreas break dietary cholesterol esters and phospholipids into their components.

Products of fat digestion combine with bile salts to form micelles.

Micelles transport lipid digestion products to the enterocytes.

Within enterocytes, components from micelles reform triglycerides and are repackaged as chylomicrons for transport into the lymphatic system.

Shorter fatty acids can be absorbed directly into the bloodstream.

**ACCESSORY ORGANS**

**SALIVARY GLANDS**

Produce saliva.

**LIVER**

Produces bile, which is stored in the gallbladder.

**GALLBLADDER**

Contracts and releases bile into the small intestine.

**PANCREAS**

Produces lipid-digesting enzymes, which are released into the small intestine.]

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[**(a)** Fat is emulsified by bile salts, then triglycerides are broken apart by pancreatic lipase.

**(b)** Micelle transports lipid digestion products to the enterocyte for absorption.]

**[FIGURE 5.11** Action of bile salts, pancreatic lipase, and micelles in fat emulsification, digestion, and absorption. **(a)** Large fat droplets filled with triglycerides are emulsified by bile into smaller and smaller droplets. Pancreatic lipase can then access the triglycerides and break them apart into free fatty acids and monoacylglycerides. **(b)** These products, along with cholesterol, are trapped in micelles, spherical compounds made up of bile salts and phospholipids. Micelles transport lipid digestion products to the enterocytes. Bile salts are taken up in the lower intestine and recycled by the liver.]

Given that fats do not mix with water, how does the absorbed fat get into the bloodstream? As the micelle nears the surface of the enterocytes, the fatty acids, monoacylglycerides, phospholipids, and cholesterol are released and absorbed. At this point the micelle itself is not absorbed; instead, it is absorbed later in the ileum of the small intestine, at which point it can be recycled back to the liver.

Once inside the enterocytes, the free fatty acids and monoacylglycerides are reformulated into triglycerides, and then packaged into lipoproteins. A **lipoprotein** is a spherical compound in which the fat clusters in the center and phospholipids and proteins form the outside of the sphere **(FIGURE 5.12).** The specific lipoprotein produced in the enterocyte to transport fat from a meal is called a **chylomicron.** Again, this unique compound is soluble in water because phospholipids and proteins are soluble in water. Once chylomicrons are formed, they are transported from the intestinal lining to the lymphatic system through the lacteals. Lymphatic vessels eventually drain into the left subclavian vein, a large vein beneath the left collarbone (clavicle). In this way, dietary fat finally arrives in your blood.

How does the fat get out of the chylomicrons in the bloodstream and into body cells? This process occurs with the help of an enzyme called **lipoprotein lipase** (LPL), which sits outside of cells, including adipose and muscle cells. LPL comes into contact with the chylomicrons when they touch the surface of a cell. As a result of this contact, LPL breaks apart the triglycerides in the core of the chylomicrons. The free fatty acids then move out of the chylomicrons and cross into the cell, whereas the glycerol is transported back to the liver or kidney.

As the cells take up the free fatty acids, the chylomicrons shrink in size and become more dense. These smaller chylomicrons, called *chylomicron remnants,* are now filled with cholesterol, phospholipids, and protein.

[Sidebar: **lipoprotein** A spherical compound in which fat clusters in the center and phospholipids and proteins form the outside of the sphere.]

[Sidebar: **chylomicron** A lipoprotein produced in the enterocyte; transports dietary fat out of the intestinal tract.]

[Sidebar: **lipoprotein lipase (LPL)** An enzyme that sits on the outside of cells and breaks apart triglycerides in chylomicrons, so that their fatty acids can be removed and taken up by the cell.]

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[**FIGURE 5.12** Structure of a lipoprotein. Notice that the fat clusters in the center of the molecule and the phospholipids and proteins, which are water soluble, form the outside of the sphere. This enables lipoproteins to transport fats in the bloodstream.]

As they pass through the liver, these remnants are removed from the bloodstream and their contents are recycled. The liver also synthesizes two other types of lipoproteins that play important roles in cardiovascular disease. They are discussed in the **In** **Depth** essay following this chapter.

For most individuals, the chylomicrons that appear in the blood after the consumption of a moderate fat meal can easily be cleared by the body within 6 to 8 hours. This is why you are asked to fast for at least 8 hours before having blood drawn for a laboratory analysis for blood lipid levels.

As mentioned earlier, short- and medium-chain fatty acids (those fewer than 14 carbons in length) can be transported in the body more readily than the long-chain fatty acids. When short- and medium-chain fatty acids are digested and transported to the enterocytes, they do not have to be incorporated into chylomicrons. Instead, they can travel bound to either a transport protein, such as albumin, or a phospholipid. For this reason, shorter-chain fatty acids can get into the bloodstream more quickly than long-chain fatty acids.

**Fat Is Stored in Adipose Tissues for Later Use**

As described earlier, with the help of LPL, the chylomicrons deliver their load of fatty acids to body cells. There are three primary fates of these fatty acids:

**1.** Body cells, especially muscle cells, can take them up and use them as a source of energy.

**2.** Cells can use them to make lipid-containing compounds needed by the body.

**3.** If the body doesn't need the fatty acids for immediate energy, muscle and adipose cells can re-create the triglycerides (using glucose for the glycerol backbone) and store them for later use.

The primary storage site for triglycerides is the adipose cell **(FIGURE 5.13),** which is the only body cell with significant fat-storage capacity. However, if you are physically active, your body will preferentially store this extra fat in muscle cells, so the next time you work out, the fat is readily available for energy. Thus, people who engage in regular physical activity are more likely to have fat stored in the muscle tissue and to have less body fat--something many of us would prefer.

**[FIGURE 5.13** Diagram of an adipose cell.]

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Of course, fat stored in the adipose tissue can also be used for energy during exercise, but it must be broken down first and then transported to the muscle cells.

**[recap**

Fat entering the small intestine is emulsified into droplets by bile. Pancreatic lipases then digest the triglycerides into two free fatty acids and one monoacylglyceride. These are transported into the enterocytes with the help of micelles. Once inside, triglycerides are re-formed and packaged into lipoproteins called *chylomicrons.* These enter the lymph, then the bloodstream, in which they travel to body cells that need energy. Fat stored in the muscle tissue is used as a source of energy during physical activity. Excess fat is stored in the adipose tissue and can be used whenever the body needs energy.]

**LO 5** Identify the DRIs for fats and common food sources of unhealthful and beneficial fats.

## **How much fat should you eat?**

Now that you know which fats are healthful and which are harmful, you may be wondering how much--or how little--of each type to consume, and how that translates into specific foods. To make the switch to more healthful fats, it helps to be aware of exactly where the fat in your diet is coming from.

**Recognize the Fat in Foods**

We add fats--such as butter, cream, mayonnaise, and salad oils--to foods because they make them taste good. This type of fat is called **visible fat** because we can easily see what we're adding and approximately how much. Still, we may not be aware of the type of fat we're using and the number of Calories it adds to the food. For instance, it's easy to make a slice of whole-grain toast even more healthful by spreading it with peanut butter, which is rich in unsaturated fats, but spreading it with 1/2 tablespoon of butter adds about 4 grams of saturated fat. When adding visible fats, use moderation and, when possible, select oils, such as canola oil, soybean oil, or olive oil, over solid fats such as butter or margarine. When selecting butter or margarine, use those made with or mixed with healthful oils.5

Also be on the lookout for **hidden fats--**that is, fats added to processed and prepared foods to improve taste and texture. Their invisibility often tricks us into choosing them over more healthful foods. For example, a blueberry scone is much higher in saturated fat (about 12 grams) than two blueberry waffles (about 1.5 grams), yet consumers assume that the saturated fat content of these foods is the same because they are both bread products. The majority of the fat in the average American diet is invisible. Foods that can be high in invisible saturated fats are baked goods, regular-fat dairy products, processed meats or meats that are highly marbled or not trimmed, and most convenience and fast foods, such as hamburgers, hot dogs, chips, ice cream, and french fries and other fried foods. When purchasing packaged foods, read the Nutrition Facts panel! The nearby **Nutrition Label Activity** shows you how to calculate the amount of fat hidden in packaged foods.

**Decipher Label Claims**

The FDA and the U.S. Department of Agriculture (USDA) have set specific regulations on allowable label claims for reduced-fat products. The following claims are defined for one serving:

- Fat free = less than 0.5 g of fat

- Low fat = 3 g or less of fat

- Reduced or less fat = at least 25% less fat as compared to a standard serving

- Light = one-third fewer Calories or 50% less fat as compared with a standard serving amount

There are now thousands of fat-modified foods in the market. However, if you're choosing such foods because of a concern about your weight, let the buyer beware!

[Image: Baked goods are often high in hidden fats and may contain *trans* fats.]

[Sidebar: **visible fats** Fats that are clearly present and visible in our food, or visibly added to food, such as butter, margarine, cream, shortening, salad dressings, chicken skin, and untrimmed fat on meat.]

[Sidebar: **hidden fats** Fats that are not apparent, or "hidden" in foods, such as the fats found in baked goods, regular-fat dairy products, marbling in meat, and fried foods.]

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## **nutrition label activity** **How Much Fat Is in This Food?**

How can you figure out how much fat is in a food you might buy? One way is to read the Nutrition Facts panel on the label. Two cracker labels are shown in **FIGURE 5.14;** one cracker is higher in fat than the other. Let's use the label to find out what percentage of energy is coming from fat in each product. The calculations are relatively simple.

**1.** Divide the total Calories from fat by the total Calories per serving, and multiply the answer by 100.

- For the regular wheat crackers:

50 kcal/150 kcal = 0.33 × 100 = 33%.

Thus, for the regular crackers, the total energy coming from fat is 33%.

- For the reduced-fat wheat crackers:

35 kcal/130 kcal = 0.269 × 100 = 27%.

Thus, for the reduced-fat crackers, the total energy coming from fat is 27%.

Although the energy per serving is not very different between these two crackers, the percentage from fat is quite different.

**2.** If the total Calories per serving from fat are not given on the label, you can quickly calculate this value by multiplying the grams of total fat per serving by 9 (because there are 9 kcal per gram of fat).

- For the regular wheat crackers:

6 g fat × 9 kcal/gram = 54 kcal of fat.

- To calculate the percentage of Calories from fat: 54 kcal/150 kcal = 0.36 × 100 = 36%.

This value is not exactly the same as the 50 kcal reported on the label or the 33% of Calories from fat calculated in example 1. That's because the values on food labels are rounded off.

In summary, you can quickly calculate the percentage of fat per serving for any packaged food in three steps: (1) multiply the grams of fat per serving by 9 kcal per gram; (2) divide this number by the total kcal per serving; (3) multiply by 100.

**[FIGURE** **5.14** Labels for two types of wheat crackers. **(a)** Regular wheat crackers. **(b)** Reduced-fat wheat crackers.]

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## **nutri-case LIZ**

"Lately I'm hungry all the time. I read online that if I limit my total fat intake to no more than 10% of my total Calories, I can eat all the carbs and protein that I want, and I won't gain weight. So, when I felt hungry after my last class, I stopped at the yogurt shop in the Student Union and ordered a sundae with nonfat vanilla yogurt and fat-free chocolate syrup. I have to admit, though, that about an hour after I ate it I was hungry again. Maybe it's stress."

What do you think of Liz's approach to her persistent hunger? What have you learned in this chapter about the role of fats--and sugars--that would be important information to share with her?

Lower-fat versions of foods may not always be lower in Calories. The reduced fat is often replaced with added simple carbohydrate, resulting in a very similar total energy intake. For example, one national brand of chocolate ice cream contains 10 grams of saturated fat per serving, whereas a low-fat brand contains 3 grams of saturated fat for the same size serving. Choosing the lower-fat ice cream will save you only 30 Calories, however, because the low-fat brand is higher in sugars. Bear in mind that when saturated fat is replaced by added sugars, risk factors for chronic disease can actually increase.6,7 There are strong data linking added sugars to a number of chronic diseases including obesity, cardiovascular disease, and cancer.7,8

**Keep Your Fat Intake Within the AMDR**

The Acceptable Macronutrient Distribution Range (AMDR) for fat is 20-35% of total energy intake.9 This recommendation is based on evidence indicating that higher intakes of fat increase the risk for obesity and its complications, especially cardiovascular disease, but that diets too low in fat and too high in carbohydrate can also increase the risk for cardiovascular disease if they cause blood triglycerides to increase.

If you're an athlete, you've probably been advised to consume less fat and more carbohydrate to replenish your glycogen stores, especially if you participate in endurance activities. Specifically, you should consume 20-25% of your total energy from fat, 55-60% of energy from carbohydrate, and 12-15% of energy from protein.10 This percentage of fat intake is still within the AMDR.

Although many people trying to lose weight consume less than 20 % of their energy from fat, this practice may do more harm than good, especially if they are also limiting energy intake (eating fewer than 1,500 kcal per day). There is no clear evidence that diets with less than 15 % of energy from fat have advantages over moderate-fat diets, and they are usually very difficult to follow. In fact, most people trying to manage their weight find they are more successful if they keep their fat within the AMDR recommendations for fat. For example, the DASH diet provides 28-30% of energy from fat on a 2,000-Calorie diet.11 (The DASH diet is discussed in the **In Depth** essay following this chapter.)

**Aim for a Balance of the Essential Fatty Acids**

The Dietary Reference Intakes (DRIs) for the two essential fatty acids are as follows:9

**-** **Linoleic acid.** The Adequate Intake (AI) for linoleic acid (an omega-6 fatty acid) is 14 to 17 g per day for adult men and 11 to 12 g per day for women 19 years and older.

**-** **Alpha-linolenic acid.** The AI for ALA (an omega-3 fatty acid) is just 1.6 g per day for adult men and 1.1 g per day for adult women.

It is unrealistic for most Americans to keep track of the number of grams of linoleic acid and ALA they consume each day. Overall, we appear to get adequate amounts of linoleic acid in our diets because of the salad dressings, vegetable oils, margarines, and mayonnaise we eat. In contrast, our consumption of ALA, including

[Concerned about the saturated fat and cholesterol in the beef you eat? Use the guide to choosing the leanest cuts at **www.mayoclinic.org.** From the home page, type "lean cuts of beef" in the search bar to find it.]

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EPA, and DHA, is more variable and can be low in the diet of people who do not eat dark green, leafy vegetables; walnuts; soy products; canola oil; flax seeds or their oils; or fish or fish oils. So rather than attempting to monitor your linoleic acid to ALA intake, focus on consuming healthful amounts of the foods listed in **TABLE 5.1.**

**Reduce Your Intake of Saturated Fats**

Research over the last two decades has shown that diets high in saturated and *trans* fatty acids can increase the risk for cardiovascular disease. Thus, the recommended intake of saturated fats is less than 10% of total energy.12 Let's look at the primary sources of saturated fats in the American diet.

**-** **Mixed dishes.** The majority of our saturated fat (36%) comes from the consumption of pizza, tacos, burgers, sandwiches, and other mixed dishes with animal protein, especially red meat and cheese.13

**-** **Animal products.** Meats and dairy products that are not part of mixed dishes are also a primary source of saturated fat in our diet (28%).13 Meats contain a mixture of fatty acids, and the precise amount of saturated fat will depend on the cut of the meat and how it is prepared. For example, red meats, such as beef, pork, and lamb, typically have more fat than skinless chicken or fish. Lean red meats are lower in saturated fat than regular cuts. In addition, broiled, grilled, or baked meats have less saturated fat than fried meats. Dairy products may also be high in saturated fat. Whole-fat milk and yogurt has three times the saturated fat as low-fat milk products, and nearly twice the energy. As a group, eggs contribute to only 3 % of our saturated fat intake.

**TABLE 5.1 Omega-3 Fatty Acid Content of Selected Food**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Total Omega-3** | **DHA grams** | **EPA** |
| Food Item | **per serving** | | |
| Flaxseed oil, 1 tbsp. | 7.25 | 0.00 | 0.00 |
| Salmon oil (fish oil), 1 tbsp. | 4.39 | 2.48 | 1.77 |
| Sardine oil, 1 tbsp. | 3.01 | 1.45 | 1.38 |
| Flaxseed, whole, 1 tbsp. | 2.50 | 0.00 | 0.00 |
| Herring, Atlantic, broiled, 3 oz | 1.83 | 0.94 | 0.77 |
| Salmon, Coho, steamed, 3 oz | 1.34 | 0.71 | 0.46 |
| Canola oil, 1 tbsp. | 1.28 | 0.00 | 0.00 |
| Sardines, Atlantic, w/ bones & oil, 3 oz | 1.26 | 0.43 | 0.40 |
| Trout, rainbow fillet, baked, 3 oz | 1.05 | 0.70 | 0.28 |
| Walnuts, English, 1 tbsp. | 0.66 | 0.00 | 0.00 |
| Halibut, fillet, baked, 3 oz | 0.53 | 0.31 | 0.21 |
| Shrimp, Canned, 3 oz | 0.47 | 0.21 | 0.25 |
| Tuna, white, in oil, 3 oz | 0.38 | 0.19 | 0.04 |
| Crab, Alaska King, steamed, 3 oz | 0.36 | 0.10 | 0.25 |
| Scallops, broiled, 3 oz | 0.31 | 0.14 | 0.17 |
| Smart Balance Omega-3 Buttery Spread (1 tbsp.) | 0.32 | 0.01 | 0.01 |
| Tuna, light, in water, 3 oz | 0.23 | 0.19 | 0.04 |
| Avocado, Calif., fresh, whole | 0.22 | 0.00 | 0.00 |
| Spinach, cooked, 1 cup | 0.17 | 0.00 | 0.00 |
| Eggland's Best, 1 large egg, with omega-3 | 0.12 | 0.06 | 0.03 |

*Note:* EPA = Eicosapentaenoic acid; DHA = docosahexaenoic acid.

*Data adapted from:* Food Processor SQL, Version 10.3, ESHA Research, Salem, OR, and manufacturer labels.

[Image: This skinless roasted chicken breast provides less than 1 g saturated fat and 131 kcal; with the skin, it would provide 3 g saturated fat and 235 kcal.]

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**Reducing Saturated Fats When Cooking**

Trim visible fat from meats before cooking.

Remove the skin from poultry before cooking.

Instead of frying meats, poultry, fish, or potatoes or other vegetables, grill, bake, or broil them.

Cook with olive oil or canola oil instead of butter.

Use oil instead of butter when stir-frying.

Substitute hard cheeses (such as parmesan), which are naturally lower in fat, for softer cheeses that are higher in fat (such as cheddar).

Substitute low-fat or nonfat yogurt for cream, cream cheese, mayonnaise, or sour cream in recipes; also on baked potatoes, tacos, salads, and in dips.]

**-** **Baked goods, sweets, and snack foods.** Muffins, pastries, cookies, and brownies may be filled with saturated fats. Tortilla chips, microwave and movie-theater popcorn, snack crackers, and packaged rice and pasta mixes may also be high in saturated fat. Overall this category contributes to 22% of our saturated fat intake.13

**-** **Prepared vegetables, salad dressings, and condiments.** We often don't think of plant foods as having high amounts of saturated fats, but if these foods are fried, breaded, or drenched in sauces they can become a source of saturated fat. For example, a small baked potato (138 g) has no fat and 134 kcal, whereas a medium serving (134 g) of french fries cooked in vegetable oil has 427 kcal, 23 g of fat, and 5.3 g of saturated fat. This is one-fourth of the saturated fat recommended for an entire day for a person on a 2,000-kcal/day diet.

You can significantly reduce your intake of saturated fats by making smart choices when you prepare and cook foods. The **Quick Tips** feature on this page will help.

**Avoid** *Trans* Fatty Acids

The Institute of Medicine (IOM; which is now the Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine) and the *2015-2020 Dietary Guidelines for Americans* recommend that we keep our intake of *trans* fatty acids to an absolute minimum.9,12 This is because diets high in *trans* fatty acids are thought to increase the risk for cardiovascular disease even more than diets high in saturated fats.14,15 A research review that involved more than 140,000 individuals showed that for every 2 % increase in energy intake from *trans* fatty acids, there was a 23% increase in incidence of cardiovascular disease.14

Currently, the majority of *trans* fats in the American diet comes from deep-fried fast or frozen foods, snacks, and bakery products.16 A 2012 review of top-selling packaged foods in the United States showed that 9 % of these foods contained PHOs, yet 84% of these products reported they had no *trans* fatty acids.16 As discussed earlier, the only way to find out if a food contains *trans* fats is to read the ingredients list on the label. If the food contains PHOs, it contains *trans* fats even if the label says it does not. Also, remember that manufacturers have until the middle of 2018 to remove all PHOs from processed foods. Next time you shop, let the **Quick Tips** feature on page 159 help guide your choices.

**What About Dietary Cholesterol?**

Consumers are confused about whether they should avoid dietary cholesterol.

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This confusion is understandable given that health experts have changed their message over the years as they have learned more about saturated fat and cholesterol metabolism and their relationship to cardiovascular disease.5,17 Here are some points to keep in mind:

- Recall that the body can make cholesterol; moreover, the body recycles cholesterol. Thus, you don't have to worry about getting enough in your diet. When you consume cholesterol, your body typically reduces its internal production, which keeps its total cholesterol pool constant.

- The body absorbs only about 40-60% of the cholesterol consumed.18 It excretes the rest in feces. The precise percentage of cholesterol absorbed can vary according to genetics, body size, health status, and the other components of the diet.17,19

- One of the dietary components that influences cholesterol metabolism is saturated fat. By keeping your intake of saturated fat low, you can avoid excessive levels of harmful cholesterol in your blood. Because saturated fat and cholesterol are typically found in the same foods, namely, fatty animal products, keeping saturated fat low also keeps dietary cholesterol low.

- Although the Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine (formerly the Institute of Medicine, or IOM)9 recommends consuming less than 300 mg/d of dietary cholesterol, there appears to be no direct link between dietary cholesterol and cardiovascular disease.20 The *2015-2020 Dietary Guidelines for Americans* recommends consuming as little dietary cholesterol as possible.12 However, if you follow a healthful eating pattern, as recommended in the Guidelines, your cholesterol intake should range from 100-300 mg/day.

**[Quick Tips**

**Shopping for Foods Low in Saturated and** *Trans* Fats

Read food labels. Look for foods low in saturated fats and avoid foods with PHOs in the ingredients list.

Select liquid or tub margarine/butters over stick forms. Fats that are solid at room temperature are usually high in *trans* or saturated fats. Also, select margarines made from healthful fats, such as canola oil.

Buy naturally occurring oils, such as olive and canola oil. These provide healthful unsaturated fatty acids.

Select 100% whole-grain baked products made with unsaturated oils instead of butter.

Cut back on packaged pastries, such as Danish, croissants, donuts, cakes, and pies. These baked goods are typically high in saturated and *trans* fatty acids. Read the ingredients list to see if PHOs have been used.

Select salad dressings made with healthful fats, such as olive oil and vinegar. Also select lower fat mayonnaise and dressings when available.

Add fish, especially those high in omega-3 fatty acids, to your shopping list. For example, select salmon, line-caught tuna, herring, and sardines.

For other healthful sources of protein, select lean cuts of meat and skinless poultry, meat substitutes made with soy, or beans or lentils.

Select lower-fat versions of dairy products such as milk, cheese, yogurt, sour cream, and cream cheese. Soy milk is naturally low in saturated fat.]

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**Select Beneficial Fats**

As mentioned earlier, it's best to switch to healthful fats without increasing your total fat intake. The following suggestions will help you find foods rich in the beneficial fats you need.

**Pick Plants**

Plant oils are excellent sources of unsaturated fats, as are avocados, olives, nuts and nut butters, and seeds. An easy way to shift your diet toward these healthful fats--without increasing your total fat intake--is to replace animal-based foods with versions derived from plants. For example, drink calcium-fortified soy milk instead of cow's milk. Order your Chinese takeout with tofu instead of beef. Use thin slices of avocado in a sandwich in place of cheese, or serve tortilla chips with guacamole instead of nachos. Use beans, peas, and lentils more frequently as the main source of protein in your meal, or add them to your meat-based dish, so that you use less meat overall.

Many nuts and seeds are high in mono- and polyunsaturated fatty acids, and walnuts, almonds, flax seeds, and chia seeds are a rich source of ALA specifically. Nuts and seeds also provide protein, minerals, vitamins, antioxidant phytochemicals, and fiber. However, a 1-oz serving of nuts (about 4 tablespoons) typically contains 160-180 kcal and could contribute to a high energy intake. So do their benefits outweigh their cost in Calories? Research shows that people who consume nuts have a reduced risk for chronic disease3 and maintain a lower body weight.21,22 The mechanisms contributing to these associations are not fully understood. However, two factors might be contributing to this effect.

- Nuts contain healthful fats that may contribute to lowering our risk of chronic disease. They may also substitute for less healthful snacks, such as chips, that are higher in saturated fat and sodium.

- The energy available from nuts is lower than the number of Calories typically identified. For example, the energy from consumption of 1 oz (28 g) of walnuts is only 146 kcal, which is 39 kcal less than attributed.23

However, even if nuts contain healthful oils and their energy content is lower than expected, we still need to eat them in moderation. One approach is to by sprinkling a few on your salad, yogurt, or breakfast cereal. Spread a nut butter on your morning toast instead of butter, or pack a peanut butter and jelly sandwich instead of a meat sandwich for lunch. Finally, add nuts or seeds to raisins and pretzel sticks for a quick trail mix.

**Switch to Fish**

To increase your intake of EPA and DHA, replace a meat-based meal with fish at least twice a week, or look for foods fortified with an adequate amount of EPA and DHA per serving. It's important to recognize, however, that there are risks associated with eating large amounts of certain fish on a regular basis. Depending on the species and the level of pollution in the water in which it is caught, the fish may contain mercury, polychlorinated biphenyls (PCBs), and other environmental contaminants. Types of fish that are currently considered safe to consume include salmon (except from the Great Lakes region), farmed trout, flounder, sole, *mahi mahi,* and cooked shellfish. Line-caught tuna, either fresh or canned, is low in mercury. These tuna are smaller, usually less than 20 pounds, and have had less exposure to mercury in their lifetime. Line-caught cod and rock fish and Pacific sardines are also good choices. Fish more likely to be contaminated are shark, swordfish, golden bass, golden snapper, marlin, bluefish, and largemouth and smallmouth bass. Women who are pregnant or breastfeeding, women who may become pregnant, and small children should avoid these fish species entirely. (For more information on seafood safety, see Chapter 12.)

As you can see, substituting beneficial fats for saturated or *trans* fats isn't difficult. See the **MEAL FOCUS FIGURE 5.15** to compare a day of meals high and low in saturated fats.

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**meal focus figure 5.15 Reducing Saturated Fat**

**a day of meals**

**HIGH in saturated fat**

**LOW in saturated fat**

**BREAKFAST**

*1* *egg, fried*

*2 slices bacon*

*2 slices white toast with*

*2 tsp. butter*

*8 fl. oz whole milk*

*2 egg whites, scrambled*

*2 slices whole-wheat toast with 2 tsp. olive oil spread*

*1 grapefruit*

*8 fl. oz skim milk*

**LUNCH**

*McDonald's Quarter Pounder with cheese*

*McDonald's French fries, small*

*12 fl. oz cola beverage*

**Tuna Sandwich**

*3 oz tuna (packed in water)*

*2 tsp. reduced fat mayonnaise*

*2 leaves red leaf lettuce*

*2 slices rye bread*

*1 large carrot, sliced with*

*1 cup raw cauliflower with*

*2 tbsp. low-fat Italian salad dressing*

*1 1-oz bag of salted potato chips*

*24 fl. oz water*

**DINNER**

*8 oz sirloin steak, grilled*

*1 large baked potato with*

*1 tbsp. butter and 1 tbsp. sour cream*

*½* cup sweet corn

*12 fl. oz diet cola beverage*

*1 cup minestrone soup*

*4 oz grilled salmon*

*1 cup brown rice with 2 tsp. slivered almonds*

*1 cup steamed broccoli*

*1 dinner roll with*

*1* *tsp. butter*

*12 fl. oz iced tea*

**nutrient analysis**

**2,316** kcal

**36.6%** of energy from carbohydrates

**39.1** % of energy from fat

**16%** of energy from saturated fat

**15.3%** of energy from unsaturated fat

**23%** of energy from protein

**15.3** grams of dietary fiber

**3,337** milligrams of sodium

**nutrient analysis**

**2,392** kcal

**46.6%** of energy from carbohydrates

**28.1%** of energy from fat

**5%** of energy from saturated fat

**18.8%** of energy from unsaturated fat

**17.5%** of energy from protein

**28** grams of dietary fiber

**2,713** milligrams of sodium

**[11%** LESS saturated fat]

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**Watch Out When You're Eating Out**

Many college students eat most of their meals in dining halls and fast-food restaurants or buy to-go foods from the grocery delicatessen. If that describes you, watch out! The menu items you choose each day may be increasing your intake of saturated and *trans* fats. The 2015 Dietary Guidelines Advisory Committee found that intakes of total energy, total fat, and saturated fat are higher among Americans who frequently eat fast food.13 And although many fast-food restaurants have eliminated commercially produced *trans* fatty acids from certain menu items, some burgers, breakfast sandwiches, desserts, and shakes may still contain them until the middle of 2018. The **Quick Tips** on this page provide specific strategies for choosing healthful fats when eating out.

**[Quick Tips**

**Selecting Healthful Fats When Eating Out**

When deciding where to eat out, choose a restaurant that allows you to order alternatives to the usual menu items. For instance, if you like burgers, look for a restaurant that will grill your burger instead of frying it, offers whole-grain rolls, and will let you substitute a salad for french fries.

Before you order, compare the saturated fat and Calorie content of the menu items you're considering.

Select healthful appetizers, such as salads, broth-based soups, vegetables, or fruit, over white bread with butter, nachos, or fried foods such as chicken wings.

Select broth-based soups, which are lower in fat and Calories than cream-based soups, which are typically made with cream, cheese, and/or butter.

Ask that all visible fat be trimmed from meats and that poultry be served without the skin.

Select menu items that use cooking methods that add little or no additional fat, such as broiling, grilling, steaming, and sauteing. Be alert to menu descriptions such as *fried,* crispy, creamed, buttered, au gratin, escalloped, and *parmesan.* Also avoid foods served in sauces such as butter sauce, alfredo, and hollandaise. All of these types of food preparation typically add saturated fat to a meal.

Avoid meat and vegetable pot pies, quiches, and other items with a pastry crust because these may be high in *trans* fats.

Substitute a salad, veggies, broth-based soup, or fruit for the chips or french fries that come with the meal.

Ask for butter, sour cream, salad dressings, and sauces to be served on the side instead of added in the kitchen. Select salsa as a condiment over higher-fat options.

Request low-fat spreads on your sandwiches, such as mustards, chutneys, or low-fat mayonnaise.

Select fruit for dessert, or share a traditional dessert with friends or family members.

Keep counting at your favorite cafe! Many specialty coffee drinks contain 5-10 grams of saturated fat, as compared to about 1 gram in a regular cup of coffee made with low-fat milk.

Select lower-fat options to accompany your coffee drink. For example, choose a biscotti or a small piece of dark chocolate instead of a croissant, a scone, a muffin, coffee cake, or a cookie.]

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**Be Aware of Fat Replacers**

One way to lower the fat content of processed foods is by using a *fat replacer.* Snack foods have been the primary target for fat replacers because it is difficult to simply reduce or eliminate the fat in these foods without dramatically changing their texture and taste. In the mid-1990s, the food industry promoted fat replacers as the answer to the growing obesity problem. They claimed that substituting fat replacers for traditional fats in snack and fast foods might reduce both energy and fat intake and help Americans manage their weight better.

Products such as olestra (brand name *Olean)* hit the market in 1996 with a lot of fanfare, but the hype was short-lived. Only a limited number of foods in the marketplace contain olestra. It is also evident from our growing obesity problem that fat replacers, such as olestra, do not help Americans lose weight or even maintain their current weight.

More recently, a new group of fat replacers has been developed using proteins, such as the whey protein found in milk. Like their predecessors, these new fat replacers lower the fat content of food, but in addition they improve the food's total nutrient profile and decrease its Calorie content. This means we can have a low-fat ice cream with the mouth-feel, finish, and texture of a full-fat ice cream that is also higher in protein and lower in Calories than traditional ice cream. So don't be surprised if you see more products containing protein-based fat replacers on your supermarket shelves in the next few years.

**Fat Blockers Contribute Minimally to Weight Loss**

To help them lose weight, many people turn to so-called fat blockers, dietary supplements and medications said to block the absorption of dietary fat and eliminate it in the stool. Two popular fat blockers are chitosan and orlistat. Chitosan is a dietary supplement containing a purified shellfish extract, which is supposed to trap fat in the GI tract and prevent its absorption. Orlistat, an over-the-counter medication sold under the brand name Alli, is a lipase inhibitor that prevents intestinal digestion and absorption of about 25% of the fat consumed.

Reviews of extensive research using double-blind randomized clinical trials has shown that, when chitosan is used alone without changing diet or physical activity, the weight loss produced is minimal (<2 pounds over 8--12 weeks).24-26 In 2014, an extensive systematic review of research studies combining the use of orlistat with changes in diet and physical activity found an average weight loss of 4 pounds in 12 months.27 Thus, these products contribute only minimally to weight loss for their cost and side effects, the most significant of which is gastrointestinal distress.

**[recap**

Visible fats are those we add to foods ourselves. Hidden fats are added to processed and prepared foods to improve taste and texture. The AMDR for total fat is 20-35% of total energy. An Al has also been set for linoleic acid, found in vegetable oils, and ALA, found in fish, flax seeds, walnuts, and leafy vegetables. No DRIs have been set for DHA or EPA. The recommended intake of saturated fats is less than 10% of total energy. Following a healthful eating pattern will limit consumption of both saturated fats and cholesterol. You should keep your intake of *trans* fats to an absolute minimum. By making simple substitutions when shopping, cooking, and eating out, such as by replacing meats with plants or fish, you can reduce the quantity of saturated and *trans* fatty acids in your diet and increase your intake of healthful fats. Fat replacers are substances used to replace the typical fats found in foods.]

