## Read the Fine Print

The labels on prepared foods are packed with nutritional information, even for the simplest items. Consider oatmeal. The label gives the calorie count for a defined serving size (half a cup, dry), and then lists the amounts in grams and percent daily requirements for the nutrients, including subtypes of fats and carbohydrates. Ingredients are listed in decreasing order by weight. The fine print defines an average daily diet as 2,000 calories, but adds that individual needs may vary. In larger print on most food labels are nutritional claims. Even the old-fashioned oatmeal canister entices with "healthy heart" and "oatmeal helps reduce cholesterol" messages.

Reading and understanding food labels helps consumers make healthful food choices, but beware of the meaning behind some frequently used terms. For example, "light" has several meanings, such as indicating that a product has one-third fewer calories or half the fat or sodium content of a comparable food. "Light" may also describe texture or color, which do not relate to nutrition. "Low fat" indicates 3 grams of fat or less per serving, which a consumer may assume also means fewer calories. In some products, however, fat is replaced with so much sugar to make it palatable that the calorie count actually increases.

A savvy shopper can easily apply the principles of nutrition to select the healthiest foods. It may be best to focus on foods so fresh that they do not need labels, such as fruits and vegetables. ■

Ingredients are listed in decreasing order by weight.

## 18.1 INTRODUCTION

The human body requires fuel as well as materials to develop, grow, and heal. Nutrients from food fulfill these requirements. **Nutrients** (nu′tre-ents) are chemicals supplied from the environment that an organism requires for survival. There are two major classes of nutrients. The **macronutrients,** needed in bulk, are the carbohydrates, lipids, and proteins. **Micronutrients** are essential in small daily doses and include vitamins and minerals. Nutrients that human cells cannot synthesize and that must be obtained in the diet, such as certain amino acids, are called **essential nutrients.** The body also requires water.

In countries with adequate food supplies, most healthy individuals can obtain nourishment by eating a variety of foods and limiting fat intake. People who do not eat meat products can also be well-nourished, but they must pay more attention to food choices to avoid developing nutrient deficiencies. For example, eliminating red meat also means eliminating an excellent source of iron, copper, zinc, and vitamin $B_{12}$. The fiber that often makes up much of a vegetarian's diet, although very healthful in many ways, also decreases absorption of iron. Therefore, a vegetarian must obtain sufficient iron from nonmeat sources. It is easy for a vegetarian to receive proper **nutrition** (adequate nutrients) by being aware of the sources, actions, and interactions of nutrients. Fortified foods, green leafy vegetables, and whole grains provide many of the nutrients that are also in meat. Table 18.1 lists types of vegetarian diets.

**TABLE 18.1** | Types of Vegetarian Diets

| Type | Food Restrictions |
|---|---|
| Vegan | No animal foods |
| Ovo-vegetarian | Eggs allowed; no dairy or meat |
| Lacto-vegetarian | Dairy allowed; no eggs or meat |
| Lacto-ovo-vegetarian | Dairy and eggs allowed; no meat |
| Pesco-vegetarian | Dairy, eggs, and fish allowed; no other meat |
| Semivegetarian | Dairy, eggs, chicken, and fish allowed; no other meat |

**PRACTICE**

1 Identify and distinguish among macronutrients and micronutrients.

## 18.2 APPETITE CONTROL

Digestion breaks down nutrients to sizes that can be absorbed and transported in the bloodstream. **Metabolism** refers to the ways that nutrients are altered chemically and used in anabolism (building up or synthesis) and catabolism (breaking down) of chemical compounds to support the activities of life. (Chapter 4, pp. 128–132, introduced metabolism of carbohydrates.)

We eat to obtain the nutrients that power the activities of life. Eating is a complex, finely tuned homeostatic mechanism that balances nutrient intake with nutrient use. Too few nutrients, and disorders associated with malnutrition result. Too many nutrients, and obesity is the consequence. Several factors influence food intake, including smell, taste, and texture of food; neural signals triggered by stretch receptors in the stomach; stress; and hormones.

**Appetite** is the drive that compels us to seek food. Several types of interacting hormones control appetite by affecting part of the hypothalamus called the *arcuate nucleus* (table 18.2).

Insulin, secreted from the pancreas, regulates fat stores by stimulating adipocytes to take up glucose and store fat, and by stimulating certain other cells to take up glucose and form glycogen, a storage carbohydrate. Eating stimulates adipocytes to secrete **leptin,** which acts on target cells in the hypothalamus. The effect suppresses appetite by inhibiting release of the hypothalamic neurotransmitter **neuropeptide Y** that stimulates eating. This is a negative feedback response to ingesting calories. Leptin also stimulates metabolic rate (fig. 18.1). Low leptin levels indicate depleted fat stores, a condition in which metabolism slows to conserve energy and appetite increases. Inherited leptin deficiency is very rare, but the resultant loss of this appetite "brake" results in obesity. Leptin injections enable these individuals to reduce their weight to normal levels.

Conversely, **ghrelin,** a hormone that the stomach secretes, enhances appetite by stimulating the release of neuropeptide Y. Therefore, a compound that blocks ghrelin production or activity might help people lose weight. Fasting and a low-calorie diet stimulate ghrelin production. The success of gastric bypass surgery may be due in part to decreased ghrelin secretion resulting from loss of stomach tissue.

**TABLE 18.2** | Substances That Control Appetite

| Substance | Site of Secretion | Function |
|---|---|---|
| Insulin | Pancreas | Stimulates adipocytes to admit glucose and store fat; glycogen synthesis |
| Leptin | Adipocytes | Suppresses appetite and increases metabolic rate after eating |
| Neuropeptide Y | Hypothalamus | Enhances appetite |
| Ghrelin | Stomach | Enhances appetite |

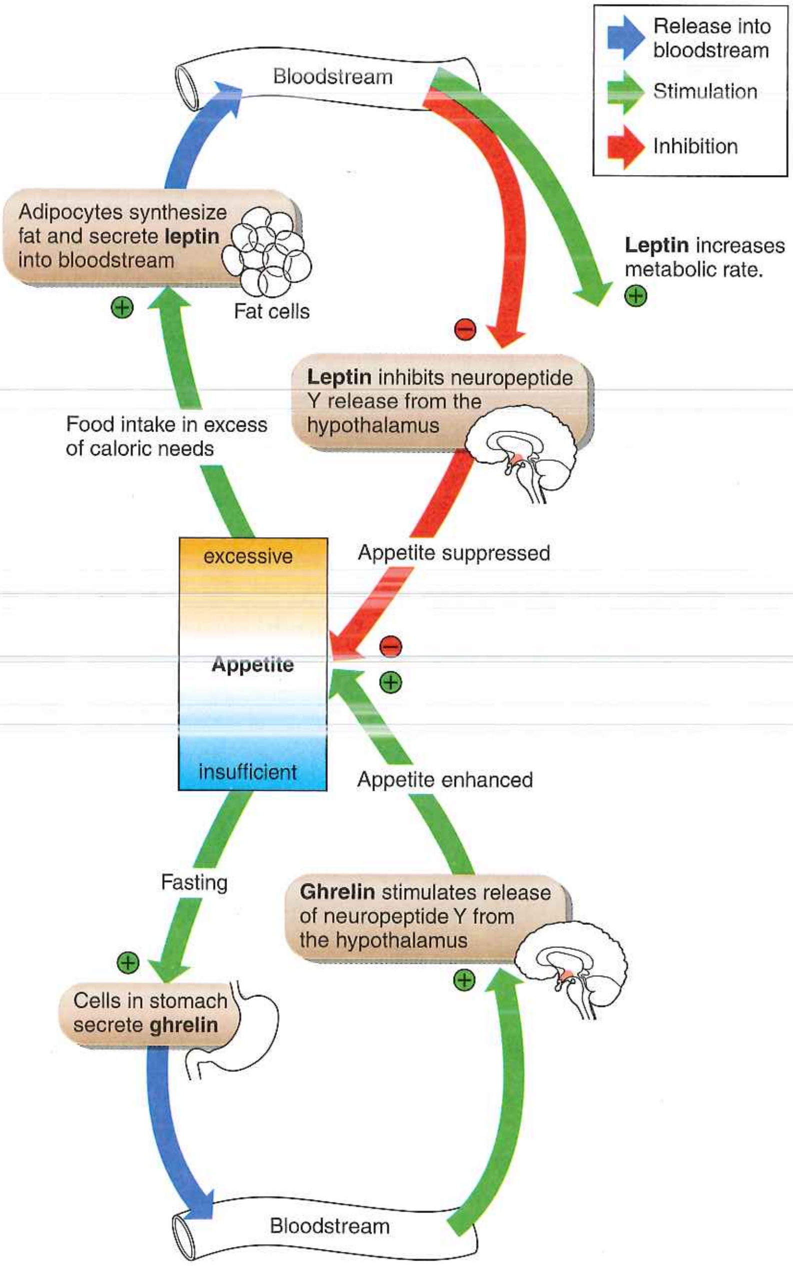


**FIGURE 18.1** Appetite control is complex. Illustrated here are the effects of leptin and ghrelin on appetite.

Adiponectin is a protein hormone synthesized in adipose cells and secreted into the bloodstream that mediates response to insulin and regulates fatty acid catabolism. Adiponectin also has an anti-inflammatory effect. The hormone increases basal metabolic rate (calories burned at rest) without affecting appetite. Because levels of adiponectin are higher in people who do not have diabetes and have healthy body weights, some studies suggest boosting its levels may help in weight loss. Most information about adiponectin, however, is still from work on laboratory animals.

**PRACTICE**

2 Describe how hormones control appetite.

## 18.3 CARBOHYDRATES

**Carbohydrates** are organic compounds and include the sugars and starches. The energy held in their chemical bonds is used to power cellular processes.

### Carbohydrate Sources

Carbohydrates are ingested in a variety of forms. Complex carbohydrates include the *polysaccharides* ("many sugars"), such as starch from plant foods and glycogen from meats. Foods containing starch and glycogen usually have many other nutrients, including valuable vitamins and minerals. The simple carbohydrates include *disaccharides* ("double sugars") from milk sugar, cane sugar, beet sugar, and molasses and *monosaccharides* ("single sugars") from honey and fruits. Digestion ultimately breaks complex carbohydrates down to monosaccharides, which are small enough to be absorbed into the bloodstream.

Sugar substitutes provide concentrated sweetness, so fewer calories are needed to sweeten a food. Stevia is extracted from leaves of an herb, and is 30 times as sweet as table sugar (sucrose). Aspartame, a dipeptide, is 200 times as sweet; the artificial sweetener saccharin is 300 times as sweet; and sucralose is 600 times as sweet as sucrose. Sucralose is derived from sucrose, and includes chloride.

**Cellulose** is a complex carbohydrate abundant in our food—it provides the crunch to celery and the crispness to lettuce. We cannot digest cellulose, and most of it passes through the alimentary canal largely unchanged. However, cellulose provides bulk (also called fiber or roughage) against which the muscular wall of the digestive system can push, facilitating the movement of intestinal contents. *Hemicellulose, pectin,* and *lignin* are other plant carbohydrates that provide fiber.

### Carbohydrate Use

The monosaccharides absorbed from the digestive tract include *fructose, galactose,* and *glucose.* Liver enzymes catalyze reactions that convert fructose and galactose into glucose (fig. 18.2). Recall that glucose is the carbohydrate most commonly oxidized in glycolysis for cellular fuel.

**RECONNECT**
**To Chapter 4, Cellular Respiration, pages 128–132.**

Some excess glucose is polymerized to form *glycogen* (glycogenesis), which the liver and muscles store as a glucose reserve. Glycogen can be rapidly broken down to yield glucose (glycogenolysis) when it is required to supply energy. However, only a certain amount of glycogen can be stored. Excess glucose beyond what is stored as glycogen usually reacts to form fat and is stored in adipose tissue (fig. 18.3).

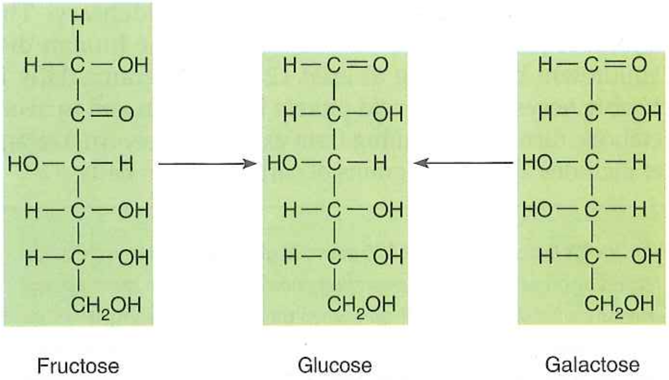


**FIGURE 18.2** Liver enzymes catalyze reactions that convert the monosaccharides fructose and galactose into glucose.

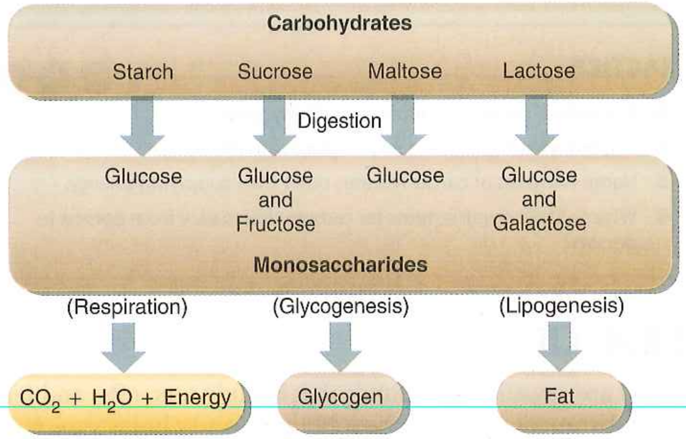


**FIGURE 18.3** APR Monosaccharides from foods are used for energy, stored as glycogen, or reacted to produce fat.

Many cells can also oxidize fatty acids to obtain energy. However, some cells, such as neurons, normally require a continuous supply of glucose for survival. (Under some conditions, such as prolonged starvation, other fuel sources may become available for neurons.) Even a temporary decrease in the glucose supply may seriously impair nervous system function. Consequently, the body requires a minimum amount of carbohydrate. If foods do not provide an adequate supply of carbohydrates, the liver may convert some noncarbohydrates, such as amino acids from proteins or glycerol from fats, into glucose—a process called *gluconeogenesis.* The requirement for glucose has physiological priority over the need to synthesize certain other substances, such as proteins, from available amino acids.

Cells also use carbohydrates as starting materials for synthesizing such vital biochemicals as the 5-carbon sugars *ribose* and *deoxyribose,* sugars required for the production of the nucleic acids RNA and DNA. The disaccharide *lactose* (milk sugar) is synthesized when the breasts are actively secreting milk.

### Carbohydrate Requirements

Carbohydrates provide the primary source of fuel for cellular processes. The need for carbohydrates varies with individual energy requirements. Physically active individuals require more carbohydrates than those who are sedentary. The minimal requirement for carbohydrates in the human diet is unknown, but getting at least 125 to 175 grams daily is probably necessary to avoid protein breakdown and to avoid metabolic disorders resulting from excess fat use. An average diet includes 200 to 300 grams of carbohydrates daily.

An adult's liver stores about 100 grams of glycogen, and muscle tissue stores another 200 grams, providing enough reserve to meet energy demands for about twelve hours when the person is resting. Whether these stores are filled depends on diet. People consume widely varying amounts of carbohydrates, often reflecting economic conditions. In the United States, a typical adult's diet supplies about 50% of total body energy from carbohydrates. In Asian countries where rice is a staple, carbohydrates contribute even more to the diet.

**PRACTICE**

3 List several common sources of carbohydrates.

4 Explain what happens to excess glucose in the body.

5 Name two uses of carbohydrates other than supplying energy.

6 Why do daily requirements for carbohydrates vary from person to person?

## 18.4 LIPIDS

**Lipids** are organic compounds that include fats, oils, and fatlike substances such as phospholipids and cholesterol (see chapter 2, pp. 71–72). They supply energy for cellular processes and help build structures, such as cell membranes. The most common dietary lipids are the fats called *triglycerides* (tri-glis'er-īdz) (see fig. 2.14, p. 72).

### Lipid Sources

Triglycerides are found in plant- and animal-based foods. Saturated fats are mainly found in foods of animal origin, such as meat, eggs, milk, and lard, as well as in palm and coconut oils. Unsaturated fats are in seeds, nuts, and plant oils. Monounsaturated fats, such as those in olive, peanut, and canola oils, are the healthiest. Saturated fats in excess are a risk factor for cardiovascular disease.

Cholesterol is abundant in liver and egg yolk and, to a lesser extent, in whole milk, butter, cheese, and meats. Foods of plant origin do not contain cholesterol. A label on a plant-based food claiming that it is "cholesterol-free" states the obvious.

Be wary of claims that a food product is "99% fat-free." This usually refers to percentage by weight—not calories, which is what counts. A 99% fat-free creamy concoction may be largely air and water, and therefore in that form, fat comprises very little of it. But when the air and the water are removed, as happens in the body, the fat percentage may skyrocket.

### Lipid Use

The lipids in foods are phospholipids, cholesterol, and, most commonly, fats (triglycerides). Lipids provide a variety of physiological functions; however, fats mainly supply energy. Gram for gram, fats contain more than twice as much chemical energy as carbohydrates or proteins.

Before a triglyceride molecule can release energy, it must undergo hydrolysis. This happens when digestion breaks triglycerides down into fatty acids and glycerol. After being absorbed, these products are transported in the lymph to the blood, then on to tissues. As figure 18.4 shows, some of the resulting fatty acid portions can then form molecules of acetyl coenzyme A (acetyl CoA) by a series of reactions called **beta oxidation,** which occurs in the mitochondria.

In the first phase of beta oxidation, fatty acids are activated. This change requires energy from ATP and a special group of enzymes called thiokinases. Each of these enzymes can act upon a fatty acid that has a particular carbon chain length.

Once fatty acid molecules have been activated, other enzymes called **fatty acid oxidases** in mitochondria break

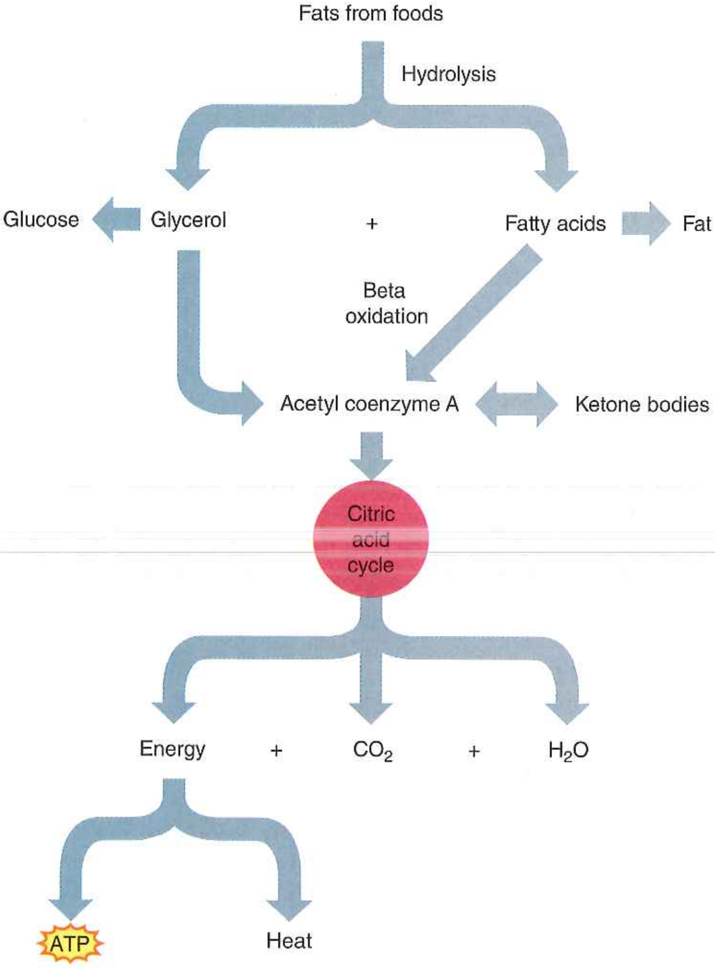


**FIGURE 18.4** The body digests fat from foods into glycerol and fatty acids, which may enter catabolic pathways and provide energy.

them down. This phase of the reactions removes successive two-carbon segments of fatty acid chains. In the liver, some of these segments react to produce acetyl coenzyme A molecules. Excess acetyl CoA molecules can be converted into compounds called **ketone bodies,** such as acetone, which later may be changed back to acetyl coenzyme A. In either case, the resulting acetyl coenzyme A can be oxidized in the citric acid cycle. The glycerol parts of the triglyceride molecules can also enter metabolic pathways leading to the citric acid cycle, or they can be used to synthesize glucose.

