9

Minerals

Learning Objectives

1. Classify minerals and describe their general roles.
2. Explain how mineral inadequacies and excesses can occur and why each might be detrimental to performance and health.
3. Explain how the Dietary Reference Intakes (DRI) and the Tolerable Upper Intake Levels (UL) should be interpreted.
4. Describe if, and how, exercise increases the need for or accelerates the loss of a particular mineral.
5. Compare and contrast the average intake of minerals by sedentary adults and athletes in the United States.
6. Explain the differences between a clinical and subclinical deficiency for calcium, iron, and zinc.
7. Discuss the minerals associated with bone formation, red blood cell production, and the immune system, and explain how low intake affects performance and health.
8. Compare and contrast minerals based on their source—naturally occurring in food, added to foods during processing, and found in supplements.
9. Evaluate the need for mineral supplements based on food intake and the safety and effectiveness of mineral supplements.

Pre-Test Assessing Current Knowledge of Minerals

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

1. The basic functions of minerals include building body tissues, regulating physiological processes, and providing energy.
2. In general, the body absorbs a high percentage of the minerals consumed.
3. In most cases, exercise does not increase mineral requirements above what is recommended for healthy, lightly active individuals.
4. If dietary calcium is inadequate over a long period of time, the body maintains its blood calcium concentration by reabsorbing skeletal calcium.
5. Iron-deficiency anemia has a negative impact on performance.

Vitamins and minerals are often mentioned in the same breath. While there are some similarities between these classes of nutrients, **minerals** differ from vitamins, especially water-soluble vitamins, in several ways. In chemistry, vitamins are described as organic, meaning they contain carbon in their structure. Minerals are inorganic, lacking carbon molecules. A single food may provide a substantial portion of the recommended daily intake for a vitamin, while minerals are generally found in proportionately smaller amounts even in foods considered to be excellent sources. For example, an 8-oz (240 ml) glass of orange juice provides approximately 100 mg of vitamin C, more than 100 percent of the Dietary Reference Intake (DRI) for males and nonpregnant females at any age. In contrast, an 8-oz glass of milk, considered to be an excellent source of calcium, provides approximately 300 mg of calcium, which is only 23 to 30 percent of what males or females need. Typically, water-soluble vitamins are well absorbed, crossing the mucosal cells of the gastrointestinal (GI) tract easily and being readily transported into the blood. Minerals are generally poorly or moderately absorbed and may be stranded in the cells lining the GI tract. Minerals also directly compete with each other for absorption while competition among vitamins is lower.

The margin of safety for potential adverse effects is smaller for most minerals than for most water-soluble vitamins. Once in the body, excess amounts of water-soluble vitamins are readily excreted via the urine; however, most minerals are not so easily removed. For most vitamins the Tolerable Upper Intake Level (UL) is many times higher than the DRI. For example, the UL for adults for vitamin C is 22 to 26 times higher than the DRI. In contrast, the UL for calcium is only 2 to 2.5 times higher.

In the case of two minerals, calcium and iron, there are medical tests that can help quantify the amount in the body. **Dual-energy X-ray absorptiometry (DEXA)** scans can estimate the density of bone, which is a large reservoir of body calcium, and a simple blood test can help determine if **anemia** due to iron deficiency is present. There are no imaging techniques that can determine vitamin stores and blood tests for most vitamins are not **clinically** meaningful.

Vitamins and minerals are found in a wide variety of foods. Both are added to foods and sold as dietary supplements, either singly or in combination with other nutrients. Both are essential to good health and performance, but there are more differences between vitamins and minerals than there are similarities. This chapter reviews information about minerals needed for the proper functioning of the skeletal, blood, and immune systems with an emphasis on studies conducted with athletes.

Classification of Minerals

Twenty-one minerals have been identified as essential as shown in Table 9.1. Minerals are often divided into two categories based on the amount found in the body. Those found in relatively large amounts (about 5 g in a 60-kg [132-lb] person) are termed macrominerals and include calcium, phosphorous, magnesium, sodium, potassium, chloride, and sulfur. Microminerals, also known as trace minerals, are found in comparatively smaller amounts in the body. These include well-known minerals, such as iron, as well as lesser-known ones, such as manganese and molybdenum.

Another classification method for minerals is based on function. Minerals critical to proper bone formation include calcium, phosphorus, magnesium, and fluoride. Several minerals are **electrolytes** and have either a positive or negative charge. Sodium, potassium, and chloride are prime examples of minerals that function as electrolytes and help to maintain body fluid balance. Iron is central to proper red blood cell formation. Many enzymes contain minerals such as zinc, selenium, or copper and some of these minerals are necessary for the proper functioning of the immune system.