[Image: Snack foods have been the primary target for fat replacers, such as Olean, because it is more difficult to eliminate the fat from these types of foods without dramatically changing the taste.]

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## **nutrition debate Are Saturated Fats Bad or Benign?**

[Decades of research have suggested that diets high in saturated fatty acids (SFAs) are associated with increased risk of coronary heart disease (CHD), the most common form of cardiovascular disease (CVD). However, some recent studies have suggested that saturated fats don't deserve their bad rap. Let's look at the studies involved in this controversy.

In 2014, a meta-analysis of 32 studies specifically examining the relationship between SFA intake and the risk of CHD concluded that no clear evidence supports high consumption of polyunsaturated fatty acids (PUFAs) and low consumption of total SFA.28 Immediately upon the publication of this article, researchers from the American Heart Association (AHA) and other public health organizations around the world began reviewing the methodology, data, and conclusions of this analysis. The following key criticisms emerged from these reviews:

- Two-thirds of the studies included in the analysis were observational and relied on self-reported diets. This means the researchers had asked people what they typically ate, and then looked at CHD outcomes 5-23 years later. These types of studies do not provide information about cause and effect. To determine whether or not

a high-SFA diet increases the risk for CHD, researchers need to conduct randomized clinical trials (RCTs) in which they feed participants diets higher and lower in SFAs and monitor the occurrence of CHD or cardiac death in subsequent years. In fact, an earlier meta-analysis of eight such RCTs had found that replacing SFAs with PUFAs reduced CHD risk by 10%.29

- The researchers included studies that other scientists thought were inappropriate, such as some in which margarines containing *trans* fatty acids were consumed as part of the intervention.30,31 Given the established link between *trans* fatty acid consumption and CHD, such studies should have been excluded.

- The researchers made some minor calculation errors, which required them to rerun their data after the original article was published.32 They also tried to generalize their results to the whole population, which is inappropriate.30 Your risk of developing CHD is based on genetics, diet, physical activity, and many other factors.

Despite these limitations of the 2014 study, significant debate about the relationship between SFA consumption and CHD remains. The current recommendation to limit SFAs is based on two key assumptions:33,34

**1.** Higher intakes of SFAs increase blood lipids associated with increased risk for CHD.

**2.** Lowering these blood lipids will reduce the risk of CHD.

As our understanding of the relationship between diet and CVD grows, these simple assumptions are being challenged. Researchers now recognize that only certain blood lipids are able to easily penetrate the wall of blood vessels and become oxidized, which is an early step in the development of CHD. Factors clearly associated with increased levels of these harmful blood lipids are obesity, inactivity, and a high intake of refined sugars.35-37 Specifically, the evidence linking diets high in refined sugars with CVD is derived from a global assessment of sugar-sweetened beverage (SSB) consumption and its contribution to body weight and chronic disease mortality.8 These researchers estimated that the SSB consumption contributed to approximately 45,000 CVD deaths globally per year.7 So what's the bottom line? National dietary recommendations are not based on one study, but on a body of research evidence. This doesn't mean the current SFA recommendations won't change, but until more conclusive research is available, eating a variety of whole foods while limiting SFAs and added sugars is currently the best recommendation for lowering your risk of CHD.

**CRITICAL THINKING QUESTIONS**

1. You want dessert. You avoid the ice cream in your freezer--too much saturated fat!--and go for the fat-free mango sorbet, which has no saturated fat, *trans* fat, or cholesterol, but does have 36 grams of added sugar in a half-cup serving. Why do researchers suggest that such trade-offs aren't as smart as you might think?

2. Look at your own diet. What whole-food dietary changes are you willing to make to help lower your lifetime risk of CHD? How much effort and cost would it take to make these changes?

3. Visit the AHA at www.heart.org/HEARTORG and type "saturated fats" in the search bar. Read the page and watch the video. What percentage of your total energy intake does the AHA recommend you consume as SFAs? Does the AHA discussion convince you consumption of SFAs increases your risk for CHD? Why or why not?

[Image: A body of research links high intake of saturated fat with an increased risk for CVD--but not all experts agree.]

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**[TEST YOURSELF** *ANSWERS*

**1** **T** Although eating too much fat, or too much of unhealthful fats (such as saturated and *trans* fatty acids), can increase our risk for diseases such as cardiovascular disease and obesity, some fats are essential to good health. We need to consume a certain minimum amount to provide adequate levels of essential fatty acids and fat-soluble vitamins.

**2** **T** Fat is our primary source of energy when we are at rest and engaging in low- and moderate-intensity exercise. Fat is also an important fuel source during prolonged exercise. During periods of high-intensity exercise, carbohydrate becomes the dominant fuel source.

**3** **F** Even foods fried in vegetable shortening can be unhealthful because they are high in *trans* fatty acids, in total fat, and in energy and can contribute to overweight and obesity.]

**review questions**

**LO 1 1.** Cholesterol is

a. a triglyceride.

b. a phospholipid.

c. available from a wide variety of plant- and animal-based foods.

d. produced by the body.

**LO 2 2.** Fatty acids with one double bond in part of the chain are

a. saturated.

b. monounsaturated.

c. polyunsaturated.

d. essential fatty acids.

**LO 2** **3.** Most plant oils contain

a. only saturated fats.

b. only unsaturated fats.

c. both saturated and unsaturated fats.

d. both EPA and DHA.

**LO 2 4.** Alpha-linolenic acid (ALA) is

a. converted by the body to linoleic acid.

b. metabolized in the body to arachidonic acid.

c. synthesized in the liver and small intestine.

d. found in leafy green vegetables, flaxseeds, soy milk, walnuts, and almonds.

**LO 3 5.** Fats

a. do not provide as much energy, gram for gram, as carbohydrates.

b. are a major source of fuel for the body at rest.

c. enable the emulsification and digestion of fat-soluble vitamins.

d. keep foods from turning rancid.

**LO 4 6.** What compound in the blood breaks apart the triglycerides in chylomicrons, freeing their fatty acids for uptake by body cells?

a. lipoprotein lipase

b. micelles

c. bile salts

d. pancreatic lipase

**LO 5 7.** Saturated fat intake should be

a. 0.5 g/kg of body weight.

b. less than 300 mg/day.

c. less than 10% of total energy.

d. 20-35% of total energy.

**LO 5 8.** Three healthful foods rich in beneficial fats are

a. skim milk, lean meats, and fruits.

b. fruits, vegetables, and low-fat yogurt.

c. vegetables, fish, and nuts.

d. whole milk, egg whites, and stick margarine.

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**LO 2** **9. True or false?** The essential fatty acids linoleic acid and alpha-linolenic acid are polyunsaturated fatty acids.

**LO 4 10.** True or false? When fatty chyme enters the small intestine, bile causes the fat droplets to dissolve in water.

**math review**

**LO 5 11.** Getting adequate amounts of the omega-3 fatty acids can be tricky. Study Table 5.1. What food or combination of foods would you need to eat today to reach 250 mg of EPA and DHA?

**LO 5 12.** Your friend Maria has determined that she needs to consume about 2,000 kcal per day to maintain her healthful weight. Create a list for Maria showing the recommended maximum number of Calories she should consume in each of the following forms: total fat; saturated fat; unsaturated fat; and *trans* fatty acids.

*Answers to Review Questions and Math Review are located at the back of this text, and in the MasteringNutrition Study Area.*

**web links**

**www.heart.org/HEARTORG/**

American Heart Association

*Learn the best way to help lower your blood cholesterol level. Access the AHA's online cookbook for healthy-heart recipes and cooking methods.*

**www.nhlbi.nih.gov**

National Heart, Lung, and Blood Institute

*Visit this site for resources on diet, physical activity, and other lifestyle choices that can lower your risk for cardiovascular disease.*

**www.nih.gov**

The National Institutes of Health, U.S. Department of Health and Human Services

*Go to this clearinghouse for a wide range of information and useful tools on the subjects we cover in this chapter.*

**www.nlm.nih.gov/medlineplus/**

MEDLINE Plus Health Information

*Search for "fats" or "lipids" to locate resources and learn the latest news on dietary fats.*

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# **in depth 5.5** **Cardiovascular Disease**

***After studying this In Depth, you should be able to:***

**1** Describe cardiovascular disease, including the major types and contributing mechanisms, pp. 168-170.

**2** Explain the role of modifiable factors and blood lipids in the development of cardiovascular disease, pp. 170-174.

**3** Identify several lifestyle choices that can reduce your risk for cardiovascular disease, pp. 174-177.]

**Pizza can be a nutritious food--if it's made with a whole-grain crust, loaded with vegetables, and only lightly sprinkled with low-fat cheese.**

But the pizza that most Americans enjoy, a refined-flour crust, topped with pepperoni or sausage and high-fat cheese, provides 25-35% of an average adult's recommended daily intake of saturated fat-- in a single slice. Why does this matter?

As you learned (in Chapter 5), many researchers have linked diets high in saturated fat with an increased risk for diseases of the heart and blood vessels. These diseases together account for more than 29% of all deaths of Americans.1 The deaths can result from a sudden cardiac arrest, heart attack, or stroke, or occur after many years of chronic, progressive heart failure.

What role does a diet high in saturated fats play in these diseases? Are genetics also to blame? What about obesity, smoking, or failure to engage in recommended levels of physical activity? We'll explore the factors behind cardiovascular disease **In Depth** here, and identify steps you can take to reduce your risk.

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## **What is cardiovascular disease?**

**LO 1** Describe cardiovascular disease, including the major types and contributing mechanisms.

**Cardiovascular disease (CVD)** is a general term used to refer to any abnormal condition involving dysfunction of the heart *(cardio-* means "heart") and blood vessels *(vasculature).* Among the many forms of this disease, the two with the highest mortality rates are the following:

- Coronary heart disease (CHD), also known as coronary artery disease (CAD), occurs when blood vessels supplying the heart (the coronary arteries) become blocked or constricted. Such blockage reduces the flow of blood--and the oxygen and nutrients it carries--to the heart muscle. This can result in chest pain, called *angina pectoris.* It can lead to a heart attack (also called a myocardial infarction, or MI), which is a loss of blood to, and death of, a region of heart muscle. It can also lead to sudden cardiac arrest, in which the heart suddenly stops beating. CHD causes about 600,000 deaths annually.1

- Stroke, also known as *cerebrovascular disease,* is caused by a blockage of one of the blood vessels supplying the brain (the cerebral arteries). When this occurs, the region of the brain that depends on that artery for oxygen and nutrients cannot function. As a result, the movement, speech, or other body functions controlled by that part of the brain suddenly stop. Stroke causes about 129,000 deaths annually.1

To understand CVD, we need to look at two conditions, atherosclerosis and hypertension, which underlie CHD and stroke.

**Atherosclerosis Is Narrowing of Arteries**

**Atherosclerosis** is a disease in which arterial walls accumulate deposits of lipids and scar tissue that build up to such a degree that they impair blood flow. It's a complex process that begins with injury to the cells that line the insides of all arteries **(FOCUS FIGURE 1).** Factors that commonly promote such injury are the forceful pounding of blood under high pressure and blood-vessel damage from irritants, such as the nicotine in tobacco, the excessive blood glucose in people with poorly controlled diabetes, or even the immune response associated with chronic infection.

Whatever the cause, the injury leads to vessel inflammation, which is increasingly being recognized as an important marker of CVD.2 Inflamed lining cells release chemicals that cause certain blood lipids to accumulate at the site. These lipids are mainly low-density lipoproteins, or LDLs, described shortly. LDLs invade beneath the lining of the artery wall and become oxidized. As they do, they attract the attention of immune cells that move to the site, squeeze between the lining cells, and ingest the lipids beneath, becoming foam cells. Accumulated foam cells form *fatty streaks* that are the first visible sign of atherosclerosis.

Over time, foam cells, along with proteins, calcium, platelets (cell fragments found in blood), and other substances, form thick, grainy deposits called *plaque.* The term *atherosclerosis* reflects the presence of these deposits: *athere* is a Greek word meaning "a thick porridge." As plaques form, they narrow the interior of the blood vessel (see Figure 1). This slowly diminishes the blood supply to any tissues "downstream." As a result, these tissues wither, and gradually lose their ability to function. The person may experience angina, shortness of breath, and fatigue.

Alternatively, the blockage may occur suddenly; this happens when an enlarging plaque ruptures and the blood vessel tears. *Platelets,* substances in blood that promote clotting, stick to the damaged area. This quickly obstructs the artery, causing the death of the tissue it supplies. As a result, the person experiences a heart attack or stroke.

Arteries damaged by atherosclerosis become not only narrow, but also stiff; that is, they lose their ability to stretch and spring back with each heartbeat. This characteristic is often referred to as "hardening of the arteries." As you can imagine, atherosclerosis strains the heart, forcing it to exert increased pressure to eject each burst of blood into narrowed, stiffened vessels. Physicians refer to this increased pressure as *systolic hypertension,* as we explain next.

[Knowing the warning signs of a heart attack could save your life. Download the wallet card from the National Institutes of Health at **www.nhlbi.nih.gov.** From the home page, type "heart attack wallet card" in the search bar to find it.]

[To view a brief animation of a stroke, visit MedlinePlus at **www.nlm.nih.gov/medlineplus.** From the home page, select "Videos and Tools," then "Health Videos," then click on "Stroke" in the index.]

[Sidebar: **cardiovascular disease (CVD)** A general term for abnormal conditions involving dysfunction of the heart and blood vessels, which can result in heart attack or stroke.]

[Sidebar: **atherosclerosis** A condition characterized by accumulation of cholesterol-rich plaque on artery walls; these deposits build up to such a degree that they impair blood flow.]

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**focus figure 1 Atherosclerosis**

Plaque accumulation within coronary arteries narrows their interior and impedes the flow of oxygen-rich blood to the heart.

**HEALTHY ARTERY**

Blood flows unobstructed through normal, healthy artery.

**ARTERIAL INJURY**

The artery's lining is injured, attracting immune cells, and prompting inflammation.

**LIPIDS ACCUMULATE IN WALL**

Lipids, particulary cholesterol-containing LDLs, seep beneath the wall lining. The LDLs become oxidized. Immune cells, attracted to the site, engulf the oxidized LDLs and are transformed into foam cells.

**FATTY STREAK**

The foam cells accumulate to a form a fatty streak, which releases more toxic and inflammatory chemicals.

**PLAQUE FORMATION**

The foam cells, along with platelets, calcium, protein fibers, and other substances, form thick deposits of plaque, stiffening and narrowing the artery. Blood flow through the artery is reduced or obstructed.

[Image: Micrograph of healthy artery cross-section]

[Image: Micrograph of artery with plaque cross-section.]

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**Hypertension Increases the Risk for Heart Attack and Stroke**

**Hypertension (HTN)** is one of the major chronic diseases in the United States. It affects over 29% of all adults in the United States and more than 64% of people over the age of 65.3 Although HTN itself is often without symptoms, it is a warning sign that a person's risk for a heart attack or stroke is increased. It can also damage the kidneys, reduce brain function, and impair physical mobility. In addition, chronically elevated blood pressure is one of the criteria for metabolic syndrome (see Chapter 4), which dramatically increases the risk of CVD and diabetes.

When we define hypertension as blood pressure above the normal range, what exactly do we mean? Blood pressure is measured in two phases, systolic and diastolic.

*-* *Systolic blood pressure* represents the pressure exerted in our arteries at the moment that the heart contracts, sending blood into our blood vessels.

*-* *Diastolic blood pressure* represents the pressure in our arteries between contractions, when the heart is relaxed.

Blood pressure measurements are recorded in millimeters of mercury (mmHg).

*-* *Normal blood pressure* includes a systolic blood pressure *less than* 120 mmHg, and a diastolic blood pressure *less than* 80 mmHg.

*-* *Prehypertension* is defined as a systolic blood pressure of 120-139 mmHg, or a diastolic blood pressure of 80-89 mmHg. About one of every three adults in the United States has prehypertension.3

*-* *Hypertension or high blood pressure* is defined as a systolic blood pressure of 140 mmHg or higher or a diastolic blood pressure of 90 mmHg or higher.

[Image: Hypertension is a major chronic disease in the United States, affecting more than 64% of adults over 65 years old.]

What causes HTN? For about 45-55% of people, the condition is hereditary. This type is referred to as *primary* or *essential hypertension.* For the other 45% of people with HTN, a variety of factors may contribute. In addition to underlying atherosclerosis, as just explained, anything that increases the volume or viscosity (thickness) of blood forces the heart to beat harder, increasing the pressure of the ejected blood against the vessel walls. Because salt draws water, high blood sodium can increase the volume of blood and, thus, blood pressure. Other factors implicated in HTN include age, race or ethnicity, family history of HTN, genetic factors, sleep apnea (a sleep disorder that affects breathing), psychosocial stressors, tobacco use, obesity, low levels of physical activity, excessive alcohol intake, and dietary factors, including sensitivity to salt and low potassium intake.3,4

## **What factors influence the risk for cardiovascular disease?**

**LO 2** Explain the role of modifiable factors and blood lipids in the development of cardiovascular disease.

Coronary heart disease is the leading cause of death in the United States, while stroke is the fourth leading cause of death.1 Overall, about 92.2 million Americans of all ages suffer from CVD or the after effects of stroke.4 So, who's at risk?

**Many CVD Risk Factors Are Within Your Control**

Over the last two decades, researchers have identified a number of factors that contribute to an increased risk for CVD. Some of these risk factors are nonmodifiable, meaning they are beyond your control. These include age--the older you are, the higher your risk. Until about age 60, men have a higher risk for CVD than women. After that, the risk is about equal. At any age, you have an increased risk for CVD if a parent suffered a heart attack, especially at a young age.

Other risk factors are modifiable--meaning they are at least partly within your control. Following is a brief description of each of these modifiable risk factors. Notice that many of them have a dietary component.4-6

**- Overweight and Obesity** Being obese is associated with CVD and higher rates of death from CVD than being overweight or normal weight. The risk is due primarily to a greater occurrence of high blood pressure, inflammation, abnormal blood lipids (discussed in more detail shortly), and type 2 diabetes in people who are overweight or obese, with the prevalence highest in the obese.

[Sidebar: **hypertension** A chronic condition characterized by above-average blood pressure levels--specifically, systolic blood pressure over 140 mmHg, or diastolic blood pressure over 90 mmHg.]

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(See Chapter 10 for information on body weight.)

**-** **Inactivity** A sedentary lifestyle increases the risk of CVD. Conversely, numerous research studies have shown that regular physical activity can protect against several risk factors associated with the disease. Physical activity can also significantly reduce the risk for type 2 diabetes, a major CVD risk factor in itself.5 According to the 2008 U.S. Physical Activity Guidelines,6 physical activity can reduce your risk for heart disease by 20-30%, stroke by 25-30%, and type 2 diabetes by 25-35%.

**-** **Smoking** There is strong evidence that smoking increases your risk for blood-vessel injury and atherosclerosis. Research indicates that smokers die 13-14 years earlier than nonsmokers, with one-third of deaths from CHD attributable to smoking or secondhand smoke.4 Smokers also have two to four times increased risk of stroke than nonsmokers, depending on age and gender.4 People who stop smoking at 25-34 years of age gain 10 years of life compared to those who continue to smoke.4

**-** **Type 2** **Diabetes Mellitus** For many people with type 2 diabetes, the condition is directly related to being overweight or obese, which is also associated with abnormal blood lipids and high blood pressure. The risk for CVD is three times higher in women with diabetes and two times higher in men with diabetes compared to individuals without diabetes.

**-** **Inflammation** We noted earlier that inflammation plays a role in atherosclerosis. C-reactive protein (CRP) is a nonspecific marker of inflammation somewhere in the body. Its level can be measured with a simple blood test. Risk for CVD appears to be higher in individuals who have an elevated CRP level in addition to other risk factors, such as abnormal blood lipids.7,8 Obesity, a diet low in omega-3 fatty acids, and a high intake of saturated fats promote inflammation. Thus, reducing these factors can lower your risk for CVD.

**-** **Abnormal Blood Lipids** As we explain next, abnormal levels of cholesterol and triglycerides in the blood are associated with an increased risk for CVD. A diet high in added sugars and saturated and *trans* fat, and low in soluble fiber, overweight and obesity, and low levels of physical activity are all associated with abnormal blood lipids. Conversely, omega-3 fatty acids reduce blood triglycerides, and increase levels of lipids that protect the health of blood vessels.9,10

**Blood Lipids Play a Significant Role in Cardiovascular Disease**

Recall that lipids are transported in the blood by lipoproteins made up of a lipid center and a protein outer coat. The names of lipoproteins reflect their proportion of lipid, which is less dense, to protein, which is very dense. For example, very-low-density lipoproteins (VLDLs) are only 10% protein, whereas high-density lipoproteins (HDLs) are 50% protein **(FIGURE 2).**

Because lipoproteins are soluble in blood, they are commonly called *blood lipids.* The mechanisms by which blood lipids are produced and transported in the body are illustrated in **FOCUS FIGURE** 3 (page 173).

**Chylomicrons**

Recall (from Chapter 5) that chylomicrons are produced in the small intestine to transport dietary fat into the lymphatic vessels and from there into the bloodstream. At 85 % triglyceride, chylomicrons have the lowest density. However, your blood contains chylomicrons only for a short time after you have consumed a meal.

**Very-Low-Density Lipoproteins**

More than half of the substance of very-low-density lipoproteins (VLDLs) is triglyceride. The liver is the primary source of VLDLs, but they are also produced in the intestines. VLDLs are primarily transport vehicles ferrying triglycerides from their source to the body's cells, including to adipose tissues for storage. The enzyme lipoprotein lipase (LPL) frees most of the triglyceride from the VLDL molecules, resulting in its uptake by the body's cells.

Diets high in fat, simple sugars, and extra Calories can increase the body's production of VLDLs, whereas diets high in omega-3 fatty acids can help reduce their production. In addition, exercise can reduce VLDLs because they're readily used for energy instead of remaining to circulate in the blood.

**Low-Density Lipoproteins**

The molecules resulting when VLDLs release their triglyceride load are higher in cholesterol, phospholipids, and protein and therefore somewhat more dense. These low-density lipoproteins (LDLs) circulate in the blood, delivering their cholesterol to cells.

LDLs not removed from the bloodstream are left to circulate in the blood. The more LDL-cholesterol circulating in the blood, the greater the risk that some of it will adhere to the walls of the blood vessels, contributing to the development of atherosclerosis. Because high blood levels of LDL-cholesterol increase the risk for CVD, it is often labeled the "bad cholesterol."

[Image: Obesity is associated with higher rates of death from cardiovascular disease.]

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**[FIGURE** **2** The chemical components of various lipoproteins. Notice that chylomicrons contain the highest proportion of triglycerides, making them the least dense, whereas high-density lipoproteins (HDLs) have the highest proportion of protein, making them the most dense.]

Diets lower in simple carbohydrate and saturated fats, along with regular physical activity, can reduce LDL-cholesterol.11,12

**High-Density Lipoproteins**

As their name indicates, high-density lipoproteins (HDLs) are small, dense lipoproteins with a very low cholesterol content and a high protein content. They are released from the liver and intestines to circulate in the blood. As they do, they pick up cholesterol from dying cells and arterial plaques and transfer it to other lipoproteins, which return it to the liver. The liver takes up the cholesterol and uses it to synthesize bile, thereby removing it from the circulatory system. High blood levels of HDL-cholesterol are therefore associated with a low risk for CVD. That's why HDL-cholesterol is often referred to as the "good cholesterol." There is some evidence that diets high in omega-3 fatty acids and participation in regular physical exercise can modestly increase HDL-cholesterol levels.13,14

**Total Serum Cholesterol**

Normally, as the dietary level of cholesterol increases, the body decreases the amount of cholesterol it makes and the amount of cholesterol it absorbs, which keeps the body's level of cholesterol constant. Unfortunately, this feedback mechanism does not work well in everyone. For some individuals, eating dietary cholesterol doesn't decrease the amount of cholesterol produced in the body, and their total body cholesterol level--including the level in their blood--rises. These individuals benefit from reducing their intake of saturated and *trans* fats, because doing so also decreases the intake of dietary cholesterol.

For most Americans, the Dietary Guidelines suggest focusing on limiting saturated fat intake.15

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**focus figure 3 Lipoprotein Transport and Distribution**

Lipids are transported in the body via several different lipoprotein compounds, such as chylomicrons, VLDLs, LDLs, and HDLs.

**CHYLOMICRONS**

Chylomicrons are produced in the enterocytes to transport dietary lipids. The enzyme lipoprotein lipase (LPL), found on the endothelial cells in the capillaries, hydrolyzes the triglycerides in the chylomicrons into fatty acids and glycerol, which enter body cells (such as muscle and adipose cells), leaving a chylomicron remnant. Chylomicron remnants are dismantled in the liver.

**VLDLS**

VLDLs (very-low-density lipoproteins) are produced primarily in the liver to transport endogenous fat in the form of triglycerides into the bloodstream. The enzyme lipoprotein lipase (LPL), found on the endothelial cells in the capillaries, breaks apart the triglycerides in the chylomicrons. The fatty acids can then enter the body cells, especially the muscle and adipose cells, leaving a chylomicron remnant. Glycerol is also released and is transported back to the liver.

**LDLS**

LDLs (low-density lipoproteins) are created with the removal of most of the VLDLs' triglyceride load. LDLs are rich in cholesterol, which they deliver to body cells with LDL receptors. LDLs not taken up by the cells are primarily taken up by the liver for degradation.

**HDLS**

HDLs (high-density lipoproteins) are produced in the liver and circulate in the blood, picking up cholesterol from dying cells, other lipoproteins, and arterial plaques. They return this cholesterol to the liver, where it can be recycled or eliminated from the body through bile.

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**TABLE 1** **Interpreting Blood Cholesterol Levels**

|  |  |
| --- | --- |
| **Total Cholesterol Level** | **Category** |
| Less than 200 mg/dL | Desirable |
| 200-239 mg/dL | Borderline high |
| 240 mg/dL and above | High |
| **LDL (Bad) Cholesterol Level** | **LDL Cholesterol Category** |
| Less than 100 mg/dL | Optimal |
| 100-129 mg/dL | Near optimal/above optimal |
| 130-159 mg/dL | Borderline high |
| 160-189 mg/dL | High |
| 190 mg/dL and above | Very High |
| **HDL (Good) Cholesterol level** | **HDL Cholesterol Category** |
| Less than 40 mg/dL | A major risk factor for heart disease |
| 40-59 mg/dL | The higher, the better |
| 60 mg/dL and higher | Considered protective against heart disease |

*Source:* National Institutes of Health. 2012, Summer. Cholesterol levels: What you need to know. *NIH Medline Plus Magazine* 7(2):6-7. www.nlm.nih.gov/medlineplus

By limiting intake of animal products or selecting low-fat versions, you can reduce your intake of both saturated fat and cholesterol. (See the suggestions for choosing healthful fats in Chapter 5.)

**You Can Estimate Your Risk for Cardiovascular Disease**

Now that you know more about blood lipids, you're probably wondering what your levels look like. If so, you can have them measured by your physician. See **TABLE 1** (above) to compare your blood lipid levels to optimal levels. You also need to know your blood pressure. Especially if you have a family history of CVD, it's important to have your blood pressure checked regularly.

After you've found this information, visit the website of the National Heart, Lung, and Blood Institute (NHLBI) to assess your 10-year risk for having a heart attack. See the **Web** **Links** at the end of this chapter.

## **How can you reduce your risk for cardiovascular disease?**

**LO 3** Identify several lifestyle choices that can reduce your risk for cardiovascular disease.

Many diet and exercise interventions aimed at reducing the risk for CVD center on reducing high levels of triglycerides and LDL-cholesterol while raising HDL-cholesterol.

Approaches aimed specifically at reducing blood pressure include most of the same recommendations, along with strict monitoring of sodium intake.

**Take Steps to Improve Your Blood Lipid Levels**

The Centers for Disease Control and Prevention and the American Heart Association have made the following dietary and lifestyle recommendations to improve blood lipid levels and reduce the risk for CVD.4,16

- Keep fat intake to within 20-35% of total energy intake.17

- Decrease dietary saturated fat to less than 7-10% of total energy intake and keep *trans* fatty acids as low as possible.11,15 (For dietary strategies, see the Quick Tips in Chapter 5.)

- Increase your intake of the omega-3 fatty acid ALA from dark green, leafy vegetables, soybeans or soybean oil, walnuts or walnut oil, flaxseed meal or oil, or canola oil. Also, consume fish, especially oily fish, at least twice a week to increase your intake of the omega-3 fatty acids EPA and DHA.

- Consume the RDA for vitamin B6, B12, and folate, because these B vitamins help maintain low blood levels of the amino acid homocysteine. High homocysteine levels in the blood are associated with increased risk for CVD.

- Increase dietary intakes of whole grains, fruits, and legumes and other vegetables, so that total dietary fiber is 20-30 g per day. Include oat bran, beans, and fruits, as these foods contain a type of fiber that helps to reduce LDL-cholesterol specifically.18

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- High blood glucose levels are associated with high blood triglycerides. To help maintain normal blood glucose, consume whole foods high in fiber (see the above bullet); select lean meats and low-fat dairy products; and limit your intake of foods high in added sugars and/ or saturated fat.

- Eat meals throughout the day instead of eating most of your Calories in the evening before bed. This approach decreases the load of fat entering the body at any one time. Exercising after a meal also helps keep blood lipids and glucose within normal ranges.

- Consume no more than two alcoholic drinks per day for men and one drink per day for women. Because heavy alcohol consumption can worsen high blood pressure, it is suggested that people with HTN abstain from drinking alcohol entirely. (Alcohol consumption is discussed In Depth following Chapter 7.)

- If you smoke, stop. As noted earlier, smoking significantly increases the risk for CVD.

- Exercise most days of the week for 30 to 60 minutes if possible. Exercise will increase HDL-cholesterol while lowering blood triglyceride levels. Exercise also helps you maintain a healthful body weight and a lower blood pressure and reduces your risk for type 2 diabetes.

- Maintain a healthful body weight. Obesity promotes inflammation; thus, keeping body weight within a healthful range helps keep inflammation low.19 In addition, blood pressure values have been shown to decrease 7-8% in people who have lost several pounds of body weight (~ 13 pounds).20

**Take Steps to Manage Your Blood Pressure**

We noted earlier that HTN is a risk factor in the development of atherosclerosis, CHD, and stroke. Therefore, the lifestyle changes just identified are appropriate for anyone diagnosed with hypertension or prehypertension. In addition, recommendations for reducing blood pressure include limiting dietary sodium intake and following the DASH diet.

**Limit Dietary Sodium**

Many people with HTN are sensitive to sodium; that is, when they consume a high-sodium diet, their blood pressure increases. We know, however, that not everyone with HTN is sensitive to sodium, and it is impossible to know who is sensitive and who is not because there is no ready test for sodium sensitivity. Moreover, lowering sodium intake does not reduce blood pressure in all people with hypertension. Thus, there is significant debate over whether everyone--or even everyone with HTN--can benefit from eating a lower-sodium diet.

Despite this debate, the leading health organizations, including the American Heart Association and the NHLBI, continue to support a reduction in dietary sodium to less than 2,300 mg/day, as recommended in the *2015-2020 Dietary Guidelines for Americans.*15 Currently, the average sodium intake in the United States is about 3,300 mg/day.

**Follow the DASH Diet**

The impact of diet on reducing the risk for cardiovascular disease-- including hypertension--was clearly demonstrated in a study from the National Institutes of Health (NIH) called Dietary Approaches to Stop Hypertension (DASH). The DASH **diet** is an eating plan that is high in several minerals that have been shown to help reduce hypertension, including calcium, magnesium, and potassium. At the same time, it is moderately low in sodium (2,300 mg/day on a 2000 kcal/d diet), low in saturated fat, and high in fiber, and it includes 10 servings of fruits and vegetables each day. **FIGURE 4** shows the DASH eating plan for a 2,000-kcal diet.

The results of the original NIH study showed that eating the DASH diet can dramatically improve blood lipids and lower blood pressure. These changes occurred within the first 2 weeks of eating the DASH diet and were maintained throughout the duration of the study. Researchers estimated that if all Americans followed the DASH diet plan and experienced reductions in blood pressure similar to this study, then CHD would be reduced by 15% and the incidence of strokes would be reduced by 27%.

A subsequent study of the DASH diet found that blood pressure decreases even more as sodium intake is reduced below 3,000 mg per day. In the study, participants ate a DASH diet that provided 3,300 mg, 2,300 mg, or 1,500 mg of sodium each day.21

[For DASH diet recipes, visit the Mayo Clinic at **www .mayo.org**. From the home page, type "DASH diet" in the search bar, then click on "DASH Diet Recipes" and get cooking!]

[Sidebar: **DASH diet** The diet developed in response to research into hypertension funded by the National Institutes of Health: DASH stands for "Dietary Approaches to Stop Hypertension."]

[Image: Consuming whole fruits and vegetables can reduce your risk for cardiovascular disease.]

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**The DASH Diet Plan**

|  |  |  |
| --- | --- | --- |
| **Food Group** | **Daily Servings** | **Serving Size** |
| Grains and grain products | 7-8 | 1 slice bread  1 cup ready-to-eat cereal\*  ½ cup cooked rice, pasta, or cereal |
| Vegetables | 4-5 | 1 cup raw leafy vegetables  ½ cup cooked vegetable  6 fl. oz vegetable juice |
| Fruits | 4-5 | 1 medium fruit  ¼ cup dried fruit  ½ cup fresh, frozen, or canned fruit  6 fl. oz fruit juice |
| Low-fat or fat-free dairy foods | 2-3 | 8 fl. oz milk  1 cup yogurt  1½ oz cheese |
| Lean meats, poultry, and fish | 2 or less | 3 oz cooked lean meats, skinless poultry, or fish |
| Nuts, seeds, and dry beans | 4-5 per week | ⅓ cup or 1½ oz nuts  1 tbsp. or ½ oz seeds  ½ cup cooked dry beans |
| Fats and oils† | 2-3 | 1 tsp. soft margarine  1 tbsp. low-fat mayonnaise  2 tbsp. light salad dressing  1 tsp. vegetable oil |
| Sweets | 5 per week | 1 tbsp. sugar  1 tbsp. jelly or jam  ½ oz jelly beans  8 fl. oz lemonade |

\*Serving sizes vary between ½ and 1¼ cups. Check the product's nutrition label.