> When ketone bodies form faster than they can be decomposed, some of them are eliminated through the lungs and kidneys. When this happens, the ketone acetone may impart a fruity odor to the breath and urine. This can happen when a person fasts, forcing body cells to metabolize a large amount of fat, and in persons suffering from diabetes mellitus who develop a serious imbalance in pH called ketoacidosis, which results when acetone and other acidic ketones accumulate.

Glycerol and fatty acid molecules resulting from the hydrolysis of fats can also combine to form fat molecules in anabolic reactions and be stored in fat tissue. Additional fat molecules can be synthesized from excess glucose or amino acids.

The liver can convert fatty acids from one form to another. However, the liver cannot synthesize certain fatty acids, called **essential fatty acids.** *Linoleic acid,* for example, is an essential fatty acid required to synthesize phospholipids, which, in turn, are necessary for constructing cell membranes and myelin sheaths, and for transporting circulating lipids. Good sources of linoleic acid include corn oil, cottonseed oil, and soy oil. *Linolenic acid* is another essential fatty acid.

The liver uses free fatty acids to synthesize triglycerides, phospholipids, and lipoproteins that may then be released into the bloodstream (fig. 18.5). These lipoproteins are large and consist of a surface layer of phospholipid, cholesterol, and protein surrounding a triglyceride core. The protein constituents of lipoproteins in the outer layer, called *apoproteins* or apolipoproteins, can combine with receptors on the membranes of specific target cells. Lipoprotein molecules vary in the proportions of the lipids they contain.

Lipids are less dense than proteins. As the proportion of lipids in a lipoprotein increases, the density of the particle decreases. Conversely, as the proportion of lipids decreases, the density increases. Lipoproteins are classified on the basis of their densities, which reflect their composition. *Very-low-density lipoproteins* (VLDL) have a high concentration of triglycerides. *Low-density lipoproteins* (LDL) have a high concentration of cholesterol and are the major cholesterol-carrying lipoproteins. *High-density lipoproteins* (HDL) have a relatively high concentration of protein and a lower concentration of lipids.

In addition to regulating circulating lipids, the liver controls the total amount of cholesterol in the body by synthesizing and releasing it into the blood or by removing cholesterol from the blood and excreting it into the bile. The liver uses cholesterol to produce bile salts. Cholesterol is not used as an energy source, but it does provide structural material for cell and organelle membranes, and it furnishes starting materials for the synthesis of certain sex hormones and hormones produced by the adrenal cortex.

Adipose tissue stores excess triglycerides. If the blood lipid concentration drops (in response to fasting, for example), some of these stored triglycerides are hydrolyzed into free fatty acids and glycerol and released into the bloodstream.

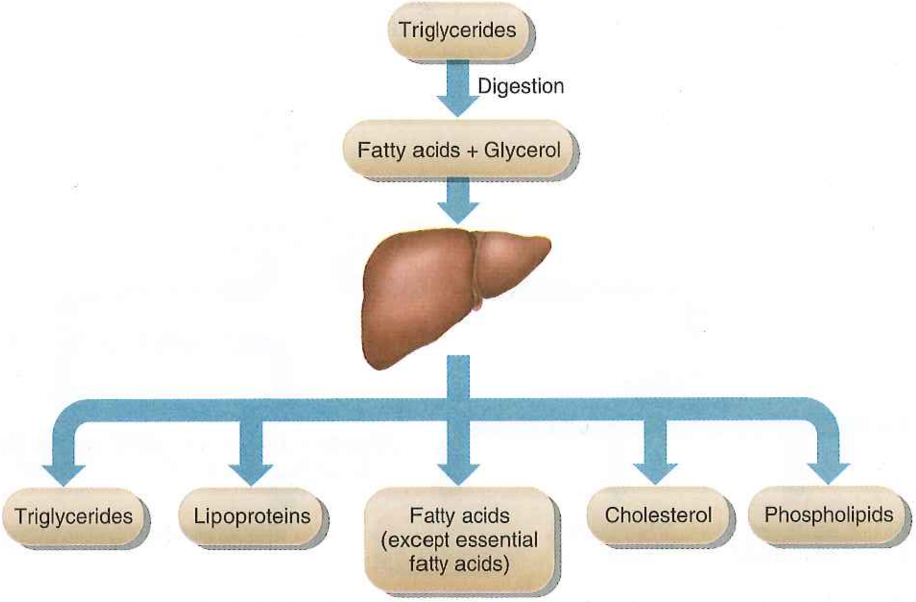


**FIGURE 18.5** The liver uses fatty acids to synthesize a variety of lipids.

## Lipid Requirements

The lipid content of human diets varies widely. A person who eats mostly burgers, fries, and shakes may consume 50% or more of total daily calories from fat. For a vegetarian, the percentage may be far lower. The USDA and the American Heart Association recommend that lipid intake not exceed 30% of total daily calories.

The types and locations of the chemical bonds between carbon atoms of fatty acid molecules affect how healthful the fat is. Monounsaturated fats (such as from avocado and olives), promote cardiovascular health, whereas saturated fats, such as those in butter or lard, contribute to heart disease. The site of the double bond that contributes to a fat's degree of unsaturation is also important. Omega-3 fatty acids, which have double bonds between the third and fourth carbons, are more healthful than omega-6 fatty acids, with double bonds between the sixth and seventh carbons. Omega-3 fatty acids are found in fish; omega-6 fatty acids are in red meat.

The amounts and types of fats required for health vary with individuals' habits, goals, and stage of life. For example, infant formula contains two long-chain polyunsaturated fatty acids (docosahexaenoic acid and arachidonic acid) that are in breast milk and are vital for development of the infant's nervous system, particularly the eyes. Fat intake must be sufficient throughout life to support absorption and transport of fat-soluble vitamins. Most adults who eat a variety of foods obtain adequate fats.

### PRACTICE

**7** Which foods commonly supply lipids?
**8** Which fatty acids are essential nutrients?
**9** What is the role of the liver in the use of lipids?
**10** What are the functions of cholesterol?

## 18.5 PROTEINS

**Proteins** are polymers of amino acids. They have a wide variety of functions. When dietary proteins are digested, the resulting amino acids are absorbed and transported by the blood to cells. Many of these amino acids are used to form new protein molecules, as specified by DNA base sequences. These new proteins include enzymes that control the rates of metabolic reactions; clotting factors; the keratins of skin and hair; elastin and collagen of connective tissue; plasma proteins that regulate water balance; the muscle components actin and myosin; certain hormones; and the antibodies that protect against infection (fig. 18.6).

Protein molecules may also supply energy. To do this, they must first be broken down into amino acids. The amino acids then undergo **deamination,** a process in the liver that removes the nitrogen-containing (—$NH_2$) groups, which then react to form a waste called **urea** (u-re'ah) (see fig. 2.17, p. 74). The blood carries urea to the kidneys, where it is excreted in urine.

Certain kidney disorders impair the removal of urea from the blood, raising the blood urea concentration. A blood test called blood urea nitrogen (BUN) determines the blood urea concentration and is often used to evaluate kidney function (see Appendix C, Laboratory Tests of Clinical Importance, p. 928).

Several pathways decompose the remaining deaminated parts of amino acids. The specific pathways that are followed depend upon the particular type of amino acid being dismantled. Some pathways form acetyl coenzyme A, and others more directly lead to steps of the citric acid cycle. As energy is released from the cycle, some of it is captured in molecules of ATP (fig. 18.7). If energy is not required immediately, the deaminated parts of the amino acids may react to form glucose or fat molecules in other metabolic pathways (see fig. 18.6).

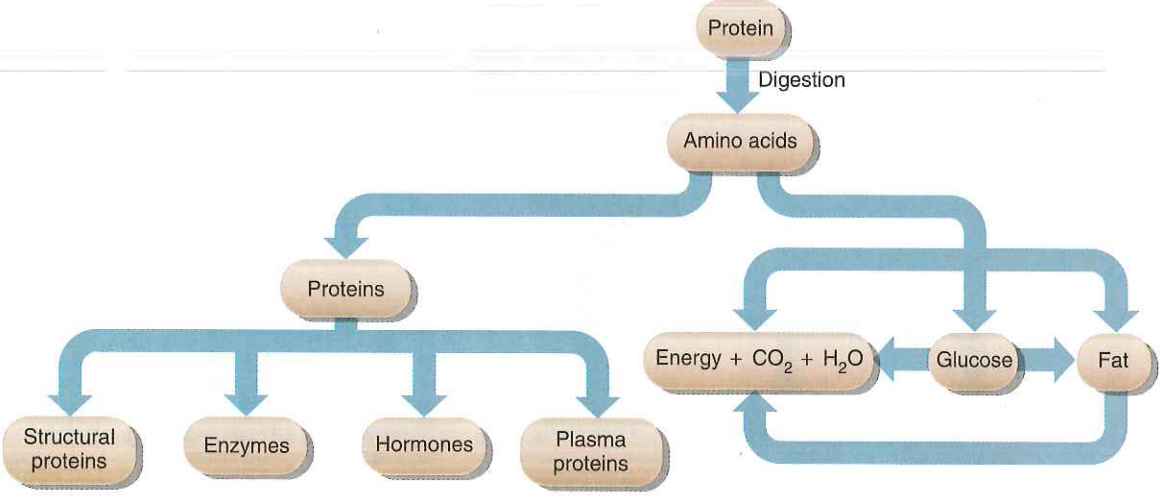


**FIGURE 18.6** Proteins are digested to their constituent amino acids. These amino acids are then linked, following genetic instructions, to build new proteins. Free amino acids are also used to supply energy under certain conditions.

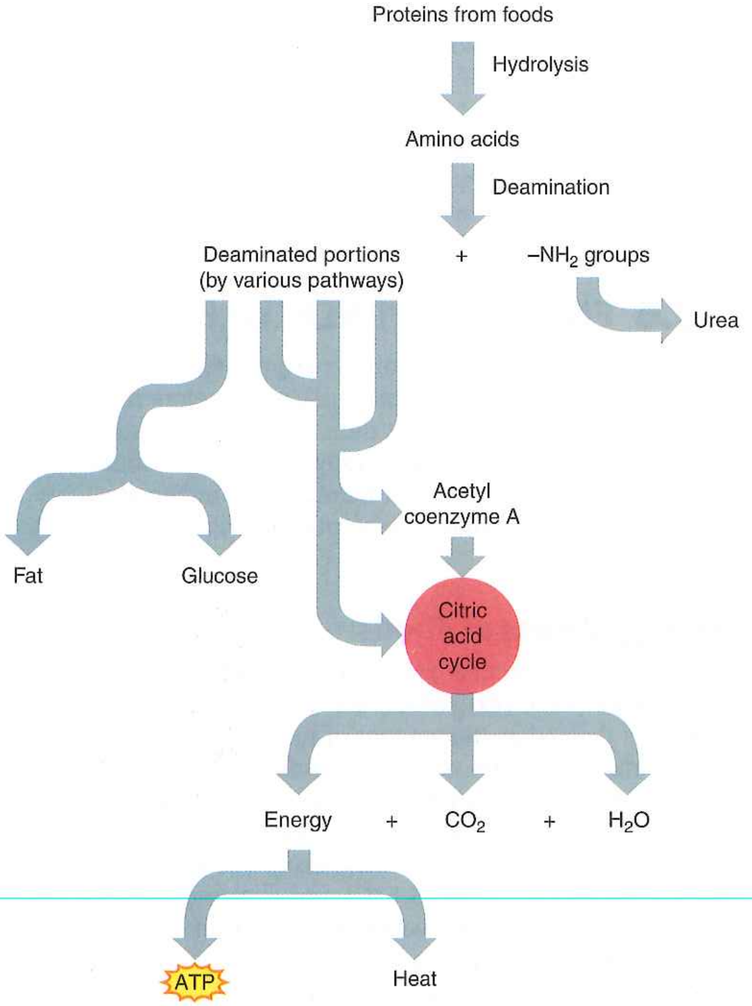


**FIGURE 18.7** The body digests proteins from foods into amino acids, but must deaminate these smaller molecules before they can be used as energy sources.

A few hours after a meal, protein catabolism, through the process of gluconeogenesis (see chapter 13, p. 514), becomes a major source of blood glucose. However, metabolism in most tissues soon shifts away from glucose and toward fat catabolism as a source of ATP. Thus, energy needs are met in a way that spares proteins for tissue building and repair, rather than being broken down and reassembled into carbohydrates to supply energy. Using structural proteins to generate energy causes the tissue-wasting of starvation.

## Protein Sources

Foods rich in proteins include meats, fish, poultry, cheese, nuts, milk, eggs, and cereals. Legumes, including beans and peas, contain less protein.

The human body can synthesize many amino acids (nonessential amino acids). However, eight amino acids the adult body needs (ten required for growing children) cannot be synthesized sufficiently or at all, and they are called **essential amino acids.** This term refers only to dietary intake, because all amino acids are required for normal protein synthesis. Table 18.3 lists the amino acids in foods and indicates those that are essential.

**TABLE 18.3** | Amino Acids in Foods

| | | |
|---|---|---|
| Alanine | Glycine | Proline |
| Arginine (ch) | Histidine (ch) | Serine |
| Asparagine | Isoleucine (e) | Threonine (e) |
| Aspartic acid | Leucine (e) | Tryptophan (e) |
| Cysteine | Lysine (e) | Tyrosine |
| Glutamic acid | Methionine (e) | Valine (e) |
| Glutamine | Phenylalanine (e) | |

Eight essential amino acids (e) cannot be synthesized by human cells and must be provided in the diet. Two additional amino acids (ch) are essential in growing children.

All twenty types of amino acids must be in the body at the same time for growth and tissue repair to occur. In other words, if the diet lacks one essential amino acid, the cells cannot synthesize protein. Essential amino acids are not stored. Those not used to make proteins are oxidized as energy sources or are converted into carbohydrates or fats.

Proteins are classified as complete or incomplete based on the amino acid types they provide. **Complete proteins** have adequate amounts of the essential amino acids to maintain human body tissues and promote normal growth and development. Certain proteins in milk, meat, and eggs are complete. Incomplete proteins cannot by themselves maintain human tissues or support normal growth and development. Zein in corn, for example, has too little of the essential amino acids tryptophan and lysine to be complete. A *partially complete protein* does not have enough amino acid variety to promote growth, but it has enough to maintain life. A protein in wheat called gliadin is a partially complete protein because it has very little of the amino acid lysine.

Many plant proteins have too little of one or more essential amino acids to provide adequate nutrition for a person. However, combining appropriate plant foods can supply an adequate diversity of dietary amino acids. For example, beans are low in methionine but have enough lysine. Rice lacks lysine but has enough methionine. A meal of beans and rice offers enough of both types of amino acids.

### PRACTICE

**11** How do cells use proteins?
**12** Which foods are rich sources of protein?
**13** Why are some amino acids called essential?
**14** Distinguish between a complete protein and an incomplete protein.

## Nitrogen Balance

A healthy adult continuously builds up and breaks down proteins. This happens at different rates in different tissues, but the overall gain of body proteins equals the loss, producing a state of **dynamic equilibrium** (di-nam′ik e″kwĭ-lib′re-um). Because proteins have a high percentage of nitrogen, dynamic equilibrium also brings **nitrogen balance** (ni′tro-jen bal′ans), in which the amount of nitrogen taken in equals the amount excreted.

A person who is starving has a *negative nitrogen balance* because the amount of nitrogen excreted as a result of amino acid oxidation exceeds the amount the diet replaces. Conversely, a growing child, a pregnant woman, or an athlete in training is likely to have a *positive nitrogen balance* because more protein is being built into new tissue and less is being used for energy or excreted.

### Protein Requirements

In addition to supplying essential amino acids, proteins provide nitrogen and other elements for the synthesis of nonessential amino acids and certain nonprotein nitrogenous substances. The amount of dietary protein individuals require varies according to body size, metabolic rate, and nitrogen balance condition.

For an average adult, nutritionists recommend a daily protein intake of about 0.8 gram per kilogram (0.4 gram per pound) of body weight or 10% of a person's diet. Another way to estimate desirable protein intake is to divide weight in pounds by 2. Most people should consume 60–150 grams of protein a day. For a pregnant woman, who needs to maintain a positive nitrogen balance, the recommendation adds 30 grams of protein per day. Similarly, a nursing mother requires an additional 20 grams of protein per day to maintain a high level of milk production.

Protein deficiency causes tissue wasting and also decreases the level of plasma proteins, which decreases the colloid osmotic pressure of the plasma. As a result, fluids collect in the tissues, producing *nutritional edema.* Table 18.4 summarizes the sources, requirements, and uses for carbohydrate, lipid, and protein nutrients.

**RECONNECT**

**To Chapter 15, Exchanges in the Capillaries, page 580.**

**PRACTICE**

**15** What is a negative nitrogen balance? A positive nitrogen balance?

**16** How can inadequate nutrition cause edema?

## 18.6 ENERGY EXPENDITURES

Carbohydrates, fats, and proteins supply energy, which is required for all metabolic processes and therefore important to cell survival. If the diet is deficient in energy-supplying nutrients, structural molecules may gradually be consumed, leading to death. On the other hand, excess intake of energy-supplying nutrients may lead to obesity, which also threatens health.

### Energy Values of Foods

The amount of potential energy a food contains is expressed as **calories** (kal′o-rēz), which are units of heat. Although a calorie is defined as the amount of heat required to raise the temperature of a gram of water by 1 degree Celsius (°C), the calorie used to measure food energy is 1,000 times greater. This *large calorie* (Cal.) equals the amount of heat required to raise the temperature of a kilogram (1,000 grams) of water by 1°C (from 14.5°C to 15.5°C) and is also equal to 4.184 joules. A joule is the international unit of heat and energy. A large calorie is also called a *kilocalorie,* but it is customary in nutritional studies to refer to it as a calorie.

Figure 18.8 shows a bomb calorimeter, which is a device used to measure the caloric contents of foods. It consists of a metal chamber submerged in a known volume of water. A food sample is dried, weighed, and placed in a nonreactive dish inside the chamber. The chamber is filled with oxygen

**TABLE 18.4** | Carbohydrate, Lipid, and Protein Nutrients

| Nutrient | Sources and RDA* for Adults | Calories per Gram | Use | Conditions Associated with | |
|---|---|---|---|---|---|
| | | | | **Excesses** | **Deficiencies** |
| Carbohydrate | Primarily from starch and sugars in foods of plant origin and from glycogen in meats<br>125–175 g | 4.1 | Oxidized for energy; used in production of ribose, deoxyribose, and lactose; stored in liver and muscles as glycogen; converted to fats and stored in adipose tissue | Obesity, dental caries, nutritional deficits | Metabolic acidosis |
| Lipid | Meats, eggs, milk, lard, plant oils<br>80–100 g | 9.5 | Oxidized for energy; production of triglycerides, phospholipids, lipoproteins, and cholesterol, stored in adipose tissue; glycerol portions of fat molecules may be used to synthesize glucose | Obesity, increased serum cholesterol, increased risk of heart disease | Weight loss, skin lesions |
| Protein | Meats, cheese, nuts, milk, eggs, cereals, legumes<br>0.8 g/kg body weight | 4.1 | Production of protein molecules used to build cell structure and to function as enzymes or hormones; used in the transport of oxygen, regulation of water balance, control of pH, formation of antibodies; amino acids may be broken down and oxidized for energy or converted to carbohydrates or fats for storage | Obesity | Extreme weight loss, wasting, anemia, growth retardation |

*RDA = recommended dietary allowance.

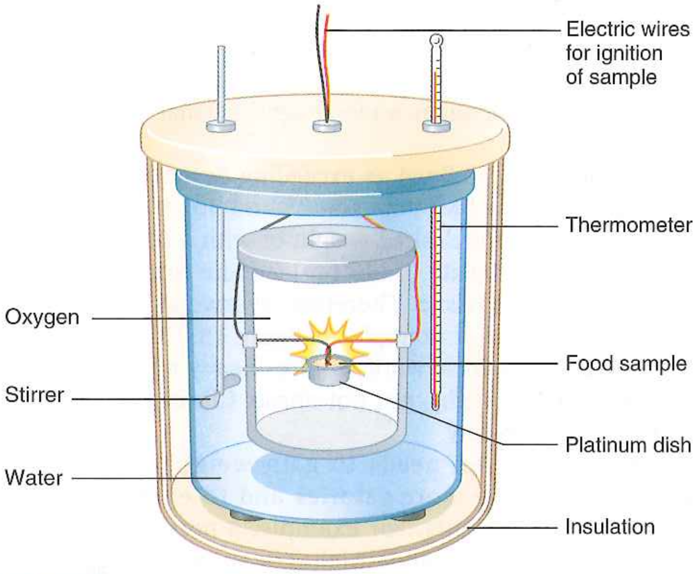


**FIGURE 18.8** A bomb calorimeter measures the caloric content of a food sample.

and submerged in the water. Then, the food is ignited and allowed to completely oxidize. Heat released from the food raises the temperature of the surrounding water, and the change in temperature is measured. Because the volume of the water is known, the amount of heat released from the food can be calculated in calories.