Table 9.1 Minerals

Macrominerals	Microminerals (Trace Minerals)
Calcium	Iron
Phosphorous (phosphorus)	Zinc
Magnesium	Copper
Sodium	Fluorine (fluoride)
Potassium	Iodine
Chloride	Chromium
Sulfur	Selenium
	Manganese
	Molybdenum
	Cobalt
	Silicon
	Boron
	Nickel
	Vanadium

Macrominerals are found in relatively large amounts in the body, while microminerals are found in trace amounts.

Although some minerals have been studied more than others, basic information about each mineral is known. This information is summarized in Table 9.2. For each mineral the following appears: chemical symbol, major physiological functions, symptoms associated with a deficiency or toxicity, and food sources. More detailed information on minerals can also be found in basic and advanced nutrition textbooks or at the Food and Nutrition Information Center at www.nal.usda.gov/fnic.

Recommended Daily Mineral Intake

Dietary Reference Intakes have been established for 15 minerals (referred to as elements). Some are needed in relatively large amounts daily, such as calcium (1,000 to 1,300 mg depending on age) and potassium (4,700 mg), while others are needed in much smaller amounts, as is the case for iron or zinc (at least 8 mg). A few are needed in very small amounts. For example, the DRI for a 20-year-old woman for chromium is 25 micrograms (equivalent to 0.025 mg). Each mineral is important for proper physiological functioning and good health, although the amount needed may vary considerably.

Absorption of minerals is generally low and well regulated but toxicities can occur. Consequently, it is important to address the question, "How much is too much?" A Tolerable Upper Intake Level has been established for adults for 14 minerals. There is a lack of data about adverse effects for the other minerals and there are occasional reports of problems associated with excessive intake.

Table 9.3 lists the DRI and UL for adult males and adult, nonpregnant females. The complete DRI and UL for minerals (elements) for all ages and both genders are listed in the gatefold located at the back of this textbook. Notice that recommended daily intake is the same for both genders of the same age for several minerals including sodium, chloride, potassium, and calcium. For some minerals, such as zinc and fluoride, values differ for men and women due to differences in average body size. For females, iron recommendations reflect life cycle stage; those between the ages of 19 and 50 need more because of menstruation and the potentially large losses of iron in blood (Institute of Medicine, 2004, 2001, 2000, and 1997).

The Dietary Reference Intakes are established using scientific studies of healthy people who are moderately active. Athletes use these same standards. However,

The Internet Café

Where Do I Find Reliable Information about Minerals?

The Office of Dietary Supplements, a part of the National Institutes of Health (NIH), was established to "strengthen knowledge and understanding of dietary supplements by evaluating scientific information, stimulating and supporting research, disseminating research results, and educating the public to foster an enhanced quality of life and health for the U.S. population." Fact sheets have been created for several minerals including calcium, chromium, iron, magnesium, selenium, and zinc. Each fact sheet gives an overview of the mineral, the foods that provide it, the Dietary Reference Intakes, information about deficiencies and toxicities, information about supplementation, a thorough discussion of current issues and controversies, and a list of references. The fact sheets are written by registered dietitians at the clinical research hospital at the NIH and reviewed by expert scientific reviewers. These fact sheets, as well as a plethora of other information, can be found at: **http://ods.od.nih.gov/health_information/health_information.aspx.**

Mineral: An inorganic (noncarbon containing) compound essential for human health.

Dual-energy X-ray absorptiometry (DEXA): Imaging procedure for measuring bone mineral density.

Anemia: A condition characterized by a reduced oxygen-carrying capacity by the red blood cells.

Clinical, Clinically: Of or relating to symptoms of disease.

Electrolyte: A substance that will dissociate into ions in solution and is capable of conducting electricity.

Table 9.2 Summary of Mineral Characteristics

Boron	
Chemical symbol	B
Major physiological functions	Needed for normal calcium metabolism; most likely functions as a reaction catalyst or regulator
Symptoms of deficiency	Abnormal growth, low sperm count
Symptoms of toxicity	Gastrointestinal symptoms (nausea, vomiting, diarrhea), loss of appetite, fatigue
Food sources	Green leafy vegetables; some fruits
Other	Little is known about this mineral
Calcium	
Chemical symbol	Ca^{+2} (divalent cation)
Major physiological functions	Mineralization of bones and teeth, muscle contraction, nerve conduction, secretion of hormones and enzymes
Symptoms of deficiency	A dietary calcium deficiency is not associated with any signs or symptoms as bone mineral density declines. Spine, wrist, or hip fractures are often the first symptoms. Low calcium intake can contribute to hypertension (high blood pressure). Low blood calcium concentration, a sign of deficiency, is associated with disease states such as renal (kidney) failure
Symptoms of toxicity	Elevated blood calcium levels, impaired renal function, decreased absorption of other minerals. Could be caused by either excessive intake of calcium or vitamin D but such cases are rare. A high blood calcium concentration is usually caused by disease
Food sources	Milk and milk products; green leafy vegetables; fish with bones such as salmon or sardines; calcium-fortified products such as soy milk or orange juice
Chloride	
Chemical symbol	Cl^- (anion)
Major physiological functions	Helps to maintain fluid balance; component of hydrochloric acid (HCl) found in the stomach
Symptoms of deficiency	Failure to thrive (infants)
Symptoms of toxicity	No toxicities from chloride in food reported; rarely toxicities can occur from extremely high ingestion of sodium chloride (table salt). Symptoms would include vomiting, muscle weakness, severe dehydration, acidosis
Food sources	Table salt (sodium chloride, abbreviated NaCl); fish; meat; milk; eggs
Chromium	
Chemical symbol	Cr^{+3} (trivalent cation)
Major physiological functions	Enhances insulin sensitivity; involved in carbohydrate, protein, and fat metabolism
Symptoms of deficiency	Rare but likely to be glucose intolerance and weight loss
Symptoms of toxicity	Few side effects reported from excess chromium from food
Food sources	Whole grain breads and cereals; mushrooms; beer
Cobalt	
Chemical symbol	Co
Major physiological functions	Part of vitamin B_{12} (cobalamin)
Symptoms of deficiency	Anemia
Symptoms of toxicity	None known due to food consumption
Food sources	Same as vitamin B_{12} (animal products)