†Fat content changes serving counts for fats and oils: for example, 1 tablespoon of regular salad dressing equals 1 serving; 1 tablespoon of a low-fat dressing equals ½ serving; 1 tablespoon of a fat-free dressing equals 0 servings.

**[FIGURE** **4** The DASH diet plan.

*Note:* This example is based on 2,000-kcal/day. Your number of servings in a food group may differ from the number listed, depending on your own energy needs. *Data adapted from:* Healthier Eating with DASH. The National Institutes of Health (NIH).]

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## **nutri-case GUSTAVO**

"Sometimes I wonder where doctors get their funny ideas. Yesterday I had my yearly checkup and my doctor says, 'You're doing great! Your weight is fine, your blood sugar's good. The only thing that concerns me is that your blood pressure is a little high, so I want you to watch your diet. Cut back on the red meats and eat fish instead. When you do eat red meat, trim off the fat. Cook with olive oil instead of lard. And go easy on the salt.' I know he means well, but my wife's finally able to move around again after breaking her hip. How am I supposed to tell her she has to learn a whole new way to cook?"

Do you think that Gustavo's objection to his doctor's advice is valid? Why or why not? Identify at least two alternatives or resources that might help Gustavo and his wife.

After 1 month on this diet, all the participants experienced a significant decrease in their blood pressure; however, those who ate the lowest-sodium version of the DASH diet experienced the largest decrease. Even more recent research shows that if you combine the DASH diet with physical activity and weight loss (of approximately 20 pounds), not only blood pressure, but blood lipids and other markers of CVD improve.22

**Prescription Medications Can Improve Blood Lipids and Blood Pressure**

For some individuals, lifestyle changes are not completely effective in normalizing blood lipids and blood pressure. When this is the case, a variety of medications can be prescribed. Some inhibit the body's production of cholesterol. These types of drugs, typically called *statins,* block an enzyme in the cholesterol synthesis pathway, which can help to lower blood levels of LDL-cholesterol and VLDL-cholesterol.2 Other medications prevent the reabsorption of bile in the gastrointestinal (GI) tract. Because bile is made from cholesterol, blocking its reabsorption and promoting its excretion in feces reduces the total cholesterol pool, which means the liver must draw on body cholesterol stores to make new bile acids. Diuretics may also be prescribed to flush excess water and sodium from the body, reducing blood volume and thus blood pressure. Other hypertension medications work to relax the blood vessel walls, allowing more room for blood flow. People taking such medications should also continue to practice the lifestyle changes listed earlier in this section because these changes will continue to benefit their long-term health.

**web links**

**www.nhlbi.nih.gov/chd**

National Cholesterol Education Program

*Check out this site for information on how a healthful diet can improve your blood lipid levels.*

**http://cvdrisk.nhlbi.nih.gov/**

National Heart, Lung, and Blood Institute Heart Attack Risk Calculator

*Visit this site to calculate your 10-year risk of having a heart attack.*

**www.nhlbi.nih.gov/health/educational/hearttruth/**

The Heart Truth. A Program of the National Institutes of Health

*Go here to learn more about how to reduce your risk of heart disease, especially focused on reducing women's risk of heart disease.*

**http://www.nhlbi.nih.gov/files/docs/public/heart/newdash.pdf**

National Heart, Lung, and Blood Institute: The DASH Diet

*Download this guide to lowering your blood pressure with DASH.*

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[**test yourself**

**1. T** **F** Protein is a primary source of energy for our body.

**2. T F** Most people in the United States consume more protein than they need.

**3. T F** Vegetarian diets are inadequate in protein.

*Test Yourself answers are located in the Study Plan at the end of this chapter.*]

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# **CHAPTER 6** **Proteins Crucial components of all body tissues**

***After studying this chapter you should be able to:***

**1** Describe the chemical structure of proteins, pp. 180-181.

**2** Discuss protein synthesis, degradation, and organization, including the role of mutual supplementation,

pp. 181-186.

**3** List eight functions of proteins in the body, pp. 187-191.

**4** Explain how proteins are digested and absorbed, pp. 191-193.

**5** Identify your recommended daily protein intake, healthful sources of protein, and consequences of high intake and deficiency,

pp. 193-202.

**6** List the benefits and potential challenges of consuming a vegetarian diet, pp. 203-207.]

**In their three years studying environmental sciences together at their small liberal arts college, Tamir, Kate, and Jian have built a strong friendship**--strong enough to withstand disagreements, which they often have over food choices in the campus dining hall: Tamir is a passionate vegan--no animal-based foods of any kind, not even eggs or cheese. He insists that everyone should adopt a vegetarian diet to preserve the environment and protect their own health. Kate takes a more nuanced view. She cites studies pointing out the benefits of fish consumption twice a week, and also eats poultry, eggs, and cheese. She believes that a diet higher in protein helps her maintain a healthful weight and that Tamir's diet would leave her exhausted. Jian is a meat eater: He knows that red meat consumption is linked to climate change and certain health risks, but says if he didn't eat it several times a week, he'd lose muscle mass and wouldn't be able to keep up his workouts at the gym. So who's right? Is there any one approach to protein intake that's best for most people?

It seems as if everybody has an opinion about protein, both how much you should consume and from what sources. In this chapter, we discuss the importance of protein in the diet and dispel common myths about this crucial nutrient.

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**LO** 1 Describe the chemical structure of proteins.

## **What are proteins?**

**Proteins** are large, complex molecules found in the cells of all living things. Although proteins are best known as a part of our muscle mass, they are, in fact, critical components of all the tissues of the human body, including bones, blood, and skin. Proteins also function in metabolism, immunity, fluid balance, and nutrient transport, and in certain circumstances they can provide energy. The functions of proteins will be discussed in detail later in this chapter.

**The Building Blocks of Proteins Are Amino Acids**

Like carbohydrates and lipids, proteins are macronutrients, but their chemical structure differs. In addition to the carbon, hydrogen, and oxygen also found in carbohydrates and lipids, proteins contain a special form of nitrogen that our body can readily use. Our body is able to break down the proteins in foods and utilize this nitrogen for many important processes. Carbohydrates and lipids do not provide nitrogen.

The proteins in our body are assembled according to instructions provided by our genetic material, or DNA, from building blocks called **amino acids.** These compounds are made up of a central carbon atom connected to four other groups: an amine group, an acid group, a hydrogen atom, and a side chain **(FIGURE 6.1a).** The word *amine* means "nitrogen-containing," and nitrogen is indeed the essential component of the amine portion of the molecule.

As shown in Figure 6.1b, the portion of the amino acid that makes each unique is its side chain. The amine group, acid group, and carbon and hydrogen atoms do not vary. Variations in the structure of the side chain give each amino acid its distinct properties.

The singular term *protein* is misleading because there are potentially an infinite number of unique types of proteins in living organisms. Most of the proteins in our body are made from combinations of just 20 amino acids, identified in **TABLE 6.1.** Two of the 20 amino acids listed in Table 6.1, cysteine and methionine, are unique in that, in addition to the components present in the other amino acids, they contain sulfur. By combining a few dozen to more than 300 of these 20 amino acids in various sequences, our body synthesizes an estimated 10,000 to 50,000 unique proteins.

**Nine Amino Acids Are Essential**

Of the 20 amino acids in our body, nine are classified as essential. This does not mean that they are more important than the others.

**[FIGURE 6.1** Structure of an amino acid. **(a)** All amino acids contain five parts: a central carbon atom; an amine group that contains nitrogen; an acid group; a hydrogen atom; and a side chain. **(b)** Only the side chain differs for each of the 20 amino acids, giving each its unique properties.]

[Image: Proteins are an integral part of our body tissues, including our muscle tissue.]

[Sidebar: **proteins** Large, complex molecules made up of amino acids and found as essential components of all living cells.]

[Sidebar: **amino acids** Nitrogen-containing molecules that combine to form proteins.]

[Sidebar: **essential** **amino acids** Amino acids not produced by the body that must be obtained from food.]

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[**FIGURE 6.2** Transamination. Our body can make nonessential amino acids by transferring the amine group from an essential amino acid to a different acid group and side chain.]

Instead, an **essential amino acid** is one that our body cannot produce at all or cannot produce in sufficient quantities to meet our physiologic needs. Thus, we must obtain essential amino acids from food. Without an adequate supply of essential amino acids in our body, we lose our ability to make the proteins and other nitrogen-containing compounds we need.

**Nonessential amino acids** are just as important to our body as essential amino acids, but our body can synthesize them in sufficient quantities, so we do not need to consume them in our diet. We make nonessential amino acids by transferring the amine group from other amino acids to a different acid group and side chain. This process is called **transamination (FIGURE 6.2).** The acid groups and side chains can be donated by amino acids, or they can be made from the breakdown products of carbohydrates and fats.

Under some conditions, a nonessential amino acid can become an essential amino acid. In this case, the amino acid is called a **conditionally essential amino acid.** Consider the disease known as phenylketonuria (PKU), in which the body cannot metabolize phenylalanine (an essential amino acid). In an infant with undiagnosed PKU, phenylalanine builds up in the blood to toxic levels that can cause irreversible brain damage. Moreover, because the body normally breaks down phenylalanine to produce the nonessential amino acid tyrosine, an inability to metabolize phenylalanine results in failure to make tyrosine, which then becomes a conditionally essential amino acid that must be provided by the diet. Other conditionally essential amino acids include arginine, cysteine, and glutamine.

**[recap**

Proteins are critical components of all the tissues of the human body. They contain carbon, hydrogen, oxygen, and nitrogen, and some contain sulfur. Their precise structure is dictated by DNA. The building blocks of proteins are amino acids. The amine group of the amino acid contains nitrogen. The portion of the amino acid that changes, giving each amino acid its distinct identity, is the side chain. Our body cannot make essential amino acids, so we must obtain them from our diet. Our body can make nonessential amino acids from parts of other amino acids, carbohydrates, and fats.]

**LO 2** Discuss protein synthesis, degradation, and organization, including the role of mutual supplementation.

## **How are proteins made?**

Cells synthesize proteins by selecting the needed amino acids from the pool of all amino acids available at any given time. Let's look more closely at how this occurs.

**TABLE 6.1 Amino Acids of the Human Body**

|  |  |
| --- | --- |
| **Essential Amino Acids** | **Nonessential Amino Acids** |
| *These amino acids must be consumed in the diet.* | *These amino acids can be manufactured by the body.* |
| Histidine | Alanine |
| Isoleucine | Arginine |
| Leucine | Asparagine |
| Lysine | Aspartic acid |
| Methionine | Cysteine |
| Phenylalanine | Glutamic acid |
| Threonine | Glutamine |
| Tryptophan | Glycine |
| Valine | Proline |
|  | Serine |
|  | Tyrosine |

[To learn more about amino acids, go to **www.johnkyrk .com**, and click on "Amino Acids and Proteins."]

[Sidebar: **nonessential amino acids** Amino acids that can be manufactured by the body in sufficient quantities and therefore do not need to be consumed regularly in our diet.]

[Sidebar: **transamination** The process of transferring the amine group from one amino acid to another in order to manufacture a new amino acid.]

[Sidebar: **conditionally essential amino acids** Amino acids that are normally considered nonessential but become essential under certain circumstances when the body's need for them exceeds the ability to produce them.]

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**[FIGURE 6.3** Amino acid bonding. Two amino acids join together to form a dipeptide. By combining multiple amino acids, proteins are made.]

**Amino Acids Bond to Form a Variety of Peptides**

**FIGURE 6.3** shows that, when two amino acids join together, the amine group of one binds to the acid group of another in a unique type of chemical bond called a **peptide bond.** In the process, a molecule of water is released as a by-product.

Two amino acids joined together form a *dipeptide,* and three amino acids joined together are called a *tripeptide.* The term *oligopeptide* is used to identify a string of four to nine amino acids, whereas a *polypeptide* is 10 or more amino acids bonded together. As a polypeptide chain grows longer, it begins to fold into any of a variety of complex shapes that give proteins their sophisticated structure.

**Genes Regulate Amino Acid Binding**

Each of us is unique because we inherited a specific "genetic code" that integrates the code from each of our parents. Each person's genetic code dictates minor differences in amino acid sequences, which in turn lead to differences in our body's individual proteins. These differences in proteins result in the unique physical and physiologic characteristics each one of us possesses.

A *gene* is a segment of deoxyribonucleic acid (DNA) that serves as a template for the synthesis--or expression--of a particular protein. That is, **gene expression** is the process by which cells use genes to make proteins.

Proteins are actually manufactured at the site of ribosomes in the cell's cytoplasm. But DNA never leaves the nucleus. So for gene expression to occur, a gene's DNA has to replicate itself--that is, it must make an exact copy of itself, which can then be carried out to the cytoplasm. DNA replication ensures that the genetic information in the original gene is identical to the genetic information used to build the protein. Through the process of replication, DNA provides the instructions for building every protein in the body.

Cells use a special molecule to copy, or transcribe, the information from DNA and carry it to the ribosomes. This molecule is *messenger RNA (messenger ribonucleic acid,* or *mRNA).* During **transcription,** mRNA copies the genetic information from DNA in the nucleus **(FOCUS FIGURE 6.4, step 1).** Then, mRNA detaches from the DNA and leaves the nucleus, carrying its genetic "message" to the ribosomes in the cytoplasm (Focus Figure 6.4, step 2).

Once the genetic information reaches the ribosomes, **translation** occurs; that is, the language of the mRNA genetic information is translated into the language of amino acid sequences. At the ribosomes, mRNA binds with ribosomal RNA (rRNA) and its genetic information is distributed to molecules of transfer RNA (tRNA) (Focus Figure 6.4, step 3). Now the tRNA molecules roam the cytoplasm until they succeed in binding with the specific amino acid that matches their genetic information. They then transfer their amino acid to the ribosome, which assembles the amino acids into proteins (Focus Figure 6.4, step 4).

Once the amino acids are loaded onto the ribosome, tRNA works to maneuver each amino acid into its proper position (Focus Figure 6.4, step 5).

[Sidebar: **peptide bond** Unique type of chemical bond in which the amine group of one amino acid binds to the acid group of another in order to manufacture dipeptides and all larger peptide molecules.]

[Sidebar: **gene expression** The process of using a gene to make a protein.]

[Sidebar: **transcription** The process through which messenger RNA copies genetic information from DNA in the nucleus.]

[Sidebar: **translation** The process that occurs when the genetic information carried by messenger RNA is translated into a chain of amino acids at the ribosome.]

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**focus figure 6.4 Protein Synthesis**

Cell \_\_\_\_\_\_\_\_\_

Nucleus \_\_\_\_\_\_\_\_

In the nucleus, genetic information from DNA is transcribed by messenger RNA (mRNA), which then carries it to ribosomes in the cytoplasm, where this genetic information is translated into a chain of amino acids that eventually make a protein.

**1** Part of the DNA unwinds, and a section of its genetic code is transcribed to the mRNA inside the nucleus.

**2** The mRNA leaves the nucleus via a nuclear pore and travels to the cytoplasm.

**3** Once the mRNA reaches the cytoplasm, it binds to a ribosome via ribosomal RNA (rRNA). The code on the mRNA is translated into the instructions for a specific order of amino acids.

**4** The transfer RNA (tRNA) binds with specific amino acids in the cytoplasm and transfers the amino acids to the ribosome as dictated by the mRNA code.

**5** The amino acid is added to the growing amino acid chain, and the tRNA returns to the cytoplasm.

**6** Once the synthesis of the new protein is complete, the protein is released from the ribosome. The protein may go through further modifications in the cell or can be functional in its current state.

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When synthesis of the new protein is completed, it is released from the ribosome and can either go through further modification in the cell or can be functional in its current state (Focus Figure 6.4, step 6).

Although the DNA for making every protein in our body is contained within each cell nucleus, not all genes are expressed, and each cell does not make every type of protein. For example, each cell contains the DNA to manufacture the hormone insulin. However, only the beta cells of the pancreas *express* the insulin gene to produce insulin. Our physiologic needs alter gene expression, as do various nutrients. For instance, a cut in the skin that causes bleeding will prompt the production of various proteins that clot the blood. Or if we consume more dietary iron than we need, the gene for ferritin (a protein that stores iron) will be expressed, so that we can store this extra iron.

**Protein Turnover Involves Synthesis and Degradation**

The process of *protein turnover* begins with the degradation of proteins from food or the breakdown of cells. This releases amino acids into the body's *amino acid pool,* from which cells select the amino acids needed for the synthesis of new proteins **(FIGURE 6.5).** This process allows the body to replace the proteins in worn-out cells and functional compounds. The body's pool of amino acids is also used to produce glucose, fat, and other compounds.

**Protein Organization Determines Function**

Four levels of protein structure have been identified **(FIGURE 6.6).** The sequential order of the amino acids in a protein is called the *primary structure* of the protein. The different amino acids in a polypeptide chain possess unique chemical characteristics that cause the chain to twist and turn into a characteristic spiral shape, or to fold into a so-called pleated sheet. These shapes are referred to as the protein's *secondary structure.*

**[FIGURE 6.5** Protein turnover involves the synthesis of new proteins and breakdown of existing proteins to provide building blocks for new proteins. Amino acids are drawn from the body's amino acid pool and can be used to build proteins, fat, glucose, and nonprotein, nitrogen-containing compounds. Urea is produced as a waste product from any excess nitrogen, which is then excreted by the kidneys.]

[Sidebar: **denaturation** The process by which proteins uncoil and lose their shape and function when they are exposed to heat, acids, bases, heavy metals, alcohol, and other damaging substances.]

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[**(a) Primary structure**

**(b) Secondary structure**

**(c) Tertiary structure**

**(d) Quaternary structure]**

**[FIGURE 6.6** Levels of protein structure. **(a)** The primary structure of a protein is the sequential order of amino acids. **(b)** The secondary structure of a protein is the twisting or folding of the amino acid chain. **(c)** The tertiary structure is a further folding that results in the three-dimensional shape of the protein. (d) In proteins with a quaternary structure, two or more polypeptides interact, forming a larger protein, such as the actin molecule illustrated here. In muscle tissue, strands of actin molecules intertwine to form contractile elements involved in generating muscle contractions.]

The stability of the secondary structure is achieved by hydrogen bonds that create a bridge between two protein strands or two parts of the same strand of protein. The spiral or pleated sheet of the secondary structure further folds into a unique three-dimensional shape, referred to as the protein's *tertiary structure.* Bonds between hydrogen atoms and between sulfur atoms, if any, maintain the tertiary shape, which is critical because it determines each protein's function in the body.

Many large proteins have a fourth level of organization. This *quaternary structure* forms when two or more identical or different polypeptides bond. The resulting larger protein may be *globular* or *fibrous.*

The importance of the shape of a protein to its function cannot be overemphasized. For example, the protein strands in muscle fibers are much longer than they are wide (see Figure 6.6d). This structure plays an essential role in enabling muscle contraction and relaxation. In contrast, the proteins that form red blood cells are globular in shape, and they result in the red blood cells being shaped like flattened discs with depressed centers, similar to a miniature doughnut **(FIGURE 6.7).** This structure and the flexibility of the proteins in the red blood cells permit them to change shape and flow freely through even the tiniest capillaries to deliver oxygen and still return to their original shape.

**Protein Denaturation Affects Shape and Function**

Proteins can uncoil and lose their shape when they are exposed to heat, acids, bases, heavy metals, alcohol, and other damaging substances. The term used to describe this change in the shape of proteins is **denaturation**. Everyday examples of protein denaturation are the stiffening of egg whites when they are whipped, the curdling of milk when lemon juice or another acid is added, and the solidifying of eggs as they cook.

Denaturation does not affect the primary structure of proteins. However, when a protein is denatured, its function is lost. For instance, denaturation of critical body proteins on exposure to heat or acidity is harmful, because it prevents them from performing their functions. This type of denaturation can occur during times of high fever or when blood pH is out of the normal range.

[To view a video showing a protein developing from primary to quaternary structure, go to **www.dnatube.com,** click on "Watch Videos," and then type "aminoacids" (as one word) into the search box. Click on the video titled "How bunch of aminoacids organise to form functional protein."]

**[FIGURE 6.7** Protein shape determines function. The globular shape of protein in red blood cells contributes to the flexible-disk shape of the cells. This in turn enables their passage through the tiniest blood vessels of the body.]

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In some cases, however, denaturation is helpful. For instance, denaturation of proteins during the digestive process allows for their breakdown into amino acids and the absorption of these amino acids from the digestive tract into the bloodstream.

**Protein Synthesis Can Be Limited by Missing Amino Acids**

For protein synthesis to occur, all essential amino acids must be available to the cell. If this is not the case, the amino acid that is missing or in the smallest supply is called the **limiting amino acid.** Without the proper combination and quantity of essential amino acids, protein synthesis slows to the point at which proteins cannot be generated. For instance, the protein hemoglobin contains the essential amino acid histidine. If we do not consume enough histidine, it becomes the limiting amino acid in hemoglobin production. Because no other amino acid can be substituted, our body becomes unable to make adequate hemoglobin, and we lose the ability to transport oxygen to our cells.

Inadequate energy consumption also limits protein synthesis. If there is not enough energy available from our diets, our body will use any accessible proteins for energy, thus preventing them from being used to build new proteins.

A protein that does not contain all of the essential amino acids in sufficient quantities to support growth and health is called an **incomplete (***low-quality)* **protein.** A protein that has all nine of the essential amino acids is considered a **complete (***high-quality)* **protein.** The most complete protein sources are foods derived from animals and include egg whites, meat, poultry, fish, and milk. Soybeans and a pseudo-grain called quinoa (pronounced keen-wah) are the most complete sources of plant protein. In general, the typical American diet is very high in complete proteins because we consume proteins from a variety of food sources.

**Protein Synthesis Can Be Enhanced by Mutual Supplementation**

We also obtain complete proteins by combining foods. Consider a meal of red beans and rice. Red beans are low in the amino acids methionine and cysteine but have adequate amounts of isoleucine and lysine. Rice is low in isoleucine and lysine but contains sufficient methionine and cysteine. Combining red beans and rice creates a complete protein.

**Mutual supplementation** is the process of combining two or more incomplete protein sources to make a complete protein. The two foods involved are called complementary foods; these foods provide **complementary proteins (FIGURE 6.8),** which, when combined, provide all nine essential amino acids.

It is not necessary to eat complementary proteins at the same meal. Recall that we maintain a free pool of amino acids in the blood; these amino acids come from food and sloughed-off cells. When we eat one complementary protein, its amino acids join those in the free amino acid pool. These free amino acids can then combine to synthesize complete proteins. However, it is wise to eat complementary-protein foods during the same day because partially completed proteins cannot be stored and saved for a later time. Mutual supplementation is important for people eating a vegetarian diet, particularly if they consume no animal products whatsoever.

**[recap**

Amino acids bind together to form proteins. Genes regulate the amino acid sequence, and thus the structure, of all proteins. The shape of a protein determines its function. When a protein is denatured by damaging substances, such as heat and acids, it loses its shape and its function. When a particular essential amino acid is unavailable, protein synthesis cannot occur. A complete protein provides all nine essential amino acids. Mutual supplementation combines two complementary-protein sources to make a complete protein.]

[Image: Stiffening egg whites adds air through the beating action, which denatures some of the proteins within them.]

[Sidebar: **limiting amino acid** The essential amino acid that is missing or in the smallest supply in the amino acid pool and is thus responsible for slowing or halting protein synthesis.]

[Sidebar: **incomplete protein** Food that does not contain all of the essential amino acids in sufficient amounts to support growth and health.]

[Sidebar: **complete protein** Food that contains sufficient amounts of all nine essential amino acids to support growth and health.]

[Sidebar: **mutual supplementation** The process of combining two or more incomplete protein sources to make a complete protein.]

[Sidebar: **complementary proteins** Two or more foods that together contain all nine essential amino acids necessary for a complete protein. It is not necessary to eat complementary proteins at the same meal.]

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[**FIGURE 6.8** Complementary food combinations.]

**LO 3** List eight functions of proteins in the body.

## **Why do we need proteins?**

The functions of proteins in the body are so numerous that only a few can be described in detail in this chapter. Note that proteins function most effectively when we also consume adequate amounts of energy as carbohydrates and fat. When there is not enough energy available, the body uses proteins as an energy source, limiting their availability for the functions described in this section.

**Proteins Contribute to Cell Growth, Repair, and Maintenance**

We've noted that the proteins in our body are constantly being broken down, repaired, and replaced. Think about all of the new proteins that are needed to allow an embryo to develop into a fetus and grow into a newborn baby with more than 10 trillion body cells. This growth continues, of course, throughout childhood, but even in adulthood, our cells are constantly turning over, as damaged or worn-out cells are broken down and their components are used to create new cells. Our red blood cells live for only 3 to 4 months and then are replaced by new cells that are produced in bone marrow. The cells lining our intestinal tract are replaced every 3 to 6 days. The "old" intestinal cells are treated just like the proteins in food; they are digested and the amino acids absorbed back into the body. The constant turnover of proteins from our diet is essential for such cell growth, repair, and maintenance.

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**Proteins Act as Enzymes and Hormones**

Recall that enzymes are compounds--usually proteins--that speed up chemical reactions without being changed by the chemical reaction themselves. Enzymes can increase the rate at which reactants bond, break apart, or exchange components.

Each cell contains thousands of enzymes that facilitate specific cellular reactions. For example, the enzyme phosphofructokinase (PFK) is critical to driving the rate at which we break down glucose and use it for energy during exercise. Without PFK, we would be unable to generate energy at a fast enough rate to allow us to be physically active.

Although some hormones are made from lipids, most are composed of amino acids. Recall that various glands in the body release hormones into the bloodstream in response to changes in the body's environment. They then act on the body's cells and tissues to restore the body to normal conditions. For example, insulin and glucagon, hormones made from amino acids, act to regulate the level of glucose in the blood (see Chapter 4). *Melatonin* is an amino-acid hormone that plays a critical role in the regulation of sleep. Other amino-acid hormones help regulate growth, metabolism, and many other processes.

**Proteins Help Maintain Fluid and Electrolyte Balance**

*Electrolytes* are electrically charged atoms (ions) that assist in maintaining fluid balance. For our body to function properly, fluids and electrolytes must be maintained at healthy levels inside and outside cells and within blood vessels. Proteins attract fluids, and the proteins that are in the bloodstream, in the cells, and in the spaces surrounding the cells work together to keep fluids moving across these spaces in the proper quantities to maintain fluid balance and blood pressure. When protein intake is deficient, the concentration of proteins in the bloodstream is insufficient to draw fluid from the tissues and across the blood vessel walls; fluid then collects in the tissues, causing **edema (FIGURE 6.9).** In addition to being uncomfortable, edema can lead to serious medical problems.

Sodium (Na+) and potassium (K+) are examples of common electrolytes. Under normal conditions, Na+ is more concentrated outside the cell, and K+ is more concentrated inside the cell. This proper balance of Na+ and K+ is accomplished by the action of **transport proteins** located within the cell membrane. **FIGURE 6.10** (page 190) shows how these transport proteins work to pump Na+ outside and K+ inside of the cell. The conduction of nerve signals and contraction of muscles depend on a proper balance of electrolytes. If protein intake is deficient, we lose our ability to maintain these functions, resulting in potentially fatal changes in the rhythm of the heart. Other consequences of chronically low protein intakes include muscle weakness and spasms, kidney failure, and, if conditions are severe enough, death.

**Proteins Help Maintain Acid-Base Balance**

The body's cellular processes result in the constant production of acids and bases. Recall that acids are fluids containing a level of hydrogen ions higher than that of pure water, whereas bases (alkaline fluids) have fewer hydrogen ions than pure water. Acids and bases are transported in the blood to be excreted through the kidneys and the lungs. The body goes into a state called **acidosis** when the blood becomes too acidic. **Alkalosis** results if the blood becomes too basic (alkaline). Both acidosis and alkalosis can be caused by respiratory or metabolic problems, and both can cause coma and death by denaturing body proteins.

You can appreciate, then, why the body maintains very tight control over the pH, or the acid-base balance, of the blood. It does this by means of several mechanisms, including **buffers,** compounds that help return acidic and alkaline fluids closer to neutral. Proteins are excellent buffers because their side chains have negative charges that can bind hydrogen ions when the blood becomes acidic, neutralizing their detrimental effects on the body. Proteins can also release the hydrogen ions when the blood becomes too basic. By buffering acids and bases, proteins maintain acid-base balance and blood pH.

[Sidebar: **edema** A disorder in which fluids build up in the tissue spaces of the body, causing fluid imbalances and a swollen appearance.]

[Sidebar: **transport proteins** Protein molecules that help transport substances throughout the body and across cell membranes.]

[Sidebar: **acidosis** A disorder in which the blood becomes acidic; that is, the level of hydrogen in the blood is excessive. It can be caused by respiratory or metabolic problems.]

[Sidebar: **alkalosis** A disorder in which the blood becomes basic; that is, the level of hydrogen in the blood is deficient. It can be caused by respiratory or metabolic problems.]

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[**FIGURE 6.9** The role of proteins in maintaining fluid balance. The heartbeat exerts pressure that continually pushes fluids in the bloodstream through the arterial walls and out into the tissue spaces. By the time blood reaches the veins, the pressure of the heartbeat has greatly decreased. In this environment, proteins in the blood are able to draw fluids out of the tissues and back into the bloodstream. **(a)** This healthy (nonswollen) tissue suggests that body fluids in the bloodstream and in the tissue spaces are in balance. **(b)** When the level of proteins in the blood is insufficient to draw fluids out of the tissues, edema can result. This foot with edema is swollen due to fluid imbalance.]

**Proteins Help Maintain a Strong Immune System**

**Antibodies** are special proteins that are critical to immune function. When a foreign substance attacks the body, the immune system produces antibodies to defend against it. Bacteria, viruses, toxins, and allergens (substances that cause allergic reactions) are examples of antigens that can trigger antibody production. (An *antigen* is any substance--but typically a protein--that our body recognizes as foreign and that triggers an immune response.)

Each antibody is designed to destroy one specific invader. When that substance invades the body, antibodies are produced to neutralize or target the specific antigen so that it can be destroyed. Once antibodies have been made, the body "remembers" this process and can respond more quickly the next time that particular invader appears. *Immunity* refers to the development of the molecular memory to produce antibodies quickly upon subsequent invasions.

Adequate protein is necessary to support the increased production of antibodies that occurs in response to a cold, flu, or an allergic reaction. If we do not consume enough protein, our resistance to illnesses and disease is weakened. On the other hand, eating more protein than we need does not improve immune function.

[Sidebar: **buffers** Proteins that help maintain proper acid-base balance by attaching to, or releasing, hydrogen ions as conditions change in the body.]

[Sidebar: **antibodies** Defensive proteins of the immune system. Their production is prompted by the presence of bacteria, viruses, toxins, allergens, and other antigens.]

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[**FIGURE 6.10** Transport proteins help maintain electrolyte balance. Transport proteins in the cell membrane pick up potassium and sodium and transport them across the cell membrane.]

**Proteins Serve as an Energy Source**

The body's primary energy sources are carbohydrate and fat. Remember that both carbohydrate and fat have specialized storage forms that can be used for energy: glycogen for carbohydrate and triglycerides for fat. Proteins do not have a specialized storage form for energy. This means that, when proteins need to be used for energy, they are taken from the blood, liver, skeletal muscle, and other body tissues. In healthy people, proteins contribute very little to energy needs. Because we are efficient at recycling amino acids, protein needs are relatively low as compared to needs for carbohydrate and fat.

To use proteins for energy, the liver removes the amine group from the amino acids in a process called **deamination.** The nitrogen bonds with hydrogen, creating ammonia, which is a toxic compound that can upset acid-base balance. This is avoided, however, because the liver quickly converts ammonia to *urea.* The urea is then transported to the kidneys, where it is filtered out of the blood and is subsequently excreted in the urine. The remaining fragments of the amino acid contain carbon, hydrogen, and oxygen. The body can use these fragments to generate energy or to build carbohydrates. Certain amino acids can be converted into glucose via gluconeogenesis. This is a critical process during times of low carbohydrate intake or starvation. Fat cannot be converted into glucose, but body proteins can be broken down and converted into glucose to provide needed energy to the brain.

To protect the proteins in our body tissues, it is important that we regularly eat an amount of carbohydrate and fat sufficient to meet our energy needs. We also need to consume enough dietary protein to meet our physiologic needs and spare the proteins in blood and other body tissues. Again, our body cannot store excess dietary protein. As a consequence, eating too much protein results in the removal and excretion of the nitrogen in the urine and the use of the remaining components for energy. Any remaining components not used for energy are converted to fatty acids and stores as triglycerides in body fat.

**Proteins Assist in the Transport and Storage of Nutrients**

Proteins act as carriers for many important nutrients in the body. As you've learned, lipoproteins contain lipids bound to proteins, which allows the transport of hydrophobic lipids through the watery medium of blood (see Chapter 5). Another example of a transport protein is transferrin, which carries iron in the blood. Ferritin, in contrast, is an example of a storage protein: it is the compound in which iron is stored in the liver.

[Sidebar: **deamination** The process by which an amine group is removed from an amino acid. The nitrogen is then transported to the kidneys for excretion in the urine, while the carbon and other components are metabolized for energy or used to make other compounds.]

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We've also said that transport proteins located in cell membranes allow the proper transport of many nutrients into and out of the cell. These transport proteins also help in the maintenance of fluid and electrolyte balance and conduction of nerve impulses.

**Proteins Are Critical to Nerve Function, Blood Clotting, and Wound Healing**

The amino acids from proteins can also be used to make **neurotransmitters,** chemicals that transmit messages from one nerve cell to another. Examples of neurotransmitters include epinephrine and norepinephrine, both of which stimulate the sympathetic nervous system; and serotonin, which is important for the functioning of the central nervous system and the enteric nervous system of the gastrointestinal (GI) tract.