Caloric values determined in a bomb calorimeter are somewhat higher than the amount of energy that metabolic oxidation releases, because nutrients generally are not completely absorbed from the digestive tract. Also, the body does not completely oxidize amino acids, but excretes parts of them in urea or uses them to synthesize other nitrogenous substances. When such losses are considered, cellular oxidation yields on the average about 4.1 calories from 1 gram of carbohydrate, 4.1 calories from 1 gram of protein, and 9.5 calories from 1 gram of fat. More than twice as much energy is derived from equal amounts by weight of fats as from either proteins or carbohydrates. This is one reason why avoiding fatty foods helps weight loss, if intake of other nutrients does not substantially increase. Fats encourage weight gain because they add flavor to food, which can cause overeating. However, fatty foods satisfy hunger longer than carbohydrate-rich foods.

### PRACTICE

**17** What term designates the potential energy in a food?

**18** What is the energy value of a gram of carbohydrate? a gram of protein? a gram of fat?

## Energy Requirements

The amount of energy required to support metabolic activities for twenty-four hours varies from person to person. The factors that influence individual energy needs include a measurement called the basal metabolic rate, the degree of muscular activity, body temperature, and rate of growth.

The **basal metabolic rate** (ba′sal met″ah-bol′ik rāt), or BMR, measures the rate at which the body expends energy under *basal conditions*—when a person is awake and at rest; after an overnight fast; and in a comfortable, controlled environment. Tests of thyroid function can be used to estimate a person's BMR.

The amount of oxygen the body consumes is directly proportional to the amount of energy released by cellular respiration. The BMR indicates the total amount of energy expended in a given time to support the activities of such organs as the brain, heart, lungs, liver, and kidneys.

The BMR for an average adult indicates a requirement for approximately 1 calorie of energy per hour for each kilogram of body weight. However, this requirement varies with sex, body size, body temperature, and level of endocrine gland activity. For example, because heat loss is directly proportional to the body surface area, and a smaller person has a greater surface area relative to body mass, he or she will have a higher BMR. Males typically have higher metabolic rates than females. As body temperature, blood level of thyroxine, or blood level of epinephrine increase, so does the BMR. The BMR can also increase when the level of physical activity increases during the day.

Maintaining the BMR usually requires the body's greatest expenditure of energy. The energy required to support voluntary muscular activity comes next, though this amount varies greatly with the type of activity (table 18.5). For example, the energy to maintain posture while sitting at a desk might require 100 calories per hour above the basal need, whereas running or swimming might require 500–600 calories per hour.

Maintenance of body temperature may require additional energy expenditure, particularly in cold weather. In this case, extra energy is expended in involuntary muscular contractions, such as shivering, or through voluntary muscular actions, such as walking. Growing children and pregnant women, because their bodies are actively producing new tissues, also require more calories.

**TABLE 18.5** | Calories Used During Various Activities

| Activity | Calories (per Hour) |
|---|---|
| Walking up stairs | 1,100 |
| Running (jogging) | 570 |
| Swimming | 500 |
| Vigorous exercise | 450 |
| Slow walking | 200 |
| Dressing and undressing | 118 |
| Sitting at rest | 100 |

## Energy Balance

A state of **energy balance** exists when caloric intake in the form of foods equals caloric expenditure from the basal metabolic rate and muscular activities. Under these conditions, body weight remains constant, except perhaps for slight variations due to changes in water content.

If, however, caloric intake exceeds expenditure, a *positive energy balance* occurs, and tissues store excess nutrients. This increases body weight because 3,500 excess calories is stored as a pound of fat. Conversely, if caloric expenditure exceeds input, the energy balance is negative, and stored materials are mobilized from the tissues for oxidation, causing weight loss. To maintain weight, calories in must equal calories expended.

## Desirable Weight

The most obvious and common nutritional disorders reflect calorie imbalances, which may result from societal and geographic factors. Obesity is prevalent in nations where food is plentiful and diverse. The tendency to become obese may be a holdover from thousands of years ago, when the ability to store energy in the form of fat was a survival advantage when food supplies were scarce or erratic. Today in many African nations, natural famines combined with political unrest cause mass starvation. Starvation is considered later in the chapter.

It is difficult to determine a desirable body weight. In the past, weight standards were based on average weights and heights in a certain population, and the degrees of underweight and overweight were expressed as percentage deviations from these averages. These standards reflected the gradual gain in weight as people age. Then medical researchers recognized that such an increase in weight after the age of twenty-five to thirty years is not necessary and may not be healthy. This lead to standards of *desirable weights.* Today a measurement termed **body mass index** (BMI) is used to assess weight considering height, and has become the basis of classifying a person as underweight, normal weight, overweight, or obese.

*Overweight* is defined as exceeding desirable weight by 10% to 20%, or a BMI between 25 and 30. A person more than 20% above the desired weight or with a BMI over 30, is *obese,* although **obesity** (o-bēs'ĭ-te) is more correctly defined as excess adipose tissue. Therefore, overweight and obesity are not the same. For example, as figure 18.9 shows, an athlete or a person whose work requires heavy muscular activity may be overweight, but not obese. Clinical Application 18.1 discusses obesity.

When a person needs to gain weight, diet can be altered to include more calories and to emphasize particular macronutrients. For example, a person recovering from a debilitating illness might consume more carbohydrates, whereas a bodybuilder might eat extra protein to hasten muscle development. An infant also needs to gain weight rapidly, best accomplished by drinking human milk, which has more total carbohydrate than prepared formulas. The high fat content of human milk is important for the rapid growth of the infant's brain, where many neurons are ensheathed in lipids.

**PRACTICE**

19 What is the basal metabolic rate?
20 What factors influence the BMR?
21 What is energy balance?
22 What is desirable weight?
23 Distinguish between being overweight and being obese.

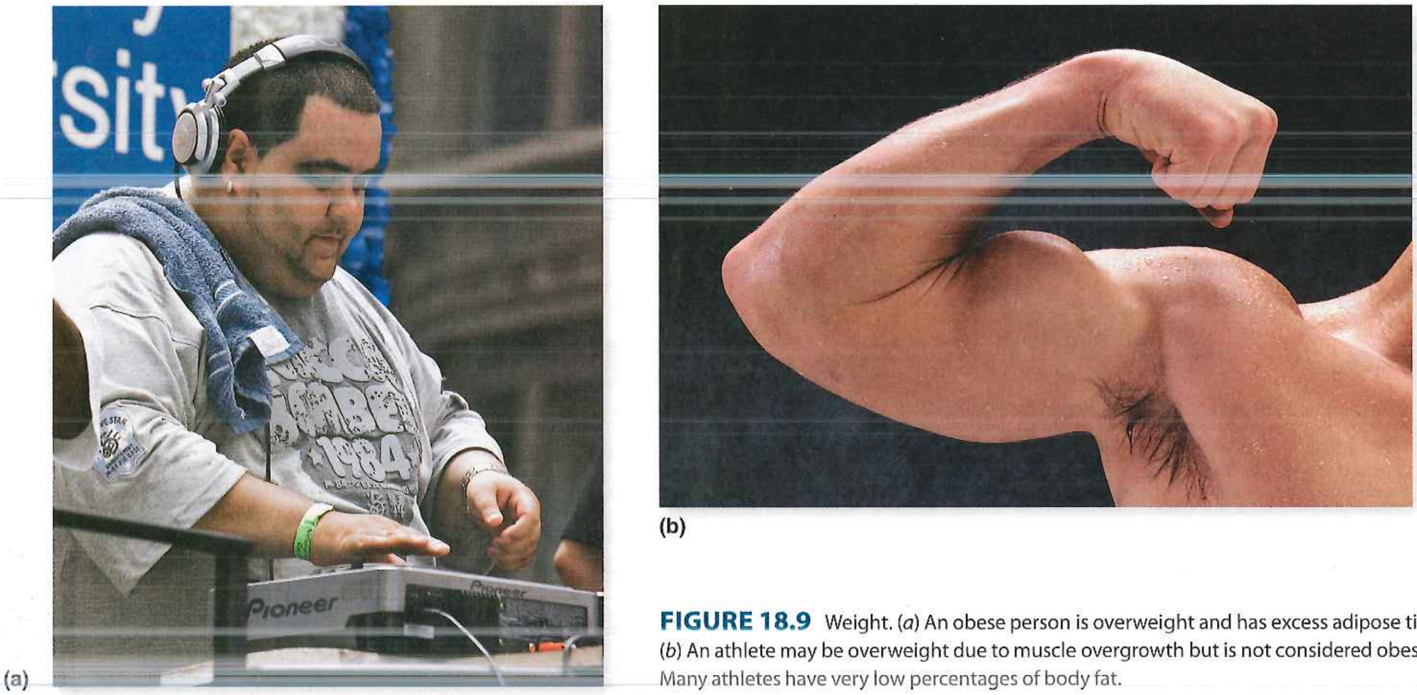


**FIGURE 18.9** Weight. (*a*) An obese person is overweight and has excess adipose tissue. (*b*) An athlete may be overweight due to muscle overgrowth but is not considered obese. Many athletes have very low percentages of body fat.

# 18.1 CLINICAL APPLICATION

## Obesity

In the United States, obesity is common. Nearly a third of all adults are obese, defined as 20% above "ideal" weight based on population statistics considering age, sex, and build, or a body mass index above 30. Obesity raises risks for type 2 diabetes, digestive disorders, heart disease, kidney failure, hypertension, stroke, and cancers of the gallbladder and female reproductive organs. The body has to support the extra weight—miles of extra blood vessels are needed to nourish the additional pounds. Obesity is the second leading cause of preventable death, following cigarette smoking.

Obesity refers to extra pounds of fat. The proportion of fat in a human body ranges from 5% to more than 50%, with "normal" for males falling between 12% and 23% and for females between 16% and 28%. An elite athlete may have a body fat level as low as 4%. Fat distribution also affects health. Excess poundage above the waist is linked to increased risk of heart disease, type 2 diabetes, hypertension, and lipid disorders. The body mass index (BMI) accounts somewhat for a person's build (fig. 18A). A person who weighs 170 pounds and is 6 feet tall is slim, whereas a person of the same weight who is 5 feet tall is obese. The tall person's BMI is 23; the short person's is 33.5.

Both heredity and the environment contribute to obesity. Dozens of genes interact to control energy balance and therefore body weight. The observation that identical twins reared in different households can grow into adults of vastly different weights indicates that environment influences weight too. Even the environment before birth can affect body weight later. Individuals born at full term, but undernourished as fetuses, are at high risk of obesity. Physiological changes that countered starvation in the uterus cause obesity when they persist.

Certain genes encode proteins that connect sensations in the gastrointestinal tract with centers in the hypothalamus that control hunger and satiety. It is how we satisfy those signals—what we eat—that provides the environmental component to body weight. A certain set of gene variants may have led to a trim figure in a human many thousands of years ago, when food had to be hunted or gathered—and meat was leaner. Today those same gene variants do not foster slimness in a person who takes in many more calories than he or she expends.

### Treatments for Obesity

#### Diet and Exercise

A safe goal for weight loss using dietary restriction and exercise is 1 pound of fat per week. A pound of fat contains 3,500 calories of energy, so that pound can be shed by an appropriate combination of calorie cutting and exercise. This might mean eating 500 fewer calories per day or exercising off 500 calories each day. More than a pound of weight will drop because water is lost as well as fat.

Dieting should apply to the energy-providing nutrients (carbohydrates, proteins, and fats) but never to the vitamins and minerals. Choose foods that you like and distribute them into three or four balanced meals of 250 to 500 calories each.

Appetite is an important consideration in dieting to control weight. Many people in the 1990s, following advice from the U.S. government, followed low-fat diets, which caused weight gain if the dieters compensated by eating more simple carbohydrates. These foods accelerate the rise and fall of blood glucose level after a meal, which stimulates hunger sooner than if the meal contained more protein and fat. Substituting whole grains for "white" carbohydrates slows the rate of entry of glucose into the bloodstream (the glycemic index), and this can better control the urge to eat.

Weight may be difficult to keep off. Two-thirds of people who lose weight regain it within five years. Some people who need to lose a great deal of weight may require more intervention than dieting and exercising.

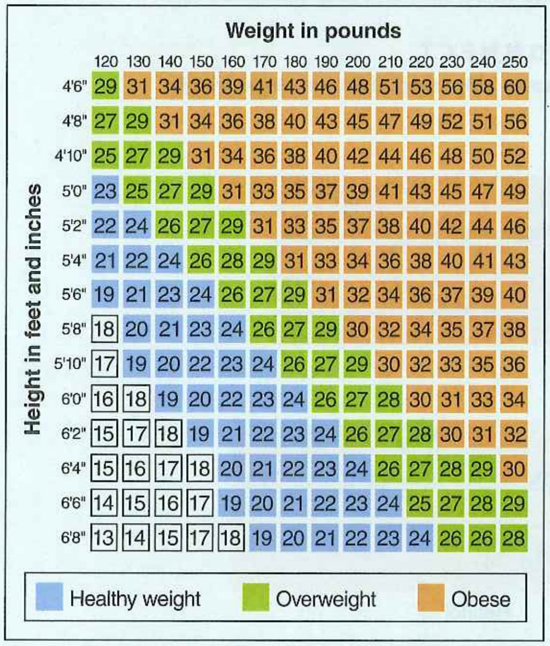
#### Drug Therapy

Some physicians recommend drug therapy if the BMI exceeds 30 or if it exceeds 27 and the person also has hypertension, type 2 diabetes mellitus, or hyperlipidemia. Several types of "diet drugs" are no longer in use because they are dangerous. Amphetamines, for example, carried the risk of addiction, and the combination of fenfluramine and phentermine damaged heart valves.

Newer antiobesity drugs target fat in diverse ways. Tetrahydrolipostatin, marketed as Orlistat and Xenical, inhibits the function of pancreatic lipase, preventing the digestion and absorption of about a third of dietary fat, which is eliminated in loose feces. This effect is not disruptive as long as the person follows a low-fat diet. Future weight control drugs may manipulate appetite-control hormones, such as ghrelin and leptin.

#### Surgery

For people with BMIs above 40, or above 35 in addition to an obesity-related disorder, bariatric (weight loss) surgery can lead to great weight loss. Two types of procedures are done. In laparoscopic adjustable gastric banding, a silicone band ties off part of the stomach, limiting its capacity to hold food. The band can be inflated or deflated in a doctor's office by adding or removing saline. The second type of bariatric surgery is gastric bypass, in which part of the stomach is stapled shut, forming a pouch surgically connected to the jejunum, bypassing the duodenum. Both procedures lead to decreased hunger, greatly reduced food intake, and some decrease in the absorption of nutrients. A special diet, liquid at first, must be followed. Many patients who have had bariatric surgery report improvement in or disappearance of type 2 diabetes, back pain, arthritis, varicose veins, sleep apnea, and hypertension. However, some patients gradually return to eating more, and gain weight back. ■



Weight in pounds

Height in feet and inches

| | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 220 | 230 | 240 | 250 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4'6" | 29 | 31 | 34 | 36 | 39 | 41 | 43 | 46 | 48 | 51 | 53 | 56 | 58 | 60 |
| 4'8" | 27 | 29 | 31 | 34 | 36 | 38 | 40 | 43 | 45 | 47 | 49 | 52 | 51 | 56 |
| 4'10" | 25 | 27 | 29 | 31 | 34 | 36 | 38 | 40 | 42 | 44 | 46 | 48 | 50 | 52 |
| 5'0" | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 |
| 5'2" | 22 | 24 | 26 | 27 | 29 | 31 | 33 | 35 | 37 | 38 | 40 | 42 | 44 | 46 |
| 5'4" | 21 | 22 | 24 | 26 | 28 | 29 | 31 | 33 | 34 | 36 | 38 | 40 | 41 | 43 |
| 5'6" | 19 | 21 | 23 | 24 | 26 | 27 | 29 | 31 | 32 | 34 | 36 | 37 | 39 | 40 |
| 5'8" | 18 | 20 | 21 | 23 | 24 | 26 | 27 | 29 | 30 | 32 | 34 | 35 | 37 | 38 |
| 5'10" | 17 | 19 | 20 | 22 | 23 | 24 | 26 | 27 | 29 | 30 | 32 | 33 | 35 | 36 |
| 6'0" | 16 | 18 | 19 | 20 | 22 | 23 | 24 | 26 | 27 | 28 | 30 | 31 | 33 | 34 |
| 6'2" | 15 | 17 | 18 | 19 | 21 | 22 | 23 | 24 | 26 | 27 | 28 | 30 | 31 | 32 |
| 6'4" | 15 | 16 | 17 | 18 | 20 | 21 | 22 | 23 | 24 | 26 | 27 | 28 | 29 | 30 |
| 6'6" | 14 | 15 | 16 | 17 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 27 | 28 | 29 |
| 6'8" | 13 | 14 | 15 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 26 | 26 | 28 |

🟦 Healthy weight 🟩 Overweight 🟧 Obese

Developed by the National Center for Health Statistics in collaboration with the National Center for Chronic Disease Prevention and Health Promotion

**FIGURE 18A** Body mass index (BMI). BMI equals weight/height², with weight measured in kilograms and height measured in meters. This chart provides a shortcut—the calculations have been done and converted to the English system of measurement. The uncolored squares indicate lower than healthy weight according to this index.

**Q:** *What is your body mass index? Based on whether you are lower than healthy weight, healthy weight, overweight, or obese, what might you do with regards to your diet and activity level to achieve/maintain healthy weight?*

***Answer can be found in Appendix G on page 938.***

## 18.7 VITAMINS

**Vitamins** (vi'tah-minz) are organic compounds (other than carbohydrates, lipids, and proteins) required in small amounts for normal metabolism that body cells cannot synthesize in adequate amounts. Vitamins are essential nutrients that must come directly from foods or indirectly from **provitamins,** which are precursor substances.

Vitamins are classified on the basis of whether they are soluble in fats (or fat solvents) or in water. *Fat-soluble* vitamins are A, D, E, and K; the *water-soluble* group includes the B vitamins and vitamin C. Table 18.6 lists, and corrects, some common misconceptions about vitamins.

> Different species have different vitamin requirements. For example, ascorbic acid is a required vitamin (C) in humans, guinea pigs, and Indian fruit bats, but not in other species, which can manufacture their own.

### Fat-Soluble Vitamins

Fat-soluble vitamins dissolve in fats. Therefore they associate with lipids and are influenced by the same factors that affect lipid absorption. For example, bile salts in the intestine promote absorption of fat-soluble vitamins. As a group, the fat-soluble vitamins are stored in moderate quantities in various tissues, which is why excess intake can lead to overdose. Fat-soluble vitamins resist the effects of heat, so cooking and food processing do not usually destroy them.

**TABLE 18.6** | Vitamin Fallacies and Facts

| Fallacy | Fact |
|---|---|
| The more vitamins, the better | Too much of a water-soluble vitamin results in excretion of the vitamin through urination; too much of a fat-soluble vitamin can harm health |
| A varied diet provides all needed vitamins | Many people do benefit from vitamin supplements, particularly pregnant and breast-feeding women |
| Vitamins provide energy | Vitamins do not directly supply energy; they aid in the release of energy from carbohydrates, fats, and proteins |

**PRACTICE**

**24** What are vitamins?

**25** How are vitamins classified?

**26** How do bile salts affect the absorption of fat-soluble vitamins?

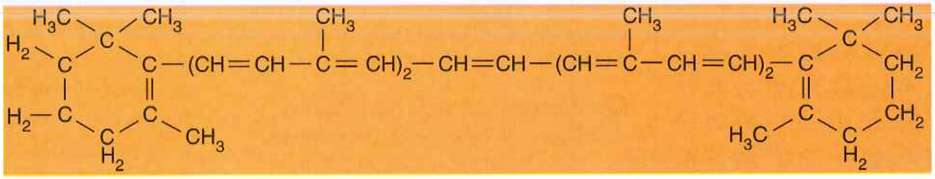
**Vitamin A** exists in several forms, including retinol and retinal (retinene). Body cells synthesize this vitamin from a group of yellowish plant pigments, which are provitamins called *carotenes* (fig. 18.10). Excess vitamin A or its precursors are mainly stored in the liver, which regulates their concentration in the body. An adult's liver stores enough vitamin A to supply body requirements for a year. Infants and children usually lack such reserves and are therefore more likely to develop vitamin A deficiencies if their diets are inadequate.

Vitamin A is relatively stable to the effects of heat, acids, and bases. However, it is readily destroyed by oxidation and is unstable in light.