Table 9.2 Summary of Mineral Characteristics (continued)

Copper	
Chemical symbol	Cu
Major physiological functions	Part of copper-containing enzymes, role in normal hemoglobin synthesis
Symptoms of deficiency	Anemia, demineralization of bone
Symptoms of toxicity	Gastrointestinal distress; liver damage
Food sources	Seafood; nuts; seeds; whole grains; dried beans; some green leafy vegetables
Fluorine (fluoride)	
Chemical symbol	F
Major physiological functions	Component of bones and teeth. Strengthens bone crystal and resists tooth decay when taken in proper but not excessive amounts
Symptoms of deficiency	Dental caries, osteoporosis
Symptoms of toxicity	Mottled teeth, fragile bones, joint pain
Food sources	Fluoridated water; fluoridated vitamins (infants and children)
Iodine	
Chemical symbol	I
Major physiological functions	Synthesis of thyroid hormones
Symptoms of deficiency	Mental retardation, impaired growth and development, goiter (enlargement of the thyroid gland), inadequate thyroid hormone production
Symptoms of toxicity	Thyroid-related medical problems
Food sources	Iodized salt; salt-water fish; mushrooms; eggs
Iron	
Chemical symbol	Fe
Major physiological functions	Component of hemoglobin, which is necessary for iron and carbon dioxide transport; component of enzymes necessary for cellular use of oxygen; immune system functions
Symptoms of deficiency	Fatigue, loss of appetite, reduced resistance to infection
Symptoms of toxicity	Gastrointestinal distress; in those who overabsorb iron, excess iron storage in liver and subsequent liver dysfunction
Food sources	Well-absorbed (heme) sources: clams, oysters, liver, meat, fish, poultry; lesser-absorbed (nonheme) sources: dried beans and legumes, green leafy vegetables, dried fruit, iron-fortified grains
Other	Fe^{+2} = ferrous (storage) form; Fe^{+3} = ferric (transport) form
Magnesium	
Chemical symbol	Mg^{+2} (divalent cation)
Major physiological functions	Bone formation, component of more than 300 enzymes
Symptoms of deficiency	Muscle weakness, confusion, loss of appetite
Symptoms of toxicity	Diarrhea
Food sources	Green leafy vegetables; nuts and seeds; dried beans and legumes

continued

Table 9.2 Summary of Mineral Characteristics (continued)

Manganese	
Chemical symbol	Mn
Major physiological functions	Role in bone formation; necessary for proper carbohydrate, protein, and fat metabolism
Symptoms of deficiency	Not likely but could result in impaired growth and metabolism
Symptoms of toxicity	Elevated blood manganese; nervous tissue toxicity
Food sources	Nuts; dried beans; whole grains; some vegetables
Molybdenum	
Chemical symbol	Mo
Major physiological functions	Component of three enzymes
Symptoms of deficiency	No reports in humans
Symptoms of toxicity	Minimal effects in humans; impaired growth and weight loss in laboratory animals
Food sources	Legumes; whole grains; nuts
Nickel	
Chemical symbol	Ni
Major physiological functions	May be a component of some enzymes and may enhance iron absorption, but few studies have been conducted in humans
Symptoms of deficiency	Not known
Symptoms of toxicity	Low toxicity in humans; gastrointestinal distress associated with nickel poisoning from accidental ingestion of large doses
Food sources	Legumes; nuts; whole grains
Phosphorous (phosphorus)	
Chemical symbol	P
Major physiological functions	Component of bone, component of phospholipids (cell membranes), helps to maintain normal pH, part of ATP, involved in cellular metabolism
Symptoms of deficiency	Impaired growth, bone pain, muscle weakness
Symptoms of toxicity	Impaired calcium regulation, calcification of the kidney, possible reduction of calcium absorption
Food sources	Widely found in foods, especially animal foods
Potassium	
Chemical symbol	K^+ (cation)
Major physiological functions	Intracellular cation, proper cellular function
Symptoms of deficiency	Severe deficiency: hypokalemia (low blood potassium) resulting in cardiac arrhythmias and muscle weakness. Moderate deficiency: contributes to hypertension and calcium loss from bone
Symptoms of toxicity	Most people readily excrete potassium in urine so toxicity is associated with impaired potassium excretion, which results in hyperkalemia (high blood potassium) and risk for cardiac arrhythmias
Food sources	Vegetables, especially green leafy vegetables; dried beans and peas; orange juice; bananas; melons; potatoes; milk and yogurt; nuts