Proteins are also critical in blood clotting. The watery portion of blood, called plasma, contains clotting factors, proteins that initiate a chain of reactions that convert another plasma protein, fibrinogen, to a fibrous protein called *fibrin.* Strands of fibrin form a mesh that helps to temporarily seal a broken blood vessel. The scar tissue that is formed to heal wounds comprises another protein, *collagen,* which is also a key component of bone, tendons, skin, and many other tissues.

**[recap**

Proteins serve eight broad functions in the body. They (1) enable growth, repair, and maintenance of body tissues; (2) act as enzymes and hormones; (3) help maintain fluid and electrolyte balance; (4) contribute to acid-base balance; (5) make antibodies, which are essential to immune function; (6) provide energy when carbohydrate and fat intake are inadequate; (7) transport and store nutrients; and (8) are components of neurotransmitters, clotting proteins, and collagen. Proteins function best when adequate amounts of carbohydrate and fat are consumed.]

**LO 4** Explain how proteins are digested and absorbed.

## **How does the body process proteins?**

Again, our body does not directly use proteins from the diet to make the proteins we need. Dietary proteins are first digested into amino acids, which are absorbed and transported to the cells. In this section, we will review this process. Refer to **FOCUS FIGURE 6.11** (page 192) for a visual overview of protein digestion.

**Stomach Acids and Enzymes Break Proteins into Short Polypeptides**

Virtually no enzymatic digestion of proteins occurs in the mouth. As shown in Focus Figure 6.11, proteins in food are chewed, crushed, and moistened with saliva to ease swallowing and to increase the surface area of the protein for more efficient digestion. There is no further digestive action on proteins in the mouth.

When proteins reach the stomach, hydrochloric acid denatures the protein strands. It also converts the inactive enzyme, *pepsinogen,* into its active form, **pepsin,** which is a protein-digesting enzyme. Although pepsin is itself a protein, it is not denatured by the acid in the stomach because it has evolved to work optimally in an acidic environment. The hormone *gastrin* controls both the production of hydrochloric acid and the release of pepsin; thinking about food or actually chewing food stimulates the gastrin-producing cells in the stomach. Pepsin begins breaking proteins into single amino acids and shorter polypeptides; these amino acids and polypeptides then travel to the small intestine for further digestion and absorption.

**Enzymes in the Small Intestine Break Polypeptides into Single Amino Acids**

As the polypeptides reach the small intestine, the pancreas and the small intestine secrete enzymes that digest them into oligopeptides, tripeptides, dipeptides, and single amino acids (see Focus Figure 6.11).

[To learn more about how blood clots and wounds heal, go to **www.medlineplus.gov**, click on "Videos and Tools," then "Health Videos," and then click "blood clotting."]

[Sidebar: **neurotransmitters** Chemical compounds that transmit messages from one nerve cell to another.]

[Sidebar: **pepsin** An enzyme in the stomach that begins the breakdown of proteins into shorter polypeptide chains and single amino acids.]

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Digestion of dietary proteins into single amino acids occurs primarily in the stomach and small intestine. The single amino acids are then transported to the liver, where they may be converted to glucose or fat, used for energy or to build new proteins, or transported to cells as needed.

**ORGANS OF THE GI TRACT**

**MOUTH**

Proteins in foods are crushed by chewing and moistened by saliva.

**STOMACH**

Proteins are denatured by hydrochloric acid.

Pepsin is activated to break proteins into single amino acids and smaller polypeptides.

**SMALL INTESTINE**

Proteases are secreted to digest polypeptides into smaller units.

Enterocytes complete the breakdown of dipeptides and tripeptides into single amino acids, which are absorbed into the bloodstream.

**ACCESSORY ORGANS**

**PANCREAS**

Produces proteases, which are released into the small intestine.

**LIVER**

Amino acids are transported to the liver, where they are converted to glucose or fat, used for energy or to build new proteins, or sent to the cells as needed.

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The enzymes that digest proteins in the small intestine are called **proteases.**

The enterocytes of the small intestine then absorb the single amino acids, dipeptides, and tripeptides. Peptidases, enzymes located in the enterocytes, break the dipeptides and tripeptides into single amino acids. The amino acids are then transported via the portal vein into the liver. Once in the liver, amino acids may be converted to glucose or fat, combined to build new proteins, used for energy, or released into the bloodstream and transported to other cells as needed.

The cells of the small intestine have different sites that specialize in transporting certain types of amino acids, dipeptides, and tripeptides. This fact has implications for users of amino acid supplements. When very large doses of supplements containing single amino acids are taken on an empty stomach, they typically compete for the same absorption sites. This competition can block the absorption of other amino acids and could in theory lead to deficiencies. In reality, people rarely take such large doses of single amino acids on an empty stomach.

**Protein Digestibility Affects Protein Quality**

Earlier in this chapter, we discussed how various protein sources differ in quality of protein. The quantity of essential amino acids in a protein determines its quality: higher-protein-quality foods are those that contain more of the essential amino acids in sufficient quantities needed to build proteins, and lower-quality-protein foods contain fewer essential amino acids. Another factor in protein quality is *digestibility.* Animal protein sources, such as meat and dairy products, are highly digestible, as are many soy products; we can absorb more than 90% of the amino acids in these protein sources. Legumes are also highly digestible (about 70% to 80%). Grains and many vegetable proteins are less digestible, ranging from 60% to 90%.

**[recap**

In the stomach, hydrochloric acid denatures proteins and converts pepsinogen to pepsin; pepsin breaks proteins into polypeptides and individual amino acids. In the small intestine, proteases break polypeptides into smaller fragments and single amino acids. Enzymes in the enterocytes break the smaller peptide fragments into single amino acids, which are then absorbed into the bloodstream and transported to the liver for distribution to body cells. Protein digestibility and the provision of essential amino acids influence protein quality.]

**LO 5** Identify your recommended daily protein intake, healthful sources of protein, and consequences of high intake and deficiency.

## **How much protein should you eat?**

Consuming adequate protein is a major concern of many people. In fact, one of the most common concerns among active people and athletes is that their diets are deficient in protein. This concern about dietary protein is generally unnecessary because we can easily consume the protein our body needs by eating an adequate and varied diet.

**Nitrogen Balance Is a Method Used to Determine Protein Needs**

A highly specialized procedure referred to as *nitrogen balance* is used to determine a person's protein needs. Nitrogen is excreted through the body's processes of recycling or using proteins; thus, the balance can be used to estimate whether protein intake is adequate to meet protein needs.

Typically performed only in experimental laboratories, nitrogen balance involves measuring both nitrogen intake and nitrogen excretion over a 2-week period. A standardized diet, the nitrogen content of which has been measured and recorded, is fed to the study participant. The person is required to consume all of the foods provided. Because the majority of nitrogen is excreted in the urine and feces, laboratory technicians directly measure the nitrogen content of the subject's urine and fecal samples. Small amounts of nitrogen are excreted in the skin, hair, and body fluids such as mucus and semen, but, because of the complexity of collecting nitrogen excreted via these routes, the measurements are estimated.

[Image: Meats are highly digestible sources of dietary protein.]

[Sidebar: **proteases** Enzymes that continue the breakdown of polypeptides in the small intestine.]

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Then, technicians add the estimated nitrogen losses to the nitrogen measured in the subject's urine and feces. Nitrogen balance is then calculated as the difference between nitrogen intake and nitrogen excretion.

People who consume more nitrogen than is excreted are considered to be in positive nitrogen balance **(FIGURE 6.12).** This state indicates that the body is retaining or adding protein, and it occurs during periods of growth, pregnancy, or recovery from illness or a protein deficiency. People who excrete more nitrogen than they consume are in negative nitrogen balance. This situation indicates that the body is losing protein, and it occurs during starvation or when people are consuming very-low-energy diets. This is because, when energy intake is too low to meet energy demands over a prolonged period, the body metabolizes body proteins for energy.

**[(a) Nitrogen consumption > Nitrogen excretion**

**Positive Nitrogen Balance**

Needed for periods of growth, pregnancy, recovery from illness, or protein deficiency

**(b) Nitrogen consumption < Nitrogen excretion**

**Negative Nitrogen Balance**

Results from starvation, consumption of very-low-energy diets, severe illness, infections, serious burns, or injuries

**(c) Nitrogen consumption = Nitrogen excretion**

**Nitrogen Balance**

Found in healthy adults who are not pregnant]

**[FIGURE 6.12** Nitrogen balance describes the relationship between how much nitrogen (protein) we consume and how much we excrete each day. **(a)** Positive nitrogen balance occurs when nitrogen consumption is greater than excretion. **(b)** Negative nitrogen balance occurs when nitrogen consumption is less than excretion. **(c)** Nitrogen balance is maintained when nitrogen consumption equals excretion.]

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## [**you do the math Calculating Your Protein Needs**

Theo wants to know how much protein he needs each day. During the off-season, he works out three times a week at a gym and practices basketball with friends every Friday night. He is not a vegetarian. Although Theo exercises regularly, he would not be considered an endurance athlete or a strength athlete during the off-season. At this level of physical activity, Theo's requirement for protein probably ranges from the RDA of 0.8 up to 1.0 g per kg body weight per day. To calculate the total number of grams of protein Theo should eat each day:

**1.** Convert Theo's weight from pounds to kilograms. Theo presently weighs 200 pounds. To convert this value to kilograms, divide by 2.2:

200 pounds ÷ 2.2 pounds/kg = 91 kg

**2.** Multiply Theo's weight in kilograms by his RDA for protein, like so:

91 kg × 0.8 g/kg = 72.8 grams of protein per day

91 kg × 1.0 g/kg = 91 grams of protein per day

What happens during basketball season, when Theo practices, lifts weights, and has games 5 or 6 days a week? This will probably raise his protein needs to approximately 1.2 to 1.7 g per kg body weight per day. How much more protein should he eat? See below:

91 kg × 1.2 g/kg = 109.2 grams of protein per day

91 kg × 1.7 g/kg = 154.7 grams of protein per day

Now calculate your own recommended protein intake based on your activity level.

*Answers will vary depending upon body weight and individual activity levels.*]

The nitrogen from these proteins is excreted in the urine and feces. Negative nitrogen balance also occurs during severe illness, infections, high fever, serious burns, or injuries that cause significant blood loss. People in these situations require increased dietary protein. A person is in nitrogen balance when nitrogen intake equals nitrogen excretion. This indicates that protein intake is sufficient to cover protein needs. Healthy adults who are not pregnant are in nitrogen balance.

Although nitrogen balance has been used for many years as a method to estimate protein needs in humans, it has been criticized because it is so time- and labor-intensive for both research participants and scientists. In addition, because it is not possible to collect and measure all of the nitrogen excreted each day, this method is recognized as underestimating protein needs.1

**Recommended Dietary Allowance for Protein**

The RDA for protein for sedentary people is 0.8 g per kg body weight per day. The recommended percentage of energy that should come from protein is 10% to 35% of total energy intake. Protein needs are higher for children, adolescents, and pregnant/lactating women because more protein is needed during times of growth and development (see Chapters 14 and 15). Protein needs can also be higher for active people, older adults, and vegetarians. For example, recent evidence indicates that the dietary intake needed to promote the needs of active people ranges from 1.2 to 2.0 g per kg body weight per day.2 To learn more about the evidence surrounding increased protein needs for various groups, refer to the **Nutrition Debate** at the end of this chapter.

How can you convert the RDA into the total grams of protein your need per day? See the **You Do the Math** box on this page to calculate Theo's protein requirements, and then calculate your own.

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**Most Americans Meet or Exceed the RDA for Protein**

Surveys indicate that Americans eat almost 16% of their total daily energy intake as protein,3 averaging about 78 to 87 g per day.4 Putting these values into perspective, let's assume that the average man weighs 75 kg (165 pounds) and the average woman weighs 65 kg (143 pounds). Their protein requirements (assuming they are sedentary) are 60 g and 52 g per day, respectively. As you can see, many adults in the United States eat more than the RDA for protein.

As previously discussed, active individuals have higher protein needs than people who are inactive. Does this mean you should add more protein to your diet if you are active? Not necessarily. You need to assess your current level of protein intake to determine if it is within the current recommendations of 1.2 to 2 g per kg body weight per day for active people. It is important to note that certain groups of athletes are at risk for low protein intakes. Athletes who consume inadequate energy and limit food choices, such as some distance runners, figure skaters, female gymnasts, wrestlers, and body builders who are dieting, are all at risk for inadequate protein intakes or increased protein needs due to low energy intakes. Unlike people who consume adequate energy, individuals who are restricting their total energy intake (kilocalories) need to pay close attention to their protein intake.

**Protein Sources Include Much More Than Meat!**

Although some people think that the only good sources of protein are meats (beef, pork, poultry, seafood), many other foods are rich in proteins. These include dairy products (milk, cheese, yogurt, etc.), eggs, legumes (including soy products), whole grains, and nuts. Fruits and many vegetables are not particularly high in protein; however, these foods are excellent sources of carbohydrates and energy, so eating them can enable your body to use proteins for building and maintaining tissues. Lean sources of protein recommended by the *2015-2020 Dietary Guidelines for Americans* include lean meats and poultry, fish, processed soy products, legumes, and nuts and seeds.5 These foods are high in nutrient density. To compare the protein and energy content of a day's meals, see **MEAL FOCUS FIGURE 6.13.**

**TABLE 6.2** (page 198) compares the protein content of a variety of foods. After reviewing this table, you might wonder how much protein you eat in a typical day-- and whether or not you're meeting your needs. See the Nutrition Label Activity (page 199) to find out.

**Legumes**

Legumes include foods such as soybeans, kidney beans, pinto beans, black beans, garbanzo beans (chickpeas), green peas, black-eyed peas, dal, and lentils. Would you be surprised to learn that the quality of the protein in some of these legumes is almost equal to that of meat? It's true! The quality of soybean protein is also nearly identical to that of meat. It's available as soy milk, tofu, textured vegetable protein, and tempeh, a firm cake that is made by cooking and fermenting whole soybeans. The protein quality of other legumes is also relatively high. In addition to being excellent sources of protein, legumes are high in fiber, iron, calcium, and many of the B-vitamins. They are also low in saturated fat and cholesterol.

Eating legumes regularly, including foods made from soybeans, may help reduce the risk for heart disease by lowering blood cholesterol levels. Diets high in legumes and soy products are also associated with lower rates of some cancers. Legumes are not nutritionally complete, however, because they do not contain vitamins B12, C, or A. Most are also deficient in methionine, an essential amino acid; however, combining them with grains, nuts, or seeds gives you a complete protein.

Considering their nutrient profile, satiety value, and good taste, it's no wonder that many experts consider legumes an almost perfect food. From main dishes to snacks, the **Quick Tips** feature (page 200) offers simple ways to add legumes to your daily diet.

Soy products are a good source of dietary protein.

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**meal focus figure 6.13 Choosing Nutrient-Dense Proteins**

**a day of meals**

**about 16% of energy from protein**

**BREAKFAST**

*2 fried eggs*

*3 slices bacon, fried*

*2 slices of white toast with*

*1 tbsp. of butter*

*8 fl. oz whole milk*

**About 21% of energy from protein**

*1 cup granola (with oats, wheat and raisins)*

*1 tbsp slivered almonds*

*1 cup soy milk*

**LUNCH**

*2 slices pepperoni pizza*

*(14" pizza, hand-tossed crust)*

*1 medium banana*

*24 fl. oz cola beverage*

*½* fillet broiled salmon

**Spinach salad:**

*2 cups fresh spinach*

*½ cup raw carrots, sliced*

*3 cherry tomatoes*

*1 tbsp. chopped green onions*

*¼* cup kidney beans

*2 tbsp. fat-free Caesar dressing*

*1 medium banana*

*24 fl. oz iced tea*

**DINNER**

*Fried chicken, 1 drumstick and 1 breast (with skin)*

*1 cup mashed potatoes with* ¼ cup gravy

*½* cup yellow sweet corn

*8 fl. oz whole milk*

*1 slice chocolate cake with chocolate frosting (1/12 of cake)*

*½* chicken breast, roasted without skin

*1 cup mashed potatoes with*

*¼* cup gravy

*1 cup steamed broccoli*

*24 fl. oz ice water with slice of lemon*

*1 cup fresh blueberries with*

**nutrient analysis**

**3,552** kcal

**40.4%** of energy from carbohydrates

**43.2%** of energy from fat

**16.3%** of energy from saturated fat

**146** grams of protein

**18.2** grams of dietary fiber

**6,246** milligrams of sodium

**nutrient analysis**

**1,899** kcal

**54%** of energy from carbohydrates

**25.5%** of energy from fat

**6%** of energy from saturated fat

**100** grams of protein

**33.3** grams of dietary fiber

**2,402** milligrams of sodium

**[Saves** 1,653 calories!]

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**TABLE 6.2 Protein Content of Commonly Consumed Foods**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Food** | **Serving Amount** | **Protein (g)** | **Food** | **Serving Amount** | **Protein (g)** |
| Beef |  |  | **Dairy** |  |  |
| Ground, lean, broiled (15% fat) | 3 oz | 22 24.7 | Whole milk (3.25% fat) | 8 fl. oz | 7.7 |
| Beef tenderloin steak, broiled (1/8-in. fat) | 3 oz |  | Skim milk | 8 fl. oz | 8.8 |
| Low-fat, plain yogurt | 8 fl. oz | 12 |
| Top sirloin, broiled (1/8-in. fat) | 3 oz | 23 | Cottage cheese, low-fat (2%) | 1 cup | 23.6 |
| **Poultry** |  |  | **Soy Products** |  |  |
| Chicken breast, broiled, no skin (bone removed)  Chicken thigh, bone and skin removed | 1/2 breast 1 thigh | 27 28 | Tofu, firm Tempeh, cooked Soy milk beverage | 1/2 cup  3 oz  1 cup | 10  5.5  8 |
| Turkey breast, roasted, luncheon meat | 3 oz | 18.7 | **Beans** |  |  |
| Refried | 1/2 cup | 6.4 |
| Seafood |  |  | Kidney, red | 1/2 cup | 6.7 |
| Salmon, Chinook, baked | 3 oz | 22 | Black | 1/2 cup | 7.2 |
| Shrimp, cooked | 3 oz | 20.4 | **Nuts** |  |  |
| Tuna, in water, drained | 3 oz | 16.5 | Peanuts, dry roasted | 1 oz | 6.9 |
| **Pork** |  |  | Peanut butter, creamy | 2 tbsp. | 7 |
| Pork loin chop, broiled | 3 oz | 22 | Almonds, blanched | 1 oz | 6 |
| Ham, roasted, extra lean (5% fat) | 3 oz | 18.7 |  |  |  |

*Source:* Data from U.S. Department of Agriculture, Agricultural Research Service. 2015. USDA National Nutrient Database for Standard Reference, Release 28.

**Nuts**

Nuts are another healthful high-protein food. In fact, the USDA Food Patterns counts one-third cup of nuts or two tablespoons of peanut butter as equivalent to 1 ounce-- about one-third of a serving--of meat! Moreover, studies show that consuming about 2 to 5 oz of nuts per week, in particular walnuts and peanuts, significantly reduces people's risk for cardiovascular disease and premature mortality from a range of causes.6-8 Although the exact mechanism behind this is not known, nuts contain many nutrients and other substances that are associated with health benefits, including fiber, unsaturated fats, potassium, folate, plant sterols, and *antioxidants,* substances that can protect body cells (see Chapter 8).

**"New" Foods**

A new source of nonmeat protein that is available on the market is *quorn,* a protein product derived from fermented fungus. It is mixed with a variety of other foods to produce various types of meat substitutes. Other "new" foods high in protein include some very ancient grains! For instance, earlier we mentioned quinoa, a pseudo-grain that provides all nine essential amino acids. Quinoa is highly digestible and was so essential to the diet of the ancient Incas that they considered it sacred. Cooked much like rice, quinoa provides 8 g of protein in a 1-cup serving. A similar pseudo-grain, called amaranth, also provides complete protein. Teff, millet, and sorghum are grains long cultivated in Africa as rich sources of protein. They are now widely available in the United States. Although these three grains are low in the essential amino acid lysine, combining them with legumes produces a complete-protein meal.

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## [**nutrition label activity How Much Protein Do You Eat?**

One way to find out if your diet contains enough protein is to keep a food diary. Record everything you eat and drink for at least 3 days, and the grams of protein each item provides. To determine the grams of protein for packaged foods, use the Nutrition Facts panel, and make sure to adjust for the amount you actually consume. For products without labels, check Table 6.3 (on page 203), or use the diet analysis tools that accompany this text, or visit the U.S. Department of Agriculture National Nutrient Database for Standard Reference to find the energy and nutrient content of thousands of foods (see **Web Links).**

Below is an example, using Theo's food choices for 1 day. Do you think he's meeting his protein needs?

As calculated in the **You Do the Math** box (on page 195), Theo's RDA is 72.8 to 91 g of protein. He is consuming 2.3 to 2.8 times that amount! You can see that he does not need to use amino acid or protein supplements because he has more than adequate amounts of protein to build lean tissue.

Now calculate your own protein intake using food labels and a diet analysis program. Do you obtain more protein from animal or nonanimal sources? If you consume mostly nonanimal sources, are you eating soy products and complementary foods throughout the day? If you eat animal-based products on a regular basis, notice how much protein you consume from even small servings of meat and dairy products.

|  |  |
| --- | --- |
| **Foods Consumed** | **Protein Content (g)** |
| **Breakfast:** |  |
| Brewed coffee (2 cups) with 2 tbsp. cream | 1.4 |
| 1 large bagel (5-in. diameter) | 13 |
| Low-fat cream cheese (2 tbsp.) | 1.6 |
| **Mid-morning snack:** |  |
| Cola beverage (32 fl. oz) | 0 |
| Low-fat strawberry yogurt **(1** cup) | 10 |
| Fruit and nut granola bar (2; 37 g each) | 5.7 |
| **Lunch:** |  |
| Ham and cheese sandwich: |  |
| Whole-wheat bread (2 slices) | 4 |
| Mayonnaise (1.5 tbsp.) | 0.2 |
| Extra lean ham (4 oz) | 24 |
| Swiss cheese (2 oz) | 15 |
| Iceberg lettuce (2 leaves) | 0.3 |
| Sliced tomato (3 slices) | 0.5 |
| Banana (1 large) | 1.5 |
| Wheat Thin crackers (20) | 3.6 |
| Bottled water (20 fl. oz) | 0.0 |

|  |  |
| --- | --- |
| **Foods** | **Protein Content (g)** |
| **Dinner:** |  |
| **Cheeseburger:** |  |
| Broiled ground beef (1/2 lb cooked) | **52** |
| American cheese (1 oz) | 5 |
| Seeded bun (1 large) | 8 |
| Ketchup (2 tbsp.) | 0.5 |
| Mustard (1 tbsp.) | 0.7 |
| Shredded lettuce (1/2 cup) | 0.3 |
| Sliced tomato (3 slices) | 0.5 |
| French fries (30; 2- to 3-in. strips) | 5 |
| Baked beans (2 cups) | 24 |
| 2% low-fat milk (2 cups) | 16 |
| **Evening snack:** | |
| Chocolate chip cookies (4; 3-in. diameter) | 3 |
| 2% low-fat milk (1 cup) | 8 |
| Total Protein Intake for the Day: | 203.8 g |

**The Health Effects of High Protein Intake Are Unclear**

Although protein deficiency is known to be life-threatening, the effect of high protein intakes on health risks is unclear. Three disorders linked in some research to high protein intakes are bone loss, kidney disease, and coronary heart disease.

Although high-protein diets can increase calcium excretion, current evidence does not support that this leads to bone loss. In fact, eating too *little* protein causes bone loss, which increases the risk for fractures and osteoporosis. Higher intakes of animal and soy protein have been shown to protect bone in middle-aged and older women.

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**[Adding Legumes to Your Daily Diet**

***Breakfast***

Instead of cereal, eggs, or a doughnut, microwave a frozen bean burrito for a quick, portable breakfast.

Make your pancakes with soy milk, or pour soy milk on your cereal.

If you normally have a side of bacon, ham, or sausage with your eggs, have a side of black beans instead.

***Lunch and Dinner***

Try a sandwich made with hummus (a garbanzo bean spread), cucumbers, tomato, avocado, and/or lettuce on whole-wheat bread or in a whole-wheat pocket.

Use deli "meats" made with soy in your sandwich. Also try soy hot dogs, burgers, and "chicken" nuggets.

Add garbanzo beans, kidney beans, or fresh peas to tossed salads, or make a three-bean salad with kidney beans, green beans, and garbanzo beans.

Make a side dish using legumes such as peas with pearl onions; succotash (lima beans, corn, and tomatoes); or homemade chili with kidney beans and tofu instead of meat.

Make black bean soup, lentil soup, pea soup, minestrone soup, or a batch of dal (a type of yellow lentil used in Indian cuisine) and serve over brown rice. Top with plain yogurt, a traditional accompaniment in many Asian cuisines.

Use soy "crumbles" in any recipe calling for ground beef.

Make burritos with black or pinto beans instead of shredded meat.

To stir-fried vegetables, add cubes of tofu or strips of tempeh.

Make a "meatloaf" using cooked, mashed lentils instead of ground beef.

For fast food at home, keep canned beans on hand. Serve over rice, couscous, or quinoa with a salad for a quick, complete, and hearty meal.

***Snacks***

Instead of potato chips or pretzels, try one of the new bean chips.

Dip fresh vegetables in bean dip.

Serve hummus on wedges of pita bread.

Spread peanut butter on celery sticks, apple slices, or whole-grain rice cakes.

Add roasted soy "nuts" to your trail mix.

Stock up on microwavable pouches of edamame (soybeans in pods). They're in the frozen foods section of most markets.

Keep frozen tofu desserts, such as tofu ice cream, in your freezer.]

A recent systematic review concluded that there is no evidence to support the contention that high-protein diets lead to bone loss, except in people consuming inadequate calcium.9

A high-protein diet can increase the risk of acquiring kidney disease in people who are susceptible. Because people with diabetes have higher rates of kidney disease, it was previously assumed that they would benefit from a lower-protein diet.

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However, the evidence is inconclusive regarding the optimal amount of protein that people with diabetes should consume. The American Diabetes Association does not recommend a reduction in protein intake even in people with diabetes-related kidney disease.10 In addition, there is no evidence that eating more protein causes kidney disease in healthy people. In fact, a recent review emphasizes that high protein intakes have no deleterious effects in athletes with normal renal function.11 Thus, experts agree that eating as much as 2 g of protein per kilogram of body weight each day is safe for healthy people.

High-protein diets composed of predominantly animal sources have long been associated with higher blood cholesterol levels and an increased risk for coronary heart disease. These effects were assumed to be due to the saturated fat in animal products. As discussed in Chapter 5, although a recent review study found that eating more saturated fat was *not* associated with an increased risk for heart disease,12 this topic is highly contentious as other studies have not supported the conclusions of this review.13 So until we reach consensus on the optimal AMDR and sources of protein, nutrition experts recommend limiting your saturated fat intake and replacing it with healthful polyunsaturated fats from foods such as nuts, avocados, fish, whole grains, and olive oil.

**Protein Deficiency Can Result in Severe Illness and Death**

Consuming too little protein can cause severe debility, increased risk for infection, and death. Typically, this occurs when people do not consume enough total energy, and the result is **protein-energy malnutrition** (also called *protein-Calorie malnutrition).* Two diseases that can follow are marasmus and kwashiorkor **(FIGURE 6.14).**

**Protein Deficiency and Marasmus**

**Marasmus** is a disease that results from a grossly inadequate intake of total energy, especially protein. Essentially, people with marasmus slowly starve to death. It is most common in young children (6 to 18 months of age) living in impoverished conditions who are severely undernourished. People suffering from marasmus have a look of "skin and bones" because their body fat and tissues are wasting (see Figure 6.14a). The consequences of marasmus include:

- Wasting and weakening of muscles, including the heart muscle.

- Stunted brain development and learning impairment.

**[FIGURE** 6**.14** Two forms of protein-energy malnutrition: **(a)** marasmus and **(b)** kwashiorkor.]

[Sidebar: **protein-energy malnutrition** A disorder caused by inadequate consumption of protein. It is characterized by severe wasting.]

[Sidebar: **marasmus** A form of protein-energy malnutrition that results from grossly inadequate intake of energy and protein and other nutrients and is characterized by extreme tissue wasting and stunted growth and development.]

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- Depressed metabolism and little insulation from body fat, causing a dangerously low body temperature.

- Stunted physical growth and development.

- Deterioration of the intestinal lining, which further inhibits the absorption of nutrients.

*-* *Anemia* (abnormally low levels of hemoglobin in the blood).

- Severely weakened immune system.

- Fluid and electrolyte imbalances.

If marasmus is left untreated, death from dehydration, heart failure, or infection will result. Treating marasmus involves carefully correcting fluid and electrolyte imbalances. Protein and carbohydrates are provided once the body's condition has stabilized. Fat is introduced much later, as the protein levels in the blood must improve to the point at which the body can use them to carry fat, so that it can be safely metabolized by the body.

**Protein Deficiency and Kwashiorkor**

**Kwashiorkor** often occurs in developing countries where infants are weaned early due to the arrival of a subsequent baby. This deficiency disease is typically seen in young children (1 to 3 years of age) who no longer drink breast milk. Instead, they often are fed a low-protein, starchy cereal. Recent research suggests that dysfunctional GI flora combined with a low-protein diet interact to contribute to the development of kwashiorkor.14 Unlike marasmus, kwashiorkor often develops quickly and causes edema, particularly in the belly (see Figure 6.14b). This is because the low protein content of the blood is inadequate to keep fluids from seeping into the tissue spaces. The following are other signs and symptoms of kwashiorkor:

- Some weight loss and muscle wasting, with some retention of body fat.

- Retarded growth and development but less severe than that seen with marasmus.

- Fatty degeneration of the liver.

- Loss of appetite, sadness, irritability, apathy.

- Development of sores and other skin problems; skin pigmentation changes.

- Dry, brittle hair that changes color, straightens, and falls out easily.

Kwashiorkor can be reversed if adequate protein and energy are given in time. Because of their severely weakened immune systems, many individuals with kwashiorkor die from infections they contract in their weakened state. Of those who are treated, many return home to the same impoverished conditions, only to develop this deficiency again.

Many people think that only children in developing countries suffer from these diseases. However, protein-energy malnutrition occurs in all countries and affects both children and adults. In the United States, poor people living in inner cities and isolated rural areas are especially affected. Others at risk include the elderly, the homeless, people with eating disorders, those addicted to alcohol and other drugs, and individuals with wasting diseases, such as AIDS or cancer.

**[recap**

The RDA for protein for most nonpregnant, nonlactating, nonvegetarian adults is 0.8 g per kg body weight. Children, pregnant women, nursing mothers, vegetarians, and active people need more. Most people who eat enough kilocalories and carbohydrates have no problem meeting their RDA for protein. Good sources of protein include meats, eggs, dairy products, legumes, nuts, quorn, and certain "ancient grains." The health effects of a high protein intake are unclear; however, eating too much protein from animal sources may increase a person's risk for coronary heart disease. Protein-energy malnutrition can lead to marasmus and kwashiorkor. These diseases primarily affect impoverished children in developing nations. However, elderly, impoverished, and critically ill people in developed countries are also at risk.]

[Sidebar: **kwashiorkor** A form of protein-energy malnutrition that is typically seen in malnourished infants and toddlers and is characterized by wasting, edema, and other signs of protein deficiency.]

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**LO 6** List the benefits and potential challenges of consuming a vegetarian diet.

## **Can a vegetarian diet provide adequate protein?**

**Vegetarianism** is the practice of restricting the diet to food substances of plant origin, including vegetables, fruits, grains, and nuts. In a 2015 nationwide poll, 3.4% of all U.S. adults reported that they are vegetarian (never eat meat, poultry, or fish), and another 10% said that more than half of their meals are vegetarian.15 And in 2014 a national poll found that 4% of youth age 8 to 18 are vegetarians.16 Although precise statistics of vegetarianism among college students aren't available, moving away from home and taking responsibility for one's eating habits appears to influence many college students to try vegetarianism.

**There Are Many Types of Vegetarian Diets**

There are almost as many types of vegetarian diets as there are vegetarians. Some people who consider themselves vegetarians regularly eat poultry and fish. Others avoid the flesh of animals but consume eggs, milk, and cheese liberally. Still others strictly avoid all products of animal origin, including milk and eggs, and even by-products such as candies and puddings made with gelatin.

**TABLE 6.3** identifies the various types of vegetarian diets, ranging from the most inclusive to the most restrictive. Notice that, the more restrictive the diet, the more challenging it becomes to achieve an adequate protein intake.

One type of "vegetarian" diet receiving significant media attention recently is the **plant-based diet:** it consists mostly of plant foods, as well as eggs, dairy, and occasionally red meat, poultry, and/or fish. A plant-based diet is consistent with the healthy eating pattern recommended in the *2015-2020 Dietary Guidelines for Americans.*5

**TABLE 6.3 Terms and Definitions of a Vegetarian Diet**

|  |  |  |
| --- | --- | --- |
| **Type of Diet** | **Foods Consumed** | **Comments** |
| Semivegetarian (also called flexitarian or plant-based diet) | Vegetables, grains, nuts, fruits, legumes; sometimes meat, seafood, poultry, eggs, and dairy products | Typically exclude or limit red meat; may also avoid other meats |
| Pescovegetarian | Similar to semivegetarian but excludes poultry | *Pesco* means "fish," the only animal source of protein in this diet |
| Lacto-ovovegetarian | Vegetables, grains, nuts, fruits, legumes, dairy products *(lacto),* and eggs (*ovo)* | Excludes animal flesh and seafood |
| Lacto-vegetarian | Similar to lacto-ovovegetarian but excludes eggs | Relies on milk and cheese for animal sources of protein |
| Ovovegetarian | Vegetables, grains, nuts, fruits, legumes, and eggs | Excludes dairy, flesh, and seafood products |
| Vegan (also called strict vegetarian) | Only plant-based foods (vegetables, grains, nuts, seeds, fruits, legumes) | May not provide adequate vitamin B12, zinc, iron, or calcium |
| Macrobiotic diet | Vegan-type diet; becomes progressively more strict until almost all foods are eliminated; at the extreme, only brown rice and small amounts of water or herbal tea | Taken to the extreme, can cause malnutrition and death |
| Fruitarian | Only raw or dried fruit, seeds, nuts, honey, and vegetable oil | Very restrictive diet; deficient in protein, calcium, zinc, iron, vitamin B12, riboflavin, and other nutrients |

[Sidebar: **vegetarianism** The practice of restricting the diet to foods and food substances of plant origin, including vegetables, fruits, grains, nuts, and seeds.]