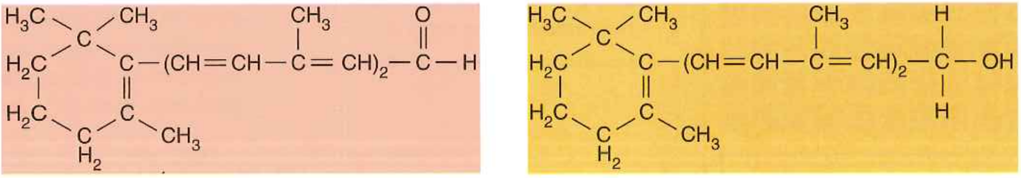
Vitamin A is important in vision. Retinal is used to synthesize *rhodopsin* (visual purple) in the rods of the retina and light-sensitive pigments in the cones. The vitamin also functions in the synthesis of mucoproteins and mucopolysaccharides, in development of normal bones and teeth, and in maintenance of epithelial cells in skin and mucous membranes. Vitamin A and beta carotenes also act as **antioxidants** (an'tĭ-ok'sĭ-dant) by readily combining with oxygen and certain oxygen-containing molecules that have unshared electrons, which makes them highly reactive and damaging to cellular structures. These unstable molecules are called oxygen free radicals, and they accumulate in certain diseases and with age.

**RECONNECT**

**To Chapter 2, Bonding of Atoms, pages 64–66.**



Beta carotene



Retinal (retinene)

Retinol

**FIGURE 18.10** A molecule of beta carotene can react to form two molecules of retinal, which, in turn, can react to form retinol.

Only foods of animal origin such as liver, fish, whole milk, butter, and eggs are sources of vitamin A. However, the vitamin's precursor, carotene, is widespread in leafy green vegetables and in yellow or orange vegetables and fruits.

Excess vitamin A produces the peeling skin, hair loss, nausea, headache, and dizziness of *hypervitaminosis A.* Chronic overdoses of the vitamin may inhibit growth and break down bones and joints. "Megadosing" on fat-soluble vitamins is particularly dangerous during pregnancy. Some forms of vitamin A, in excess, can cause birth defects.

A deficiency of vitamin A causes *night blindness,* in which a person cannot see normally in dim light. Xeropthalmia, a dryness of the conjunctiva and cornea, is due to vitamin A deficiency. Vitamin A deficiency also causes degenerative changes in certain epithelial tissues, and the body becomes more susceptible to infection.

**PRACTICE**

**27** Which chemical in the body is the precursor to vitamin A?

**28** Which foods are good sources of vitamin A?

**Vitamin D** is a group of steroids that have similar properties. One of these substances, vitamin $D_3$ (cholecalciferol), is found in foods such as milk, egg yolk, and fish liver oils. Vitamin $D_2$ (ergocalciferol) is commercially produced by exposing a steroid obtained from yeasts (ergosterol) to ultraviolet light. Vitamin D can also be synthesized from dietary cholesterol that has been metabolized to provitamin D by intestinal enzymes, then stored in the skin and exposed to ultraviolet light (see chapter 6, p. 180).

Like other fat-soluble vitamins, vitamin D resists the effects of heat, oxidation, acids, and bases. It is primarily stored in the liver and is less abundant in the skin, brain, spleen, and bones.

Vitamin D stored in the form of hydroxycholecalciferol is released as needed into the blood. When parathyroid hormone is present, this form of vitamin D is converted in the kidneys into an active form of the vitamin (dihydroxycholecalciferol). This substance, in turn, is carried as a hormone in the blood to the intestines where it stimulates production of calcium-binding protein. Here, it promotes absorption of calcium and phosphorus, ensuring that adequate amounts of these minerals are available in the blood for tooth and bone formation and metabolic processes.

Some natural foods are poor sources of vitamin D, so the vitamin is often added to them during processing. For example, homogenized, nonfat, and evaporated milk are typically fortified with vitamin D. *Fortified* means essential nutrients have been added to a food where they originally were absent or scarce. *Enriched* means essential nutrients have been partially replaced in a food that has lost nutrients during processing.

Excess vitamin D, or *hypervitaminosis D,* produces diarrhea, nausea, and weight loss. Over time it may also calcify certain soft tissues and irreversibly damage the kidneys.

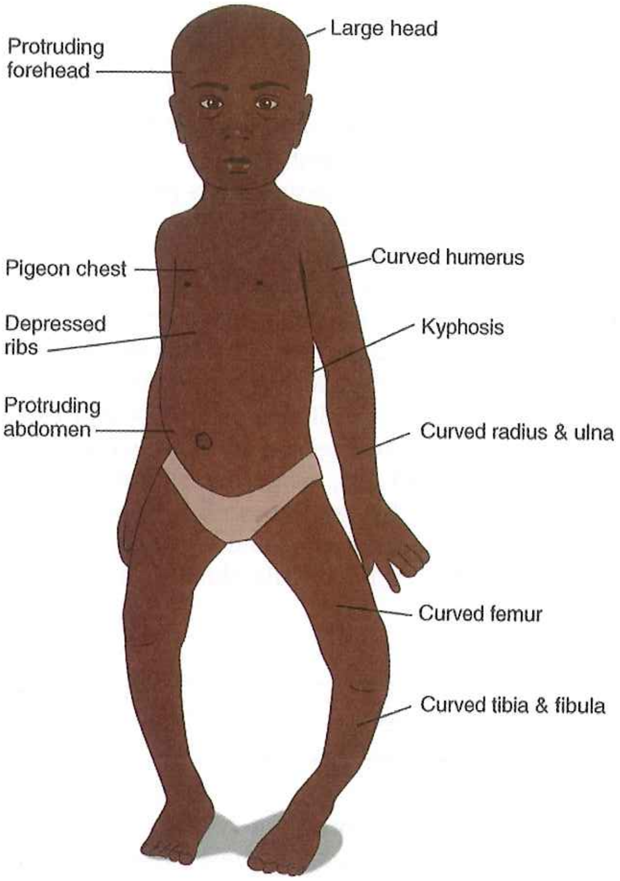


**FIGURE 18.11** Vitamin D deficiency in childhood causes bone deformities.

**Q:** *Why would vitamin D deficiency cause bone deformities?*

*Answer can be found in Appendix G on page 938.*

In children, vitamin D deficiency results in *rickets,* in which the bones, teeth, and abdominal muscles do not develop normally (fig. 18.11). In adults or in the elderly who have little exposure to sunlight, vitamin D deficiency may lead to *osteomalacia,* in which the bones decalcify and weaken due to disturbances in calcium and phosphorus metabolism. Just five minutes of sun exposure two to three times a week can maintain skeletal health without elevating skin cancer risk. Because many older people stay indoors, the Institute of Medicine suggests that daily vitamin D intake increase with age (table 18.7).

**PRACTICE**

**29** What are the functions of vitamin D?

**30** Which foods are good sources of vitamin D?

**TABLE 18.7** | Vitamin D Requirements Increase with Age

| Age Range (Years) | International Units of Vitamin D |
|---|---|
| <50 | 200 |
| 50–70 | 400 |
| 70+ | 600 |

**Vitamin E** includes a group of compounds, the most active of which is *alpha-tocopherol*. This vitamin is resistant to the effects of heat, acids, and visible light but is unstable in bases and in the presence of ultraviolet light or oxygen. Vitamin E is a strong antioxidant.

Vitamin E is found in all tissues but is primarily stored in the muscles and adipose tissue. It is also highly concentrated in the pituitary and adrenal glands.

The precise functions of vitamin E are unknown, but it is thought to act as an antioxidant by preventing oxidation of vitamin A and polyunsaturated fatty acids in the tissues. It may also help maintain the stability of cell membranes.

Vitamin E is widely distributed among foods. Its richest sources are oils from cereal seeds such as wheat germ. Other good sources are salad oils, margarine, shortenings, fruits, nuts, and vegetables. Excess vitamin E may cause nausea, headache, fatigue, easy bruising and bleeding, and muscle weakness. This vitamin is so easily obtained that deficiency conditions are rare.

**PRACTICE**

**31** Where is vitamin E stored?

**32** Which foods are good sources of vitamin E?

**Vitamin K,** like the other fat-soluble vitamins, is in several chemical forms. One of these, vitamin K$_1$ (phylloquinone), is found in foods, whereas another, vitamin K$_2$, is produced by bacteria *(Escherichia coli)* that normally inhabit the human intestinal tract. These vitamins resist the effects of heat but are destroyed by oxidation or by exposure to acids, bases, or light. The liver stores them to a limited degree.

Vitamin K primarily functions in the liver, where it is necessary for the formation of several proteins needed for blood clotting, including *prothrombin* (see chapter 14, p. 541). Consequently, deficiency of vitamin K prolongs blood clotting time and may increase risk of hemorrhage. Excess vitamin K may occur in formula-fed infants, causing jaundice, hemolytic anemia, and hyperbilirubinemia.

The richest sources of vitamin K are leafy green vegetables. Other good sources are egg yolk, pork liver, soy oil, tomatoes, and cauliflower. Table 18.8 summarizes the fat-soluble vitamins and their properties.

About 1 in every 200 to 400 newborns develops vitamin K deficiency because of an immature liver, poor transfer of vitamin K through the placenta, or lack of intestinal bacteria that can synthesize this vitamin. The deficiency causes "hemorrhagic disease of the newborn," in which abnormal bleeding occurs two to five days after birth. Injections of vitamin K shortly after birth prevent this condition. Adults may develop vitamin K deficiency if they take antibiotic drugs that kill the intestinal bacteria that manufacture the vitamin. People with cystic fibrosis may develop vitamin K deficiency, and/or deficiency of other fat-soluble vitamins, because they cannot digest fats well.

**PRACTICE**

**33** Name two sources of vitamin K.

**34** What is the function of vitamin K?

## TABLE 18.8 | Fat-Soluble Vitamins

| Vitamin | Characteristics | Functions | Sources and RDA* for Adults | Conditions Associated with | |
|---|---|---|---|---|---|
| | | | | **Excesses** | **Deficiencies** |
| *Vitamin A* | Exists in several forms; synthesized from carotenes; stored in liver; stable in heat, acids, and bases; unstable in light | An antioxidant necessary for synthesis of visual pigments, mucoproteins, and mucopolysaccharides; for normal development of bones and teeth; and for maintenance of epithelial cells | Liver, fish, whole milk, butter, eggs, leafy green vegetables, yellow and orange vegetables and fruits<br>4,000–5,000 IU** | Nausea, headache, dizziness, hair loss, birth defects | Night blindness, degeneration of epithelial tissues |
| *Vitamin D* | A group of steroids; resistant to heat, oxidation, acids, and bases; stored in liver, skin, brain, spleen, and bones | Promotes absorption of calcium and phosphorus; promotes development of teeth and bones | Produced in skin exposed to ultraviolet light; in milk, egg yolk, fish liver oils, fortified foods<br>400 IU | Diarrhea, calcification of soft tissues, renal damage | Rickets, bone decalcification and weakening |
| *Vitamin E* | A group of compounds; resistant to heat and visible light; unstable in presence of oxygen and ultraviolet light; stored in muscles and adipose tissue | An antioxidant; prevents oxidation of vitamin A and polyunsaturated fatty acids; may help maintain stability of cell membranes | Oils from cereal seeds, salad oils, margarine, shortenings, fruits, nuts, and vegetables<br>30 IU | Nausea, headache, fatigue, easy bruising and bleeding | Rare, uncertain effects |
| *Vitamin K* | Exists in several forms; resistant to heat but destroyed by acids, bases, and light; stored in liver | Required for synthesis of prothrombin, which functions in blood clotting | Leafy green vegetables, egg yolk, pork liver, soy oil, tomatoes, cauliflower<br>55–70 μg | Jaundice in formula-fed newborns | Prolonged clotting time |

*RDA = recommended daily allowance.

**IU = international unit.

## Water-Soluble Vitamins

The water-soluble vitamins include the B vitamins and vitamin C. Cooking and food processing destroy some of them. The **B vitamins** are several compounds essential for normal cellular metabolism. They help oxidize (remove electrons from) carbohydrates, lipids, and proteins during cellular respiration. The B vitamins are usually in the same foods, so they are called the *vitamin B complex*. Members of this group differ chemically and functionally.

The B-complex vitamins include the following:

1. **Thiamine,** or **vitamin $B_1$**, in its pure form is a crystalline compound called thiamine hydrochloride. Exposure to heat and oxygen destroys it, especially in alkaline environments. (See fig. 18.18 for its molecular structure.)

   Thiamine is part of a coenzyme called *cocarboxylase,* which oxidizes carbohydrates. Specifically, thiamine is required for pyruvic acid to enter the citric acid cycle (see chapter 4, p. 130). Without this vitamin, pyruvic acid accumulates in the blood. Thiamine also functions as a coenzyme in the synthesis of the sugar ribose, which is part of the nucleic acid RNA.

   Thiamine is primarily absorbed through the wall of the duodenum and is transported by the blood to body cells. Only small amounts are stored in the tissues, and excess is excreted in the urine.

   Vitamin $B_1$ oxidizes carbohydrates, and therefore cellular requirements vary with caloric intake. It is recommended that an adult diet contain 0.5 milligram (mg) of thiamine for every 1,000 calories ingested daily. Good sources of thiamine are lean meats, liver, eggs, whole-grain cereals, leafy green vegetables, and legumes.

   Excess thiamine is not as common as excesses of fat-soluble vitamins, due to the excretion of thiamine in urine. Toxicity effects include vasodilation, cardiac dysrhythmias, headache, weakness, and convulsions.

   A mild deficiency of thiamine produces loss of appetite, fatigue, and nausea. Prolonged deficiency leads to a disease called *beriberi,* which causes gastrointestinal disturbances, mental confusion, muscular weakness and paralysis, and heart enlargement. In severe cases, the heart may fail.

In developed nations, beriberi affects mostly people with chronic alcoholism who have substituted alcohol for foods. Because thiamine is required for the metabolic oxidation of alcohol, people with alcoholism are particularly likely to develop a thiamine deficiency.

2. **Riboflavin,** or **vitamin $B_2$**, is a yellowish brown crystalline substance that is relatively stable to the effects of heat, acids, and oxidation but is destroyed by exposure to bases and ultraviolet light. This vitamin is part of several enzymes and coenzymes known as *flavoproteins*. One such coenzyme, FAD, is an electron carrier in the citric acid cycle and electron transport chain of aerobic respiration. Flavoproteins are essential for the oxidation of glucose and fatty acids and for cellular growth. An active transport system controls the amount of riboflavin entering the intestinal mucosa. Riboflavin is carried in the blood combined with proteins called *albumins*. Excess riboflavin in the blood is excreted in the urine, turning it yellow-orange, and any that remains unabsorbed in the intestine is lost in the feces.

   The amount of riboflavin the body requires varies with caloric intake. About 0.6 mg of riboflavin per 1,000 calories is sufficient to meet daily cellular requirements.

   Riboflavin is widely distributed in foods, and rich sources include meats and dairy products. Leafy green vegetables, whole-grain cereals, and enriched cereals provide lesser amounts. Vitamin $B_2$ deficiency produces dermatitis and blurred vision.

3. **Niacin** or **vitamin $B_3$**, also known as *nicotinic acid,* is in plant tissues and is stable in the presence of heat, acids, and bases. After ingestion, it is converted to a physiologically active form called *niacinamide* (fig. 18.12). Niacinamide is the form of niacin in foods of animal origin.

   Niacin functions as part of two coenzymes (coenzyme I, also called NAD [fig. 18.13], and coenzyme II, called NADP) essential in glucose oxidation. These coenzymes are electron carriers in glycolysis, the citric acid cycle, and the electron transport chain, as well as in

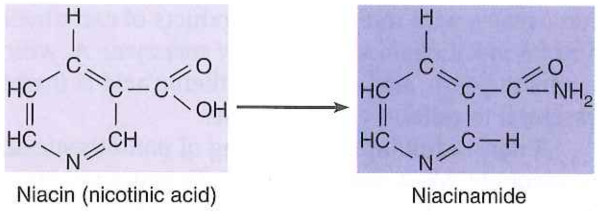


**FIGURE 18.12** Enzymes catalyze reactions that convert niacin from foods into physiologically active niacinamide.

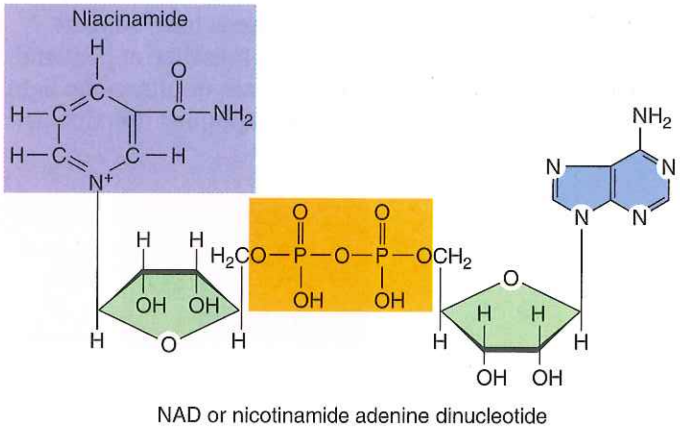


**FIGURE 18.13** Niacinamide is incorporated into molecules of NAD.

the synthesis of proteins and fats. They are also required for the synthesis of the sugars (ribose and deoxyribose) that are part of nucleic acids.

Niacin is readily absorbed from foods, and human cells synthesize it from the essential amino acid *tryptophan*. Consequently, the daily requirement for niacin varies with tryptophan intake. Nutritionists recommend a daily niacin (or niacin equivalent) intake of 6.6 mg per 1,000 calories.

Rich sources of niacin (and tryptophan) include liver, lean meats, peanut butter, and legumes. Milk is a poor source of niacin but a good source of tryptophan.

Excess niacin can cause acute toxicity with effects such as flushing, wheezing, vasodilation, headache, diarrhea, and vomiting. Chronic toxicity effects include liver problems.

Historically, niacin deficiencies have been associated with diets based on corn and corn products, which are very low in niacin and lack tryptophan. Niacin deficiency causes *pellagra,* which produces dermatitis, inflammation of the digestive tract, diarrhea, and mental disorders.

Pellagra is rare today, but it was a serious problem in the rural South of the United States in the early 1900s. Pellagra is less common in cultures that extensively treat corn with lime ($CaCO_3$) to release niacin bound to protein. Like beriberi, pellagra affects people who consume alcoholic beverages instead of food.

4. **Pantothenic acid,** or **vitamin $B_5$,** is a yellowish oil destroyed by heat, acids, and bases. It functions as part of a complex molecule called *coenzyme A,* which, in turn, reacts with intermediate products of carbohydrate and fat metabolism to yield *acetyl coenzyme A,* which enters the citric acid cycle. Pantothenic acid is therefore essential to cellular energy release.

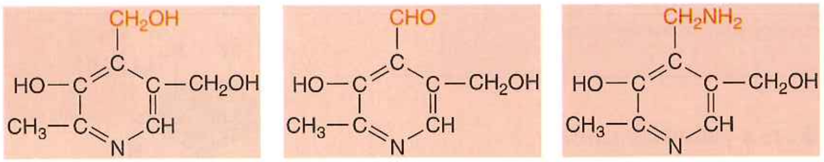
   A daily adult intake of 4–7 mg of pantothenic acid is adequate. Most diets provide sufficient amounts, and therefore deficiencies are rare. Good sources of pantothenic acid include meats, whole-grain cereals, legumes, milk, fruits, and vegetables.
5. **Vitamin $B_6$** is a group of three compounds, *pyridoxine, pyridoxal,* and *pyridoxamine,* which are chemically similar (fig. 18.14). These compounds have similar actions and are fairly stable in the presence of heat and acids. Oxidation or exposure to bases or ultraviolet light destroys them. The vitamin $B_6$ compounds function as coenzymes essential in several metabolic pathways, including those that synthesize proteins, amino acids, antibodies, and nucleic acids, as well as the reaction of tryptophan to produce niacin.

   Vitamin $B_6$ functions in the metabolism of nitrogen-containing substances. Thus, the requirement for this vitamin varies with the protein content of the diet rather than with caloric intake. The recommended daily allowance of vitamin $B_6$ is 2.0 mg, but because it is so widespread in foods, deficiency conditions are rare. Good sources of vitamin $B_6$ include liver, meats, bananas, avocados, beans, peanuts, whole-grain cereals, and egg yolk. Excess vitamin $B_6$ produces burning pains, numbness, clumsiness, diminished reflexes, and paralysis.
6. **Biotin,** or **vitamin $B_7$,** is a simple compound that is unaffected by heat, acids, and light but may be destroyed by oxidation or bases. (See fig. 18.18 for the molecular structure of biotin.) It is a coenzyme in metabolic pathways for amino acids and fatty acids. It also plays a role in the synthesis of the purine nitrogenous bases of nucleic acids.