Table 9.2 Summary of Mineral Characteristics (continued)

Selenium	
Chemical symbol	Se
Major physiological functions	Part of antioxidant enzymes
Symptoms of deficiency	Depressed immune function. Keshan disease, which results in cardiac problems, and Keshan-Beck disease, which affects cartilage, have been reported in Asia
Symptoms of toxicity	Selenosis resulting in brittle hair and nails, gastrointestinal distress, fatigue, impaired nervous system
Food sources	Found in plants; amount varies depending on the selenium content of the soil in which they are grown
Silicon	
Chemical symbol	Si
Major physiological functions	Not known but probably involved with bone formation
Symptoms of deficiency	Not known
Symptoms of toxicity	None known due to food consumption
Food sources	Water; grains; vegetables
Sodium	
Chemical symbol	Na^+ (cation)
Major physiological functions	Extracellular cation, helps to maintain fluid balance
Symptoms of deficiency	Not likely since sodium is widely found in foods and the body has a remarkable capacity to conserve sodium by limiting loss in urine and sweat
Symptoms of toxicity	Elevated blood pressure (depends on genetic predisposition to sodium sensitivity)
Food sources	Table salt (NaCl); addition of sodium to processed foods
Sulfur	
Chemical symbol	S
Major physiological functions	Needed for the synthesis of sulfur-containing compounds, which are essential for the synthesis of many compounds in the body
Symptoms of deficiency	Not likely in the U.S. but deficiencies could result in stunted growth
Symptoms of toxicity	Diarrhea
Food sources	Protein-containing foods and water; the majority of sulfur is provided by the breakdown of body protein and the re-use of the sulfur found in the sulfur-containing amino acids
Vanadium	
Chemical symbol	V
Major physiological functions	Not known
Symptoms of deficiency	Not known
Symptoms of toxicity	None known due to food consumption
Food sources	Mushrooms; shellfish; black pepper; parsley; dill
Other	Use vanadium with caution. There is no justification for adding vanadium to food

continued

Table 9.2 Summary of Mineral Characteristics (continued)

Zinc	
Chemical symbol	Zn
Major physiological functions	Component of hundreds of enzymes; needed for proper cellular function and proper immune system function
Symptoms of deficiency	Impaired growth, poor immunity
Symptoms of toxicity	Immunosuppression; decrease in high-density lipoproteins (HDL); impaired copper metabolism
Food sources	Animal foods (e.g., meat and milk); whole grains

1) Dietary Reference Intakes, The National Academies Press, 2) Gropper, S.S., Smith, J.L. and Groff, J.L. *Advanced Nutrition and Human Metabolism.* Thomson/Wadsworth, Belmont, CA, 2005, and 3) Office of Dietary Supplements, National Institutes of Health, http://dietary-supplements.info.nih.gov/Health_Information/Information_About_Individual_Dietary_Supplements.aspx

Table 9.3 DRI and UL for Adult Males and Adult, Nonpregnant Females

Mineral	Dietary Reference Intakes (DRI)	Tolerable Upper Intake Level (UL)
Calcium	1,000 mg (ages 19 to 50) 1,200 mg (ages 51 and above)	2,500 mg
Chromium	25 mcg (females, ages 19 to 50) 20 mcg (females, ages 51 and above) 35 mcg (males, ages 19 to 50) 30 mcg (males, ages 51 and above)	Not established
Copper	900 mcg	10,000 mcg
Fluoride	3 mg (females) 4 mg (males)	10 mg
Iodine	150 mcg	1,100 mcg
Iron	8 mg (males; females 51 and above) 18 mg (females, ages 19 to 50)	45 mg
Magnesium	310 mg (females, ages 19 to 30) 320 mg (females, ages 31 and above) 400 mg (males, ages 19 to 30) 420 mg (males, ages 31 and above)	350 mg (supplement sources only)
Manganese	1.8 mg (females) 2.3 mg (males)	11 mg
Molybdenum	45 mcg	2,000 mcg
Phosphorus	700 mg	4,000 mg (ages 19 to 70) 3,000 mg (ages 71 and above
Selenium	55 mcg	400 mcg
Zinc	8 mg (females) 11 mg (males)	40 mg
Boron	Not established	20 mg
Nickel	Not established	1 mg
Vanadium	Not established	1.8 mg

Legend: mg = milligram; mcg = microgram

Dietary Reference Intakes

exercise does influence the body's mineral status and there are athletes who lose substantial amounts of certain minerals due to a high level of training, which results in larger-than-normal losses of sweat, blood, or urine (see section below). Although some athletes have exceptional losses, most do not, and the DRI remains the standard that athletes use to judge the adequacy of their dietary mineral intake.