[Sidebar: **plant-based diet** A diet consisting mostly of plant sources of foods, especially whole foods, with only limited amounts, if any, of animal-based and processed foods.]

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[**FIGURE 6.15** A comparison of the energy and macronutrient content of a vegan meal and a meat-based meal. Note that the amount and quality of protein in a vegan meal is comparable to that of a meat-based meal when the vegan meal combines a variety of vegetables, whole grain, and legumes.]

Vegan diets have also attracted a great deal of attention in recent years. People who are vegans who do not eat meat, fish, or poultry, or foods considered to be animal products or by-products such as eggs and dairy products.17 Some vegans also restrict the consumption of honey and the use of leather, fur, silk, wool, cosmetics, and soaps that have been derived from animal products. It is estimated that almost 15% of people who identify as vegetarians in the U.S. are vegans.15 Although a vegan diet is more restrictive than some forms of vegetarianism, if carefully planned with a variety of foods, including fortified foods, it can be as nutritionally sound as an eating plan that includes animal products. **FIGURE 6.15** compares the macronutrient content of a vegan meal to that of a meat-based meal. As illustrated in this figure, a meal of vegan stew served with brown rice can provide more protein and fiber, and less fat and saturated fat, than a beef stew with potatoes and carrots served with a dinner roll.

**People Choose Vegetarianism for Many-Different Reasons**

When discussing vegetarianism, one of the most often asked questions is why people would make this food choice. The most common responses are included here.

**Religious, Ethical, and Food-Safety Reasons**

Some make the choice for religious or spiritual reasons. Several religions prohibit or restrict the consumption of animal flesh; however, generalizations can be misleading. For example, whereas certain sects within Hinduism forbid the consumption of meat, perusing the menu at any Indian restaurant will reveal that many other Hindus regularly consume small quantities of meat, poultry, and fish. Many Buddhists are vegetarians, as are some Christians, including Seventh-Day Adventists.

Many vegetarians are guided by their personal philosophy to choose vegetarianism. These people feel that it is morally and ethically wrong to consume animals and, in the case of veganism, any products from animals (such as dairy or egg products), usually because they view the practices in the modern animal industries as inhumane. If vegetarians do consume milk and eggs, they may choose to purchase them only from family farms where they feel animals are treated humanely.

There is also a great deal of concern about meat handling practices, because contaminated meat has occasionally made its way into our food supply.

[Image: People who follow certain sects of Hinduism refrain from eating meat.]

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[Image: Some people choose vegetarianism out of concern for the environmental effects of meat production. For example, livestock production **(a)** and aggressive deforestation that clears land for grazing **(b)** both contribute to increased greenhouse gas emissions.]

Many outbreaks of severe illness, sometimes resulting in permanent disability and even death, have been traced to hamburgers and other meat items served at fast-food restaurants and meats sold in markets and consumed at home.

**Ecological Benefits**

Many people choose vegetarianism because of their concerns about the effect of meat production on the global environment. The growing global population and rising standard of living has increased the demand for meat in developed and developing nations. As a result, meat production has evolved from small family farming operations to the larger system of agribusiness. Critics point to the environmental costs of agribusiness: massive uses of natural resources to support animals; release of methane and other greenhouse gases produced by the animals; pollution of water and soils; and deforestation for land use to support livestock. For an in-depth discussion of this complex and often emotionally charged topic, refer to Chapter 13.

**Health Benefits**

Still others practice vegetarianism because of its health benefits. Research over several years has consistently shown that a varied and balanced vegetarian diet can reduce the risk for many chronic diseases. Its health benefits include the following:

- Reduced intake of fat and total energy, which reduces the risk for obesity. This may in turn lower a person's risk for type 2 diabetes.

- Lower blood pressure, which may be due to a higher intake of fruits and vegetables. However, people who eat vegetarian diets tend to be nonsmokers, to drink alcohol in moderation if at all, and to exercise regularly, all of which are also factors known to reduce blood pressure.

- Reduced risk for heart disease, which may be due to lower saturated fat intake and a higher consumption of dietary fiber and *antioxidant vitamins, minerals, and phytochemicals.* As noted earlier, antioxidants (discussed in detail in Chapter 8) help protect our cells. They are abundant in fruits and vegetables.

- Fewer digestive problems such as constipation and diverticular disease, perhaps due to the higher fiber content of vegetarian diets. Diverticular disease (discussed in Chapter 4) occurs when the wall of the large intestine pouches and becomes inflamed.

- Reduced risk for some cancers. Research shows that vegetarians may have lower rates of cancer, particularly colorectal cancer. Many components of a vegetarian diet could contribute to reducing cancer risks, including antioxidants, fiber, no intake of red meats and processed meats (which increase the risk for colorectal cancer), and lower consumption of *carcinogens* (cancer-causing agents) that are formed when cooking meat.18

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- Reduced risk for kidney stones and gallstones. The lower protein contents of vegetarian diets, plus the higher intake of legumes and vegetable proteins such as soy, may be protective against these conditions.

A recent review of the evidence from three prospective cohort studies of Seventh-Day Adventists in North America confirmed that vegetarian diets conferred greater health benefits as highlighted above.19 In addition, this review stated that consuming a vegan-type eating pattern appeared to provide additional benefits of reduced obesity, hypertension, type 2 diabetes, and premature mortality from cardiovascular disease as compared to a lacto-ovovegetarian eating pattern.19

**A Vegetarian Diet Can Present Some Challenges**

Although a vegetarian diet can be healthful, it also presents some challenges. Limiting the consumption of flesh and dairy products introduces the potential for inadequate intakes of certain nutrients, especially for people consuming a vegan, macrobiotic, or fruitarian diet. **TABLE 6.4** lists the nutrients that can be deficient in a vegan type of diet plan and describes good nonanimal sources that can provide these nutrients. Vegetarians who consume dairy and/or egg products obtain these nutrients more easily.

Research indicates that individuals with a history of disordered eating are more likely to switch to a vegetarian diet.20 Instead of eating a healthful variety of nonanimal foods, people with disordered eating problems may use vegetarianism as an excuse to restrict many foods from their diet. To learn more about disordered eating, refer to In Depth 11.5.

Can a vegetarian diet provide enough protein? In developed countries, where high-quality nonmeat protein sources are easy to obtain, the answer is yes. In fact, the Academy of Nutrition and Dietetics endorses an appropriately planned vegetarian diet as healthful, nutritionally adequate, and beneficial in reducing and preventing various diseases. Like any diet, however, a vegetarian diet should be *balanced* and *adequate;* thus, it is important for vegetarians to eat complementary proteins and obtain enough energy from other macronutrients to spare protein from being used as an energy source.

**TABLE 6.4** **Nutrients of Concern in a Vegan Diet**

|  |  |  |
| --- | --- | --- |
| **Nutrient** | **Functions** | **Nonmeat/Nondairy Food Sources** |
| Vitamin B12 | Assists with DNA synthesis; protection and growth of nerve fibers | Vitamin B12-fortified cereals, yeast, soy products, and other meat analogs; vitamin B12 supplements |
| Vitamin D | Promotes bone growth | Vitamin D-fortified cereals, margarines, and soy products; adequate exposure to sunlight; supplementation may be necessary for those who do not get adequate exposure to sunlight |
| Riboflavin (vitamin B2) | Promotes release of energy; supports normal vision and skin health | Whole and enriched grains, green leafy vegetables, mushrooms, beans, nuts, and seeds |
| Iron | Assists with oxygen transport; involved in making amino acids and hormones | Whole-grain products, prune juice, dried fruits, beans, nuts, seeds, and leafy vegetables (such as spinach) |
| Calcium | Maintains bone health; assists with muscle contraction, blood pressure, and nerve transmission | Fortified soy milk and tofu, almonds, dry beans, leafy vegetables, calcium-fortified juices, and fortified breakfast cereals |
| Zinc | Assists with DNA and RNA synthesis, immune function, and growth | Whole-grain products, wheat germ, beans, nuts, and seeds |

[Image: Vegetarians should eat two to three servings of beans, nuts, seeds, eggs, or meat substitutes (such as tofu) daily.]

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## **nutri**-**case** **THEO**

"No way would I ever become a vegetarian! The only way to build up muscle is to eat meat. I read in a bodybuilding magazine about some guy who doesn't eat anything from animals, not even milk or eggs, and he did look pretty

buff... but I don't buy it. They can do anything to pictures these days. Besides, after a game I just crave red meat. If I don't have it, I feel sort of like my batteries don't get recharged. It's just not natural for a competitive athlete to go without meat!" What claims does Theo make here about the role of red meat in his diet? Do you think his claims are valid? Why or why not? Without trying to convert Theo to vegetarianism, what facts might you offer him about the nature of plant and animal proteins?

Although the digestibility of a vegetarian diet is potentially lower than that of an animal-based diet, there is no separate protein recommendation for vegetarians who consume complementary plant proteins.21

**MyPlate Can Help** You **Plan a Vegetarian Diet**

Although the USDA has not designed a version of MyPlate specifically for people following a vegetarian diet, healthy eating tips for vegetarians are available at MyPlate online (see the **Web Links** at the end of this chapter). For example, to meet their needs for protein and calcium, lacto-vegetarians can consume low-fat or nonfat dairy products. Vegans and ovovegetarians can consume calcium-fortified soy milk or one of the many protein bars fortified with calcium.

Vegans need to consume vitamin B12 either from fortified foods or supplements because this vitamin is found naturally only in foods derived from animals. They should also pay special attention to consuming foods high in vitamin D, riboflavin (B2), and the minerals zinc and iron. Supplementation of these micronutrients may be necessary for some people if they do not consume adequate amounts in their diet.

**[recap**

Vegetarian diets vary from vegan diets, which include no animal-based foods or ingredients of any kind, to plant-based diets, which may include eggs, dairy, and even limited amounts of meat, poultry, and fish. A balanced vegetarian diet may reduce the risk for obesity, type 2 diabetes, hypertension and heart disease, digestive problems, some cancers, kidney stones, and gallstones. Whereas varied vegetarian diets can provide enough protein, vegans need to make sure they consume adequate plant sources of complementary proteins and foods fortified with vitamin B12. They also need to ensure their diet provides adequate vitamin D, riboflavin, iron, calcium, and zinc.]

[If you're interested in trying a vegetarian diet but don't know where to begin, check out the website of the Physicians Committee for Responsible Medicine at **www.pcrm.org.** Click on "Health and Nutrition," and then select "Vegetarian and Vegan Diets." Scroll down until you see the "Vegetarian Starter Kit."]

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**nutrition debate Are Current Protein Recommendations High Enough?**

[In 2005, the Institute of Medicine (IOM, which is now the Health and Medicine Division of the National Academies of Sciences, Engineering, and Medicine) concluded that a protein intake of 0.8 gram per kilogram body weight is sufficient to maintain nitrogen balance in healthy adults no matter what their activity level.21 However, there is now increasing evidence that the current RDA may not be sufficient to support optimal health and function for various groups, and experts are calling for a critical reexamination of the RDA to determine whether or not it should be increased.22

Specifically, experts working with athletes and highly active people have argued for a number of years that ample evidence indicates that the protein needs of these groups are higher than the current RDA.2 Although the IOM states there is insufficient evidence to support this contention,21 these experts point to several factors that increase athletes' protein requirements:

- Regular exercise increases the transport of oxygen to body tissues, requiring changes in the oxygen-carrying capacity of the blood. To carry more oxygen, we need to produce more of the protein that carries oxygen in the blood (that is, hemoglobin, which is a protein).

- During intense exercise, we use a small amount of protein directly for energy.

- We also use protein to make glucose to prevent hypoglycemia (low blood sugar) during exercise.

- Regular exercise stimulates tissue growth and causes tissue damage, which must be repaired by additional proteins.

As a result of these increased demands for protein, the American College of Sports Medicine has concluded that athletes need 1.2 to 2 grams of protein per kilogram body weight per day, which is equivalent to 1.8 to 2.5 times more protein than the current RDA. They state that there should no longer be a distinction made between strength and endurance athletes, as protein needs vary based on training, personal performance goals, energy and nutrient needs, and a person's food choices.2 Based on this evidence, protein intake recommendations should be flexible and individualized.

Research examining protein needs in adults older than 65 years of age and children suggests that the protein needs for these populations--to meet optimal growth, tissue repair, and regeneration, function, and health--also are higher than the current RDA.23-26 For instance, some researchers suggest that, to preserve lean body tissue and physical function, older adults may need 1.0 to 1.5 grams of protein per kilogram of body weight, which is 1.25 to 1.88 times the current RDA. Children's protein needs may be 1.63 to 1.71 higher than the current RDA.

What could be contributing to this discrepancy between recent research findings and the evidence used to set the RDAs for protein? One factor may be that the current RDAs are based on evidence determined by the nitrogen balance method, which is known to underestimate protein needs. In contrast, a relatively new method, referred to as the *indicator amino acid technique (IAAO)*, appears to overestimate protein needs.21 A second factor in the discrepancy may be a lack of correspondence between nitrogen balance and health; that is, we don't currently know whether or not consuming enough protein to meet nitrogen balance optimizes health and functioning. As such, there is clearly a need for research that critically examines the methods used to measure protein needs, and the amounts needed to support health.

Should you worry about your protein intake? As discussed earlier in this chapter, most Americans, no matter what their activity level, already consume more than twice the RDA for protein. Thus, even if the RDA were increased, it is highly likely that you are already meeting or exceeding it.

**CRITICAL THINKING QUESTIONS**

1. Before taking this course, did you feel you would benefit from consuming more protein? Why or why not?

2. Based on your estimate of your current protein intake in the Nutrition Label Activity, do you already meet or exceed the suggested protein intake for athletes indicated above?

3. Using an Internet search, identify at least two adverse effects to people's health, and two adverse effects on the environment, that could result from increasing the current RDA for protein. How would your answer differ if people increased their protein exclusively through consuming plant-based sources?

[Image: A growing body of research suggests that the current RDA for protein is not high enough to support the needs of athletes or older adults.]]

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**TEST YOURSELF** *ANSWERS*

**1** **F** Although protein can be used for energy in certain circumstances, fats and carbohydrates are the primary sources of energy for our body.

**2** **T** Most people in the United States consume up to two times more protein than they need.

**3 F** Vegetarian diets can meet and even exceed an individual's protein needs, assuming that adequate energy-yielding macronutrients, a variety of protein sources, and complementary protein sources are consumed.

**LO 1 1.** Proteins contain

a. carbon, nitrogen, and aluminum.

b. hydrogen, oxygen, and nitrates.

c. hydrogen, carbon, oxygen, and nitrogen.

d. helium, carbon, oxygen, and ammonia.

**LO 2 2.** Which of the following statements about protein synthesis is true?

a. Protein synthesis occurs in the nucleus of the cell.

b. Messenger RNA carries amino acids to ribosomes for assembly into proteins.

c. In the process of transcription, transfer RNA transfers its DNA onto a ribosome.

d. None of the above is true.

**LO 2 3.** The process of combining peanut butter and whole-wheat bread to make a complete protein is called

a. deamination.

b. vegetarianism.

c. transamination.

d. mutual supplementation.

**LO 3 4.** Proteins in the blood

a. exert pressure that draws fluid out of tissue spaces, preventing edema.

b. can bind to excessive hydrogen ions, preventing alkalosis.

c. can be converted to urea, which can then be used as energy.

d. all of the above.

**LO 4 5.** The enzyme that helps break down polypeptides in the small intestine is called

a. hydrochloric acid.

b. pepsin.

c. protease.

d. bile.

**LO 5 6.** Which of the following statements about the RDA for protein is true?

a. Athletes typically require about three times as much protein as nonathletes.

b. The RDA for protein is higher for men than for women.

c. The RDA for protein is higher for children and adolescents than for adults.

d. Most Americans eat about three times the RDA for protein.

**LO 5 7.** In treating protein-energy malnutrition, why is protein intake restored before feeding the patient fats?

a. Protein is a more readily available source of energy than fats.

b. Protein levels in the blood must be adequate to transport fat.

c. Protein is made up of DNA, which directs the metabolism of fats.

d. Protein is the primary component of bile, which is required to emulsify fats.

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**LO 6 8.** Which of the following meals is typical of a vegan diet?

a. Rice, pinto beans, acorn squash, soy butter, and almond milk

b. Veggie dog, bun, and a banana blended with yogurt

c. Brown rice and green tea

d. Egg salad on whole-wheat toast, broccoli, carrot sticks, and soy milk

**LO 4 9. True or false?** After leaving the small intestine, amino acids are transported to the liver and stored for later use.

**LO 5 10. True or false?** The only sources of complete proteins are foods derived from animals.

**math review**

**LO 5 11.** Barry is concerned he is not eating enough protein. After reading this chapter, he recorded his diet each day for 1 week to calculate how much protein he is eating. Barry's average protein intake for the week is equal to 190 g, his body weight is 75 kg, and his daily energy intake averages 3,000 kcal. Based on your calculations, is Barry (a) meeting or exceeding the AMDR for protein and (b) meeting or exceeding the RDA for protein?

*Answers to Review Questions and Math Review are located at the back of this text and in the MasteringNutrition Study area.*

**web links**

**www.eatright.org**

Academy of Nutrition and Dietetics

*Search for "vegetarian diets" to learn more about vegetarian lifestyles, types of vegetarianism, and how to plan healthful meat-free meals.*

**ndb.nal.usda.gov**

USDA National Nutrient Database for Standard Reference

*Click on "Start your search here" to find a searchable database of the nutrient values of many foods.*

**www.who.int/nutrition/en/**

World Health Organization Nutrition

*Visit this site to find out more about the worldwide scope of protein-deficiency diseases and related topics, in their nutrition topics.*

**www.vrg.org**

The Vegetarian Resource Group

*Visit this site for additional information on how to build a balanced vegetarian diet, or to download their vegan MyPlate.*

**www.choosemyplate.gov**

The USDA's MyPlate Website

*The MyPlate website contains useful, healthy eating tips for vegetarians. Enter "vegetarian" in the search box, then click on "Tips for Vegetarians."*

**www.meatiessmonday.com**

Meatless Monday Campaign

*Find* *out how to start going meatless one day a week with this innovative campaign's website.*

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# **in** **depth 6.5** **Vitamins and Minerals: Micronutrients with Macro Powers**

***After studying this In Depth, you should be able to:***

**1** Identify some observations that led to the discovery of micronutrients, p. 212.

**2** Distinguish between fat-soluble and water-soluble vitamins, pp. 212-214.

**3** Describe the differences between major, trace, and ultra-trace minerals, pp. 214-218.

**4** Explain why the amount of a micronutrient we consume differs from the amount our body absorbs and uses, p. 218.

**5** Discuss three controversial topics in micronutrient research, pp. 218-221.]

**Have you ever heard about the college student on a junk-food diet who developed scurvy, a disease caused by inadequate intake of vitamin C?** This urban legend seems to circulate on many college campuses every year, but that might be because there's some truth behind it. Away from their families, many college students adopt diets that are deficient in one or more micronutrients. For instance, some students adopt a vegan diet with insufficient iron, while others neglect foods rich in calcium and vitamin D. Why is it important to consume adequate levels of the micronutrients, and exactly what constitutes a micronutrient, anyway? This **In Depth** essay explores the discovery of micronutrients, their classification and naming, and their impact on our health.

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## **How were the micronutrients discovered?**

**LO 1** Identify some observations that led to the discovery of micronutrients.

Recall that the macronutrients carbohydrates, fats, and proteins provide energy; thus, we need to consume them in relatively large amounts. In contrast, the micronutrients, vitamins and minerals, are needed in very small amounts. They are nevertheless essential to our survival, assisting critical body functions such as energy metabolism and the formation and maintenance of healthy cells and tissues.

Much of our knowledge of vitamins and minerals comes from accidental observations of animals and humans. For instance, in the 1890s, a Dutch physician named C. Eijkman noticed that chickens fed polished rice developed paralysis, which could be reversed by feeding them whole-grain rice. Noting the high incidence of *beriberi*--a disease that results in extensive nerve damage--among hospital patients fed polished rice, Eijkman hypothesized that a highly refined diet was the primary cause of beriberi. We now know that whole-grain rice, with its nutrient-rich bran layer, contains the vitamin thiamin and that thiamin deficiency results in beriberi.

Similarly, in the early 1900s, it was observed that Japanese children living in fishing villages rarely developed a type of blindness that was common among Japanese children who did not eat fish. Experiments soon showed that cod liver oil, chicken liver, and eel fat prevented the disorder. We now know that each of these foods contains vitamin A, which is essential for healthy vision.

Such observations were followed by years of laboratory research before nutritionists came to fully accept the idea that very small amounts of substances present in food are critical to good health. In 1906, English scientist F. G. Hopkins coined the term *accessory factors* for those substances; we now call them vitamins and minerals.

## **How are vitamins classified?**

**LO 2** Distinguish between fat-soluble and water-soluble vitamins.

Vitamins are organic compounds that regulate a wide range of body processes. Of the 13 vitamins recognized as essential, humans can synthesize only small amounts of vitamins D and K and niacin (a B vitamin), so we must consume virtually all of the vitamins in our diet. Most people who eat a varied and healthful diet can readily meet their vitamin needs from foods alone. The exceptions to this will be discussed shortly.

[Image: Avocados are a source of fat-soluble vitamins.]

Fat-Soluble Vitamins

Vitamins A, D, E, and K are fat-soluble vitamins **(TABLE** **1).** They are found in the fatty portions of foods (butterfat, cod liver oil, corn oil, etc.) and are absorbed along with dietary fat. Fat-containing meats, dairy products, nuts, seeds, vegetable oils, and avocados are all sources of one or more fat-soluble vitamins.

In general, the fat-soluble vitamins are readily stored in the body's adipose tissue; thus, we don't need to consume them every day. While this may simplify day-to-day menu planning, there is also a disadvantage to our ability to store these nutrients. When we consume more of them than we can use, they build up in the adipose tissue, liver, and other tissues and can reach toxic levels. Symptoms of fat-soluble vitamin toxicity, described in Table 1, include damage to our hair, skin, bones, eyes, and nervous system. Overconsumption of vitamin supplements is the most common cause of vitamin toxicity in the United States; rarely do our dietary choices lead to toxicity. Of the four fat-soluble vitamins, vitamins A and D are the most toxic; **megadosing** with 10 or more times the recommended intake of either can result in irreversible organ damage and even death.

Even though we can store the fat-soluble vitamins, deficiencies can occur, especially in people who have a malabsorption disorder, such as celiac disease, that reduces their ability to absorb dietary fat. In addition, people who eat very little dietary fat are at risk for a deficiency due to low intake and poor absorption. The consequences of fat-soluble vitamin deficiencies, described in Table 1, include osteoporosis, the loss of night vision, and even death in the most severe cases.

**Water-Soluble Vitamins**

Vitamin C (ascorbic acid) and the B-vitamins (thiamin, riboflavin, niacin, vitamin B6, vitamin B12, folate, pantothenic acid, and biotin) are all water-soluble vitamins**(TABLE 2)** (see page 215).

[Sidebar: **megadosing** Taking a dose of a nutrient that is 10 or more times greater than the recommended amount.]

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Vitamin Name** | **Primary Functions** | **Recommended Intake\*** | **Reliable Food Sources** | **Toxicity/Deficiency Symptoms** |
| A (retinol, retinal, retinoic acid) | Required for ability of eyes to adjust to changes in light  Protects color vision Assists cell differentiation Required for sperm production in men and fertilization in women Contributes to healthy bone  Contributes to healthy immune system | RDA:  Men: 900 µg/day  Women: 700 (µg/day UL: 3,000 µg/day | Preformed retinol: beef and chicken liver, egg yolks, milk Carotenoid precursors: spinach, carrots, mango, apricots, cantaloupe, pumpkin, yams | *Toxicity:* Fatigue, bone and joint pain, spontaneous abortion and birth defects of fetuses in pregnant women, nausea and diarrhea, liver damage, nervous system damage, blurred vision, hair loss, skin disorders  *Deficiency:* Night blindness and xerophthalmia; impaired growth, immunity, and reproductive function |
| D  (cholecalciferol) | Regulates blood calcium levels  Maintains bone health Assists cell differentiation | RDA:  Adults aged 19-70:  15µg/day  Adults aged >70: 20 µg/day  UL 100 µg/day | Canned salmon and mackerel, milk, fortified cereals | *Toxicity:* Hypercalcemia *Deficiency:* Rickets in children, osteomalacia and/or osteoporosis in adults |
| E (tocopherol) | As a powerful antioxidant, protects cell membranes, polyunsaturated fatty acids, and vitamin A from oxidation  Protects white blood cells Enhances immune function  Improves absorption of vitamin A | RDA:  Men: 15 mg/day Women: 15 mg/day  UL: 1,000 mg/day | Sunflower seeds, almonds, vegetable oils, fortified cereals | *Toxicity:* Rare  *Deficiency:* Hemolytic anemia; impairment of nerve, muscle, and immune function |
| K  (phylloquinone,  menaquinone,  menadione) | Serves as a coenzyme during production of specific proteins that assist in blood coagulation and bone metabolism | Al:  Men: 120 µg/day Women: 90 µg/day | Kale, spinach, turnip greens, brussels sprouts | *Toxicity:* None known  *Deficiency:* Impaired blood clotting,  possible effect on bone health |

\*RDA: Recommended Dietary Allowance; UL: upper limit; Al: Adequate Intake.

They are found in a wide variety of foods, including whole grains, fruits, vegetables, meats, and dairy products. In general, they are easily absorbed through the intestinal tract directly into the bloodstream, where they then travel to target cells.

[Image: Water-soluble vitamins can be found in a variety of foods.]

With the exception of vitamin B12, we do not store large amounts of water-soluble vitamins. Instead, our kidneys filter from our bloodstream any excess, which is excreted in urine. Because our tissues don't store these vitamins, toxicity is rare. When it does occur, however, it is often from the overuse of high-potency vitamin supplements. Toxicity can cause nerve damage and skin lesions.

Because most water-soluble vitamins are not stored in large amounts, they need to be consumed on a daily or weekly basis. Deficiency symptoms, including serious disorders, can arise fairly quickly, especially during fetal development and in growing infants and children. The signs of water-soluble vitamin deficiency vary widely and are identified in Table 2.

**Same Vitamin, Different Names and Forms**

Food and supplement labels, magazine articles, and even nutrition textbooks often use simple, alphabetic (A, D, E, K, etc.) names for the fat-soluble vitamins. The letters reflect their order of discovery: vitamin A was discovered in 1916, whereas vitamin K was not isolated until 1939.

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These lay terms, however, are more appropriately viewed as "umbrellas" that unify a small cluster of chemically related compounds. For example, the term *vitamin A* refers to the specific compounds retinol, retinal, and retinoic acid. Similarly, *vitamin E* occurs naturally in eight forms, known as tocopherols, of which the primary form is alpha-tocopherol. Compounds with *vitamin D* activity include cholecalciferol and ergocalciferol, and the *vitamin K* "umbrella" includes phylloquinone and menaquinone. As you can see, most of the individual compounds making up a fat-soluble vitamin cluster have similar chemical designations (tocopherols, calciferols, and so on). Table 1 lists both the alphabetic and the chemical terms for the fat-soluble vitamins.

Similarly, there are both alphabetic and chemical designations for water-soluble vitamins.

**[Quick Tips**

**Retaining the Vitamins in Foods**

**Watch the water.** Use as little as possible when storing or cooking foods to minimize the loss of water-soluble vitamins. For maximal retention of these vitamins, steam or microwave vegetables.

**Lower the heat.** Avoid high temperatures for long periods of time to maximize retention of vitamin C, thiamin, and riboflavin.

**Avoid air.** Store foods in tightly sealed containers. Exposure to air dramatically reduces the amount of vitamins A, C, E, and K, as well as B-vitamins. Whenever possible, eat raw fruits and vegetables as soon as they are prepared.

**Limit the light.** Keep milk and other dairy foods out of direct light. When exposed to light, the riboflavin in these foods is rapidly destroyed. Using coated cardboard cartons or opaque plastic bottles protects the riboflavin in milk.

**Don't play with pH.** Although the addition of baking soda to certain vegetables enhances their color, it also increases the pH of the cooking water (makes it more alkaline), destroying thiamin, riboflavin, vitamin K, and vitamin C.]

In some cases, such as *vitamin C* and *ascorbic acid,* you may be familiar with both terms. But few people would recognize *cobalamin* as *vitamin* B12. Some of the water-soluble vitamins, such as niacin and vitamin B6, mimic the "umbrella" clustering seen with vitamins A, E, D, and K: the term *vitamin B*6 includes pyridoxal, pyridoxine, and pyridoxamine. If you read any of these three terms on a supplement label, you'll know it refers to vitamin B6.

The vitamins pantothenic acid and biotin exist in only one form. There are no other related chemical compounds linked to either vitamin. Table 2 lists both the alphabetic and chemical terms for the water-soluble vitamins.

Since all vitamins are organic compounds, they are all more or less vulnerable to degradation from exposure to heat, oxygen, or other factors. For tips on preserving the vitamins in the foods you eat, see the nearby Quick Tips.

## **How are minerals classified?**

**LO 3** Describe the differences between major, trace, and ultra-trace minerals.

Minerals--such as calcium, iron, and zinc--are crystalline elements; that is, you'll find them on the periodic table. Because they are already in the simplest chemical form possible, the body does not digest or break them down prior to absorption. For the same reason, they cannot be degraded on exposure to heat or any other natural process, so the minerals in foods remain intact during storage and cooking. Furthermore, unlike vitamins, they cannot be synthesized in the laboratory or by any plant or animal, including humans. Minerals are the same wherever they are found--in soil, a car part, or the human body. The minerals in our foods ultimately come from the environment; for example, the selenium in soil and water is taken up into plants and then incorporated into the animals that eat the plants. Whether we eat the plant foods directly or the animal products, we consume the minerals.

Minerals are classified according to the intake required and the amount present in the body. The three groups include major, trace, and ultra-trace minerals.

**Major Minerals**

Major minerals are those the body requires in amounts of at least 100 mg per day. In addition, these minerals are found in the body in amounts of 5 g (5,000 mg) or higher. There are seven major minerals: sodium, potassium, phosphorus, chloride, calcium, magnesium, and sulfur.

[Image: Plants absorb minerals from soil and water.]

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|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Vitamin Name** | **Primary Functions** | **Recommended Intake\*** | **Reliable Food Sources** | **Toxicity/Deficiency Symptoms** |
| Thiamin (vitamin B1) | Required as enzyme cofactor for carbohydrate and amino acid metabolism | RDA:  Men: 1.2 mg/day Women: 1.1 mg/day | Pork, fortified cereals, enriched rice and pasta, peas, tuna, legumes | *Toxicity:* None known  *Deficiency:* Beriberi; fatigue, apathy, decreased memory, confusion, irritability, muscle weakness |
| Riboflavin (vitamin B2) | Required as enzyme cofactor for carbohydrate and fat metabolism | RDA:  Men: 1.3 mg/day Women: 1.1 mg/day | Beef liver, shrimp, milk and other dairy foods, fortified cereals, enriched breads and grains | *Toxicity:* None known  *Deficiency:* Ariboflavinosis, swollen mouth and throat; seborrheic dermatitis; anemia |
| Niacin,  nicotinamide, nicotinic acid | Required for carbohydrate and fat metabolism Plays a role in DNA replication and repair and cell differentiation | RDA:  Men: 16 mg/day Women: 14 mg/day  UL: 35 mg/day | Beef liver, most cuts of meat/fish/poultry, fortified cereals, enriched breads and grains, canned tomato products | *Toxicity:* Flushing, liver damage, glucose intolerance, blurred vision  *Deficiency:* Pellagra; vomiting, constipation, or diarrhea; apathy |
| Pyridoxine, pyridoxal, pyridoxamine (vitamin B6) | Required as enzyme cofactor for carbohydrate and amino acid metabolism Assists synthesis of blood cells | RDA:  Men and women aged 19-50: 1.3 mg/day  Men aged >50: 1.7 mg/day Women aged >50:  1.5 mg/day  UL: 100 mg/day | Chickpeas (garbanzo beans), most cuts of meat/fish/poultry, fortified cereals, white potatoes | *Toxicity:* Nerve damage, skin lesions *Deficiency:* Anemia; seborrheic dermatitis; depression, confusion, and convulsions |
| Folate (folic acid) | Required as enzyme cofactor for amino acid metabolism  Required for DNA synthesis Involved in metabolism of homocysteine | RDA:  Men: 400 µg/day Women: 400 µg/day  UL: 1,000 µg/day | Fortified cereals, enriched breads and grains, spinach, legumes (lentils, chickpeas, pinto beans), greens (spinach, romaine lettuce), liver | *Toxicity:* Masks symptoms of vitamin B12 deficiency, specifically signs of nerve damage  *Deficiency:* Macrocytic anemia, neural tube defects in a developing fetus, elevated homocysteine levels |
| Cobalamin (vitamin B12) | Assists with formation of blood cells Required for healthy nervous system function Involved as enzyme cofactor in metabolism of homocysteine | RDA:  Men: 2.4 µg/day Women: 2.4 µg/day | Shellfish, all cuts of meat/fish/poultry, milk and other dairy foods, fortified cereals | *Toxicity:* None known  *Deficiency:* Pernicious anemia; tingling and numbness of extremities; nerve damage; memory loss, disorientation, and dementia |
| Pantothenic acid | Assists with fat metabolism | Al:  Men: 5 mg/day Women: 5 mg/day | Meat/fish/poultry, shiitake mushrooms, fortified cereals, egg yolk | *Toxicity:* None known *Deficiency:* Rare |
| Biotin | Involved as enzyme cofactor in carbohydrate, fat, and protein metabolism | RDA:  Men: 30 µg/day Women: 30 µg/day | Nuts, egg yolk | *Toxicity:* None known  *Deficiency:* Rare |
| Ascorbic acid (vitamin C) | Antioxidant in extracellular fluid and lungs Regenerates oxidized vitamin E  Assists with collagen synthesis  Enhances immune function Assists in synthesis of hormones, neurotransmitters, and DNA  Enhances iron absorption | RDA:  Men: 90 mg/day Women: 75 mg/day Smokers: 35 mg more per day than RDA UL: 2,000 mg | Sweet peppers, citrus fruits and juices, broccoli, strawberries, kiwi | *Toxicity:* Nausea and diarrhea, nosebleeds, increased oxidative damage, increased formation of kidney stones in people with kidney disease *Deficiency:* Scurvy, bone pain and fractures, depression, anemia |

\*RDA: Recommended Dietary Allowance; UL: upper limit; Al: Adequate Intake.