   Metabolically active organs such as the brain, liver, and kidneys store some biotin. Bacteria that inhabit the intestinal tract synthesize biotin. The vitamin is widely distributed in foods, and dietary deficiencies are rare. Good sources include liver, egg yolk, nuts, legumes, and mushrooms. Excess biotin does not produce toxic effects.
7. **Folacin or vitamin $B_9$,** also known as *folic acid,* is a yellow crystalline compound that exists in several forms. It is easily oxidized in an acid environment and is destroyed by heat in alkaline solutions; consequently, this vitamin may be lost in stored or cooked foods.

   Folacin is readily absorbed from the digestive tract and is stored in the liver, where it is converted to a physiologically active substance called *folinic acid.* Folinic acid functions as a coenzyme necessary for the metabolism of certain amino acids and for the synthesis of DNA. It also acts with cyanocobalamin in producing normal red blood cells.

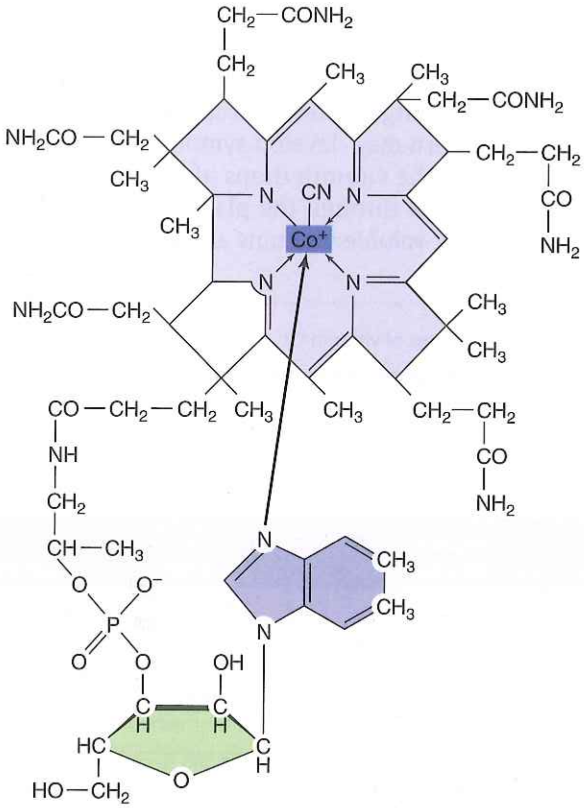
   Good sources of folacin include liver, leafy green vegetables, whole-grain cereals, and legumes. Because excess folacin is excreted in the urine, toxicity is rare. Folacin deficiency leads to *megaloblastic anemia,* in which the number of normal red blood cells is reduced and large, nucleated red cells appear. Folacin deficiency has been linked to neural tube defects, in which the



Pyridoxine Pyridoxal Pyridoxamine

Vitamin $B_6$

**FIGURE 18.14** Vitamin $B_6$ includes three similar chemical compounds.



Vitamin $B_{12}$ (cyanocobalamin)

**FIGURE 18.15** Vitamin $B_{12}$, which has the most complex molecular structure of the vitamins, contains cobalt (Co).

tube that becomes the central nervous system in a fetus fails to entirely close. Neural tube defects include spina bifida and anencephaly. Taking synthetic folic acid supplements just before and during pregnancy can greatly reduce the risk of a neural tube defect.

Naturally occurring folate is a mixture of compounds that collectively have the same activity as synthetic folic acid, also called pteroylmonoglutamic acid. However, synthetic folic acid is much more stable and enters the bloodstream much more readily. This difference has led to confusion. For example, 200 micrograms of synthetic folic acid is prescribed to treat anemia, but the same effect requires 400 micrograms of folate from foods. Synthetic folic acid used to enrich grain foods has a greater effect on health than folate.

8. **Cyanocobalamin,** or **vitamin $B_{12}$**, has a complex molecular structure, including a single atom of the element *cobalt* (fig. 18.15). In its pure form, this vitamin is red. It is stable to the effects of heat but is inactivated by light or strong acids or strong bases.

Secretion of *intrinsic factor* from the parietal cells of the gastric glands regulates cyanocobalamin absorption. Intrinsic factor combines with cyanocobalamin and facilitates its transfer through the epithelial lining of the small intestine and into the blood. Calcium ions must be present for the process to take place.

Inability of the gastric glands to secrete adequate amounts of intrinsic factor impairs vitamin $B_{12}$ absorption. This leads to *pernicious anemia,* which produces abnormally large red blood cells, called macrocytes, when bone marrow cells do not divide properly because of defective DNA synthesis.

Various tissues store cyanocobalamin, particularly those of the liver. An average adult has a reserve sufficient to supply cells for three to five years. This vitamin is essential for the functions of all cells. It is part of coenzymes required for the synthesis of nucleic acids and the metabolism of carbohydrates and fats. Vitamin $B_{12}$ is important to erythrocyte production. Cyanocobalamin also helps form myelin in the central nervous system.

Only foods of animal origin contain cyanocobalamin. Good sources include liver, meats, milk, cheese, and eggs. Excessive intake does not appear to be toxic. In most countries, dietary lack of this vitamin is rare, although strict vegetarians may develop a deficiency.

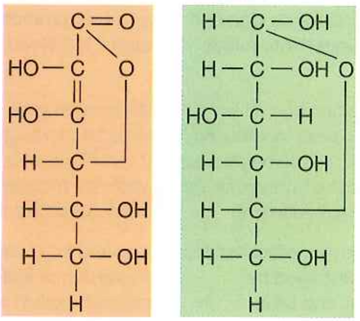
**PRACTICE**

**35** Which biochemicals comprise the vitamin B complex?
**36** Which foods are good sources of vitamin B complex?
**37** What is the general function of each member of the vitamin B complex?

**Vitamin C,** or **ascorbic acid.** Ascorbic acid is a crystalline compound that has six carbon atoms. Chemically, it is similar to the monosaccharides (fig. 18.16). Vitamin C is one of the least stable vitamins in that oxidation, heat, light, or bases destroy it. However, vitamin C is fairly stable in acids.

Ascorbic acid is necessary for the production of the connective tissue protein *collagen,* for conversion of folacin to folinic acid, and in the metabolism of certain amino acids. It also promotes iron absorption and synthesis of certain hormones from cholesterol.

Overall, vitamin C is not stored in any great amount, but the adrenal cortex, pituitary gland, and intestinal glands



Vitamin C (ascorbic acid)

Glucose (a monosaccharide)

**FIGURE 18.16** Vitamin C is chemically similar to some 6-carbon monosaccharides.

contain high concentrations of it. Excess vitamin C is excreted in the urine or oxidized.

Individual requirements for ascorbic acid may vary. Ten mg per day is sufficient to prevent deficiency symptoms, and 80 mg per day saturate the tissues within a few weeks. Many nutritionists recommend a daily adult intake of 60 mg, which is enough to replenish normal losses and satisfy cellular requirements.

Ascorbic acid is fairly widespread in plant foods, with high concentrations in citrus fruits and tomatoes. Leafy green vegetables are also good sources.

Prolonged deficiency of ascorbic acid leads to *scurvy*, which is more likely to affect infants and children. Scurvy impairs bone development and causes swollen, painful joints. The gums may swell and bleed easily, resistance to infection is lowered, and wounds heal slowly (fig. 18.17). If a woman takes large doses of ascorbic acid during pregnancy, the newborn may develop symptoms of scurvy when the daily dose of the vitamin drops after birth because it is no longer delivered through the placenta. Table 18.9 summarizes the water-soluble vitamins and their characteristics.

**PRACTICE**

**38** What are functions of vitamin C?

**39** Which foods are good sources of vitamin C?

**TABLE 18.9** | Water-Soluble Vitamins

| Vitamin | Characteristics | Functions | Sources and RDA* for Adults | Conditions Associated with | |
|---|---|---|---|---|---|
| | | | | Excesses | Deficiencies |
| *Thiamine* (Vitamin $B_1$) | Destroyed by heat and oxygen, especially in alkaline environment | Part of coenzyme required for oxidation of carbohydrates; coenzyme required for ribose synthesis | Lean meats, liver, eggs, whole-grain cereals, leafy green vegetables, legumes<br>1.5 mg | Uncommon, vasodilation, cardiac dysrhythmias | Beriberi, muscular weakness, enlarged heart |
| *Riboflavin* (Vitamin $B_2$) | Stable to heat, acids, and oxidation; destroyed by bases and ultraviolet light | Part of enzymes and coenzymes, such as FAD, required for oxidation of glucose and fatty acids and for cellular growth | Meats, dairy products, leafy green vegetables, whole-grain cereals<br>1.7 mg | None known | Dermatitis, blurred vision |
| *Niacin* (Vitamin $B_3$, Nicotinic acid) | Stable to heat, acids, and bases; converted to niacinamide by cells; synthesized from tryptophan | Part of coenzymes NAD and NADP required for oxidation of glucose and synthesis of proteins, fats, and nucleic acids | Liver, lean meats, peanuts, legumes<br>20 mg | Flushing, vasodilation, wheezing, liver problems | Pellagra, photosensitive dermatitis, diarrhea, mental disorders |
| *Pantothenic acid* (Vitamin $B_5$) | Destroyed by heat, acids, and bases | Part of coenzyme A required for oxidation of carbohydrates and fats | Meats, whole-grain cereals, legumes, milk, fruits, vegetables<br>10 mg | None known | Rare, loss of appetite, mental depression, muscle spasms |
| *Vitamin* $B_6$ | Group of three compounds; stable to heat and acids; destroyed by oxidation, bases, and ultraviolet light | Coenzyme required for synthesis of proteins and various amino acids, for conversion of tryptophan to niacin, for production of antibodies, and for nucleic acid synthesis | Liver, meats, bananas, avocados, beans, peanuts, whole-grain cereals, egg yolk<br>2 mg | Numbness, clumsiness, paralysis | Rare, convulsions, vomiting, seborrhea lesions |
| *Biotin* (Vitamin $B_7$) | Stable to heat, acids, and light; destroyed by oxidation and bases | Coenzyme required for metabolism of amino acids and fatty acids and for nucleic acid synthesis | Liver, egg yolk, nuts, legumes, mushrooms<br>0.3 mg | None known | Rare, elevated blood cholesterol, nausea, fatigue, anorexia |
| *Folacin* (Vitamin $B_9$, Folic acid) | Occurs in several forms; destroyed by oxidation in acid environment or by heat in alkaline environment; stored in liver where it is converted into folinic acid | Coenzyme required for metabolism of certain amino acids and for DNA synthesis; promotes production of normal red blood cells | Liver, leafy green vegetables, whole-grain cereals, legumes<br>0.4 mg | None known | Megaloblastic anemia |
| *Cyanocobalamin* (Vitamin $B_{12}$) | Complex, cobalt-containing compound; stable to heat; inactivated by light, strong acids, and strong bases; absorption regulated by intrinsic factor from gastric glands; stored in liver | Part of coenzyme required for synthesis of nucleic acids and for metabolism of carbohydrates; plays role in myelin synthesis; required for normal red blood cell production | Liver, meats, milk, cheese, eggs<br>3–6 μg | None known | Pernicious anemia |
| *Ascorbic acid* (Vitamin C) | Chemically similar to monosaccharides; stable in acids but destroyed by oxidation, heat, light, and bases | Required for collagen production, conversion of folacin to folinic acid, and metabolism of certain amino acids; promotes absorption of iron and synthesis of hormones from cholesterol | Citrus fruits, tomatoes, potatoes, leafy green vegetables<br>60 mg | Exacerbates gout and kidney stone formation | Scurvy, lowered resistance to infection, wounds heal slowly |

*RDA = recommended daily allowance.

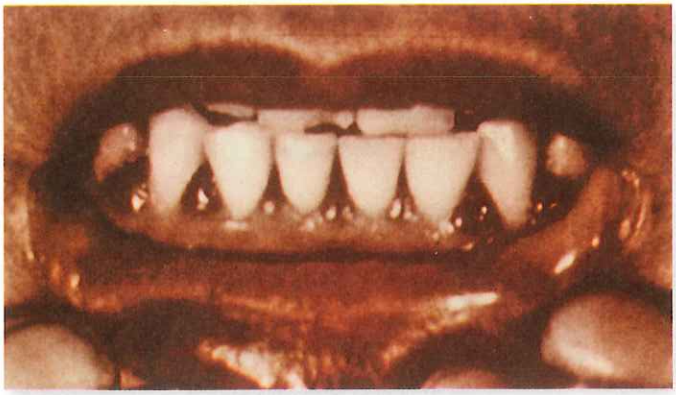


**FIGURE 18.17** Vitamin C deficiency causes bleeding gums and other symptoms of scurvy.

Millions of Americans regularly take vitamin supplements. Consumer spending on vitamins and minerals is well into the billions of dollars annually. This practice has led to clinical signs of excess vitamin and mineral toxicity. Iron-containing vitamins are the most toxic, especially in acute pediatric ingestions.

## 18.8 MINERALS

Carbohydrates, lipids, proteins, and vitamins are organic compounds. Dietary **minerals** are inorganic elements essential in human metabolism. Plants usually extract these elements from the soil, and humans obtain them from plant foods or from animals that have eaten plants.

### Characteristics of Minerals

Minerals contribute about 4% of body weight and are most concentrated in the bones and teeth. The minerals *calcium* and *phosphorus* are very abundant in these tissues.

Minerals are usually incorporated into organic molecules. Examples include phosphorus in phospholipids, iron in hemoglobin, and iodine in thyroxine. However, some minerals are part of inorganic compounds, such as the calcium phosphate of bone. Other minerals are free ions, such as sodium, chloride, and calcium ions in the blood.

Minerals compose parts of the structural materials of all body cells. They also constitute portions of enzyme molecules, contribute to the osmotic pressure of body fluids, and play vital roles in nerve impulse conduction, muscle fiber contraction, blood coagulation, and maintenance of the pH of body fluids. The physiologically active form of minerals is the ionized form, such as $Ca^{+2}$.

Homeostatic mechanisms regulate the concentrations of minerals in body fluids. This ensures that excretion of minerals matches intake. Mineral toxicity may result not only from consumption of too much of a mineral, but also from overexposure to industrial pollutants, household chemicals, or certain drugs. Certain diseases lead to mineral toxicity. Hemochromatosis, for example, is an inherited form of "iron overload" resulting from excess iron absorption. Injuries may also lead to mineral toxicity, such as severe trauma causing hyperkalemia (high plasma potassium).

**PRACTICE**

40 How do minerals differ from other nutrients?

41 What are the major functions of minerals?

### Major Minerals

Calcium and phosphorus account for nearly 75% by weight of the mineral elements in the body. Therefore, they are considered **major minerals** (macrominerals). Other major minerals, each of which accounts for 0.05% or more of body weight, include potassium, sulfur, sodium, chlorine, and magnesium. Descriptions of the major minerals follow:

1. **Calcium (Ca)** is widely distributed in cells and body fluids, even though 99% of the body's supply is in the inorganic salts of the bones and teeth. It is essential for neurotransmitter release, muscle fiber contraction, the cardiac action potential, and blood coagulation. Calcium also activates certain enzymes.

   The amount of calcium absorbed varies with a number of factors. For example, the proportion of calcium absorbed increases as the body's need for calcium increases. Vitamin D and high protein intake promote calcium absorption. Increased motility of the digestive tract or an excess intake of fats decreases absorption. Daily intake of 800 mg of calcium is sufficient to cover adult requirements even with variations in absorption.

   Only a few foods contain significant amounts of calcium. Milk and milk products and fish with bones, such as salmon or sardines, are the richest sources. Leafy green vegetables, such as mustard greens, turnip greens, and kale, are good sources, but because very large servings of these vegetables are necessary to obtain sufficient minerals, most people must regularly consume milk or milk products to get enough calcium.

   Calcium toxicity is rare, but overconsumption of calcium supplements can deposit calcium phosphate in soft tissues. Calcium deficiency in children causes stunted growth, misshapen bones, and enlarged wrists and ankles. In adults, such a deficiency may remove calcium from the bones, thinning them and raising risk of fracture. Calcium is required for normal closing of the sodium channels in nerve cell membranes. Because of this, too little calcium (hypocalcemia) can cause tetany. Extra calcium demands in pregnancy can cause cramps.
2. **Phosphorus (P)** accounts for about 1% of total body weight, most of it in the calcium phosphate of bones and teeth. The remainder serves as structural components and plays important roles in nearly all metabolic reactions. Phosphorus is a constituent of nucleic acids, many proteins, some enzymes, and some vitamins. It is also in the phospholipids of cell membranes, in the energy-carrying molecule ATP, and in the phosphates

of body fluids that regulate pH. (Review the molecular structure of ATP in fig. 4.7, p. 127.)

The recommended daily adult intake of phosphorus is 800 mg, and because this mineral is abundant in protein foods, diets adequate in proteins are also adequate in phosphorus. Phosphorus-rich foods include meats, cheese, nuts, whole-grain cereals, milk, and legumes.

## PRACTICE

**42** Which are the most abundant minerals in the body?
**43** What are the functions of calcium?
**44** What are the functions of phosphorus?
**45** Which foods are good sources of calcium and phosphorus?

3. **Potassium (K)** is widely distributed throughout the body and is concentrated inside cells rather than in extracellular fluids. On the other hand, sodium, which has similar chemical properties, is concentrated outside cells. The ratio of potassium to sodium in a cell is 10:1, whereas the ratio outside the cell is 1:28.

   Potassium helps maintain intracellular osmotic pressure and pH. It is a cofactor for enzymes that catalyze reactions of carbohydrate and protein metabolism. Potassium is vital in establishing the membrane potential and in impulse conduction in neurons.

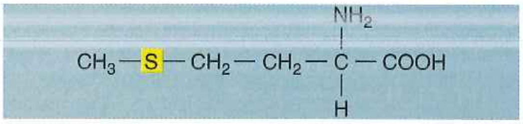
   Nutritionists recommend a daily adult intake of 2.5 grams (2,500 mg) of potassium. This mineral is in many foods, so a typical adult diet provides between 2 and 6 grams each day. Excess potassium in the blood is uncommon because of the uptake of potassium by body cells and the excretion of potassium in urine. Potassium deficiency due to diet is rare, but it may occur for other reasons. For example, when a person has diarrhea, the intestinal contents may pass through the digestive tract so rapidly that potassium absorption is greatly reduced. Vomiting or using diuretic drugs may also deplete potassium. Such losses may cause muscular weakness, cardiac abnormalities, and edema.

   Foods rich in potassium are avocados, dried apricots, meats, milk, peanut butter, potatoes, and bananas. Citrus fruits, apples, carrots, and tomatoes provide lesser amounts.

## PRACTICE

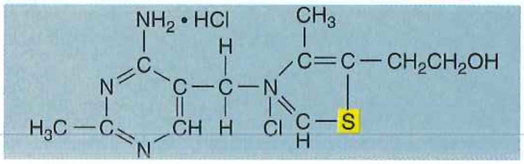
**46** How is potassium distributed in the body?
**47** What is the function of potassium?
**48** Which foods are good sources of potassium?

4. **Sulfur (S)** is responsible for about 0.25% of body weight and is widely distributed throughout tissues. It is abundant in skin, hair, and nails. Most sulfur is part of the amino acids *methionine* and *cysteine*. Other sulfur-containing compounds include thiamine, insulin, and biotin (fig. 18.18). In addition, sulfur is a constituent of mucopolysaccharides in cartilage, tendons, and bones and of sulfolipids in the liver, kidneys, salivary glands, and brain.

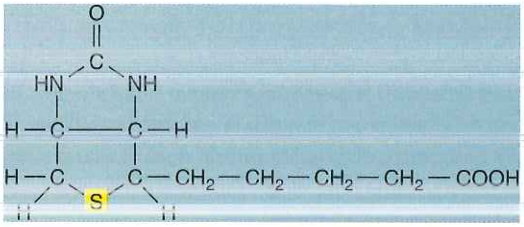


$$CH_3-S-CH_2-CH_2-\overset{NH_2}{\underset{H}{C}}-COOH$$

Methionine



Thiamine hydrochloride
(vitamin $B_1$)



Biotin

**FIGURE 18.18** Three essential sulfur-containing nutrients.

   No daily requirement for sulfur has been established. However, a diet providing adequate amounts of protein will also likely meet the body's sulfur requirement. Good food sources of this mineral include meats, milk, eggs, and legumes.

5. **Sodium (Na)** makes up about 0.15% of adult body weight, and is widely distributed throughout the body. Only about 10% of this mineral is inside cells, and about 40% is in the extracellular fluids. The remainder is bound to the inorganic salts of bone.

   Active transport readily absorbs sodium from foods. The kidneys regulate the blood concentration of sodium under the influence of the adrenal cortical hormone *aldosterone,* which causes the kidneys to reabsorb sodium while expelling potassium.

   Sodium makes a major contribution to the solute concentration of extracellular fluids and thus helps regulate water movement between cells and their surroundings. It is necessary for impulse conduction in neurons and helps to move substances, such as chloride ions, through cell membranes (see chapter 21, p. 811).