THE INFLUENCE OF EXERCISE ON MINERAL REQUIREMENTS

The influence of exercise on minerals has been difficult to study. Sweat and urine represent the two most likely sources of larger-than-normal losses. Sweat contains several macrominerals such as sodium, chloride, and potassium; losses of these electrolytes, including the substantial loss of sodium by "salty" sweaters, are discussed in detail in Chapter 7. The other macrominerals lost in sweat are magnesium and calcium. One study of magnesium loss in men who worked for eight hours in the heat found that the men lost approximately 4 to 5 percent of their daily magnesium intake via sweat (Lukaski, 2000). Some calcium is also lost but there is no evidence that substantial losses of magnesium or calcium occur.

Three trace minerals—zinc, iron, and copper—may be lost in sweat or urine. Acute exercise results in increased postexercise zinc blood concentration, as zinc moves from muscle cells into the **extracellular fluid.** Some of this zinc may then be excreted via the urine. A few studies have also found that the zinc concentration in sweat is increased with exercise in the heat (Lukaski, 2000). Similarly, more iron may be lost in the sweat and urine of athletes than in sedentary individuals (Gleeson, Nieman, and Pedersen, 2004; Gleeson, Lancaster, and Bishop, 2001). Copper concentrations of sweat are increased, which may help to kill bacteria on the skin (Speich, Pineau, and Ballereau, 2001). Although the number of studies is small and some of the results are contradictory, there is evidence that the loss of some minerals is greater in athletes than in the general population.

While it is recognized that mineral loss can be greater in athletes, it is also known that the consumption of excess minerals, such as zinc and iron, can be detrimental to the athlete by compromising the immune system (Gleeson, Nieman, and Pedersen, 2004). Thought must be given to the best way to compensate for larger-than-normal losses due to exercise. Moderate losses of minerals via sweat or urine can be offset by adequate mineral intake from food. Athletes who have substantial losses may need to increase their dietary intake or supplement the diet with the lost mineral(s). The best approach should be determined on an individual basis.

Mineral Deficiencies and Toxicities

Survival requires that the body be in a state of **homeostasis** and the status of minerals is no exception to this rule. One of the major ways the body maintains its mineral balance is by altering either the amount absorbed, the amount excreted, or both. In general, absorption is low or moderate for most minerals, in part, because **excretion** is normally low. For example, a male would not be expected to absorb more than 10 to 15 percent of the iron in his diet. Assuming that he consumed the DRI for iron, 8 mg, absorption would be approximately 0.8 to 1.2 mg daily. Excretion of iron in the urine and the feces generally amounts to 0.9 to 1.0 mg per day. Many minerals are similar to iron, for which both absorption and excretion are low.

Most minerals can be stored in tissues, and high or low storage levels alter the amount absorbed or excreted. For example, when iron storage is high, absorption may drop to 0.5 mg daily, whereas if iron storage is low (due to voluntary or involuntary blood loss) the body can increase absorption by 3 to 4 mg per day. High storage levels may also affect excretion. Iron is absorbed into the mucosal cells of the GI tract but it does not automatically leave the cells to be transported in the blood. When the body needs to limit iron intake, it may leave iron stranded in the mucosal cells. These cells have a very short life span—on average three days—and not transferring the iron out of the cell and into the blood means that the iron will be excreted in the feces when the dead mucosal cells are sloughed off the intestinal villa. In this example, homeostasis is maintained through the interplay of storage levels, absorption, and excretion (Gropper, Smith, and Groff, 2005).

However, mineral metabolism is much more complicated than simply adjusting intake and output. Calcium is an example of a mineral under substantial hormonal control. Its metabolism is regulated by several hormones that not only influence calcium absorption and excretion but also its deposition and **resorption** from bone. Hormonal regulation is needed because blood calcium concentration must be kept within a narrow physiologic range. The amount of calcium in the extracellular fluid must be very stable to support critical and continuous functions such as muscle contraction

Extracellular fluid: All fluids found outside cells. Includes interstitial fluid and plasma.

Homeostasis: A state of equilibrium.

Excretion: The process of eliminating compounds from the body, typically in reference to urine and feces.