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**TABLE 3** summarizes the primary functions, recommended intakes, food sources, and toxicity/deficiency symptoms of these minerals.

**Trace and Ultra-Trace Minerals**

Trace minerals are those we need to consume in amounts of less than 100 mg per day. They are found in the human body in amounts of less than 5 g (5,000 mg). Four trace minerals have an established RDA or AI: fluoride, iron, manganese, and zinc.1 **TABLE 4** identifies the primary functions, recommended intakes, food sources, and toxicity/deficiency symptoms of these minerals.

A subset of trace minerals is a group known as *ultra-trace minerals* because they are required in amounts less than 1 mg per day. The DRI Committee has established an RDA or AI guideline for five ultra-trace minerals: chromium, copper, iodine, molybdenum, and selenium.1

**TABLE 3** **Major Minerals**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Mineral Name** | **Primary Functions** | **Recommended Intake\*** | **Reliable Food Sources** | **Toxicity/Deficiency Symptoms** |
| Sodium | Fluid balance Acid-base balance Transmission of nerve impulses  Muscle contraction | AI:  Adults: 1.5 g/day (1,500 mg/day) | Table salt, pickles, most canned soups, snack foods, cured luncheon meats, canned tomato products | *Toxicity:* Water retention, high blood pressure in some populations, loss of calcium in urine  *Deficiency:* Muscle cramps, dizziness, fatigue, nausea, vomiting, mental confusion |
| Potassium | Fluid balance Transmission of nerve impulses  Muscle contraction | AI:  Adults: 4.7 g/day (4,700 mg/day) | Most fresh fruits and vegetables: potatoes, bananas, tomato juice, orange juice, melons | *Toxicity:* Muscle weakness, vomiting, irregular heartbeat  *Deficiency:* Muscle weakness, paralysis, mental confusion, irregular heartbeat |
| Phosphorus | Fluid balance Bone formation Component of ATP, which provides energy for our body | RDA:  Adults: 700 mg/day | Milk/cheese/yogurt, soy milk and tofu, legumes (lentils, black beans), nuts (almonds, peanuts and peanut butter), poultry | *Toxicity:* Muscle spasms, convulsions, low blood calcium  *Deficiency:* Muscle weakness, muscle damage, bone pain, dizziness |
| Chloride | Fluid balance Transmission of nerve impulses  Component of stomach acid (HCI) Antibacterial | AI:  Adults: 2.3 g/day (2,300 mg/day) | Table salt | *Toxicity:* None known  *Deficiency:* dangerous blood acid-base imbalances, irregular heartbeat |
| Calcium | Primary component of bone  Acid-base balance Transmission of nerve impulses  Muscle contraction | RDA:  Adults aged 19-50 and men  aged 51-70: 1,000 mg/day  Women aged 51-70  and adults aged >70:  1,200 mg/day  UL for adults 19-50:  2,500 mg/day  UL for adults aged 51 and  above: 2,000 mg/day | Milk/yogurt/cheese (best-absorbed form of calcium), sardines, collard greens and spinach, calcium-fortified juices | *Toxicity:* Mineral imbalances, shock, kidney failure, fatigue, mental confusion *Deficiency:* Osteoporosis, convulsions, heart failure |
| Magnesium | Component of bone Muscle contraction Assists more than 300 enzyme systems | RDA:  Men aged 19-30: 400 mg/day  Men aged >30: 420 mg/day Women aged 19-30:  310 mg/day  Women aged >30:  320 mg/day  UL: 350 mg/day | Greens (spinach, kale, collard greens), whole grains, seeds, nuts, legumes (navy and black beans) | *Toxicity:* None known *Deficiency:* Low blood calcium, muscle spasms or seizures, nausea, weakness, increased risk for chronic diseases (such as heart disease, hypertension, osteoporosis, and type 2 diabetes) |
| Sulfur | Component of certain B-vitamins and amino acids Acid-base balance Detoxification in liver | No DRI | Protein-rich foods | *Toxicity:* None known *Deficiency:* None known |

\*RDA: Recommended Dietary Allowance; UL: upper limit; AI: Adequate Intake; DRI: Dietary Reference Intake.

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**TABLE** 4 **Trace and Ultra-Trace Minerals**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Mineral Name** | **Primary Functions** | **Recommended Intake\*** | **Reliable Food Sources** | **Toxicity/Deficiency Symptoms** |
| **Trace Minerals** | | | | |
| Fluoride | Development and maintenance of healthy teeth and bones | RDA:  Men: 4 mg/day Women: 3 mg/day  UL: 2.2 mg/day for children aged 4-8; 10 mg/day for children aged >8 | Fish, seafood, legumes, whole grains, drinking water (variable) | *Toxicity:* Fluorosis of teeth and bones  *Deficiency:* Dental caries, low bone density |
| Iron | Component of hemoglobin in blood cells Component of myoglobin in muscle cells Assists many enzyme systems | RDA:  Adult men: 8 mg/day  Women aged 19-50: 18 mg/day Women aged >50:  8 mg/day | Meat/fish/poultry (best-absorbed form of iron), fortified cereals, legumes, spinach | *Toxicity:* Nausea, vomiting, and diarrhea; dizziness and confusion; rapid heartbeat; organ damage; death  *Deficiency:* Iron-deficiency microcytic anemia (small red blood cells), hypochromic anemia |
| Manganese | Assists many enzyme systems  Synthesis of protein found in bone and cartilage | Al:  Men: 2.3 mg/day Women: 1.8 mg/day  UL: 11 mg/day for adults | Whole grains, nuts, leafy vegetables, tea | *Toxicity:* Impairment of neuromuscular system  *Deficiency:* Impaired growth and reproductive function, reduced bone density, impaired glucose and lipid metabolism, skin rash |
| Zinc | Assists more than 100 enzyme systems Immune system function  Growth and sexual maturation Gene regulation | RDA:  Men: 11 mg/day Women: 8 mg/day  UL: 40 mg/day | Meat/fish/poultry (best-absorbed form of zinc), fortified cereals, legumes | *Toxicity:* Nausea, vomiting, and diarrhea; headaches; depressed immune function; reduced absorption of copper *Deficiency:* Growth retardation, delayed sexual maturation, eye and skin lesions, hair loss, increased incidence of illness and infection |
| **Ultra-Trace Minerals** | | | | |
| Chromium | Glucose transport Metabolism of DNA and RNA  Immune function and growth | Al:  Men aged 19-50: 35 µg/day  Men aged >50: 30 µg/day Women aged 19-50: 25 µg/day Women aged >50: 20 µg/day | Whole grains, brewers yeast | *Toxicity:* None known *Deficiency:* Elevated blood glucose and blood lipids, damage to brain and nervous system |
| Copper | Assists many enzyme  systems  Iron transport | RDA:  Adults: 900 µg/day UL: 10 mg/day | Shellfish, organ meats, nuts, legumes | *Toxicity:* Nausea, vomiting, and diarrhea; liver damage  *Deficiency:* Anemia, reduced levels of white blood cells, osteoporosis in infants and growing children |
| Iodine | Synthesis of thyroid  hormones  Temperature  regulation  Reproduction and  growth | RDA:  Adults: 150 µg/day  UL: 1,100 µg/day | Iodized salt, saltwater seafood | *Toxicity:* Goiter  *Deficiency:* Goiter, hypothyroidism, cretinism in infant of mother who is iodine deficient |
| Molybdenum | Assists many enzyme systems | RDA:  Adults: 45 µg/day  UL: 2 mg/day | Legumes, nuts, grains | *Toxicity:* Symptoms not well defined in humans  *Deficiency:* Abnormal metabolism of sulfur containing compounds |
| Selenium | Required for carbohydrate and fat metabolism | RDA:  Adults'. 55 µg/day  UL: 400 µg/day | Nuts, shellfish, meat/ fish/poultry, whole grains | *Toxicity:* Brittle hair and nails, skin rashes, nausea and vomiting, weakness, liver disease  *Deficiency:* Specific forms of heart disease and arthritis, impaired immune function, muscle pain and wasting, depression, hostility |

\*RDA: Recommended Dietary Allowance; UL: upper limit; Al: Adequate Intake.

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These are included in Table 4. Other ultra-trace minerals such as arsenic, nickel, and vanadium are thought to be important or essential for human health, but there is not yet enough research to establish an RDA or AI guideline.1 As research into these ultra-trace minerals continue, scientists may soon be able to define a DRI value.

**Same Mineral, Different Forms**

Unlike vitamins, most of which can be identified by either alphabetic designations or their chemical name, minerals are simply referred to by their chemical name. Minerals in foods and supplements are often bound to other chemicals in compounds called salts; for example, a supplement label might identify calcium as calcium lactate, calcium gluconate, or calcium citrate. As we will discuss shortly, these different salts, while all containing the same elemental mineral, may differ in their ability to be absorbed by the body.

## **How does our body use micronutrients?**

**LO 4** Explain why the amount of a micronutrient we consume differs from the amount our body absorbs and uses.

The micronutrients found in foods and supplements are not always in a chemical form that our cells can use. This discussion will highlight some of the ways in which our body modifies the food forms of vitamins and minerals to maximize their absorption and utilization.

**What We Eat Differs from What We Absorb**

The most healthful diet is of no value unless the body can absorb its nutrients and transport them to the cells that need them. Unlike carbohydrates, fats, and proteins, which are efficiently absorbed (85-99% of what is eaten makes it into the blood), some micronutrients are so poorly absorbed that only 3-10% of what is eaten ever enters the bloodstream.

The absorption of many vitamins and minerals depends on their chemical form. Dietary iron, for example, can be in the form of *heme iron* (found only in meats, fish, and poultry) or *non-heme iron* (found in plant and animal foods, as well as iron-fortified foods and supplements). Healthy adults absorb heme iron more readily than non-heme iron.

In addition, the presence of other factors within the same food influences mineral absorption. For example, approximately 30% to 45% of the calcium found in milk and dairy products is absorbed, but the calcium in spinach, Swiss chard, seeds, and nuts is absorbed at a much

lower rate because factors in these foods bind the calcium and prevent its absorption.

Some micronutrients actually compete with one another for absorption. Several minerals, for example, use the same protein carriers to move across the enterocytes for release into the bloodstream. Iron and zinc compete for intestinal absorption, as do iron and copper.

The absorption of many vitamins and minerals is also influenced by other foods within the meal. For example, the fat-soluble vitamins are much better absorbed when the meal contains some dietary fat. Calcium absorption is increased by the presence of lactose, found in milk, and non-heme iron absorption can be doubled if the meal includes vitamin C-rich foods, such as red peppers, oranges, or tomatoes. On the other hand, high-fiber foods, such as whole grains, and foods high in oxalic acid, such as tea, spinach, and rhubarb, can decrease the absorption of zinc and iron. It may seem an impossible task to correctly balance your food choices to optimize micronutrient absorption, but the best approach, as always, is to eat a variety of healthful foods every day. See an example in **MEAL FOCUS FIGURE 1,** which compares a day's meals high and low in micronutrients.

**What We Eat Differs from What Our Cells Use**

Many vitamins undergo one or more chemical transformations after they are eaten and absorbed into our body. For example, before they can go to work for our body, thiamin and vitamin B6 must combine with phosphate groups, and vitamin D must have two hydroxyl (OH) groups added to its structure. These transformations activate the vitamin; because the reactions don't occur randomly, but only when the active vitamin is needed, they help the body maintain control over its metabolic pathways.

While the basic nature of minerals does not change, they can undergo minor modifications that change their atomic structure. Iron (Fe) may alternate between Fe2+ (ferrous) and Fe3+ (ferric); copper (Cu) may exist as Cu1+ or Cu2+. These are just two examples of many modifications that help the body make the best use of dietary micronutrients.

**What are some controversies in micronutrient research?**

**LO 5** Discuss three controversial topics in micronutrient research.

The science of nutrition continues to evolve, and our current understanding of vitamins and minerals will no doubt change over the next several years or decades. While some people interpret the term *controversy* as negative, nutrition controversies are exciting developments, proof of new information, and a sign of continued growth in the field.

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**meal focus figure 1 Maximizing Micronutrients**

**a day of meals**

**low in MICRONUTRIENTS**

**high in MICRONUTRIENTS**

**BREAKFAST**

*1 large butter croissant*

*1 tbsp. strawberry jam*

*1 16 fl. oz latte with whole milk*

*1 cup All-Bran cereal*

*1 cup skim milk*

*1* grapefruit

*8 fl. oz low-fat plain yogurt*

*2 slices rye toast with*

*2 tsp. butter and 1 tbsp. blackberry preserves*

**LUNCH**

*3 slices pepperoni pizza (14-inch pizza)*

*1.5 oz potato chips*

*24 fl. oz cola beverage*

*1 chicken breast, boneless, skinless, grilled*

**Spinach salad**

*2 cups spinach leaves*

*1 boiled egg*

*1 tbsp. chopped green onions*

*4 cherry tomatoes*

*½* medium carrot, chopped

*1 tbsp. pine nuts*

*2 tbsp. Ranch dressing (reduced fat)*

*2 falafels (2-¼ inch diameter) with 2 tbsp. hummus*

**DINNER**

*6 fried chicken tenders*

*1* cup mashed potatoes with

*½* cup chicken gravy

*24 fl. oz diet cola beverage*

*1 yogurt and fruit parfait*

*2 cups minestrone soup, low sodium*

*2 whole-grain dinner rolls with*

*2 tsp. margarine*

*2 pork loin chops, roasted*

*1 cup mixed vegetables, cooked*

*8 fl. oz skim milk*

*1 cup fresh strawberries (sliced) with 1 tbsp. low-fat whipped cream*

**nutrient analysis**

**2,789** kcal

**46** milligrams of vitamin C

**28.6** milligrams of niacin

**929** milligrams of calcium

**13.4** milligrams of iron

**490** mcg of folate

**5,792** milligrams of sodium

**nutrient analysis**

**2,528** kcal

**255** milligrams of vitamin C

**42.8** milligrams of niacin

**1,780** milligrams of calcium

**27.5** milligrams of iron

**1,335** mcg of folate

**2,832** milligrams of sodium

**[Provides** more nutrients!]

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**Are Supplements Healthful Sources of Micronutrients?**

For millions of years, humans relied solely on natural foodstuffs as their source of nutrients. Only within the past 75 years or so has a second option become available: purified supplemental nutrients, including those added to fortified foods. We discuss the effects and safety of dietary supplements in In Depth 12.5. For now, consider these differences between micronutrients from foods and from supplements:

- In general, it is much easier to develop a toxic overload of nutrients from supplements than it is from foods. It is very difficult, if not impossible, to develop a vitamin or mineral toxicity through food alone.

- Consumption of certain micronutrient supplements appears to be harmful. For example, recent research has shown that the use of antioxidant supplements, including beta-carotene, vitamin A, and vitamin E, may actually increase mortality.2 There is also some evidence that a high intake of vitamin A, including supplement use, increases the risk for osteoporosis and bone fractures in older women with low intakes of vitamin D.3

- Most minerals are better absorbed from animal food sources than they are from supplements or fortified foods. The one exception might be calcium citrate-malate, used in calcium-fortified juices. The body uses this form as effectively as the calcium from milk or yogurt.

- Enriching a low-nutrient food with a few vitamins and/or minerals does not turn it into a healthful food. For example, soda that has been fortified with selected micronutrients is still a sugary drink.

- Eating a variety of healthful foods provides you with many more nutrients, phytochemicals, and other dietary factors than supplements alone. Nutritionists are not even sure they have identified all the essential nutrients; it is possible that the list will expand in the future. Supplements provide only those nutrients that the manufacturer puts in; foods provide the nutrients that have been identified as well as yet-unknown factors, which likely work in concert with one another to maintain health and functioning.

**Can Micronutrients Prevent or Treat Chronic Disease?**

Researchers continue to investigate the links between macronutrients such as dietary fat and carbohydrate and the prevention and/or treatment of chronic diseases such as heart disease and diabetes. For example, there is strong agreement that *trans* fats increase the risk of heart disease and that high-fiber diets help regulate blood glucose levels.

## **nutri-case LIZ**

"I used to have dinner in the campus dining hall, but not anymore. It's too tempting to see everyone eating all that fattening food and then topping it off with a big dessert. My weight would balloon up in a week if I ate like that! So instead I stay in my dorm room and have a bowl of cereal with nonfat milk. The cereal box says it provides a full day's supply of all the vitamins and minerals, so I know it's nutritious. And when I eat cereal for dinner, it doesn't matter if I didn't eat all the right things earlier in the day!"

What do you think of Liz's "cereal suppers"? If the cereal provides 100% of the DRI for all vitamins and minerals, then is Liz correct that it doesn't matter what else she eats during the day? If not, why not? What factors besides the percentage of DRI does Liz need to consider?

Less clear, however, are the links between individual vitamins and minerals and certain chronic diseases.

A number of research studies have suggested, but not proven, links between the following micronutrients and disease states. In each case, adequate intake of the nutrient has been associated with a reduced risk for the condition.

- Vitamin D and colon cancer

- Vitamin E and complications of diabetes

- Vitamin K and osteoporosis

- Calcium and pregnancy-induced hypertension

- Magnesium and muscle wasting (sarcopenia) in older adults

- Potassium and high blood pressure

The DRIs identify intake recommendations for large population groups; however, another subject of controversy is the question, "What is the optimal intake of each micronutrient for any given individual?" Contemporary research suggests that the answer to this question should take into account aspects of the individual's genetic profile. For example, researchers have identified genetic variations in certain populations that modify their need for dietary folate.4 Future studies may identify other examples of how our genetic profile may influence our need for vitamins and minerals.

Again, it's important to critically evaluate any claim about the protective or disease-preventing ability of a specific vitamin or mineral. Supplements that provide megadoses of micronutrients are potentially harmful and should be avoided unless prescribed by your healthcare provider.

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**Do More Essential Micronutrients Exist?**

Nutrition researchers continue to explore the potential of a variety of substances to qualify as essential micronutrients. Vitamin-like factors such as carnitine and trace minerals such as boron, nickel, and silicon seem to have beneficial roles in human health, yet additional information is needed to fully define their metabolic roles. Until more research is done, such substances can't be classified as essential micronutrients.

As the science of nutrition continues to evolve, the next 50 years will be an exciting time for micronutrient research. Consult the Office of Dietary Supplements at the National Institutes of Health for updates on the research into micronutrients.

**web links**

**www.fda.gov/food/dietarysupplements/default.htm**

U.S. Food and Drug Administration

*Select "Using Dietary Supplements" for information about the advantages and potential risks of supplement use.*

**fnic.nal.usda.gov/dietary-supplements**

Food and Nutrition Information Center

*Click on "General Information and Resources" to obtain information on vitamin and mineral supplements.*

**www.ods.od.nih.gov**

Office of Dietary Supplements

*This site provides summaries of current research results and helpful information about the use of dietary supplements.*

**lpi.oregonstate.edu**

Linus Pauling Institute of Oregon State University

*This site provides information on vitamins and minerals that promote health and lower disease risk. You can search for individual nutrients (for example, vitamin C) as well as types of nutrients (e.g., antioxidants).*

[Before you purchase a dietary supplement, check out this one-minute video from the Office of Dietary Supplements (ODS) at **http://ods.od.nih.gov.** From the home page, search for "ODS Videos" and choose "Thinking About Taking a Dietary Supplement?"]

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[**test yourself**

**1. T F** Drinking until you're no longer thirsty ensures that you're properly hydrated.

**2. T F** Caffeine is a powerful diuretic, causing your body to lose excessive fluid in the urine.

**3. T F** Sodium is an unhealthful nutrient you should strictly avoid.

*Test Yourself answers are located in the Study Plan at the end of this chapter.*]

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# **CHAPTER 7** **Nutrients Essential to** **Fluid and Electrolyte Balance**

***After studying this chapter you should be able to:***

**1** Describe the location and composition of body fluid, pp. 224-225.

**2** Identify the critical contributions of water and electrolytes to human functioning, pp. 226-230.

**3** Discuss the mechanisms by which the body gains or loses fluids, pp. 230-232.

**4** Identify the DRIs for water and compare the nutritional quality of several common beverages, pp. 233-237.

**5** Identify the functions, DRIs, and common dietary sources of sodium, potassium, chloride, and phosphorus, pp. 237-243.

**6** Discuss several disorders related to fluid and electrolyte balance, pp. 243-245.]

**Vani used to buy her favorite energy drink by the case.**

She'd gulp one on the way to her first class, another before working out at the gym, and a couple more to get through a long night of studying. Then, alone in her dorm room one night, she was hit with a wave of nausea. Her heart began to beat erratically, and she broke out in a sweat. A premed student, she knew it was unlikely she was having a heart attack. Had she overdosed on caffeine? Her hands shaking, she logged on to her favorite medical website. The symptoms fit exactly. Now Vani lets herself buy just one can of her favorite energy drink a day. And even though she pays more per can, she still saves money, because the rest of her day's fluid intake is water.

Energy drinks are increasingly popular among teens and young adults despite their known health risks.1 In 2013, the U.S. Food and Drug Administration (FDA) released records of nearly 150 adverse events between 2004 and 2012 that were linked to energy drinks. The reports included incidents of vomiting, difficulty breathing, seizures, cardiac arrests, miscarriages, and at least 18 deaths. Since 2012, 17 additional deaths have been linked to these products.2

In this chapter, we'll review the health and nutritional profile of energy drinks, sugary drinks, sports drinks, and many other popular beverages. But first, we'll explain the role of fluids and electrolytes in keeping the body properly hydrated and maintaining nerve and muscle function. We'll also discuss some disorders related to fluid and electrolyte balance. Immediately following this chapter, we'll take an **In Depth** look at the health benefits and concerns related to consumption of alcohol.

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**LO 1** Describe the location and composition of body fluid.

## **What is body fluid?**

Of course, you know that orange juice, blood, and shampoo are all fluids, but what makes them so? A **fluid** is characterized by its ability to move freely, adapting to the shape of the container that holds it. This might not seem very important, but as you'll learn in this chapter, the fluid composition of your cells and tissues is critical to your body's ability to function.

**Body Fluid Is the Liquid Portion of Our Cells and Tissues**

Between 50% and 70% of a healthy adult's body weight is fluid. When we cut a finger, we can see some of this fluid dripping out as blood, but the fluid in the bloodstream can't account for such a large percentage. So where is all this fluid hiding?

About two-thirds of an adult's body fluid is held within the walls of cells and is therefore called **intracellular fluid (FIGURE 7.1a).** Every cell in our body contains fluid. When our cells lose their fluid, they quickly shrink and die.

**[FIGURE 7.1** The components of body fluid. **(a)** Intracellular fluid is contained inside the cells that make up body tissues. **(b)** Extracellular fluid is external to cells. Tissue fluid is external to tissue cells. **(c)** Another form of extracellular fluid is intravascular fluid--that is, fluid contained within vessels. Plasma is the fluid in blood vessels and is external to blood cells.]

[Sidebar: **fluid** A substance composed of molecules that move past one another freely. Fluids are characterized by their ability to conform to the shape of whatever container holds them.]

[Sidebar: **intracellular fluid** The fluid held at any given time within the walls of the body's cells.]

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On the other hand, when cells take in too much fluid, they swell and burst apart. This is why appropriate fluid balance--which we'll discuss throughout this chapter--is so critical to life.

The remaining third of body fluid is referred to as **extracellular fluid** because it flows outside our cells (Figure 7.1a). There are two types of extracellular fluid:

**1.** *Tissue fluid* (sometimes called *interstitial fluid)* flows between the cells that make up a particular tissue, such as muscle or liver tissue (Figure 7.1b). Other extracellular fluids, such as cerebrospinal fluid, mucus, and synovial fluid within joints, are also considered tissue fluid.

**2.** *Intravascular fluid* is found within blood and lymphatic vessels. Plasma is the fluid portion of blood that transports blood cells through blood vessels. Plasma also contains proteins that are too large to leak out of blood vessels into the surrounding tissue fluid. As you learned (in Chapter 6), protein concentration plays a major role in regulating the movement of fluids into and out of the bloodstream (Figure 7.1c).

Not every tissue contains the same amount of fluid. Lean tissues, such as muscle, are more than 70 % fluid by weight, whereas fat tissue is only between 10 % and 20 % fluid. This is not surprising, considering the water-repellant nature of lipids (see Chapter 5).

Body fluid levels also vary according to gender and age. Compared to females, males have more lean tissue and thus a higher percentage of body weight as fluid. The amount of body fluid as a percentage of total weight decreases with age. About 75% of an infant's body weight is water, whereas the total body water of an elderly person is generally less than 50% of body weight. This decrease in total body water is the result of the loss of lean tissue that typically occurs as people age.

**Body Fluid Is Composed of Water and Electrolytes**

Water is made up of molecules consisting of two hydrogen atoms bound to one oxygen atom (H2O). You might think that pure water would be healthful, but we would quickly die if our cell and tissue fluids contained only pure water. Instead, body fluids contain a variety of dissolved substances (called *solutes)* critical to life. These include six major minerals: sodium, potassium, chloride, phosphorus, calcium, and magnesium. We consume these minerals in compounds called *salts,* including table salt, which is made of sodium and chloride.

These mineral salts are called **electrolytes** because when they dissolve in water, the two component minerals separate and form charged particles called **ions,** which can carry an electrical current and themselves are also commonly referred to as electrolytes. An ion's electrical charge, which can be positive or negative, is the "spark" that stimulates the transmission of nerve impulses and causes muscles to contract, making electrolytes critical to body functioning.

Of the six major minerals just mentioned, sodium and potassium are positively charged, whereas chloride and phosphorus (in the form of hydrogen phosphate) are negatively charged. Calcium and magnesium, because they play critical roles in bone health, are discussed in Chapter 9. In the intracellular fluid, potassium and phosphate are the predominant ions. In the extracellular fluid, sodium and chloride predominate. There is a slight difference in electrical charge on either side of the cell's membrane that is needed in order for the cell to perform its normal functions.

**[recap**

Between 50% and 70% of a healthy adult's body weight is fluid. About two-thirds is intracellular fluid and the remaining third is extracellular fluid; that is, either tissue fluid or intravascular fluid. Body fluid consists of water plus a variety of solutes (dissolved substances), including six major minerals called electrolytes because they can carry an electrical current. Electrolytes are critical to the body's fluid balance, nerve-impulse transmission, and muscle contraction.]

[Image: As we age, our body's water content decreases: approximately 75% of an infant's body weight is composed of water, whereas an elderly adult's body weight is only 50% water (or less).]

[Sidebar: **extracellular fluid** The fluid outside the body's cells, either in the body's tissues or as the liquid portion of blood or lymph.]

[Sidebar: **electrolyte** A substance that disassociates in solution into positively and negatively charged ions and is thus capable of carrying an electrical current; the ions in such a solution.]

[Sidebar: **ion** Any electrically charged particle, either positively or negatively charged.]

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**LO 2** Identify the critical contributions of water and electrolytes to human functioning.

## **Why do we need water and electrolytes?**

The functions of water and electrolytes are interrelated and their levels in the body delicately balanced.

**Water Performs Functions Critical to Life**

Water not only quenches our thirst; it also performs functions critical to life.

**Solubility and Transport**

Water is an excellent **solvent;** that is, it's capable of dissolving a wide variety of substances. The chemical reactions upon which life depends would not be possible without water. Because blood is mostly water, it's able to transport a variety of solutes--such as water-soluble nutrients and medications--to body cells. In contrast, fats do not dissolve in water. To overcome this chemical incompatibility, lipids and fat-soluble vitamins are either attached to or surrounded by water-soluble proteins, so that they, too, can be transported in the blood to the cells.

**Blood Volume and Blood Pressure**

**Blood volume** is the amount of fluid in blood; thus, appropriate fluid levels are essential to maintaining healthful blood volume. When blood volume rises inappropriately, blood pressure increases; when blood volume decreases inappropriately, blood pressure decreases. Hypertension is an important risk factor for heart attacks and strokes. (For more information, see the **In Depth** essay following Chapter 5.) In contrast, low blood pressure can cause people to feel tired, confused, or dizzy.

**Body Temperature**

Just as overheating is disastrous to a car engine, a high internal temperature can impair body functioning. Fluids are vital to the body's ability to maintain its temperature within a safe range. Two factors account for the ability of fluids to keep us cool. First, water has a relatively high capacity for heat: in other words, it takes a lot of energy to raise its temperature. Because the body contains a lot of water, only prolonged exposure to high heat can increase body temperature.

Second, body fluids are our primary coolant **(FIGURE 7.2).** When heat needs to be released from the body, there is an increase in blood flow from the warm body core to the vessels lying just under the skin. This action transports heat from the body core out to the periphery, where it can be released from the skin.

**[FIGURE 7.2** Evaporative cooling occurs when heat is transported from the body core through the bloodstream to the surface of the skin. The water evaporates into the air and carries away heat. This cools the blood, which circulates back to the body core, reducing body temperature.]

[Would the proteins in your body tissues "cook" at the same temperature that would fry an egg? For a short, fun video on an experiment that answers this question, go to **www.npr.org** and type in the search bar "How Much Heat Can You Take?"]

[Sidebar: **solvent** A substance that **is** capable of mixing with and breaking apart a variety of compounds. Water is an excellent solvent.]

[Sidebar: **blood volume** The amount of fluid in blood.]

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At the same time, sweat glands secrete more sweat from the skin. As this sweat evaporates off the skin's surface, heat is released and the skin and underlying blood are cooled. This cooler blood flows back to the body's core and reduces internal body temperature.

**Tissue Protection and Lubrication**

Water is a major part of the fluids that protect and lubricate tissues. The cerebrospinal fluid that surrounds the brain and spinal cord protects them from damage, and a fetus in a mother's womb is protected by amniotic fluid. Synovial fluid lubricates joints, and tears cleanse and lubricate the eyes. Saliva moistens the food we eat and the mucus lining the walls of the gastrointestinal (GI) tract eases the movement of food. Finally, pleural fluid covering the lungs allows their friction-free expansion and retraction within the chest cavity.

**Electrolytes Support Many Body Functions**

Now that you know why fluid is so essential to the body's functioning, we're ready to explore the critical roles of electrolytes.

**Fluid Balance**

Cell membranes are *permeable* to water, meaning water flows easily through them. Cells cannot voluntarily regulate this flow of water and thus have no active control over the balance of fluid between the intracellular and extracellular environments. In contrast, cell membranes are *not* freely permeable to electrolytes. Sodium, potassium, and the other electrolytes stay where they are, either inside or outside a cell, unless they are actively transported across the cell membrane by special transport proteins. So how do electrolytes help cells maintain their fluid balance? To answer this question, a short review of chemistry is needed.

Imagine that you have a special filter with the same properties as cell membranes; in other words, this filter is freely permeable to water but not permeable to electrolytes. Now imagine that you insert this filter into a glass of dilute salt water to divide the glass into two separate chambers **(FIGURE 7.3a).** Of course, the water levels on both sides of the filter would be identical because the filter is freely permeable to water. Now imagine that you add a teaspoon of salt (which would immediately dissolve into sodium and chloride ions) to the water on only one side of the filter (Figure 7.3b).

**[FIGURE 7.3** Osmosis. **(a)** A filter that is freely permeable to water but not permeable to solutes is placed in a glass of dilute salt water. **(b)** Additional salt is sprinkled on one side of the glass only. **(c)** Drawn by the high concentration of electrolytes, water flows to the "saltier" side of the filter. This flow of water into the more concentrated solution will continue until the concentration of electrolytes on both sides of the membrane is equal.]

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Immediately, you would see the water on the "dilute salt water" side of the glass begin to flow through the filter to the "saltier" side of the glass (Figure 7.3c).

Why would this movement of water occur? It is because water always moves from areas where solutes, such as sodium and chloride, are low in concentration (or completely absent) to areas where they are high in concentration. To put it another way, solutes *attract* water toward areas where they are more concentrated. This movement of water toward solutes, called **osmosis,** continues until the concentration of solutes is equal on both sides of the cell membrane.

Osmosis governs the movement of fluid into and out of cells. Recall that cells can regulate the balance of fluids between their cytoplasm and the extracellular environment by using special transport proteins to actively pump electrolytes across the cell membrane (see Chapter 6). The health of the body's cells depends on maintaining an appropriate balance of fluid and electrolytes between the intracellular and extracellular environments. If the concentration of electrolytes is much higher inside cells as compared to outside, water will flow into the cells in such large amounts that the cells can burst. On the other hand, if the extracellular environment contains too high a concentration of electrolytes, water flows out of the cells, and they can dry up. **FOCUS FIGURE 7.4** provides an illustration of how an imbalance between fluid and electrolyte intake during strenuous exercise can affect the balance of fluid and electrolytes between the intracellular and extracellular environments. Keep in mind that when you exercise, what and how much you should drink depends on multiple factors, including how strenuously you are exercising, how long the exercise session is, and how warm or humid the environment is.