   The usual human diet probably provides more than enough sodium to meet the body's requirements. Sodium toxicity, which shrinks cells, including those of the brain, requires unusual ingestion of additional sodium, such as drinking ocean water. Sodium may be lost as a result of diarrhea, vomiting, kidney disorders, sweating, or using diuretics. Sodium loss may cause a variety of symptoms, including nausea, cramps, and convulsions.

The amount of sodium naturally present in foods varies greatly, and it is commonly added to foods in the form of table salt. In some geographic regions, drinking water contains significant concentrations of sodium. Foods high in sodium include cured ham, sauerkraut, and cheese.

**PRACTICE**

**49** In which compounds and tissues of the body is sulfur found?

**50** What are the functions of sodium?

6. **Chlorine (Cl)** in the form of chloride ions is found throughout the body and is most highly concentrated in cerebrospinal fluid and in gastric juice. With sodium, chlorine helps to regulate pH and maintain electrolyte balance and the solute concentration of extracellular fluids. Chlorine is also essential for the formation of hydrochloric acid in gastric juice and in the transport of carbon dioxide by red blood cells.

   Chlorine and sodium are usually ingested in table salt, and as in the case for sodium, an ordinary diet usually provides considerably more chlorine than the body requires. Vomiting, diarrhea, kidney disorders, sweating, or using diuretics can deplete chlorine in the body.

7. **Magnesium (Mg)** is responsible for about 0.05% of body weight and is found in all cells. It is particularly abundant in bones in the form of phosphates and carbonates.

   Magnesium is important in ATP-forming reactions in mitochondria, as well as in breaking down ATP to ADP. Therefore, it is important in providing energy for cellular processes.

   Magnesium absorption in the intestinal tract adapts to dietary intake of the mineral. When the intake of magnesium is high, a smaller percentage is absorbed from the intestinal tract, and when the intake is low, a larger percentage is absorbed. Absorption increases as protein intake increases, and decreases as calcium and vitamin D intake increase. Bone tissue stores a reserve supply of magnesium, and excess is excreted in the urine.

   The recommended daily allowance of magnesium is 300 mg for females and 350 mg for males. A typical diet usually provides only about 120 mg of magnesium for every 1,000 calories, barely meeting the body's needs. Good sources of magnesium include milk and dairy products (except butter), legumes, nuts, and leafy green vegetables. Table 18.10 summarizes the major minerals.

**TABLE 18.10** | Major Minerals

| Mineral | Distribution | Functions | Sources and RDA* for Adults | Conditions Associated with | |
|---|---|---|---|---|---|
| | | | | Excesses | Deficiencies |
| *Calcium* (Ca) | Mostly in the inorganic salts of bones and teeth | Structure of bones and teeth; essential for neurotransmitter release, muscle fiber contraction, the cardiac action potential, and blood coagulation; activates certain enzymes | Milk, milk products, leafy green vegetables<br>800 mg | Kidney stones, deposition of calcium phosphate in soft tissues | Stunted growth, misshapen bones, fragile bones, tetany |
| *Phosphorus* (P) | Mostly in the inorganic salts of bones and teeth | Structure of bones and teeth; component of nearly all metabolic reactions; in nucleic acids, many proteins, some enzymes, and some vitamins; in cell membrane, ATP, and phosphates of body fluids | Meats, cheese, nuts, whole-grain cereals, milk, legumes<br>800 mg | None known | Stunted growth |
| *Potassium* (K) | Widely distributed; tends to be concentrated inside cells | Helps maintain intracellular osmotic pressure and regulate pH; required for impulse conduction in neurons | Avocados, dried apricots, meats, nuts, potatoes, bananas<br>2,500 mg | Uncommon | Muscular weakness, cardiac abnormalities, edema |
| *Sulfur* (S) | Widely distributed; abundant in skin, hair, and nails | Essential part of certain amino acids, thiamine, insulin, biotin, and mucopolysaccharides | Meats, milk, eggs, legumes<br>No RDA established | None known | None known |
| *Sodium* (Na) | Widely distributed; mostly in extracellular fluids and bound to inorganic salts of bone | Helps maintain osmotic pressure of extracellular fluids; regulates water movement; plays a role in impulse conduction in neurons; regulates pH and transport of substances across cell membranes | Table salt, cured ham, sauerkraut, cheese, graham crackers<br>2,500 mg | Hypertension, edema, body cells shrink | Nausea, cramps, convulsions |
| *Chlorine* (Cl) | Closely associated with sodium; most highly concentrated in cerebrospinal fluid and gastric juice | Helps maintain osmotic pressure of extracellular fluids, regulates pH; maintains electrolyte balance; forms hydrochloric acid; aids transport of carbon dioxide by red blood cells | Same as for sodium<br>No RDA established | Vomiting | Cramps |
| *Magnesium* (Mg) | Abundant in bones | Required in metabolic reactions in mitochondria that produce ATP; plays a role in the breakdown of ATP to ADP | Milk, dairy products, legumes, nuts, leafy green vegetables<br>300–350 mg | Diarrhea | Neuromuscular disturbances |

*RDA = recommended daily allowance.

**PRACTICE**

**51** Where are chloride ions most highly concentrated in the body?

**52** What are the functions of magnesium?

## Trace Elements

**Trace elements** (microminerals) are essential minerals found in minute amounts, each making up less than 0.005% of adult body weight. They include iron, manganese, copper, iodine, cobalt, zinc, fluorine, selenium, and chromium.

**Iron (Fe)** is most abundant in the blood, but is stored in the liver, spleen, and bone marrow and is found to some extent in all cells. Iron enables *hemoglobin* molecules in red blood cells to carry oxygen (fig. 18.19). Iron is also part of *myoglobin,* which stores oxygen in muscle cells. In addition, iron assists in vitamin A synthesis, is incorporated into a number of enzymes, and is included in the cytochrome molecules that participate in ATP-generating reactions.

An adult male requires from 0.7 to 1 mg of iron daily, and a female needs 1.2 to 2 mg. A typical diet supplies about 10 to 18 mg of iron each day, but only 2% to 10% of the iron is absorbed. For some people, this may not be enough iron. Eating foods rich in vitamin C along with iron-containing foods can increase absorption of this important mineral.

Liver is the only rich source of dietary iron, and because liver is not a popular food, iron is one of the more difficult nutrients to obtain from natural sources in adequate amounts. Foods that contain some iron include lean meats; dried apricots, raisins, and prunes; enriched whole-grain cereals; legumes; and molasses.

Pregnant women require extra iron to support the formation of a placenta and the growth and development of a fetus. Iron is required for the synthesis of hemoglobin in a fetus as well as in a pregnant woman, whose blood volume increases by a third.

**Manganese (Mn)** is most concentrated in the liver, kidneys, and pancreas. It is necessary for normal growth and development of skeletal structures and other connective tissues. Manganese is part of enzymes essential for the synthesis of fatty acids and cholesterol, for urea formation, and for the normal functions of the nervous system.

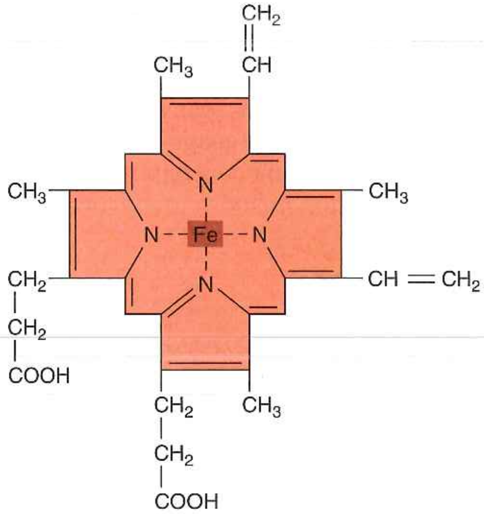
The daily requirement for manganese is 2.5–5 mg. The richest sources include nuts, legumes, and whole-grain cereals. Leafy green vegetables and fruits are good sources of manganese too.

**PRACTICE**

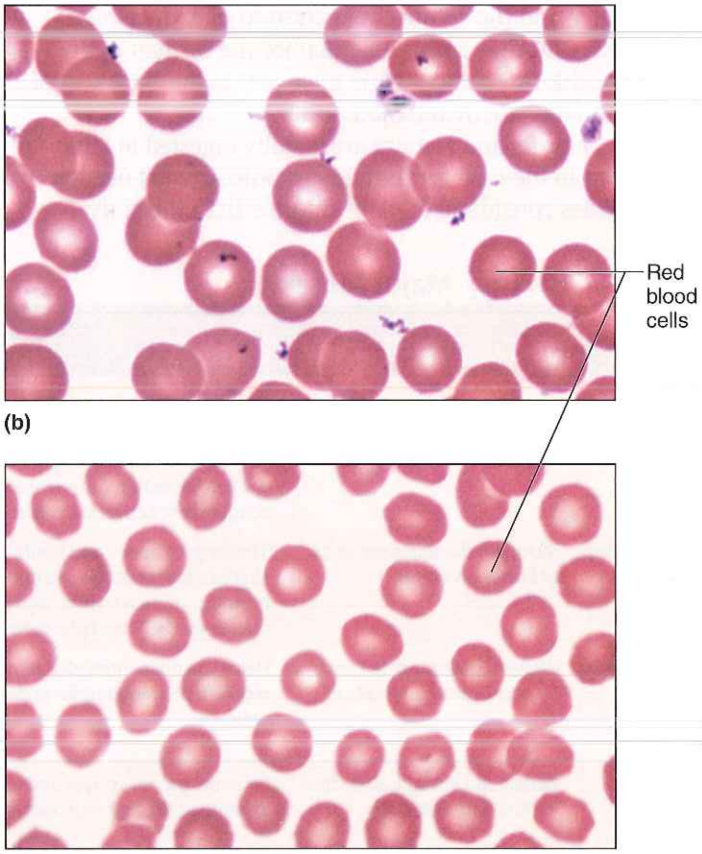
**53** What is the primary function of iron?

**54** How is manganese used?

**55** Which foods are good sources of manganese?



**(a)** Heme group



**(b)**

**(c)**

**FIGURE 18.19** Iron in hemoglobin. *(a)* A hemoglobin molecule contains four heme groups, each of which houses a single iron atom (Fe) that can combine with oxygen. The red blood cells in *(b)* are normal (1250×), but many of those in *(c)* are small and pale (1250×). They contain too little hemoglobin, which may be the result of a diet lacking in iron.

**Copper (Cu)** is in all body tissues but is most highly concentrated in the liver, heart, and brain. It is essential for hemoglobin synthesis, bone development, melanin production, and formation of myelin in the nervous system.

A daily intake of 2 mg of copper is sufficient to supply cells. A typical adult diet has about 2–5 mg of this mineral, so adults seldom develop copper deficiencies. Foods rich in copper include liver, oysters, crabmeat, nuts, whole-grain cereals, and legumes.

**Iodine (I)** is found in minute quantities in all tissues but is highly concentrated in the thyroid gland. Its only known function is as an essential component of thyroid hormones. (Fig. 13.20 on p. 505 shows the molecular structures of these hormones, thyroxine and triiodothyronine.)

A daily intake of 1 microgram (0.001 mg) of iodine per kilogram of body weight is adequate for most adults. The iodine content of foods varies with the iodine content of soils in different geographic regions. In many places, people use *iodized* table salt to season foods, which prevents iodine deficiency.

**Cobalt (Co)** is widely distributed in the body because it is an essential part of cyanocobalamin (vitamin $B_{12}$). It is also necessary for the synthesis of several important enzymes.

The amount of cobalt required in the daily diet is unknown. This mineral is found in a great variety of foods, and the quantity in the average diet is apparently sufficient. Good sources of cobalt include liver, lean meats, and milk.

**Zinc (Zn)** is most concentrated in the liver, kidneys, and brain. It is part of many enzymes involved in digestion, respiration, and bone and liver metabolism. It is also necessary for normal wound healing and for maintaining the integrity of the skin.

The daily requirement for zinc is about 15 mg, and most diets provide 10–15 mg. Only some may be absorbed, so zinc deficiencies may occur. Meat provides the most zinc. Cereals, legumes, nuts, and vegetables provide lesser amounts.

**Fluorine (F)**, as part of the compound fluoroapatite, replaces hydroxyapatite in teeth, strengthening the enamel and preventing dental caries. **Selenium (Se)** is stored in the liver and kidneys. It is a constituent of certain enzymes and participates in heart function. This mineral is found in lean meats, whole-grain cereals, and onions. **Chromium (Cr)** is widely distributed throughout the body and regulates glucose use. It is found in liver, lean meats, yeast, and pork kidneys. Table 18.11 summarizes the characteristics of trace elements.

## TABLE 18.11 | Trace Elements

| Trace Element | Distribution | Functions | Sources and RDA* for Adults | Conditions Associated with | |
|---|---|---|---|---|---|
| | | | | Excesses | Deficiencies |
| *Iron* (Fe) | Primarily in blood; stored in liver, spleen, and bone marrow | Part of hemoglobin molecule; catalyzes formation of vitamin A; incorporated into a number of enzymes | Liver, lean meats, dried apricots, raisins, enriched whole-grain cereals, legumes, molasses<br>10–18 mg | Liver damage | Anemia |
| *Manganese* (Mn) | Most concentrated in liver, kidneys, and pancreas | Activates enzymes required for fatty acids and cholesterol synthesis, urea formation, and normal functioning of the nervous system | Nuts, legumes, whole-grain cereals, leafy green vegetables, fruits<br>2.5–5 mg | None known | None known |
| *Copper* (Cu) | Most highly concentrated in liver, heart, and brain | Essential for hemoglobin synthesis, bone development, melanin production, and myelin formation | Liver, oysters, crabmeat, nuts, whole-grain cereals, legumes<br>2–3 mg | Rare | Rare |
| *Iodine* (I) | Concentrated in thyroid gland | Essential component for synthesis of thyroid hormones | Food content varies with soil content in different geographic regions; iodized table salt<br>0.15 mg | Autoimmune thyroid disease | Decreased synthesis of thyroid hormones |
| *Cobalt* (Co) | Widely distributed | Component of cyanocobalamin; required for synthesis of several enzymes | Liver, lean meats, milk<br>No RDA established | Heart disease | Pernicious anemia |
| *Zinc* (Zn) | Most concentrated in liver, kidneys, and brain | Component of enzymes involved in digestion, respiration, bone metabolism, liver metabolism; necessary for normal wound healing and maintaining integrity of the skin | Meats, cereals, legumes, nuts, vegetables<br>15 mg | Slurred speech, problems walking | Depressed immunity, loss of taste and smell, learning difficulties |
| *Fluorine* (F) | Primarily in bones and teeth | Component of tooth structure | Fluoridated water<br>1.5–4 mg | Mottled teeth | None known |
| *Selenium* (Se) | Concentrated in liver and kidneys | Component of certain enzymes | Lean meats, fish, cereals<br>0.05–2 mg | Vomiting, fatigue | None known |
| *Chromium* (Cr) | Widely distributed | Essential for use of carbohydrates | Liver, lean meats, wine<br>0.05–2 mg | None known | None known |

RDA = recommended daily allowance.

# 18.2 CLINICAL APPLICATION

## Dietary Supplements—Proceed with Caution

Displayed prominently among the standard vitamin and mineral preparations in the pharmacy or health food store is a dizzying collection of products (fig. 18B). Some obviously come from organisms (bee pollen and shark cartilage), some have chemical names (glucosamine with chondroitin; see the chapter 8 opening vignette on p. 270), and some names are historical or cultural (St. John's Wort). These "dietary supplements" are classified as neither food nor drug, but despite regulatory language, they may contain active compounds that function as pharmaceuticals in the human body.

By law dietary supplements include: "a product (other than tobacco) that is intended to supplement the diet that bears or contains one or more of the following dietary ingredients: a vitamin, a mineral, an herb or other botanical, an amino acid, a dietary substance for use by man to supplement the diet by increasing the total daily intake, or a concentrate, metabolite, constituent, extract, or combinations of these ingredients."

Labels cannot claim that a dietary supplement diagnoses, prevents, mitigates, treats, or cures any specific disease. Instead, the language is positive and guarded, as in claims that valerian root "promotes restful sleep" and that echinacea and goldenseal "may help support the immune system." The U.S. Food and Drug Administration allows only certain specific food and health claims that are supported by evidence. These include:

- Dietary calcium decreases the risk of osteoporosis (see the chapter 7 opening vignette on p. 202).
- A low-fat diet lowers the risk of some cancers.
- A diet low in saturated fat and cholesterol lowers the risk of coronary heart disease.
- Fruits and vegetables reduce the risk of cancers and heart disease.
- Lowering sodium intake lowers blood pressure.
- Folic acid lowers the risk of neural tube defects.

Taking dietary supplements may be dangerous, because their active ingredients may interact with certain drugs. For example, the active ingredient in St. John's Wort, hypericin, lowers blood levels of nearly half of all prescription drugs by interfering with liver enzymes that metabolize those drugs. Some patients have experienced intracranial hemorrhage after taking ginkgo biloba, a tree extract reported to enhance memory. Always tell a health-care provider if you are taking a dietary supplement.

Certain dietary supplements are of dubious value. For example, the marketing of shark cartilage followed initial studies that suggested sharks do not get cancer. Sharks have cartilaginous skeletons, so the idea arose that their cartilage protects against cancer. Sharks indeed get cancer, and their cartilage has no magical properties. Similarly, pyruvic acid and ATP are sold in health-food stores to boost energy levels. However, these biochemicals are abundant in the cellular respiration pathways. Some stores sell DNA, in a form that is merely expensive brewer's yeast, and the supplement is unnecessary because any food consisting of cells is packed with DNA. The list of supplements with little scientific evidence of value is long. ■

**FIGURE 18B** Some dietary supplements are natural substances that function as drugs in the human body.

The term "dietary supplement" traditionally refers to minerals, vitamins, carbohydrates, proteins, and fats—the micronutrients and macronutrients. Clinical Application 18.2 discusses the more commercial meaning of "dietary supplement."

### PRACTICE

**56** How is copper used?

**57** What is the function of iodine?

**58** Why might zinc deficiencies be common?

A compulsive disorder that may result from mineral deficiency is *pica,* in which people consume large amounts of nondietary substances such as ice chips, soil, sand, laundry starch, clay and plaster, and even hair, toilet paper, matchheads, inner tubes, mothballs, and charcoal. The condition is named for the magpie bird, *Pica pica,* which eats a range of odd things.

Pica affects people of all cultures and was noted as early as 40 B.C. The connection to dietary deficiency stems from the observation that slaves suffering from pica in the colonial United States recovered when their diets improved, particularly when given iron supplements. Another clue comes from a variation of pica called geophagy—"eating dirt"—that affects many types of animals, including humans. Researchers discovered that when parrots eat a certain claylike soil in their native Peru, soil particles bind alkaloid toxins in their seed food and carry the toxins out of the body. Perhaps pica in humans is protective in some way, too.

## 18.9 HEALTHY EATING

An *adequate diet* provides sufficient energy (calories), essential fatty acids, essential amino acids, vitamins, and minerals to support optimal growth and to maintain and repair body tissues. Because individual nutrient requirements vary greatly with age, sex, growth rate, level of physical activity, and stress, as well as with genetic and environmental factors, it is not possible to design a diet adequate for everyone. However, nutrients are so widely found in foods that consuming satisfactory amounts and combinations is usually possible despite individual food preferences, assuming that foods are available.

It is difficult to track the different nutrients in a diet and be certain that an adequate amount of each is consumed daily. Nutritionists have devised several ways to help consumers make healthy food choices, recognizing that people can meet dietary requirements in many and diverse ways. Most familiar is the RDA guideline that has appeared on several tables in the chapter. *RDA* stands for United States Recommended Daily Allowance. An RDA is the upper limit of another measurement, the Recommended Dietary Allowance, which lists optimal calorie intake for each sex at various ages, and the amounts of vitamins and minerals needed to avoid deficiency or excess conditions. The RDA values on food packages are set high, ensuring that most people who follow them receive sufficient amounts of each nutrient. Government panels meet every five years to evaluate the RDAs in light of new data.

Placing foods into groups is a simpler way to follow a healthy diet. For years, diagrams called *food pyramids* organized foods according to suggested proportions in the diet, often in serving sizes. One food pyramid developed by the United States Department of Agriculture (USDA) dominated, but other pyramids offered more specific suggestions geared to age, health, ethnicity, food preferences such as vegetarianism, or weight loss goals. Past pyramids can seem strange in light of today's **My Plate** (developed by the USDA) replacement, depicted in figure 18.20. As discussed in this chapter's opening vignette, when making individual food choices, it helps to read and understand food labels. Clinical Application 18.3 discusses some ways that understanding nutrition can help athletic performance.