Resorb, Resorption: To break down and assimilate something that was previously formed.

and nerve impulse conduction, so the body cannot depend solely on intestinal absorption and excretion to maintain calcium balance.

Calcium is also an example of a mineral that has a large storage site—bone. This allows the body to maintain calcium homeostasis even when dietary calcium intake is low over years or decades. However, removing large amounts of calcium from its storage site negatively affects the integrity and functionality of the skeletal tissue. Zinc, on the other hand, has no designated storage site. Zinc that is deposited in bone is not available for resorption, so zinc is essentially stored in the compounds that need it to function, the more than 100 zinc-containing enzymes that are found in various cells. If dietary zinc intake is low over years or decades and the body becomes deficient, then zinc is removed from those enzymes that are considered less crucial for cellular functions. These examples highlight the eventual effects of long-term poor mineral intake (Gropper, Smith, and Groff, 2005).

In summary, many mechanisms are available to the body so that it can maintain mineral homeostasis. Some of the manipulations are subtle and not easily detected, such as small increases and decreases in absorption. Changes in excretion help the body maintain balance and guard against excessive amounts in the blood or in storage. Absorption and excretion may be the bookends, but in between there are other substantial influences such as hormones, altered metabolism, or storage capacity. From the perspective of nutrition, the focus for minerals is on the consumption of an adequate amount by eating a variety of mineral-containing foods. This approach assumes adequate absorption.

MINERAL ABSORPTION

It is not possible to know exactly how much of any nutrient is absorbed from the GI tract. A number of factors can affect mineral absorption, including age, gender, stage in the life cycle, genetics, general health, and the health of the GI tract. This section will discuss factors that directly affect absorption such as the presence of a deficiency state, the amount consumed, competition from other nutrients, the presence or absence of food in the intestinal tract, and any compounds that interfere with or enhance absorption. Table 9.4 summarizes the factors that are known to influence mineral absorption.

The amount of any nutrient absorbed from food depends on whether the body is in a state of deficiency. For example, under normal conditions 70 percent of the phosphorus consumed is absorbed. When the body is deficient in phosphorus, as is the case of some elderly women, absorption can increase to about 90 percent. Notice that the body tries to compensate for a deficiency by increasing absorption but that it cannot increase absorption to 100 percent. There are limits to the body's ability to adapt. This is one reason mineral deficiencies occur.

Table 9.4 Factors Influencing Mineral Absorption

Factor	Influence on Absorption
Age	Generally decreases with age
Gender	Varies with the mineral
Life cycle stage	Growth states generally increase absorption; growth states include infancy and childhood growth, puberty, and pregnancy
Genetics	Varies with the individual; absorption could be low, normal, high, or excessive
General and gastrointestinal (GI) health	Poor health, especially poor gastrointestinal health, generally results in poorer absorption
Presence of a deficiency state	Generally results in increased absorption
Amount consumed	In food, higher intakes usually result in greater absorption
Presence of other minerals	In food, reduces absorption to a small degree; large amounts found in supplements may reduce absorption of competing minerals to a large degree
Presence of food in the GI tract	Generally enhances absorption
Compounds found in food	Phytic acid, oxalate, and insoluble fiber are known to inhibit absorption; soluble fiber enhances absorption. Some compounds enhance absorption (e.g., lactose aids calcium absorption, vitamin C aids iron absorption)
Chemical form of the mineral	Most minerals have a chemical form that results in greater absorption; some supplements and fortified foods contain highly absorbable forms

The amount consumed on a daily basis is important to prevent eventual mineral deficiencies. The percentage absorbed decreases as the amount consumed increases. However, the total amount absorbed is greater when more is consumed. For example, when 5 mg of zinc is consumed maximum absorption is approximately 40 percent or 2 mg. When 10 mg of zinc is consumed, absorption declines to about 30 percent, but the total amount absorbed is higher, about 3 mg (10 mg $\times$ 0.30) (Krebs, 2000). The best way to prevent mineral deficiencies is to consume enough of each mineral daily; in other words, the amount recommended in the Dietary Reference Intakes.

Minerals compete with each other for absorption due to chemical similarities. Minerals that are divalent

cations (i.e., 2 positively charged atoms), such as calcium, iron, zinc, copper, and magnesium, use the same binding agents and cellular receptor sites. The major factor influencing the competition appears to be the amount of each mineral consumed.

Problems can occur when intake of one mineral is excessive, such as the consumption of a large amount through supplementation. Copper, iron, and calcium absorption are all reduced when zinc intake is excessive. In the case of magnesium or calcium, if either is taken in excess, then the absorption of the other is substantially decreased. Calcium and iron are also competitors. These interactions raise questions about both the benefits and potential problems associated with supplementation of minerals, either singly or as part of a multimineral supplement. Obtaining minerals from food may be more beneficial than obtaining them from supplements that provide excessive amounts because of the effects on absorption.