Certain illnesses can threaten the delicate balance of fluid inside and outside the cells. You may have heard of someone being hospitalized because of excessive diarrhea and/or vomiting. When this happens, the body loses a great deal of fluid from the intestinal tract and extracellular fluid compartment. This causes the loss of both water and electrolytes. In some cases, the relative loss of water is greater than the loss of electrolytes, and the body's extracellular electrolyte concentration then becomes very high. In response, a great deal of fluid flows out of body cells. These imbalances in fluid and electrolytes change the flow of electrical impulses through the heart, causing an irregular heart rate that can be fatal if left untreated. Severe food poisoning and eating disorders involving repeated vomiting and diarrhea can result in death from life-threatening fluid and electrolyte imbalances.

**Nerve Impulse Conduction**

In addition to their role in maintaining fluid balance, electrolytes are critical in allowing our nerves to respond to stimuli **(FIGURE 7.5)** (page 230). Nerve impulses are initiated at the membrane of a nerve cell in response to a stimulus--for example, the touch of a hand or the clanging of a bell. Stimuli prompt changes in membranes that allow an influx of sodium into the nerve cell, causing the cell to become slightly less negatively charged. This is called *depolarization.* If enough sodium enters the cell, an electrical impulse is generated along the cell membrane (Figure 7.5b).

Once this impulse has been transmitted, the cell membrane returns to its normal electrical state through the release of potassium to the outside of the cell (Figure 7.5c). This return to the initial electrical state is termed *repolarization.* Thus, both sodium and potassium play critical roles in ensuring that nerve impulses are generated, transmitted, and completed.

**Muscle Contraction**

Muscles contract in response to a series of complex physiological changes that we will not describe in detail here. Simply stated, muscle contraction occurs in response to stimulation of nerve cells. As described earlier, sodium and potassium play a key role in the generation of nerve impulses, or electrical signals. Stimulation from an electrical signal causes changes in the muscle cell membrane that lead to an increased flow of calcium from their storage site in the muscle cell.

[Sidebar: **osmosis** The movement of water (or any solvent) through a semipermeable membrane from an area where solutes are less concentrated to areas where solutes are highly concentrated.]

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**focus figure 7.4 Fluid and Electrolyte Balance**

The health of our body's cells depends on maintaining the proper balance of fluids and electrolytes on both sides of the cell membrane, both at rest and during exercise. Let's examine how this balance can be altered under various conditions of exercise and fluid intake.

**MODERATE EXERCISE**

When you are appropriately hydrated, engaged in moderate exercise, and not too hot, the concentration of electrolytes is likely to be the same on both sides of cell membranes. You will be in fluid balance.

**STRENUOUS EXERCISE WITH RAPID AND HIGH WATER INTAKE**

If a person drinks a great deal of water quickly during intense, prolonged exercise, the extracellular fluid becomes diluted. This results in the concentration of electrolytes being greater inside the cells, which causes water to enter the cells, making them swell. Drinking moderate amounts of water or sports drinks more slowly will replace lost fluids and restore fluid balance.

**STRENUOUS EXERCISE WITH INADEQUATE FLUID INTAKE**

If a person does not consume adequate amounts of fluid during strenuous exercise of long duration, the concentration of electrolytes becomes greater outside the cells, drawing water away from the inside of the cells and making them shrink. Consuming sports drinks will replace lost fluids and electrolytes.

[Image: Concentration of electrolytes about equal inside and outside cell

Lower concentration of electrolytes outside

Higher concentration of electrolytes inside

Higher concentration of electrolytes outside

Lower concentration of electrolytes inside]

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[**FIGURE 7.5** The role of electrolytes in conduction of a nerve impulse. **(a)** In the resting state, the intracellular fluid has slightly more electrolytes with a negative charge. **(b)** A stimulus causes changes to occur that prompt the influx of sodium into the interior of the cell. Sodium has a positive charge so when this happens, the charge inside the cell becomes slightly positive. This is called depolarization. If enough sodium enters the cell, an electrical signal is transmitted to adjacent regions of the cell membrane. **(c)** Release of potassium to the exterior of the cell allows the first portion of the membrane almost immediately to return to the resting state. This is called repolarization.]

This movement of calcium ions triggers muscle contraction. The muscle cell can relax after a contraction once the electrical signal is complete and calcium has been pumped back into its storage site.

**[recap**

Water serves many important functions in the body, including dissolving and transporting substances, accounting for blood volume and thereby influencing to blood pressure, regulating body temperature, and protecting and lubricating body tissues. Via the process of osmosis, electrolytes help regulate fluid balance by controlling the movement of fluid into and out of cells. Electrolytes, specifically sodium and potassium, play a key role in the generation and transmission of nerve impulses in response to stimuli. Calcium is an electrolyte essential to muscle contraction.]

**LO 3** Discuss the mechanisms by which the body gains and loses fluids.

## **How does the body maintain fluid balance?**

The proper balance of fluid is maintained in the body by a series of mechanisms that prompt us to drink and retain fluid when we are dehydrated and to excrete fluid as urine when we consume more than we need.

**The Hypothalamus Regulates Thirst**

Imagine that, at lunch, you ate a ham sandwich and a bag of salted potato chips. Now it's almost time for your afternoon seminar to end and you are very thirsty. The last 5 minutes of class are a torment, and when the instructor ends the session you dash to the nearest drinking fountain. What prompted you to suddenly feel so thirsty?

The body's command center for fluid intake is a cluster of nerve cells in the same part of the brain we studied in relation to food intake; that is, the *hypothalamus.* Within the hypothalamus is a group of cells, collectively referred to as the **thirst mechanism,** which causes you to consciously desire fluids.

[Sidebar: **thirst mechanism** A cluster of nerve cells in the hypothalamus that stimulate the desire to drink fluids in response to an increase in the concentration of blood solutes or a decrease in blood pressure and blood volume.]

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The thirst mechanism prompts us to feel thirsty whenever it is stimulated by the following:

- An increased concentration of salt and other dissolved substances in our blood. Remember that ham sandwich and those potato chips? Both of these foods are salty, and eating them increased the blood's sodium concentration.

- A reduction in blood volume and blood pressure. This can occur when fluids are lost because of profuse sweating, blood loss, vomiting, or diarrhea, or simply when fluid intake is too low.

- Dryness in the tissues of the mouth and throat. Tissue dryness reflects a lower amount of fluid in the bloodstream, which causes a reduced production of saliva.

Once the hypothalamus detects such changes, it stimulates the release of a hormone called ADH (for *antidiuretic hormone)* from the pituitary gland, which signals the kidneys to reabsorb more water, thereby returning more water to the bloodstream and reducing the volume of urine **(FIGURE 7.6).** The kidneys also secrete an enzyme that triggers the retention of water. Water is drawn out of the salivary glands, for example, diluting the concentration of blood solutes; this causes the mouth and throat to become even more dry, and we feel the sensation of thirst. Together, these mechanisms prevent a further loss of body fluid and help the body avoid dehydration.

**We Gain Fluids Through Intake and Metabolism**

Typically, when we experience thirst, we drink. Water and other beverages are our primary fluid sources. However, fluid intake alone is not always sufficient: We tend to drink until we're no longer thirsty, but the amount of fluid we consume may not be enough to achieve fluid balance. This is particularly true when body water is lost rapidly, such as during intense exercise in the heat. Because the thirst mechanism has some limitations, it's important to drink regularly throughout the day, especially when you're active.

You can clearly see that beverages are mostly water, but foods are another source of water intake. For example, iceberg lettuce is almost 99% water, and even almonds contain a small amount of water **(FIGURE 7.7).**

**[FIGURE 7.7** Water content of different foods. Much of your daily water intake comes from the foods you eat.

*Data from:* U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference, Release 28. Version Current: September 2015. Internet: http://www.ars.usda.gov/nea/bhnrc/ndl]

**[FIGURE 7.6** Regulation of blood volume and blood pressure by the brain and kidneys. The hypothalamus senses increased concentration of solutes in the blood, triggering the release of ADH from the pituitary gland. ADH signals the kidneys to increase water reabsorption.]

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**Metabolic water** is the water formed from the body's metabolic reactions such as the breakdown of carbohydrates, fats, and proteins. This water contributes about 10 % to 14% of the water the body needs each day.

**We Lose Fluids Through Urine, Sweat, Evaporation, Exhalation, and Feces**

We can perceive--or sense--water loss through urine output and sweating, so we refer to this as **sensible water loss.** Most of the water we consume is excreted through the kidneys in the form of urine. When we consume more water than we need, the kidneys process and excrete the excess in the form of dilute urine.

The second type of sensible water loss is via sweat. Our sweat glands produce more sweat during exercise or when we are in a hot environment. The evaporation of sweat from the skin releases heat, which cools the skin and reduces the body's core temperature.

Water is continuously evaporated from the skin, even when a person is not visibly sweating, and water is continuously exhaled from the lungs during breathing. Water loss through these routes is known as **insensible water loss** because we do not perceive it. Under normal resting conditions, insensible water loss is less than 1 liter (L) of fluid each day; during heavy exercise or in hot weather, a person can lose up to 2 L of water per hour from insensible water loss.

On average, only about 150 to 200 ml of water is lost each day in feces. The GI tract typically absorbs most of the fluid that passes through it, unless a person is experiencing diarrhea.

In addition to these five common routes of fluid loss, certain situations can cause a significant loss of fluid from our body:

- Illnesses that involve fever, coughing, vomiting, diarrhea, and a runny nose significantly increase fluid loss. This is one reason that doctors advise people to drink plenty of fluids when they are ill.

- Traumatic injury, internal bleeding, blood donation, and surgery also increase loss of fluid because of the blood loss involved.

- Exercise increases fluid loss via sweat and respiration; although urine production typically decreases during exercise, fluid losses increase through the skin and lungs.

- Environmental conditions that increase fluid loss include high altitudes, cold and hot temperatures, and low humidity, such as in a desert or an airplane. Because the water content of these environments is low, water from the body more easily evaporates into the surrounding air. We also breathe faster at high altitudes to compensate for the lower oxygen pressure, leading to greater fluid loss via the lungs. We sweat in the heat, but cold temperatures can trigger hormonal changes that also increase fluid loss.

- Pregnancy increases fluid loss for the mother because fluids are continually diverted to the fetus and amniotic fluid.

- Breastfeeding requires a tremendous increase in fluid intake to make up for the loss of fluid as breast milk.

- Consumption of **diuretics**--substances that increase fluid loss via the urine--can result in dangerously excessive fluid loss. Diuretics include certain prescription medications, alcohol, and many over-the-counter weight loss remedies. In the past, it was believed that caffeine acted as a diuretic, but recent research suggests that caffeinated drinks do not significantly influence fluid status in healthy adults.3,4

**[recap**

A healthful fluid level is maintained by balancing intake and excretion. The thirst mechanism in the hypothalamus prompts us to feel thirsty whenever it is stimulated by a high concentration of blood solutes, reduction in blood volume and blood pressure, or dryness of the mouth and throat. The primary sources of fluids are intake of water, other beverages, and foods, and the production of metabolic water. Fluid losses occur through urination, sweating, the feces, exhalation from the lungs, and insensible evaporation from the skin.]

[Image: Fluid losses increase in hot, dry environments.]

[Sidebar: **metabolic water** The water formed as a by-product of our body's metabolic reactions.]

[Sidebar: **sensible water loss** Water loss that is noticed by a person, such as through urine output and visible sweating.]

[Sidebar: **insensible water loss** The loss of water not noticeable by a person, such as through evaporation from the skin and exhalation from the lungs during breathing.]

[Sidebar: **diuretic** A substance that increases fluid loss via the urine.]

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**LO 4** Identify the DRIs for water and compare the nutritional quality of several common beverages.

## **How much water should you drink?**

Water is essential for life. Although we can live weeks without food, we can survive only a few days without water, depending on the environmental temperature. The human body does not have the capacity to store water, so we must continuously replace the water lost each day.

**Our Requirements for Water Are Individualized**

The DRI for water for adult men aged 19 to 50 years is 3.7 L of total water per day. This includes approximately 3.0 L (about 13 cups) as beverages, including water and 0.7 L (about 3 cups) from foods. The DRI for adult women aged 19 to 50 years is 2.7 L of total water per day, including about 2.2 L (about 9 cups) as beverages and 0.5 L (about 2 cups) from foods.5

**FIGURE 7.8** shows the amount and sources of water intake and output for a woman expending 2,500 kcal per day. This woman loses about 3,000 ml (3 L) of fluid per day, which she replaces with beverages (2,200 ml), food (500 ml), and metabolism (300 ml).

An 8-oz glass of fluid is equal to 240 ml. In this example, the woman would need to drink nine glasses of fluid to meet her needs. Although you may have heard the recommendation to drink eight glasses of fluid each day, this is a myth. Fluid requirements are highly individualized, and even the DRIs are only a general guideline. For example, athletes and other people who are active, especially those working in very hot environments, require more fluid than people working a desk job in an air-conditioned office. In fact, a recent study reported that competitive athletes can lose up to 2 liters of sweat per hour when they are intensely exercising in the heat.6 Thus, these individuals need to drink more to replace the fluid they lose. Dehydration and other disorders related to fluid imbalances are discussed later in this chapter.

**Tap Water Is as Healthful as Bottled Water**

In 2016, the FBI joined a criminal investigation of lead-contaminated tap water in Flint, Michigan. Does this suggest that municipal water supplies are unsafe? Is bottled water better? Let's have a look.

Millions of Americans routinely consume the tap water found in homes and public places, which generally comes from two sources: surface water comes from lakes, rivers, and reservoirs, and groundwater is from underground rock formations called *aquifers.*

**[FIGURE 7.8** Amount and sources of water intake and output for a woman expending 2,500 kcal/day.]

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The Environmental Protection Agency (EPA) sets and monitors the standards for public water systems. The most common chemical used to treat and purify public water supplies is *chlorine,* which is effective in killing many microorganisms. Water treatment plants also routinely check water supplies for hazardous chemicals, including toxic minerals such as lead (which damages the nervous system). Because of these efforts, the United States has one of the safest water systems in the world. The criminal investigation in Flint, Michigan, can be seen as evidence of federal commitment to safe public water supplies.

Many people who live in rural areas depend on groundwater pumped from a well as their water source. The EPA does not monitor water from private wells, but it publishes recommendations for well owners to help them maintain a safe water supply. For more information on drinking water safety, go to the EPA website (see the **Web** **Links** at the end of this chapter).

Decades before the crisis in Flint, a major shift in consumption from tap water to bottled water began. Americans now drink about 34 gallons of bottled water per person, per year, totaling more than 11 billion gallons!7 The meteoric rise in bottled water production and consumption is most likely due to the convenience of drinking bottled water, the health messages related to drinking more water, and the public's fears related to the safety of tap water. Even with this growth, however, bottled water represents only a small fraction of the over 1 billion gallons of tap water the U.S. public water systems supply every hour of every day.7 Recent environmental concerns related to the disposal of water bottles has begun to limit the growth of bottled water, and the industry has responded by using smaller bottle caps, thinner bottles, and a higher proportion of recyclable materials.

The FDA is responsible for the regulation of bottled water. Like tap water, bottled water is taken from either surface water or groundwater sources. But it is often treated and filtered differently. Although this treatment may make bottled water taste better than tap water, it doesn't necessarily make it any safer to drink. Also, although some types of bottled water contain more minerals than tap water, there are no other additional nutritional benefits of drinking bottled water. How can you tell what's in your favorite brand of bottled water? See the **Nutrition Label Activity** to find out!

Many types of bottled water are available in the United States. Carbonated water (seltzer water) contains carbon dioxide gas that either occurs naturally or is added to the water. Mineral waters contain various levels of minerals and offer a unique taste. Some brands, however, contain high amounts of sodium and should be avoided by people who are trying to reduce their sodium intake. Distilled water is mineral free but has a "flat" taste. For more information on bottled water, go to www.bottledwater.org.

**All Beverages Are Not Created Equal**

Many commercial beverages contain several important nutrients in addition to their water content, whereas others provide water and refined sugar but very little else. Let's review the health benefits and potential concerns of some of the most popular beverages on the market.

**Milk and Milk Alternatives**

Milk is a healthful beverage choice because it provides protein, calcium, phosphorus, vitamin D, and, usually, vitamin A. Many brands of fluid milk are now "specialized" and provide additional calcium, vitamin E, essential fatty acids, and/or plant sterols (to lower serum cholesterol). Kefir, a blended yogurt drink, is also a good source of most of these nutrients. Calcium-fortified soy milk provides protein and calcium, and many brands provide vitamin D. In contrast, almond and rice milks are low in protein, with only 1 gram per cup.

When purchasing flavored milk, kefir, or milk alternatives, check the Nutrition Facts panel for the sugar content. Some brands of chocolate milk, for example, can contain 6 or more teaspoons of sugar in a single cup!

[Image: Drinking bottled water is convenient, but costly to your budget and the environment.]

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## **nutrition** **label activity Is Bottled Water Better Than Tap?**

[The next time you reach for a bottle of water, check the label! If it doesn't identify a specific water source, the bottle may actually contain tap water with minerals added to improve the taste. To avoid paying a high price for bottled tap water, make sure the label includes the phrase "Bottled at the source." Water that comes from a protected groundwater source is less likely to have contaminants, such as disease-causing microbes. If the label doesn't identify the water's source, it should at least provide contact information, such as a phone number or website of the bottled water company, so that you can track down the source.

Although many labels lack information about treatment methods, you might use the company's website to find out how their bottled water was treated. There are several ways of treating water, but what you're looking for is either of the following two methods, which have been proven to be most effective against the most common waterborne disease-causing microorganisms:

*-* *Micron filtration,* which is a process whereby water is filtered through screens with various-sized microscopic holes. High-quality micron filtration can eliminate most chemical contaminants and microbes.

*-* *Reverse osmosis,* which is a process often referred to as *ultrafiltration* because it uses a membrane with microscopic openings that allow water to pass through but not larger compounds. Reverse osmosis membranes also utilize electrical charges to reject harmful chemicals.

[Image: Numerous varieties of drinking water are available to consumers.]

If the label on your bottle of water says that the water was purified using any of the following methods, you might want to consider switching brands: filtered, carbon-filtered, particle-filtered, ozonated or ozone-treated, ultraviolet light, ion exchange, or deionized. These methods have not been proven to be effective against the most common waterborne disease-causing microorganisms.

It is also a good idea to check the nutrient content on the water bottle label. Ideally, water should be high in magnesium (at least 20 mg per 8 fl. oz serving) and calcium but low in sodium (less than 5 mg per 8 fl. oz serving). Avoid bottled waters with sweeteners because their "empty Calories" can contribute significantly to your energy intake. These products are often promoted as healthful beverage choices with names including words such as *vitamins, herbs, nature,* and *life,* but they are essentially "liquid candy." Check the Nutrition Facts panel and don't be fooled.]

**Hot Beverages Containing Caffeine**

Coffee made without cream or nondairy creamer can be a healthful beverage choice if consumed in moderation. As mentioned earlier, recent research suggests that its caffeine content does not significantly decrease the body's hydration status, and the calcium in coffee drinks made with milk, such as cafe con leche and cafe latte, can be significant. Coffee is also known to provide several types of phytochemicals that may lower risk of certain chronic diseases such as type 2 diabetes, liver disease, heart disease, and stroke.8 The 2015 Dietary Guidelines Advisory Committee reported that intake of 1 cup of coffee per day was associated with a 3% to 4% decrease in risk of total mortality.9

Tea is second only to water as the most commonly consumed beverage in the world. With the exception of red tea and herbal teas, which do not contain caffeine, all forms of tea come from the same plant, *Camellia sinesis,* and all contain caffeine. However, the level is typically about half that of the same amount of brewed coffee. Black tea is the most highly processed (the tea leaves are fully fermented). Oolong tea leaves are only partially fermented, and both green and white tea leaves have been dried but not fermented. As compared to black and oolong teas, green and white teas are higher in phytochemicals.

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Consumption of green tea decreases the risk of cardiovascular disease, including strokes.10 Research has also shown that green tea mouthwash has an effective antiplaque effect.11 If consumed without added sugar, tea is an excellent source of fluid that may have unexpected long-term health benefits.

Hot chocolate also provides caffeine, although the levels are much lower than those found in coffee or tea. Dark chocolate is rich in phytochemicals known as flavanols, which may reduce the risk of heart attacks and strokes12 and the onset of age-related cognitive decline.13 Hot chocolate made with dark cocoa powder and skim or low-fat milk is a nutritious and satisfying drink.

**Energy Drinks**

Energy drinks represent another popular beverage option, with over $10 billion in U.S. sales in 2015. About 30% of teenagers and 65% of Millennials drink them on a regular basis, even though public health experts have raised significant concerns over their harmful effects.14 Many energy drinks contain more than three times the amount of caffeine in a comparable serving of cola, and some also contain guarana seed extract, which is a potent source of additional caffeine. Moreover, unlike hot coffee, which is sipped slowly, the drinks are typically downed in a few minutes. Some are even packaged as a "shot." This sudden surge of caffeine can cause a dramatic rise in blood pressure and heart rate. Seizures, miscarriage, mood swings, insomnia, dehydration, and other health problems, as well as over 20,000 emergency department visits, have been linked to consumption of energy drinks. Although the FDA limits the amount of caffeine in soft drinks, it has no legal authority to regulate the ingredients, including caffeine, in energy drinks because they are classified as dietary supplements, not food. In contrast, Canada now caps caffeine levels in energy drinks, and Mexico is proposing to ban their sale to adolescents.

Energy drinks are also a source of significant added sugars. For example, a 16-oz bottle of Rockstar Original contains 62 grams--more than 15 teaspoons--of added sugars. In short, as a source of fluid, energy drinks should be avoided by children and adolescents and used sparingly by adults.

**Beverages with Added Sugars**

Soft drinks, juice drinks, flavored waters, and bottled teas and coffee drinks made with added sugars are referred to as *sugary drinks.* Whether they are sweetened with high fructose corn syrup (HFCS), honey, cane sugar, or fruit juice concentrate is unimportant: all forms of sugar provide the same number of Calories per gram, no matter their molecular structure. Even 100 % fruit juice with no added sugar is high in Calories. For instance, an 8-oz carton of a popular brand of premium orange juice provides 110 Calories.

As we've discussed (see Chapters 4 and 5), added sugars contribute not only to obesity, but also to chronic disease. Research data has linked diets high in added sugars to increased risk of cardiovascular disease and overall mortality due to chronic diseases.15,16

In the past, very few people realized how many Calories were in the beverages they drank. Recently, however, public health agencies have been raising awareness of the empty Calorie content of sugary drinks. Some are advocating that a first step in any weight loss program should be to entirely eliminate these products from the diet. The city of Berkeley, California, recently became the first community to impose a sales tax on sugary drinks, and the FDA's proposed changes to the Nutrition Facts panel will identify added sugars separately from total sugars. In addition, the American Beverage Association's "Clear on Calories" campaign now puts Calorie information per package on the front of the product. Thus, when buying a 20-oz bottle of sweetened tea, consumers will know they'll be consuming, for example, 250 Calories if they drink the whole bottle. Some beverage companies have reduced the average Calorie content of their products by introducing a variety of smaller cans and bottles. Most consumer advocates, however, view these efforts simply as a marketing ploy.

[Image: After water, tea is the most commonly consumed beverage in the world.]

[To watch a video of the American Beverage Association's Clear on Calories ad, go to **www .ameribev.org,** and type in "nutrition," and then "ads clear on calories" to connect to a link to the video.]

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**Specialty Waters**

Specialty waters are made with added nutrients, herbs, or a higher pH. The labels claim they enhance memory, delay aging, boost energy levels, or strengthen the immune response. Notice, however, that these claims are accompanied by a disclaimer such as, "This statement has not been evaluated by the FDA. This product is not intended to diagnose, treat, cure, or prevent any disease." The FDA requires this disclaimer whenever a food manufacturer makes a structure-function claim (see Chapter 2)*.* It acknowledges that the statement made on the label is not based on research!

In fact, the amounts of nutrients, phytochemicals, or other substances added to these waters are usually so low, compared to what can be obtained from foods, that they rarely make much of an impact on the consumer's health. In contrast, some of these designer waters can add more than 300 Calories to the day's intake, and they are expensive.

**Sports Beverages and Coconut Water**

Because of the potential for fluid and electrolyte imbalances during rigorous exercise, many endurance athletes drink sports beverages, which provide water, electrolytes, and a source of carbohydrate, before, during, and after workouts. Others are turning to coconut water, marketed as a good source of electrolytes and "natural sugars." Recently, these beverages have become popular with nonathletes, including children and adolescents.17 However, as a general rule, only people who exercise or do manual labor vigorously for 60 minutes or more benefit from drinking either sports beverages or coconut water. (Fluid requirements for physical activity are discussed in detail in Chapter 11.)

**[recap**

According to the DRIs, adult males need to drink about 13 cups of beverages each day, and females need about 9 cups. However, fluid intake needs are highly variable and depend on body size, age, physical activity, health status, and environmental conditions. All beverages provide water, and some, such as milk and milk alternatives, provide other important nutrients as well. Coffee and tea provide phytochemicals and are considered healthful if consumed in moderation. Energy drinks typically release more caffeine more quickly into the bloodstream, and can be harmful. Sugary drinks can contribute substantially to weight gain and an increased risk for chronic disease. Most nonathletes do not need to consume sports beverages or coconut water.]

**LO 5** Identify the functions, DRIs, and common dietary sources of sodium, potassium, chloride, and phosphorus.

## **How do four major minerals contribute to fluid balance?**

The micronutrients involved in maintaining hydration and neuromuscular function are the major minerals sodium, potassium, chloride, and phosphorus **(TABLE 7.1).**

**TABLE 7.1** **Overview of Minerals Involved in Hydration and Neuromuscular Function**

To see the full profile of all micronutrients, turn to the In Depth essay following Chapter 6, Vitamins and Minerals: Micronutrients with Macro Powers (pages 211-221).

|  |  |
| --- | --- |
| **Nutrient** | **Recommended Intake** |
| Sodium | Al for 19 to 50 years of age: 1.5 g/day |
| Potassium | Al for 19 years of age and older: 4.7 g/day |
| Chloride | Al for 19 to 50 years of age: 2.3 g/day |
| Phosphorus | RDA for 19 years of age and older: 700 mg/day |

[Image: Sports beverages can help meet the nutrient needs of athletes, but are unnecessary for most consumers.]

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Calcium and magnesium also function as electrolytes and influence the body's fluid balance and neuromuscular function; however, because of their critical importance to bone health, they are discussed in Chapter 9.

**Sodium Is a Positively Charged Extracellular Electrolyte**

Over the last 20 years, researchers have linked high sodium intake to an increased risk for hypertension among some groups of individuals. Because of this link, many people have come to believe that sodium is harmful to the body. This oversimplification, however, is just not true: sodium is essential for survival.

**Functions of Sodium**

Sodium is the major positively charged electrolyte in the extracellular fluid. Its exchange with potassium across cell membranes allows cells to maintain proper fluid balance. Moreover, the kidneys' excretion and reabsorption of sodium contribute to blood pressure regulation. Sodium also assists with the initiation and transmission of nerve signals. The stimulation of muscles by nerve impulses provides the impetus for muscle contraction.

**Recommended Intakes and Food Sources of Sodium**

The Al for sodium is listed in Table 7.1. Most people in the United States consume two to four times the Al daily. Several national guidelines, including the *2015-2020 Dietary Guidelines for Americans* (DGAs) recommend a daily sodium intake of no more than 2,300 mg per day. The DGAs specifically recommend that persons who have prehypertension or hypertension limit their daily sodium intake to no more than 1,500 mg.18

Sodium is found naturally in many whole foods, but most dietary sodium comes from processed foods and restaurant foods, which typically contain large amounts of added sodium. Try to guess which of the following foods contains the most sodium: 1 cup of tomato juice, 1 oz of potato chips, or 4 saltine crackers. Now look at **TABLE 7.2** to find the answer. This table shows foods that are high in sodium and gives lower-sodium alternatives. Are you surprised to find out that, of all of these food items, the tomato juice has the most sodium?

Because sodium is so abundant, it's easy to overdo it. See the **Quick Tips** feature for ways to reduce your sodium intake. For more help curbing your sodium intake, try the DASH diet (see the **In Depth** essay on cardiovascular disease following Chapter 5).

**TABLE 7.2 High-Sodium Foods and Lower-Sodium Alternatives**

|  |  |  |  |
| --- | --- | --- | --- |
| **High-Sodium Food** | **Sodium (mg)** | **Lower-Sodium Food** | **Sodium (mg)** |
| Dill pickle (1 large, 4 in.) | 1,731 | Low-sodium dill pickle (1 large, 4 in.) | 23 |
| Ham, cured, roasted (3 oz) | 1,023 | Pork, loin roast (3 oz) | 54 |
| Turkey pastrami (3 oz) | 915 | Roasted turkey, cooked (3 oz) | 54 |
| Tomato juice, regular (1 cup) | 877 | Tomato juice, lower sodium (1 cup) | 24 |
| Macaroni and cheese (1 cup) | 800 | Spanish rice (1 cup) | 5 |
| Ramen noodle soup (chicken flavor) (1 package [85 g]) | 1,960 | Ramen noodle soup made with sodium-free chicken bouillon (1 cup) | 0 |
| Teriyaki chicken (1 cup) | 3,210 | Stir-fried pork/rice/vegetables (1 cup) | 575 |
| Tomato sauce, canned (1/2 cup) | 741 | Fresh tomato (1 medium) | 11 |
| Creamed corn, canned (1 cup) | 730 | Cooked corn, fresh (1 cup) | 28 |
| Tomato soup, canned (1 cup) | 695 | Lower-sodium tomato soup, canned (1 cup) | 480 |
| Potato chips, salted (1 oz) | 168 | Baked potato, unsalted (1 medium) | 14 |
| Saltine crackers (4 crackers) | 156 | Saltine crackers, unsalted (4 crackers) | 100 |

*Data from:* U.S. Department of Agriculture. 2011. USDA Nutrient Database for Standard Reference, Release 24.

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**[Reducing the Sodium in Your Diet**

Put away the salt shaker--keep it off the table and train your taste buds to prefer foods with less salt.

Follow the DASH diet plan (see page 176), which is high in fruits, vegetables, whole grains, and lean protein foods. The more you include fresh, whole foods in your diet, the less sodium you will be eating.

Look for the words *low sodium* or *no added salt* when buying processed foods. Use the Nutrition Facts panel to find foods that contain 5% or less of the daily value for sodium or less than 200 mg per serving.

Look for *hidden* salt content on food labels; for example, both monosodium glutamate and sodium benzoate are forms of sodium.

Choose fresh or frozen vegetables (without added sauces) because they are usually much lower in sodium than canned vegetables. Alternatively, choose salt-free canned vegetables.

Stay away from prepared stews, canned and dried soups, gravies, and pasta sauces as well as packaged pasta, rice, and potato dishes that are high in sodium.

Choose low-sodium versions of pickles, olives, three-bean salad, salad dressings, smoked meats and fish, and nuts.

Snack on fruits and vegetables instead of salty pretzels, chips, and other snack items.

When cooking, experiment with herbs, spices, lemon juice, chutneys, salsas, and cooking wine to flavor your food. Products that end in the word *salt,* such as garlic salt or celery salt, are high in sodium and should be avoided.

Rinse canned legumes, such as black, navy, garbanzo, or kidney beans, with cold water to lower the sodium content before heating and consuming them.

Limit the amounts of condiments you use. Condiments such as ketchup, mustard, pickle relish, and soy sauce can add a considerable amount of sodium to your foods.

When eating out, look for entrees labeled "heart healthy" or "lower in sodium"; if nutrition information is provided, compare foods to select those with lower amounts of sodium.

Check the labels of the beverages you consume as well; fluids are often a "hidden" source of dietary sodium.

Also check your medications. Some are high in sodium.]

**Sodium Toxicity and Deficiency**

Hypertension is typically more common in people who consume high-sodium diets, especially if potassium intake is low. This strong relationship has prompted many health organizations to recommend lowering sodium intakes. Whether high-sodium diets actually cause hypertension is a matter of continuing debate; many researchers believe that a high-sodium/low-potassium dietary pattern is the greatest risk factor. Researchers also debate the effect of high-sodium intake on bone loss: some studies suggest high-sodium intakes have a negative effect on bone density, whereas other research has shown no impact on bone density.

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**Hypernatremia** refers to an abnormally high blood sodium concentration. Although theoretically it could be caused by a rapid intake of high amounts of sodium--for instance, if a shipwrecked sailor resorted to drinking seawater--consuming too much sodium does not usually cause hypernatremia in a healthy person because the kidneys are able to excrete excess sodium in the urine. But people with congestive heart failure or kidney disease are not able to excrete sodium effectively, making them more prone to the condition. Hypernatremia is dangerous because it causes an abnormally high blood volume, again, by pulling water from the intracellular environment to dilute the sodium in the extracellular tissue spaces and vessels. This leads to edema (swelling) of tissues and elevation of blood pressure to harmful levels.

Because the dietary intake of sodium is so high among Americans, deficiencies of sodium are extremely rare. Nevertheless, certain conditions can cause **hyponatremia,** abnormally low blood sodium levels.

Hyponatremia can occur during periods of intense physical activity, such as a marathon or day-long hike in warm weather, when people drink large volumes of water and fail to replace sodium. Severe diarrhea, vomiting, or excessive, prolonged sweating can also cause hyponatremia. Symptoms include headaches, dizziness, fatigue, nausea, vomiting, and muscle cramps.

If hyponatremia is left untreated, it can progress to seizures, coma, and death. Treatment includes careful sodium replacement, such as the intravenous administration of an electrolyte-rich solution.

**Potassium Is a Positively Charged Intracellular Electrolyte**

As we discussed previously, potassium is the major positively charged electrolyte in the intracellular fluid. It is a major constituent of all living cells and is found in both plants and animals.