### PRACTICE

**59** What is an adequate diet?

**60** What factors influence individual needs for nutrients?

### Malnutrition

**Malnutrition** (mal″nu-trish′un) is poor nutrition that results from a lack of essential nutrients or an inability to utilize them. It may result from *undernutrition* and produce the symptoms of deficiency diseases, or it may be due to *overnutrition* arising from excess nutrient intake.

A variety of factors can lead to malnutrition. For example, a deficiency condition may stem from lack of availability or poor quality of food. On the other hand, malnutrition may result from overeating or taking too many vitamin supplements. Malnutrition from diet alone is called *primary malnutrition.*

*Secondary malnutrition* occurs when an individual's characteristics make a normally adequate diet insufficient. For example, a person who does not secrete enough bile salts is likely to develop a deficiency of fat-soluble vitamins, because bile salts promote absorption of fats. Severe and prolonged emotional stress may lead to secondary malnutrition, because stress can change hormonal concentrations in ways that break down amino acids or excrete nutrients, and affect appetite.

### Starvation

A healthy human can stay alive for fifty to seventy days without food. In prehistoric times, this margin allowed survival during seasonal famines. In some areas of Africa today, famine is not a seasonal event but a constant condition, and millions of people have starved to death. Starvation is also seen in hunger strikers, in prisoners of concentration camps, and in sufferers of psychological eating disorders such as *anorexia nervosa* and *bulimia.*

Whatever the cause, the starving human body begins to digest itself. After only one day without eating, the body's reserves of sugar and starch are gone. Next, the body extracts energy from fat and then from muscle protein. By the third day, hunger ceases as the body uses energy from fat reserves. Gradually, metabolism slows to conserve energy, blood pressure drops, the pulse slows, and chills set in. Skin becomes dry and hair falls out as the proteins in these structures are broken down to release amino acids used for the more vital

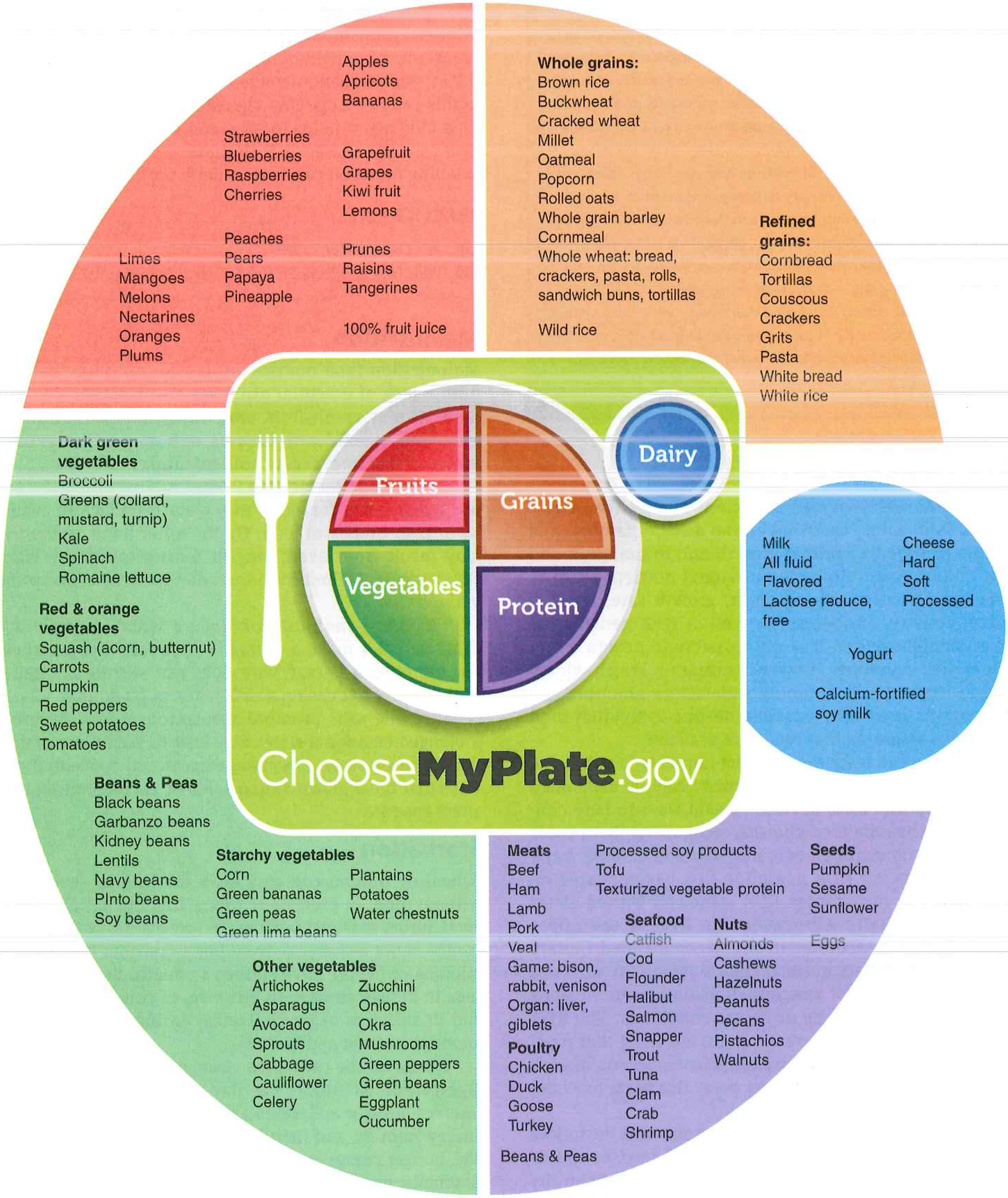


**FIGURE 18.20** My Plate, developed by the United States Department of Agriculture, depicts the foods and appropriate proportions that should make up a healthy diet.

## 18.3 CLINICAL APPLICATION

### Nutrition and the Athlete

An endurance athlete and a sedentary individual have different nutritional requirements. A diet that is 60% or more carbohydrate, 18% protein, and 22% fat supports a lifestyle that includes frequent, strenuous activity.

#### Macronutrients

Athletes should get the bulk of their carbohydrates from vegetables and grains to avoid cholesterol. They should eat frequently, because the muscles can store only 1,800 calories worth of glycogen.

Athletes need to consume only 25% more protein than less-active individuals. The American Dietetic Association suggests that athletes eat 1 gram of protein per kilogram of weight per day, compared to 0.8 gram for nonathletes. Athletes should not rely solely on meat for protein, because these foods can be high in fat. Protein supplements may be necessary for young athletes at the start of training, under a doctor's supervision. Too little protein in an athlete is linked to "sports anemia," in which hemoglobin levels decline and blood may appear in the urine.

#### Water

A sedentary person loses a quart of water a day as sweat; an athlete may lose 2 to 4 quarts of water an hour! To stay hydrated, athletes should drink 3 cups of cold water two hours before an event, then 2 more cups fifteen minutes before the event, and small amounts every fifteen minutes during the event. They should drink afterward too. Another way to determine water needs is to weigh in before and after training. For each pound lost, athletes should drink a pint of water. They should avoid alcohol, which increases fluid loss. However, athletes should also avoid drinking too much water during competition, which can cause hyponatremia (too little sodium in the bloodstream, see Clinical Applications 21.1 and 21.2, on pp. 808–809 and 811, respectively).

#### Vitamins and Minerals

If an athlete eats an adequate, balanced diet, vitamin supplements are not needed. Supplements of sodium and potassium are usually not needed either, because the active body naturally conserves these nutrients. To be certain of enough sodium, athletes may want to salt their food; to get enough potassium, they can eat bananas, dates, apricots, oranges, or raisins.

A healthy pregame meal should be eaten two to five hours before the game, provide 500 to 1,500 calories, and include 4 or 5 cups of fluid. It should also be high in carbohydrates, which taste good, provide energy, and are easy to digest.

#### Creatine

Creatine is advertised to increase energy stores and provide a safe alternative to steroids for bulking up muscles. This is deceptive.

Creatine may be obtained from foods, through supplements, or by synthesis from the amino acids arginine, glycine, and methionine. Creatine, in the form of creatine phosphate, provides energy to muscle cells by phosphorylating ADP to generate ATP. Creatine is converted to its metabolite, creatinine, at such a constant rate that the excretion of creatinine in the urine is used as a marker for normal kidney function.

Do creatine supplements enhance performance? The emerging picture suggests that during peak exertion, especially repetitive peak exertion (such as multiple sprints), conditions in which creatine levels may become depleted, supplemental creatine may be advantageous. Muscle mass may appear to increase in athletes taking creatine supplements because creatine draws water into muscle cells by osmosis. However, the disturbance in water distribution that creatine supplementation can cause may create problems if the athlete encounters extreme heat—sweating becomes inadequate to effectively cool the body. Swelled muscle cells may burst, causing a potentially fatal condition called rhabdomyolysis. The Food and Drug Administration has received many adverse event reports of muscle cramps, seizures, diarrhea, loss of appetite, muscle strains, dehydration and even deaths, associated with creatine use among athletes. ■

functioning of the brain, heart, and lungs. When the immune system's antibody proteins are dismantled for their amino acids, protection against infection declines. Mouth sores and anemia develop, the heart beats irregularly, and bone begins to degenerate. After several weeks without food, coordination is gradually lost. Near the end, the starving human is blind, deaf, and emaciated.

### Marasmus and Kwashiorkor

Lack of nutrients is called **marasmus** (mah-raz′mus), and it causes people to lose so much weight that they resemble living skeletons (fig. 18.21*a*). It is common for children under the age of two with marasmus to die of measles or other infectious diseases as their immune systems become too weakened to fight off normally mild viral illnesses.

Some starving children have protruding bellies. These youngsters suffer from a form of protein starvation called **kwashiorkor** (kwash″-e-or′kor), which in the language of Ghana means "the evil spirit which infects the first child when the second child is born" (fig. 18.21*b*). Kwashiorkor typically appears in a child who has recently been weaned from the breast, usually because of the birth of a sibling. The switch from protein-rich breast milk to the protein-poor gruel that is the staple of many developing nations is the source of this protein deficiency. The children's bellies swell with filtered fluid, which is lost from capillaries in excess due to a lack of plasma proteins. This swelling is called **ascites** (ah-si′tēz). The skin of children with kwashiorkor may develop lesions. Infections overwhelm the body as the immune system becomes depleted of its protective antibodies.

### Anorexia Nervosa

**Anorexia nervosa** (an″o-rek′se-ah ner′vo-sah) is self-imposed starvation. The condition is reported to affect 1 out of 250 adolescents, most of them female, although the true number among males is not known and may be higher than has been thought. The sufferer, typically a


(a)
(b)

**FIGURE 18.21** Two types of starvation in the young. (*a*) This child, suffering from marasmus, did not have adequate nutrition as an infant. (*b*) This child suffers from kwashiorkor. Although he may have received adequate nourishment from breast milk early in life, he became malnourished when his diet switched to a watery, white extract from cassava that looks like milk but has very little protein. The lack of protein in the diet causes edema and the ascites that swells his belly.

well-behaved adolescent girl from an affluent family, perceives herself to be overweight and eats barely enough to survive (fig. 18.22). She is terrified of gaining weight and usually loses 25% of her original body weight. In addition to eating only small amounts of low-calorie foods, she further loses weight by vomiting, taking laxatives and diuretics, or exercising intensely. Her eating behavior is often ritualized. She may meticulously arrange her meager meal on her plate or consume only a few foods. She develops low blood pressure, a slowed or irregular heartbeat, constipation, and constant chilliness. She stops menstruating as her body fat level plunges. Like any starving person, the hair becomes brittle and the skin dries out. To conserve body heat, she may develop soft, pale, fine body hair called *lanugo,* normally seen only on a fetus.

When the person with anorexia reaches an obviously emaciated state, her parents usually have her hospitalized, where she is fed intravenously so that she does not starve to death or die suddenly of heart failure due to an electrolyte imbalance. She also receives psychotherapy and nutritional counseling. Despite these efforts, 15% to 21% of people with anorexia die.

What causes anorexia nervosa is unknown. One hypothesis is that the person is rebelling against approaching womanhood. Indeed, her body is astonishingly childlike, and she has often ceased to menstruate. She typically has low self esteem and believes that others, particularly her parents, are controlling her life. Her weight is something that she can control. Genetics and chemical imbalances in the brain may also elevate the risk of developing anorexia. Cases of anorexia nervosa are increasing in the elderly, possibly as a result of diminished smell and taste sensations, as well as difficulties chewing and swallowing. This eating disorder can be a onetime, short-term experience or a lifelong obsession.

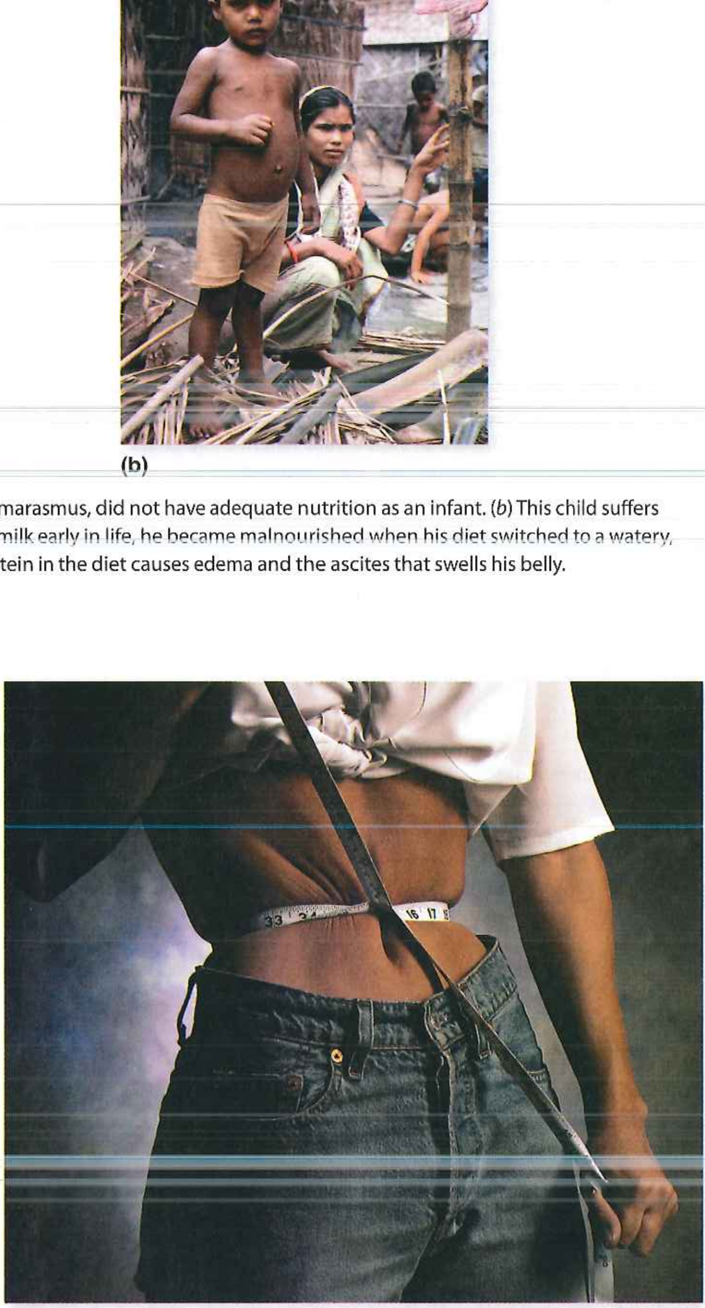


**FIGURE 18.22** Perceiving herself overweight, this young woman is tying the measuring tape extraordinarily tight around her waist to have a waist measurement as small as possible.

### Bulimia

A person suffering from **bulimia** (bu-lim'e-ah) is often of normal weight. She eats whatever she wants, often in huge amounts, but she then rids her body of the thousands of extra calories by vomiting, taking laxatives, or exercising frantically. For an estimated one in five college students, the majority of them female, "bingeing and purging" appears to be a way of coping with stress.

A dentist, who can observe the tooth decay caused by frequent vomiting, may be the first to spot bulimia. The backs of the hands of a person with bulimia may bear telltale scratches from efforts to induce vomiting. In addition, the throat is raw and the esophageal lining ulcerated from the stomach acid forced forward by vomiting. The binge and purge cycle is hard to break, even with psychotherapy and nutritional counseling.

Underweight and overweight are socioeconomic as well as physiological problems. A phenomenon called a "dual-burden household" affects nations that have recently transitioned from developing status to having an emerging economy. The problem is that in poor countries, the poorest people lack food and toil at physically taxing jobs, and so are severely underweight. But as the economy improves, poor people who find jobs in newly urbanized areas begin to eat the cheapest, least nutritious food, and sometimes too much of it. Office jobs rather than working in fields, and wider availability of television, promote a sedentary lifestyle. The result: weight gain. At the same time, underweight in children under five is increasing in urban areas of countries whose socioeconomic status is changing, according to the World Bank. This may reflect lack of home-grown foods, previously a major dietary staple, as both parents work in nonagricultural jobs.

**PRACTICE**

**61** What is primary malnutrition? Secondary malnutrition?

**62** What happens to the body during starvation?

**63** How do marasmus and kwashiorkor differ?

**64** How do anorexia nervosa and bulimia differ?

## 18.10 LIFE-SPAN CHANGES

Dietary requirements remain generally the same throughout life, but the ability to acquire nutrients may change. The basal metabolic rate (BMR) changes with age. It rises from birth to about age five and then declines until adolescence, when it peaks again. During adulthood, the BMR drops in parallel to decreasing activity levels and shrinking muscle mass. In women, it may spike during pregnancy and breastfeeding, when caloric requirements likewise increase. Table 18.12 shows changes in energy requirements for adults who are healthy and engage in regular, light exercise.

**TABLE 18.12** | Energy Requirements Decline with Age

| | CAL/DAY | |
|---|---|---|
| Age | Female | Male |
| 23–50 | 2,000 | 2,700 |
| 51–74 | 1,800 | 2,400 |
| 75+ | 1,600 | 2,050 |

People of all ages gain weight when energy intake exceeds energy output, and lose weight when energy output exceeds energy intake. Age fifty seems to be a key point in energy balance. Before this age, most adults have a positive energy balance and maintain a constant weight, but after fifty their weight may creep up. However, being aware of a decrease in activity and curbing food consumption enables many people over the age of fifty to maintain their weight.

Changing nutrition with age often reflects effects of medical conditions, many of which are more common among older people, and social and economic circumstances. Medications can dampen appetite directly through side effects such as nausea or altered taste perception or affect a person's mood in a way that prevents eating. Poverty may take a greater nutritional toll on older people who either cannot get out to obtain food or who give whatever is available to younger people.

Medical conditions that affect the ability to obtain adequate nutrition include depression, tooth decay and periodontal disease, diabetes mellitus, lactose intolerance, and alcoholism. These conditions may lead to deficiencies that are not immediately obvious. Vitamin A deficiency, for example, may take months or years to become noticeable because the liver stores this fat-soluble vitamin. Calcium depletion may not produce symptoms, even as the mineral is taken from bones. The earliest symptom of malnutrition, fatigue, may easily be attributed to other conditions or ignored.

Evidence for vitamin D deficiency related to sun avoidance has a long history. The link between lack of sunlight and development of rickets was noted in 1822, and a century later, researchers realized that sun exposure helps reverse the disease in children. Other evidence comes from diverse sources, such as women who wear veils and naval personnel serving three-month tours of duty on submarines.

It is important to obtain a good balance of nutrients and enough energy throughout life. Many studies link caloric restriction to increased longevity in species such as mice and fruit flies. However, these observations cannot be extrapolated to humans because the experimental laboratory animals were kept extremely healthy. Human starvation is usually the consequence of many other problems and is more likely to lead to malnutrition than increased longevity.

**PRACTICE**

**65** List factors that affect nutrient acquisition as people age.

# CHAPTER SUMMARY

## 18.1 INTRODUCTION (PAGE 695)

Nutrients include carbohydrates, lipids, and proteins, which are required in large amounts and are called macronutrients, and the vitamins and minerals, required in lesser amounts and called micronutrients. Essential nutrients are required for health, and body cells cannot synthesize them.

## 18.2 APPETITE CONTROL (PAGE 696)

1. Metabolism is the body's use of nutrients in various ways to support life processes.
2. Appetite is the drive that compels us to eat. Food powers the activities of life.
3. Hormones control appetite by affecting the arcuate nucleus, a part of the hypothalamus.
4. Leptin, neuropeptide Y, and ghrelin are hormones that affect appetite.

## 18.3 CARBOHYDRATES (PAGE 697)

Carbohydrates are organic compounds primarily used to supply cellular energy.