Minerals taken in adequate but not excessive amounts seem to circumvent the problem of substantially reduced or favored absorption. Competition is still present because minerals normally share the same absorption mechanisms and pathways. However, when all the minerals are present in reasonable amounts, no one mineral has an overwhelming absorption advantage. In nature, calcium-containing foods, such as milk, are poor sources of iron, and iron-containing foods, such as meat, are poor sources of calcium. When eaten apart, the competing nutrient is absent. When both meat and milk are eaten as part of the same meal there will be some competition for absorption but one will not be absorbed to the exclusion of the other.

Minerals are better absorbed when food is present in the GI tract. This may be due to the slower movement of undigested food, known as an increased transit time, the presence of enzymes that are secreted as part of the normal digestive process, or a favorable pH (Sabatier et al., 2002). Some mineral supplements, such as calcium carbonate, are also better absorbed when consumed with food. However, large doses of single supplements, such as iron, may be better if taken on an empty stomach so that they do not interfere with absorption of other minerals.

A number of compounds found naturally in food are known to interfere with or enhance absorption. Those that interfere include phytic acid, oxalate, insoluble fiber, and fat. Phytic acid (phytates) and oxalates are known to inhibit the absorption of iron, zinc, calcium, and manganese by binding with the mineral and blocking absorption. These compounds are found in spinach, Swiss chard, seeds, nuts, beans, and legumes (Hurrell, 2003). Insoluble fiber, such as wheat, decreases calcium, magnesium, manganese, and zinc absorption because of a decreased transit time. In other words, the insoluble fiber causes the contents to move through the GI tract more quickly, resulting in less contact time with the mucosal cells and less opportunity for the minerals to be absorbed (Greger, 1999).

Table 9.5 Probability of Adequate Mineral Intake for Adult Males and Females

Nutrient	% Adequacy in Men	% Adequacy in Women
Calcium	58.6	45.7
Phosphorus	94.3	85.1
Magnesium	36.1	34.3
Iron	95.5	79.4
Copper	87.4	73.3
Zinc	65.7	62.0

Many men and women do not consume an adequate amount of minerals daily.

Table D1–2. Probabilities of Adequacy for Selected Nutrients on the First 24-hour Recall among Adult CSFII 1994–96 Participants. Dietary Guidelines, 2005. (www.health.gov/DietaryGuidelines/dga2005/report/HTML/D1_Tables.htm#top)

Sugars such as lactose (milk sugar) may increase calcium absorption as well as magnesium and zinc. The mechanism is not entirely known but it may be due to the effect the sugar has on increasing the permeability of the GI tract. Soluble fibers, such as pectins or gums, may also have a favorable effect (Greger, 1999). Several factors can enhance iron absorption, including ascorbic acid (vitamin C) and the presence of the meat, fish, poultry (MFP) factor (Diaz et al., 2003).

Although numerous factors have been identified as either increasing or decreasing absorption, their influences are probably subtle when considered in the larger context of daily, weekly, and yearly intake. Most reports of clinical mineral deficiencies are from poor countries where the food supply is severely limited. Eating a variety of nutrient-dense foods may be the best approach for minimizing competition and maximizing mineral absorption.

AVERAGE MINERAL INTAKES BY SEDENTARY ADULTS AND ATHLETES

Table 9.5 shows the probability of adequate mineral intakes from food for U.S. adult males and females for six minerals. Only 36 percent of men and 34 percent of women are likely to receive an adequate amount of magnesium from their diets. Calcium intake is also low for many adults with approximately 46 percent of women and 59 percent of men meeting recommended

Cation: A positively charged ion.

guidelines. Zinc consumption is adequate for 62 percent of women and ~66 percent of men. Most men meet the recommended intake for iron and phosphorus. These figures are from data obtained between 1994 and 1996.

Adequate mineral intake for athletes is generally associated with adequate energy intake. Athletes with a low energy intake are likely to be deficient in one or more of the following minerals: calcium, iron, zinc, selenium, magnesium, and copper. Energy-restricted athletes known to be at risk include distance runners, female gymnasts, ballet dancers, teenaged synchronized skaters, wrestlers, and jockeys. Some studies have shown substantial deficits, particularly of iron and zinc. Some of the trace minerals have not been assessed but it is likely that athletes who are deficient in iron and zinc are also deficient in some of the other trace minerals. These athletes are also likely to have low vitamin intakes (Ziegler et al., 2005; Jonnalagadda, Ziegler, and Nelson, 2004; Leydon and Wall, 2002; Ziegler et al., 2002 and 1999; Venkatraman and Pendergast, 2002). However, it is possible for athletes who are restricting food intake to consume a sufficient amount of some minerals if the foods chosen are highly fortified (e.g., calcium and iron added).