**Functions of Potassium**

Potassium and sodium work together to maintain proper fluid balance and regulate the transmission of nerve impulses and the contraction of muscles. And in contrast to a high-sodium diet, a diet high in potassium actually helps maintain a lower blood pressure.

**Recommended Intakes and Food Sources of Potassium**

Potassium is found in abundance in many fresh foods, especially fresh fruits and vegetables. Processed foods generally have less potassium than fresh foods.

The Al for potassium is listed in Table 7.1. Just as most Americans' sodium intake exceeds the recommended limits, the average potassium intake of Americans falls well below the recommended amount. Many researchers think that this sodium-potassium imbalance is a major factor contributing to the increased incidence of hypertension in the United States. By avoiding processed foods and eating more fresh fruits, legumes and other vegetables, whole grains, and dairy foods, you'll increase your potassium intake and decrease your sodium intake, achieving a more healthful diet. **FIGURE 7.9** identifies foods that are high in potassium. See the **Quick Tips** for suggestions on how to increase your dietary potassium.

**Potassium Toxicity and Deficiency**

People with healthy kidneys are able to excrete excess potassium effectively. However, people with kidney disease are not able to regulate their blood potassium levels. **Hyperkalemia,** or high blood potassium levels, occurs when potassium is not excreted efficiently from the body. Because of potassium's role in cardiac muscle contraction, severe hyperkalemia can alter the normal rhythm of the heart, resulting in heart attack and death. People with kidney failure must monitor their potassium intake very carefully. Individuals at risk for hyperkalemia should avoid consuming salt substitutes because these products are high in potassium.

Because potassium is widespread in many foods, a dietary potassium deficiency is rare. However, potassium deficiency, called **hypokalemia,** is not uncommon among people who have serious medical disorders.

[Image: Many popular snack foods are high in sodium.]

[Sidebar: **hypernatremia** A condition in which blood sodium levels are dangerously high.]

[Sidebar: **hyponatremia** A condition in which blood sodium levels are dangerously low.]

[Sidebar: **hyperkalemia** A condition in which blood potassium levels are dangerously high.]

[Sidebar: **hypokalemia** A condition in which blood potassium levels are dangerously low.]

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[**FIGURE 7.9** Common food sources of potassium. The Al for potassium is 4.7 g (or 4,700 mg) per day.

*Data from:* U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference, Release 28. Version Current: September 2015. Internet: http://www.ars.usda.gov/nea/bhnrc/ndl]

In addition, people with hypertension who are prescribed diuretic medications are at risk. Diuretics promote the excretion of fluid as urine through the kidneys. Whereas some diuretics spare potassium, others increase the excretion of potassium. People who are taking diuretic medications therefore require close medical monitoring.

Extreme dehydration, vomiting, diarrhea, alcohol abuse, and laxative abuse increase the risk for hypokalemia. Symptoms include confusion, loss of appetite, and muscle weakness.

**Quick Tips**

**[Increasing Your Potassium Intake**

Avoid processed foods that are high in sodium and low in potassium. Check the Nutrition Facts panel of the food before you buy it!

For breakfast, look for cereals containing bran and/or wheat germ, or add wheat germ to homemade bran muffins.

Sprinkle wheat germ on yogurt and top with banana slices.

Drink milk! If you don't like milk, try kefir. Many brands of soy milk are also good sources of potassium.

Make a smoothie by blending ice cubes and yogurt with a banana.

Pack a can of low-sodium vegetable or tomato juice in your lunch in place of a soft drink.

Serve avocado or bean dip with I veggie slices.

Replace the meat in your sandwich with thin slices of avocado or marinated tofu.

Replace the meat in tacos and burritos with black or pinto beans.

For a healthful alternative to french fries, toss slices of sweet potato in olive oil, place on a cookie sheet, and oven bake at 400°F for 10-15 minutes.

Toss a banana, some dried apricots, or a bag of sunflower seeds into your lunch bag.

Make a fruit salad with apricots, bananas, cantaloupe, honeydew melon, mango, or papaya.

Bake and enjoy a fresh pumpkin pie!]

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Severe cases result in fatal changes in heart rate; many deaths attributed to extreme dehydration or eating disorders are caused by abnormal heart rhythms due to hypokalemia.

**Chloride Is a Negatively Charged Extracellular Electrolyte**

Chloride should not be confused with *chlorine,* which is a poisonous gas used to kill bacteria and other germs in our water supply. Chloride is a negatively charged ion that is obtained almost exclusively in our diet from sodium chloride, or table salt.

Coupled with sodium in the extracellular fluid, chloride assists with the maintenance of fluid balance. Chloride is also a part of hydrochloric acid in the stomach, which aids in preparing food for further digestion (see Chapter 3). Chloride works with the white blood cells of our body during an immune response to help kill bacteria, and it assists in the transmission of nerve impulses.

The AI for chloride is listed in Table 7.1. Our primary dietary source of chloride is the sodium chloride in the salt in our foods. Chloride is also found in some fruits and vegetables. As you've learned, consuming excess amounts of salt over a prolonged period leads to hypertension in salt-sensitive individuals. There is no other known toxicity symptom for chloride. Moreover, because of the relatively high salt intake in the United States, chloride deficiency is rare, even when a person consumes a low-sodium diet. A chloride deficiency can occur, however, during conditions of severe dehydration and frequent vomiting, including in people with eating disorders who vomit after food intake.

**Phosphorus Is a Negatively Charged Intracellular Electrolyte**

Phosphorus is the major intracellular negatively charged electrolyte. In the body, phosphorus is most commonly found in the form of phosphate. Phosphorus is an essential constituent of all cells and is found in both plants and animals.

Phosphorus works with potassium inside cells to maintain proper fluid balance. It also plays a critical role in bone formation because it is part of the mineral complex of bone. In fact, about 85% of our body's phosphorus is stored in our bones.

As a primary component of adenosine triphosphate (ATP), phosphorus plays a key role in the conversion of food to energy. It also helps regulate many other chemical reactions by activating and deactivating enzymes. Phosphorus is a part of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), and it is a component in cell membranes (as phospholipids) and lipoproteins.

The RDA for phosphorus is listed in Table 7.1. The average U.S. adult consumes about twice this amount each day; thus, phosphorus deficiencies are rare. Phosphorus is widespread in many foods; high-protein foods such as milk, meats, and eggs are good sources. **FIGURE 7.10** shows the phosphorus content of various foods. Phosphorus is absorbed more readily from animal sources than from plant sources. Another beneficial role of the GI flora is to help release the phosphorus in plant foods, allowing more of it to be absorbed.

People suffering from kidney disease, who cannot efficiently excrete phosphorus; people consuming excessive amounts of supplemental vitamin D, which tends to increase absorption and retention of phosphorus; and people taking too many phosphorus-containing antacids can suffer from high blood phosphorus levels. Severely high levels of blood phosphorus cause muscle spasms and convulsions. Deficiencies of phosphorus are rare except in people with very poor diets, vitamin D deficiency, or oversecretion of parathyroid hormone. People who overuse antacids that bind with phosphorus may also have low blood phosphorus levels.

**[recap**

The four electrolytes critical for hydration and neuromuscular function are sodium, potassium, chloride, and phosphorus. Sodium and potassium are positively charged electrolytes. Most Americans consume more than the recommended 2,300 mg of sodium per day, and many consume too little potassium.]

[Image: Almost all chloride is consumed through table salt.]

[Image: Milk is a good source of phosphorus.]

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[**FIGURE 7.10** Common food sources of phosphorus. The RDA for phosphorus is 700 mg/day.

*Data from:* U.S. Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory. USDA National Nutrient Database for Standard Reference, Release 28. Version Current: September 2015. Internet: http://www.ars.usda.gov/nea/bhnrc/ndl]

This imbalance, which tends to reflect Americans' high intake of processed foods and low intake of fresh fruits and vegetables, has been associated with an increased risk for cardiovascular disease. Intakes of the negatively charged electrolytes chloride and phosphorus are almost always adequate, except in people with very poor diets or serious disorders. Toxicities are also rare. Electrolyte imbalances can result in heart failure, seizures, and death.

**LO 6** Discuss several disorders related to fluid and electrolyte balance.

## **What disorders are related to fluid and electrolyte balance?**

A number of serious, and potentially fatal, disorders, including dehydration and heat illnesses, are related to fluid and electrolytes imbalances. We review some of these here.

**Dehydration Develops as Fluid Loss Exceeds Fluid Intake**

**Dehydration** is a serious condition that develops when fluid losses exceed fluid intake. It is classified in terms of the percentage of weight loss that is exclusively due to the loss of fluid **(TABLE 7.3)** (page 244).

Dehydration most commonly develops as a result of heavy exercise or hard physical labor in high environmental temperatures, when the body loses significant amounts of water through increased sweating and breathing. However, elderly people and infants can get dehydrated even when inactive, as their risk for dehydration is much higher than that of healthy young and middle-aged adults. The elderly are at increased risk because they have a lower total amount of body fluid and their thirst mechanism is less effective than that of a younger person; they are therefore less likely to meet their fluid needs. Infants, on the other hand, excrete urine at a higher rate, cannot tell us when they are thirsty, and have a greater ratio of body surface area to body core, causing them to respond more dramatically to heat and cold and to lose more body water than an older child. Finally, extended bouts of diarrhea, vomiting, or fever can also lead to dehydration.

[Image: Adequate fluid replacement during and after physical activity is critical in preventing dehydration.]

[Sidebar: **dehydration** The depletion of body fluid. It results when fluid excretion exceeds fluid intake.]

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**TABLE 7.3** **Percentages of Body Fluid Loss Correlated with Weight Loss and Symptoms**

|  |  |  |  |
| --- | --- | --- | --- |
| **Body Water Loss (%)** | **Weight Lost If You Weigh 160** **lb** | **Weight Lost If You Weigh 130** **lb** | **Symptoms** |
| 1-2 | 1.6-3.2 lb | 1.3-2.6 lb | Strong thirst, loss of appetite, feeling uncomfortable |
| 3-5 | 4.8-8.0 lb | 3.9-6.5 lb | Dry mouth, reduced urine output, greater difficulty working and concentrating, flushed skin, tingling extremities, impatience, sleepiness, nausea, emotional instability |
| 6-8 | 9.6-12.8 lb | 7.8-10.4 lb | Increased body temperature that doesn't decrease, increased heart rate and breathing rate, dizziness, difficulty breathing, slurred speech, mental confusion, muscle weakness, blue lips |
| 9-11 | 14.4-17.6 lb | 11.7-14.3 lb | Muscle spasms, delirium, swollen tongue, poor balance and circulation, kidney failure, decreased blood volume and blood pressure |

*Data from: Nutrition and Aerobic Exercise,* edited by D. K. Layman. © 1986 American Chemical Society.

Adequate fluid replacement is the most important factor in preventing dehydration. If you're physically active, how can you tell whether you are drinking enough fluid before, during, and after your exercise or training sessions? First, you can hop on the scale before and after each session, ideally when unclothed or just wearing underclothes. If you weighed in at 160 pounds before basketball practice, and immediately afterwards you weighed 158 pounds, then you would have lost 2 pounds of body weight, virtually all as fluid. This is equal to 1.3% of your body weight prior to practice. As you can see in Table 7.3, you would most likely experience strong thirst and diminished appetite, and you might even feel generally uncomfortable.

If you find you have lost weight during a session of physical activity, what should you do about it? Your goal is to consume enough water and other fluids to replace 11/2 times as much fluid as was lost--and to do this prior to your next exercise session. Fortunately, this isn't difficult. Every 1 pound of weight loss equals about 2 cups of fluid, which you would need to replace by drinking 3 cups of fluid (2 multiplied by 1.5 equals 3). In general, by following the daily fluid intake recommendations discussed earlier, plus replacing fluids lost during sessions of physical activity, you should be able to avoid becoming dehydrated.

If you don't have time to weigh yourself before and after every workout, don't despair! A simpler method of monitoring your fluid levels is to observe the color of your urine. If you are properly hydrated, your urine should be clear to pale yellow in color, similar to diluted lemonade **(FIGURE 7.11).** Urine that is medium to dark yellow in color, similar to apple juice, indicates an inadequate fluid intake. Very dark or brown urine, such as the color of a cola beverage, is a sign of severe dehydration and indicates potential muscle breakdown and kidney damage. Your goal should be to maintain a urine color that is clear or pale yellow.

**Water Intoxication Can Be Fatal**

**Overhydration,** or water intoxication, generally occurs only in people with disorders that cause the kidneys to retain too much water, diluting blood sodium and leading to hyponatremia, as discussed earlier. However, individuals have died of overhydration while following a fad diet or participating in a hazing ritual or competition involving excessive water intake. Thus, no one should ever be encouraged to drink excessive amounts of water.

**Heat Illnesses Are Linked to Dehydration**

Three common types of heat illness are closely linked to dehydration: in order of severity, these are heat cramps, heat exhaustion, and heat stroke.

**Heat Cramps**

**Heat cramps** are painful muscle cramps, usually in the abdomen, arms, or legs, that develop during sessions of vigorous physical activity in the heat. The spasms can last for several seconds or even minutes and are caused by a fluid and electrolyte imbalance.

**[FIGURE 7.11** Urine color chart. Color variations indicate levels of hydration.]

[Sidebar: **overhydration** The dilution of body fluid. It results when water retention or intake is excessive.]

[Sidebar: **heat cramps** Involuntary, spasmodic, and painful muscle contractions that are caused by electrolyte imbalances occurring as a result of strenuous physical activity in high environmental heat.]

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## **nutri-case GUSTAVO**

"Something is going on with me this week. Every day, at work, I've been feeling weak and like I'm going to be sick to my stomach. It's been really hot, over a hundred degrees out in the fields, but I'm used to that, and besides, I've been drinking lots of water. It's probably just my high blood pressure acting up again."

What do you think might be affecting Gustavo? If you learned that he was following a low-sodium diet to manage his hypertension, would this information argue for or against your assumptions about the source of his discomfort? Why or why not? What would you advise Gustavo to do differently at work tomorrow?

If you ever experience muscle cramps during a workout or athletic event, stop your activity immediately. Go to a cool place, rest, and sip a sports beverage, juice, or--if these are not available--plain water. You can also sprinkle a dash of salt into a full glass of water. If the cramps don't subside within an hour, seek medical attention.

**Heat Exhaustion**

Like heat cramps, **heat exhaustion** typically occurs when people are engaging in vigorous physical activity in a hot environment. It can also develop after several days in high temperatures when fluid intake is inadequate.

Signs and symptoms typically include increased thirst; weakness; muscle cramps; nausea and vomiting; dizziness and possibly fainting; and possibly elevated blood pressure and pulse. In a person with heat exhaustion, the sweat mechanism still functions; in fact, the person is typically sweating heavily. Immediate cooling and fluid intake are essential to avoid heat stroke.

**Heat Stroke**

**Heat stroke** is a potentially fatal heat illness characterized by failure of the body's heat-regulating mechanisms. Thus, the person's skin is hot and dry, not sweaty. Other signs and symptoms include rapid pulse; high core body temperature; rapid, shallow breathing; and disorientation or loss of consciousness.

Recall that evaporative cooling is less efficient in a humid environment because the sweat is less able to evaporate. Therefore, athletes who work out in hot, humid weather are particularly vulnerable to heat stroke. Heat-related deaths occur among high school, collegiate, and professional athletes. The deaths are more common in overweight or obese athletes for two reasons: Significant muscle mass produces a lot of body heat, whereas excess body fat adds an extra layer of insulation that makes it more difficult to dissipate that heat. In football players, tight-fitting uniforms and helmets also trap warm air and blunt the ability of the body to cool itself.

If you are active in a hot environment and begin to feel dizzy, light-headed, disoriented, or nauseated, stop exercising at once. Get into a cool environment, such as a cool shower or a bath. Drink a sports beverage. If you are working out with someone who exhibits the symptoms of heat stroke, call 911 immediately.

**[recap**

Dehydration is the depletion of body fluid, and occurs when fluid losses exceed fluid intake. If you are properly hydrated, your urine should be clear to pale yellow in color. Overhydration is dilution of body fluid, whether because of a medical disorder or excessive water intake. Heat cramps develop during sessions of vigorous physical activity in the heat, and are caused by fluid and electrolyte imbalances. Heat exhaustion is a more serious condition that develops with inadequate fluid intake in a hot environment. If not addressed, it can lead to heat stroke, a medical emergency characterized by failure of the body's heat-regulating mechanisms.]

[Image: Athletes who train or compete in hot weather are vulnerable to heat stroke.]

[Sidebar: **heat exhaustion** A serious condition, characterized by heavy sweating and moderately elevated body temperature, that develops from dehydration in high heat.]

[Sidebar: **heat stroke** A potentially fatal response to high temperature characterized by failure of the body's heat-regulating mechanisms; also commonly called *sunstroke.*]

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## **nutrition debate Low-Sodium Diets: Fit for All or Just a Few?**

[For decades, U.S. and international public health organizations recommended a low-sodium diet to prevent and treat hypertension (HTN) and reduce the risk for cardiovascular disease. Many still do.18 Yet recently, some organizations have modified their sodium-intake recommendations in response to research suggesting that a low intake of sodium may not benefit the population as a whole and may even increase health risks for some. So who should reduce their sodium intake? Should you? Keeping in mind that nutrition research is always providing new information, let's explore our current understanding of this issue.

**How Have Sodium Intake Recommendations Evolved Over Time?**

Prior to 2005, the *Dietary Guidelines for Americans* used only descriptive phrases, not specific numerical targets, for their sodium intake recommendations. For example, the 1990 recommendation was to "Use salt and sodium only in moderation."19 In contrast, the 2005, 2010, and 2015-2020 DGAs all recommended a specific sodium intake of less than 2,300 mg per day. The 2015-2020 Guidelines also advise people with prehypertension and HTN to limit their sodium intake to 1,500 mg per day and follow the DASH diet.18 These recommendations were based on a careful review of available research, including epidemiologic studies, double-blind clinical trials, and community-based interventions.

In 2009 and 2012, however, some public health organizations released recommendations that were lower than those of the DGAs: In 2009, the American Heart Association (AHA) proposed "no more than 1,500 mg of sodium per day" for everyone.20 In 2012, the World Health Organization (WHO) recommended a target intake of 2,000 mg per day--300 mg per day lower than the DGA guideline.21 Then a 2014 meta-analysis of 25 studies found that a sodium intake between 2,645 and 4,945 mg/day was associated with the lowest mortality risk. The researchers concluded that a sodium intake both lower and higher than these levels was associated with premature mortality.22 As new research becomes available each year, the controversy over sodium guidelines is likely to continue!

**Should You Reduce Your Sodium Intake?**

Given the uncertainty regarding what level of sodium intake is the most healthful, should you take steps to reduce your sodium intake?

- First, recognize that lifestyle interventions, including food choices, are low-risk, low-cost approaches to preventing chronic diseases and, for people already affected by disease, can be effective treatments. Because most Americans currently consume well above recommended levels, almost everyone would do well to reduce their current intake of sodium by at least 1,000 mg per day.

- Second, the most practical approach is to follow a healthful dietary pattern. Following the DASH diet or Mediterranean diet can greatly reduce your sodium intake without your having to monitor your milligrams of sodium. These diets have no known health risks; moreover, they will increase your potassium intake, which is known to lower your risk of HTN.

- Third, limit your choice of highly processed foods. Choose fresh foods as much as possible.

- Fourth, remember that the cardiovascular benefits of reducing your sodium intake will be even stronger if you also participate in regular physical activity, maintain a healthful weight, avoid smoking, and drink alcohol only in moderation if you drink at all.18

- Finally, focus on gradual change. A modest increase in fruit and vegetable intake and regular physical activity along with fewer restaurant and packaged meals can make a significant and lasting impact.

In addition to the steps just described, if you have been diagnosed with HTN and/or have a family history of cardiovascular disease, consult your health care team, including a Registered Dietitian Nutritionist (RDN), for help designing a dietary pattern for your needs.

**CRITICAL THINKING QUESTIONS**

1. Has reading about the sodium controversy inspired you to try to reduce your sodium intake? Why or why not?

2. The DASH diet recommends increasing your fruit and vegetable intake to 10 servings a day. Would this fit into your current lifestyle? Why or why not?

3. Visit the CDC's "How to Reduce Sodium" web page at http://www.cdc.gov/salt/reduce\_sodium\_tips.htm. Check out the tips for shopping and eating out. How many of these behaviors do you practice? Which seem practical for you to begin following, and why?

[Image: The influence of sodium intake on blood pressure is the subject of ongoing research.]

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**[TEST YOURSELF** *ANSWERS*

**1** **F** Although your thirst mechanism signals that you need to drink, it is not sufficient to ensure that you're completely hydrated.

**2** **F** Recent research suggests that caffeine intake has virtually no effect on fluid balance.

**3** **F** Sodium is a nutrient critical to human functioning; however, the Dietary Guidelines for Americans advise us to keep our intake below 2,300 milligrams per day.]

**review questions**

**LO 1 1.** Plasma is one example of

a. extracellular fluid.

b. intracellular fluid.

c. tissue fluid.

d. metabolic water.

**LO 2** 2. Which of the following is a critical function of water?

a. It dissolves fat-soluble vitamins.

b. Its relatively low capacity for heat keeps the body warm.

c. It provides protection for the brain and spinal cord.

d. All of the above are true.

**LO 2 3.** Which of the following is true of the cell membrane?

a. It is freely permeable to electrolytes but not to water.

b. It is freely permeable to water but not to electrolytes.

c. It is freely permeable to both water and electrolytes.

d. It is freely permeable to neither water nor electrolytes.

**LO 3 4.** We lose fluids through

a. sweat.

b. breath.

c. feces.

d. all of the above.

**LO 4 5.** Which of the following is the most healthful beverage for most people most of the time?

a. tap water

b. vitamin water sweetened with honey

c. tomato or other vegetable juice

d. black coffee with non-Caloric sweetener

**LO 5 6.** Which of the following statements about sodium is true?

a. One serving of ramen noodle soup provides nearly half the Al for sodium.

b. High-sodium diets are the primary cause of hypertension.

c. The kidney's excretion and reabsorption of sodium contribute to blood pressure regulation.

d. Sodium intake should be kept to an absolute minimum.

**LO 5 7.** Which of the following is a characteristic of potassium?

a. It is the major positively charged electrolyte in the extracellular fluid.

b. It can be found in fresh fruits and vegetables.

**c.** It is a critical component of the mineral complex of bone.

d. It is found only in plants, not in animals.

**LO 6 8.** Which of the following factors commonly contributes to dehydration?

a. drinking too much plain water while active in a hot environment

b. sweating and breathing heavily while active in a hot environment

c. failure of the body's heat-regulating mechanisms

d. failure of the kidneys to excrete sufficient water

**LO 4 9. True or false?** The chemical most commonly used to treat and purify public water supplies is chlorine.

**LO 5 10. True or false?** Chloride's only important body function is to help maintain fluid balance.

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**LO 6 11.** Theo comes home after basketball practice, weighs himself, and discovers he has lost 3 pounds. Knowing that 1 pound of body weight loss represents the loss of 2 cups of fluid, how much fluid should he consume over the next few hours in order to fully rehydrate?

*Answers to Review Questions and Math Review are located at the back of this text and in the MasteringNutrition Study Area.*

**web links**

**www.epa.gov**

U.S. Environmental Protection Agency: Water

*Go to the EPA's water website, then enter "your drinking water" into the search bar to find the link to information about drinking water quality, standards, and safety.*

**www.bottledwater.org**

International Bottled Water Association

*Find current information about bottled water from this trade association, which represents the bottled water industry.*

**www.mayoclinic.org**

Mayo Clinic

*Search for "hyponatremia" to learn more about this potentially fatal condition.*

**www.nhlbi.nih.gov**

National Heart, Lung, and Blood Institute

*Go to this site to learn more about cardiovascular disease, including how to reduce your risk for high blood pressure by following the DASH diet.*

**www.heart.org**

American Heart Association

*The American Heart Association provides plenty of tips on how to lower your blood pressure.*

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# **in** **depth 7.5** **Alcohol**

***After reading this In Depth, you should be able to:***

**1** Explain what happens to alcohol in the body, pp. 250-251.

**2** Identify some potential benefits and concerns related to moderate drinking, pp. 251-252.

**3** Distinguish two types of alcohol use disorders and discuss their health effects, pp. 252-257.

**4** Identify at least three strategies for limiting your drinking and three signs of an alcohol use disorder, pp. 257-258.

**5** Explain how to talk to someone about an alcohol use disorder, p. 258.]

**No one should have to spend his 21st birthday in an emergency room, but that's what happened to Todd the night he turned 21.** His friends took him off campus to celebrate, and, with their encouragement, he attempted to drink 21 shots before the bar closed at 2 AM. Fortunately for Todd, when he passed out and couldn't be roused, his best friend noticed his cold, clammy skin and erratic breathing and drove him to the local emergency room. There, his stomach was pumped and he was treated for alcohol poisoning. He regained consciousness but felt sick and shaky for several more hours.

Not everyone is so lucky. Alcohol poisoning, which occurs when people consume more alcohol than their liver can metabolize, impairs essential body functions, including breathing, heart rate, and the transmission of nerve signals in the brain. In the United States, 2,200 people die of alcohol poisoning each year. That's about six deaths every day.1

What makes excessive alcohol intake so dangerous, and why is moderate alcohol consumption often considered healthful? How can you tell if someone is struggling with problem drinking, and what can you do to help? What if that someone is you? We explore these questions **In Depth** here.

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**Alcohol** is a chemical compound structurally similar to carbohydrates. *Ethanol* is the specific type of alcohol found in beer, wine, and distilled spirits such as whiskey and vodka. Throughout this discussion, the common term *alcohol* will be used to represent the specific compound *ethanol.*

Alcohol intake is usually described as "drinks per day." A **drink** is defined as the amount of a beverage that provides ½ fluid ounce of pure alcohol. For example, 12 oz of beer, 10 oz of a wine cooler, 4 to 5 oz of wine, and 1½ oz of 80**-proof** whiskey, scotch, gin, or vodka are each equivalent to one drink **(FIGURE 1).** The term "proof" reflects the alcohol content of distilled spirits: 100-proof liquor is 50% alcohol whereas 80-proof liquor is 40% alcohol.

## **What happens to alcohol in the body?**

**LO 1** Explain what happens to alcohol in the body.

Alcohol is absorbed directly from both the stomach and the small intestine; it does not require digestion prior to absorption. Consuming foods with some fat, protein, and fiber slows the absorption of alcohol and can reduce blood alcohol concentration (BAC) by as much as 50% compared to peak BAC when drinking on an empty stomach. Carbonated alcoholic beverages are absorbed very rapidly, which explains why champagne and sparkling wines are so quick to generate an alcoholic "buzz." Women typically absorb 30% to 35% more of a given alcohol intake compared to a man of the same size, which may explain why women often show a greater response to alcohol compared to men.

Once absorbed, most alcohol is oxidized, or broken down, in the liver at a fairly steady rate. However, a small amount is oxidized in the stomach before it has even been absorbed.

**[FIGURE 1** What does one drink look like? A drink is equivalent to 1½ oz of distilled spirits, 4 to 5 oz of wine, 10 oz of wine cooler, or 12 oz of beer.]

**[FIGURE 2** Metabolism of alcohol.]

Cells in both the stomach and the liver secrete the enzyme alcohol dehydrogenase (ADH), which triggers the first step in alcohol degradation, while aldehyde dehydrogenase (ALDH) takes the breakdown process one step further **(FIGURE 2).** In women, ADH in the stomach is less active than in men; thus, women do not oxidize as much alcohol in their stomach, leaving up to 30% to 35% more intact alcohol to be absorbed.

On average, a healthy adult metabolizes the equivalent of one drink per hour. If someone has more than one drink in an hour, the excess alcohol is released back into the bloodstream, where it elevates BAC and triggers a range of behavioral and metabolic reactions. Through the blood, alcohol is quickly and completely distributed throughout all body fluids, exposing every tissue in your body-- including your brain--to its toxic effects.

Despite what you may have heard, there is no effective intervention to speed up the breakdown of alcohol **(TABLE 1).**

[To find out how many Calories are in your favorite drink, go to **http://rethinkingdrinking.niaaa.nih.gov/.** From the "Tools" tab, click the "Calculators" link and select "Alcohol Calorie calculator."]

[Sidebar: **alcohol** Chemically, a compound characterized by the presence of a hydroxyl group; in common usage, a beverage made from fermented fruits, vegetables, or grains and containing ethanol.]

[Sidebar: **drink** The amount of an alcoholic beverage that provides approximately 0.5 fl. oz of pure ethanol.]

[Sidebar: **proof** A measure of the alcohol content of a liquid; 100-proof liquor is 50% alcohol by volume, 80-proof liquor is 40% alcohol by volume, and so on.]

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**TABLE** **1 Myths about Alcohol Metabolism**

|  |  |
| --- | --- |
| **The Claim** | **The Reality** |
| Physical activity, such as walking around, will speed up the breakdown of alcohol. | Muscles don't metabolize alcohol; the liver does. |
| Drinking a lot of coffee will keep you from getting drunk. | Coffee intake simply leaves you both wired and drunk. |
| Using a sauna or steam room will force the alcohol out of your body. | Very little alcohol is lost in sweat; the alcohol will remain in your bloodstream. |
| Herbal and nutritional products are available that speed up the breakdown of alcohol. | No commercial supplement is effective in increasing the rate of alcohol metabolism. |

The key to keeping your BAC low is to drink alcoholic beverages while eating a meal or large snack, to drink very slowly, to have no more than one drink per hour, and to limit your total consumption of alcohol on any one occasion.

A person who steadily increases his or her alcohol consumption over time becomes more tolerant of a given intake of alcohol. Chronic drinkers experience *metabolic tolerance,* a condition in which the liver becomes more efficient in its breakdown of alcohol. This means that the person's BAC rises more slowly after consuming a certain number of drinks. In addition, chronic drinkers develop what is called *functional tolerance,* meaning they show few, if any, signs of impairment or intoxication, even at high BACs. As a result, these individuals may consume twice as much alcohol as when they first started drinking before they reach the same state of euphoria.

## **What do we know about moderate drinking?**

**LO 2** Identify some potential benefits and concerns related to moderate drinking.

The *2015-2020 Dietary Guidelines for Americans* (DGAs) advise "If alcohol is consumed, it should be consumed in moderation and only by adults of legal drinking age."2 The definition of **moderate drinking** is based on a maximal daily intake of up to one drink per day for women and two drinks per day for men. A person who does not drink any alcohol on weekdays but downs a six-pack of beer most Saturday nights would *not* be classified as a "moderate drinker"! The DGAs also identify groups of individuals who should not consume alcohol at all, including women who are or may become pregnant and women who are breastfeeding.

The DGAs do not recommend that anyone begin consuming alcohol or drink more often in order to achieve certain health benefits because, as we discuss here, moderate alcohol intake is associated with both benefits and risks. When deciding whether or how much alcohol to drink, you need to weigh the pros and cons of alcohol consumption against your own personal health history.

**Moderate Drinking Has Certain Health Benefits**

In most people, moderate alcohol intake offers some psychological benefits, reducing stress and anxiety. Moderate use of alcohol can also improve appetite, especially for savory foods high in protein.3 This can be of great value to the elderly and people with a chronic disease that suppresses appetite.

In addition, light/moderate alcohol consumption appears to lower the risk of subsequent age-related dementia compared to those who abstain from alcohol and those who consume increasingly greater amounts.4 It has also been linked to lower rates of cardiovascular disease, especially in older adults and in people already at risk, such as those with type 2 diabetes. Consumption of a moderate amount of alcohol in any form (wine, beer, or distilled spirits) increases levels of the "good" type of cholesterol (HDL) while decreasing the concentration of "bad" cholesterol (LDL); it also reduces the risk of abnormal clot formation in the blood vessels.5

Recently, there has been a great deal of interest in *resveratrol,* a phytochemical found in red wines, grapes, and other plant foods. Some researchers are proposing that resveratrol may be able to reduce the risk for certain chronic diseases. However, the amount of resveratrol in a glass of red wine may be too small to provide a meaningful health benefit for most individuals.6

**Moderate Drinking Is Associated with Certain Risks**

Not everyone responds to alcohol in the same manner. A person's age, genetic makeup, state of health, and use of medications can influence both immediate and long-term responses to alcohol intake, even at moderate levels. For example, women consuming low to moderate amounts of alcohol appear to have a slightly increased risk for breast cancer.7 In some studies, moderate drinking has been linked to a higher risk of bleeding in the brain *(hemorrhagic stroke)*; however, other research has not found this association.8

Another concern is the effect of alcohol on our waistlines! As we pointed out in Chapter 1, alcohol is not classified as a nutrient because it does not serve any unique metabolic role in humans. It does, however, provide energy: 7 Calories per gram. Only fat has more Calories per gram. As illustrated in **FIGURE 3** on page 252, if you're watching your weight, it makes sense to strictly limit your consumption of alcohol to stay within your daily energy needs.

[Sidebar: **moderate drinking** Alcohol consumption of up to one drink per day for women and up to two drinks per day for men.]

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Alcohol intake may also increase your *food* intake, because alcoholic beverages enhance appetite, particularly during social events, leading some people to overeat.

Both current and lifelong intakes of alcohol increase the risk for obesity in both males and females, particularly for those who binge drink.9

Because the liver detoxifies both alcohol and medications, harmful drug-alcohol interactions are common. Many medications carry a warning label advising consumers to avoid alcohol while taking the drug. Alcohol magnifies the effect of certain pain relievers, sleeping pills, antidepressants, and antianxiety medications and can lead to loss of consciousness. It also increases the risk for gastrointestinal bleeding in people taking aspirin, as well as the risk for both bleeding and liver damage in people taking ibuprofen or acetaminophen.10 In diabetics using insulin or oral medications to lower blood glucose, alcohol can exaggerate the drug's effect, leading to an inappropriately low level of blood glucose.

As you can see, there are risks to moderate alcohol consumption. Although moderate drinkers at low risk for alcohol addiction or medication interaction can safely continue their current level of use, individuals who have a personal or family history of alcoholism or fall into any other risk category should consider abstaining.