1. Carbohydrate sources
    a. Carbohydrates are ingested in a variety of forms.
    b. Polysaccharides, disaccharides, and monosaccharides are carbohydrates.
    c. Cellulose is a polysaccharide that human enzymes cannot digest, but it provides bulk that facilitates movement of intestinal contents.
2. Carbohydrate use
    a. Carbohydrates are absorbed as monosaccharides.
    b. Enzymes in the liver catalyze reactions that convert fructose and galactose into glucose.
    c. Oxidation releases energy from glucose.
    d. Excess glucose is stored as glycogen or combined to produce fat.
3. Carbohydrate requirements
    a. Most carbohydrates supply energy; some are used to produce sugars (ribose, deoxyribose, lactose).
    b. Some cells, such as neurons, require a continuous supply of glucose to survive.
    c. If glucose is scarce, amino acids may react to produce glucose.
    d. Humans survive with a wide range of carbohydrate intakes.
    e. Poor nutritional status is usually related to low intake of nutrients other than carbohydrates.

## 18.4 LIPIDS (PAGE 698)

Lipids are organic compounds that supply energy and are used to build cell structures. They include fats, phospholipids, and cholesterol.

1. Lipid sources
    a. Triglycerides are obtained from foods of plant and animal origins.
    b. Cholesterol is mostly obtained in foods of animal origin.
2. Lipid use
    a. Before fats can be used as an energy source, they must be broken down into glycerol and fatty acids.
    b. Beta oxidation decomposes fatty acids.
        (1) Beta oxidation activates fatty acids and breaks them down into segments of two carbon atoms each.
        (2) Fatty acid segments are converted into acetyl coenzyme A, which can then be oxidized in the citric acid cycle.
    c. The liver and adipose tissue control triglyceride metabolism.
    d. Liver enzymes can alter the molecular structures of fatty acids.
    e. Linoleic acid and linolenic acid are essential fatty acids.
    f. The liver regulates cholesterol level by synthesizing or excreting it.
3. Lipid requirements
    a. Humans survive with a wide range of lipid intakes.
    b. The amounts and types of lipids needed for health are unknown.
    c. Fat intake must be sufficient to support absorption and transport of fat-soluble vitamins.

## 18.5 PROTEINS (PAGE 700)

Proteins are broken down in digestion. The resulting amino acids can be used to form new protein molecules such as enzymes, clotting factors, keratin, elastin, collagen, actin, myosin, hormones, and antibodies, or can be used as energy sources. Before amino acids can be used as energy sources, they must be deaminated, forming the waste urea. During starvation, tissue proteins may be used as energy sources, causing the tissues to waste away.

1. Protein sources
    a. Proteins are mainly obtained from meats, dairy products, cereals, and legumes.
    b. Eight amino acids are essential for adults, whereas ten are essential for growing children.
    c. All essential amino acids must be present at the same time for growth and repair of tissues to take place.
    d. Complete proteins contain adequate amounts of all the essential amino acids needed to maintain the tissues and promote growth.
    e. Incomplete proteins lack adequate amounts of one or more essential amino acids.
2. Nitrogen balance
    a. In healthy adults, the gain of protein equals the loss of protein, and a nitrogen balance exists.
    b. A starving person has a negative nitrogen balance; a growing child, a pregnant woman, or an athlete in training usually has a positive nitrogen balance.
3. Protein requirements
    a. Proteins and amino acids are needed to supply essential amino acids and nitrogen for the synthesis of nitrogen-containing molecules.
    b. The consequences of protein deficiencies are particularly severe among growing children.

## 18.6 ENERGY EXPENDITURES (PAGE 702)

Energy is of prime importance to survival and may be obtained from carbohydrates, fats, or proteins.

1. Energy values of foods
    a. The potential energy values of foods are expressed in calories.
    b. When energy losses due to incomplete absorption and incomplete oxidation are taken into account, 1 gram of carbohydrate or 1 gram of protein yields about 4 calories, whereas 1 gram of fat yields about 9 calories.
2. Energy requirements
    a. The amount of energy required varies from person to person.
    b. Factors that influence energy requirements include basal metabolic rate, muscular activity, body temperature, and nitrogen balance.
3. Energy balance
    a. Energy balance exists when caloric intake equals caloric output.
    b. If energy balance is positive, body weight increases; if energy balance is negative, body weight decreases.
4. Desirable weight
    a. The most common nutritional disorders involve caloric imbalances.
    b. Average weights of persons 25–30 years of age are desirable for older persons as well.
    c. Body mass index assesses weight taking height into account.
    d. A BMI between 25 and 30 indicates overweight, and above 30, obesity.

## 18.7 VITAMINS (PAGE 706)

Vitamins are organic compounds (other than carbohydrates, lipids, and proteins), that cannot be synthesized by body cells in adequate amounts and are essential for normal metabolic processes.

1. Fat-soluble vitamins
    a. General characteristics
        (1) Fat-soluble vitamins are carried in lipids and are influenced by the same factors that affect lipid absorption.
        (2) They resist the effects of heat; thus, they are not destroyed by cooking or food processing.
    b. Vitamin A
        (1) Vitamin A exists in several forms, is synthesized from carotenes, and is stored in the liver.
        (2) It is an antioxidant required for production of visual pigments.
    c. Vitamin D
        (1) Vitamin D is a group of related steroids.
        (2) It is found in certain foods and is produced commercially; it can also be synthesized in the skin.
        (3) When needed, vitamin D is converted by the kidneys to an active form that functions as a hormone and promotes the intestine's absorption of calcium and phosphorus.
    d. Vitamin E
        (1) Vitamin E is an antioxidant.
        (2) It is stored in muscles and adipose tissue.
        (3) It prevents breakdown of polyunsaturated fatty acids and stabilizes cell membranes.
    e. Vitamin K
        (1) Vitamin K is in foods and is produced by intestinal bacteria.
        (2) Some vitamin K is stored in the liver.
        (3) It is used to produce prothrombin, required for blood clotting.
2. Water-soluble vitamins
    a. General characteristics
        (1) Water-soluble vitamins include the B vitamins and vitamin C.
        (2) Cooking or processing food destroys some water-soluble vitamins.
        (3) B vitamins make up a group called the vitamin B complex and oxidize carbohydrates, lipids, and proteins.
    b. Vitamin B complex
        (1) Thiamine (vitamin $B_1$)
            (a) Thiamine functions as part of coenzymes that oxidize carbohydrates and synthesize essential sugars.
            (b) Small amounts are stored in the tissues; excess is excreted in the urine.
            (c) Quantities needed vary with caloric intake.
        (2) Riboflavin (vitamin $B_2$)
            (a) Riboflavin functions as part of several enzymes and coenzymes essential to the oxidation of glucose and fatty acids.
            (b) Its absorption is regulated by an active transport system; excess is excreted in the urine.
            (c) Quantities required vary with caloric intake.
        (3) Niacin (vitamin $B_3$ or nicotinic acid)
            (a) Niacin functions as part of coenzymes required for the oxidation of glucose and for the synthesis of proteins and fats.
            (b) It can be synthesized from tryptophan; daily requirement varies with the tryptophan intake.
        (4) Pantothenic acid (vitamin $B_5$)
            (a) Pantothenic acid functions as part of coenzyme A; thus, it is essential for energy-releasing mechanisms.
            (b) Most diets provide sufficient amounts; deficiencies are rare.
        (5) Vitamin $B_6$
            (a) Vitamin $B_6$ is a group of compounds that function as coenzymes in metabolic pathways that synthesize proteins, certain amino acids, antibodies, and nucleic acids.
            (b) Its requirement varies with protein intake.
        (6) Biotin (vitamin $B_7$)
            (a) Biotin is a coenzyme required for the metabolism of amino acids and fatty acids, and for nucleic acid synthesis.
            (b) It is stored in metabolically active organs, including the brain, liver, and kidneys.
        (7) Folacin (vitamin $B_9$ or folic acid)
            (a) Liver enzymes catalyze reactions that convert folacin to physiologically active folinic acid.
            (b) It is a coenzyme needed for the metabolism of certain amino acids, DNA synthesis, and the normal production of red blood cells.

- (8) Cyanocobalamin (vitamin $B_{12}$)
    - (a) The cyanocobalamin molecule contains cobalt.
    - (b) Its absorption is regulated by the secretion of intrinsic factor from the gastric glands.
    - (c) It functions as part of coenzymes needed for nucleic acid synthesis and for the metabolism of carbohydrates and fats.
    - (d) It is important to erythrocyte production and myelin formation in the central nervous system.

c. Ascorbic acid (vitamin C)
  - (1) Vitamin C is similar chemically to monosaccharides.
  - (2) It is required for collagen production, the metabolism of certain amino acids, and iron absorption.
  - (3) It is not stored in large amounts; excess is excreted in the urine.

## 18.8 MINERALS (PAGE 713)

1. Characteristics of minerals
   - a. Minerals account for about 4% of body weight.
   - b. Minerals are usually incorporated into organic molecules, although some are in inorganic compounds or are free ions.
   - c. They compose structural materials, function in enzymes, and play vital roles in various metabolic processes.
   - d. Homeostatic mechanisms regulate mineral concentrations.
   - e. The physiologically active form of minerals is the ionized form.
2. Major minerals
   - a. Calcium
     - (1) Calcium is essential for forming bones and teeth, neurotransmitter release, contracting muscle fibers, the cardiac action potential, clotting blood, and activating various enzymes.
     - (2) Existing calcium concentration, vitamin D, protein intake, and motility of the digestive tract affect calcium absorption.
   - b. Phosphorus
     - (1) Phosphorus is incorporated into the salts of bones and teeth.
     - (2) It participates in nearly all metabolic reactions as a constituent of nucleic acids, proteins, and some vitamins.
     - (3) It also is in the phospholipids of cell membranes, in ATP, and in phosphates of body fluids.
   - c. Potassium
     - (1) Potassium is concentrated inside cells.
     - (2) It maintains osmotic pressure, regulates pH, and plays a role in impulse conduction in neurons.
   - d. Sulfur
     - (1) Sulfur is incorporated into two of the twenty amino acids.
     - (2) It is also in thiamine, insulin, biotin, and mucopolysaccharides.
   - e. Sodium
     - (1) Most sodium is in extracellular fluids or is bound to the inorganic salts of bone.
     - (2) The kidneys, under the influence of aldosterone, regulate the blood concentration of sodium.
     - (3) Sodium helps maintain solute concentration and regulates water balance.
     - (4) It is essential for impulse conduction in neurons and moving substances through cell membranes.
   - f. Chlorine
     - (1) Chlorine is closely associated with sodium as chloride ions.
     - (2) It acts with sodium to help maintain osmotic pressure, regulate pH, and maintain electrolyte balance.
     - (3) Chlorine is essential for hydrochloric acid formation and for carbon dioxide transport by red blood cells.
   - g. Magnesium
     - (1) Magnesium is abundant in the bones as phosphates and carbonates.
     - (2) It functions in ATP production and in the breakdown of ATP to ADP.
     - (3) A reserve supply of magnesium is stored in the bones; excesses are excreted in the urine.
3. Trace elements
   - a. Iron
     - (1) Iron is part of hemoglobin in red blood cells and myoglobin in muscles.
     - (2) A reserve supply of iron is stored in the liver, spleen, and bone marrow.
     - (3) It is required to catalyze vitamin A formation; it is also incorporated into various enzymes and the cytochrome molecules.
   - b. Manganese
     - (1) Most manganese is concentrated in the liver, kidneys, and pancreas.
     - (2) It is necessary for normal growth and development of skeletal structures and other connective tissues; it is essential for the synthesis of fatty acids, cholesterol, and urea.
   - c. Copper
     - (1) Most copper is concentrated in the liver, heart, and brain.
     - (2) It is required for hemoglobin synthesis, bone development, melanin production, and myelin formation.
   - d. Iodine
     - (1) Iodine is most highly concentrated in the thyroid gland.
     - (2) It is an essential component of thyroid hormones.
     - (3) It is often added to foods as iodized table salt.
   - e. Cobalt
     - (1) Cobalt is widely distributed throughout the body.
     - (2) It is an essential part of cyanocobalamin and is required for the synthesis of several enzymes.
   - f. Zinc
     - (1) Zinc is most concentrated in the liver, kidneys, and brain.
     - (2) It is a component of several enzymes that take part in digestion, respiration, and metabolism.
     - (3) It is necessary for normal wound healing.

g. Fluorine
    (1) The teeth concentrate fluorine.
    (2) It is incorporated into enamel and prevents dental caries.

h. Selenium
    (1) The liver and kidneys store selenium.
    (2) It is a component of certain enzymes.

i. Chromium
    (1) Chromium is widely distributed throughout the body.
    (2) It regulates glucose use.

## 18.9 HEALTHY EATING (PAGE 719)

1. An adequate diet provides sufficient energy and essential nutrients to support optimal growth, as well as maintenance and repair, of tissues.
2. Individual needs vary so greatly that it is not possible to design a diet adequate for everyone.
3. Devices to help consumers make healthy food choices include Recommended Daily Allowances, Recommended Dietary Allowances, food group plans such as "My Plate", and food labels.
4. Malnutrition
    a. Poor nutrition is due to lack of foods or failure to wisely use available foods.
    b. Primary malnutrition is due to poor diet.
    c. Secondary malnutrition is due to an individual characteristic that makes a normal diet inadequate.
5. Starvation
    a. A person can survive fifty to seventy days without food.
    b. A starving body digests itself, starting with carbohydrates, then fats, then proteins.
    c. Symptoms include low blood pressure, slow pulse, chills, dry skin, hair loss, and poor immunity. Finally, vital organs cease to function.
    d. Marasmus is lack of all nutrients.
    e. Kwashiorkor is protein starvation.
    f. Anorexia nervosa is a self-starvation eating disorder.
    g. Bulimia is an eating disorder characterized by bingeing and purging.

## 18.10 LIFE-SPAN CHANGES (PAGE 723)

1. Basal metabolic rate rises in early childhood, declines, then peaks again in adolescence, with decreasing activity during adulthood.
2. Weight gain, at any age, occurs when energy in exceeds energy out, and weight loss occurs when energy out exceeds energy in.
3. Changing nutrition with age reflects medical conditions and social and economic circumstances.

# CHAPTER ASSESSMENTS

### 18.1 Introduction

1 Define *nutrition.* (p. 695)
2 Contrast nutrients and essential nutrients. (p. 695)
3 Contrast macronutrients and micronutrients. (p. 695)

### 18.2 Appetite Control

4 Define *appetite.* (p. 696)
5 Identify the part of the brain where hormones act, controlling appetite. (p. 696)
6 Explain how leptin and ghrelin influence appetite. (p. 696)

### 18.3–18.5 Carbohydrates–Proteins

7 Identify dietary sources of carbohydrates. (p. 697)
8 Summarize the importance of cellulose in the diet. (p. 697)
9 Explain what happens to excess glucose in the body. (p. 697)
10 Explain why a temporary drop in blood glucose concentration may impair nervous system functioning. (p. 697)
11 List some factors that affect an individual's need for carbohydrates. (p. 697)
12 Identify dietary sources of lipids. (p. 698)
13 Define *beta oxidation.* (p. 698)
14 Explain how fats may provide energy. (p. 698)
15 Describe the liver's role in fat metabolism. (p. 699)
16 Review the major functions of cholesterol. (p. 699)
17 Define *deamination,* and explain its importance. (p. 700)
18 Identify dietary sources of proteins. (p. 701)
19 Distinguish between essential and nonessential amino acids. (p. 701)
20 Explain why all of the essential amino acids must be present for growth. (p. 701)
21 Distinguish between complete and incomplete proteins. (p. 701)
22 ____________________ is when the amount of nitrogen taken in is equal to the amount excreted. (p. 701)
23 Explain why a protein deficiency may accompany edema. (p. 702)

### 18.6 Energy Expenditures

24 Define *calorie.* (p. 702)
25 Explain how the caloric values of foods are determined. (p. 702)
26 Define *basal metabolic rate.* (p. 703)
27 List some of the factors that affect the BMR. (p. 703)
28 ____________________ exists when caloric intake in the form of foods equals caloric output from basal metabolic rate and muscular activities. (p. 704)
29 Distinguish among desirable weight, overweight, and obesity. (p. 704)

## 18.7 Vitamins

30 Match the vitamins with their general functions, and indicate if the vitamin is fat-soluble or water-soluble. Functions may be used more than once, and more than one function may be applied to a vitamin. (pp. 706–712)

(1) vitamin A
(2) vitamin $B_1$ (thiamine)
(3) vitamin $B_2$ (riboflavin)
(4) vitamin $B_3$ (niacin)
(5) vitamin $B_5$ (pantothenic acid)
(6) vitamin $B_6$
(7) vitamin $B_7$(biotin)
(8) vitamin $B_9$ (folacin)
(9) vitamin $B_{12}$ (cyanocobalamin)
(10) vitamin C (ascorbic acid)
(11) vitamin D
(12) vitamin E
(13) vitamin K

A. part of coenzyme A in oxidation of carbohydrates
B. required for ribose synthesis
C. necessary for synthesis of visual pigments
D. required for synthesis of prothrombin
E. required to produce collagen
F. required to synthesize nucleic acids
G. promotes red blood cell production
H. plays a role in myelin synthesis
I. antioxidant, helps stabilize cell membranes
J. promotes development of teeth and bones
K. required to produce antibodies
L. required for cellular reproduction
M. part of coenzymes to synthesize proteins, fats, and nucleic acids

## 18.8 Minerals

31 Match the minerals/elements with their functions, and indicate whether each is a major mineral or a trace element required for nutrition. Functions may be used more than once, and more than one function may be applied to a mineral or trace element. (pp. 713–717)

(1) calcium
(2) chlorine
(3) chromium
(4) cobalt
(5) copper
(6) fluorine
(7) iodine
(8) iron
(9) magnesium
(10) manganese
(11) phosphorus
(12) potassium
(13) selenium
(14) sodium
(15) sulfur
(16) zinc

A. essential for the use of carbohydrates
B. component of certain enzymes
C. component of tooth enamel
D. component of teeth and bones
E. helps maintain intracellular osmotic pressure
F. essential part of certain amino acids
G. helps maintain extracellular fluid osmotic pressure
H. necessary for normal wound healing
I. component of cyanocobalamin
J. essential for synthesis of thyroid hormones
K. required in metabolic reactions associated with ATP production
L. component of hemoglobin
M. essential for hemoglobin synthesis and melanin production
N. required for cholesterol synthesis and urea formation

## 18.9 Healthy Eating

32 Define *adequate diet.* (p. 719)
33 Explain various methods to eat an adequate diet. (p. 719)
34 Define *malnutrition.* (p. 719)
35 Contrast primary and secondary malnutrition. (p. 719)
36 Discuss bodily changes during starvation. (p. 719)
37 Distinguish among marasmus, kwashiorkor, anorexia nervosa, and bulimia. (p. 721)

## 18.10 Life-Span Changes

38 Factors that may lead to inadequate nutrition later in life include _________. (p. 723)

a. medical conditions
b. social circumstances
c. economic circumstances
d. medication
e. all of the above

39 Name some medical conditions that affect the ability to obtain adequate nutrition as a person ages. (p. 723)

## INTEGRATIVE ASSESSMENTS/CRITICAL THINKING

### OUTCOMES 4.5, 9.4, 18.3, 18.4, 18.5, 18.6, 18.9

1. Which of the diets described in the following chart would be most appropriate for an athlete training for a triathlon (biking, swimming, running event)? What is a problem with all of these diets for such a person?

| Diet | Total Calories/Day | % Fat | % Carbohydrate | % Protein |
|---|---|---|---|---|
| I | 1450 | 10–20 | 70 | 17 |
| II | 1450 | 25 | 60 | 15 |
| III | 1400 | 60 | 10 | 30 |

### OUTCOMES 4.5, 18.3, 18.4, 18.5, 18.6, 18.7

2. A young man takes several vitamin supplements each day, claiming that they give him energy. Is he correct? Why or why not?

### OUTCOMES 13.9, 18.2, 18.3, 18.4, 18.5

3. Why does the blood sugar concentration of a person whose diet is low in carbohydrates remain stable?

### OUTCOMES 18.2, 18.3, 18.4, 18.5

4. Using nutrient tables, calculate the number of grams of carbohydrate, lipid, and protein that you eat in a typical day, and the total calories in these foods. Suggest ways to improve your diet.

### OUTCOMES 18.2, 18.3, 18.4, 18.5, 18.6, 18.7, 18.8, 18.9, 18.10

5. How do you think the nutritional requirements of a healthy twelve-year-old boy, a twenty-four-year-old pregnant woman, and a healthy sixty-year-old man differ?

### OUTCOMES 18.3, 18.4, 18.5, 18.7, 18.8

6. Examine the label information on the packages of a variety of breakfast cereals. Which types of cereals provide the best sources of carbohydrates, lipids, proteins, vitamins, and minerals? Which major nutrients are lacking in these cereals?

### OUTCOME 18.5

7. If a person decided to avoid eating meat and other animal products, such as milk, cheese, and eggs, what foods might be included in the diet to provide essential amino acids?

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