DEVELOPING CLINICAL AND SUBCLINICAL MINERAL DEFICIENCIES

Despite the body's adaptive mechanisms, mineral deficiencies can occur if intakes are too low over time. Any mineral deficiency will be progressive—at first mild and difficult to detect, then moderate, and ultimately, severe, if not detected and treated. As with vitamin deficiencies, mild and moderate mineral deficiencies, also called **subclinical** deficiencies, often progress over a long period of time with no visible signs or symptoms. When signs or symptoms do appear, they are usually subtle and nonspecific.

Zinc deficiency is a good illustration. A mild zinc deficiency forces the body to prioritize the functions of its zinc-containing enzymes to ensure that the available zinc is incorporated into higher-priority enzymes. Initially, a small reduction in the number and type of zinc-containing enzymes would not be noticeable and, because of limitations in measuring such activity, not likely to be detected with laboratory tests. As a mild deficiency became a moderate one, signs and symptoms would emerge but they would be nonspecific—reduced appetite, poor wound healing, or dermatitis (inflammation of the skin)—making a diagnosis of zinc deficiency difficult since many medical conditions have these same general symptoms. As a zinc deficiency became more severe (i.e., a clinical deficiency) specific signs would emerge such as impaired taste or night blindness.

Prevalence of Clinical Mineral Deficiencies. In industrialized countries where food is abundant and iodine is added to salt, clinical mineral deficiencies are typically limited to iron and calcium. In individuals with cirrhosis (scar tissue in the liver), a zinc deficiency may be present. A clinical iron deficiency results in iron-deficiency anemia. It is estimated that 3 percent of women ages 12 to 49 have iron deficiency anemia (Centers for Disease Control and Prevention, 2002). The percentage of female athletes who have a clinical iron deficiency is not known, but it is not likely to be less than 3 percent and may be considerably higher. Some males, including a few male endurance athletes, may manifest iron deficiency anemia but the prevalence is very low. Iron deficiency anemia results in fatigue and impairs performance by reducing aerobic capacity and endurance.

Normally, a clinical calcium deficiency (e.g., **osteoporosis**) develops over many decades. Based on 2002 figures, 8 million women and 2 million men in the United States have osteoporosis (National Osteoporosis Foundation, 2005). Loss of calcium from bone is exacerbated in women when **estrogen** production declines substantially. For most women this estrogen decline is a result of **menopause,** but for some female athletes low circulating estrogen is a result of a prolonged low caloric intake concurrent with the high energy expenditure of intense training. This low energy availability may be a result of disordered eating, but that is not always the case (see Chapter 13 for a full explanation). Low energy availability can result in **amenorrhea,** the cessation of menstruation. In two studies of amenorrheic female distance runners between the ages of 20 and 30, 10 to 13 percent were diagnosed with osteoporosis (Khan et al., 2002). Cobb et al. (2003) reported that of 33 well-trained distance runners (aged 18 to 26) with amenorrhea or **oligomenorrhea,** two had already developed osteoporosis. Female athletes who are not menstruating or who have infrequent menstruation should seek medical attention.

Prevalence of Subclinical Mineral Deficiencies. In the early stages of a subclinical mineral deficiency a person would show few or no outward signs that mineral status is declining. A subclinical iron deficiency is known as iron deficiency without anemia. Such deficiencies are prevalent in the United States, with estimates ranging from 2 to 5 percent of males (highest prevalence in 12 to 16 year olds), 9 to 16 percent of female adolescents, and 12 percent of nonpregnant females (Centers for Disease Control and Prevention, 2002). Malczewska, Raczynski, and Stupnicki (2000) report that 26 percent of the female endurance athletes in their study had a subclinical iron deficiency. Some researchers estimate that the prevalence is higher in vegetarians (Beard and Tobin, 2000). There is controversy about the effect of iron deficiency without anemia on human athletes because study results have been contradictory but studies in animals suggest it affects endurance capacity (Haas and Brownlie, 2001).

A subclinical calcium deficiency is known as **osteopenia** or low bone mineral density (BMD). Using 2002 data, the National Osteoporosis Foundation estimates that approximately 22 million women and 12 million men have low BMD. Those with osteopenia are at risk for developing osteoporosis. Studies of amenorrheic runners and ballet dancers found that 22 to 50 percent of the subjects had osteopenia, some mild and some substantial (Khan et al., 2002). Cobb et al. (2003) report that nearly half of the 33 oligo/amenorrheic distance runners studied had osteopenia as did a quarter of the 58 distance runners with normal menstruation. Some athletes in their 20s are experiencing bone mineral loss and they are at higher risk for fractures. While this is more prevalent in amenorrheic athletes, it is also true for some athletes with normal menstruation.

The prevalence of those in the United States who have a subclinical zinc deficiency is not known. However, a handful of studies of U.S. children and adults have shown that some people benefit from zinc supplementation, suggesting that subclinical deficiencies do exist in the United States (Hambidge, 2000). A lack of zinc could result in a depressed immune system and a higher incidence of colds (Failla, 2003).

In addition to iron, calcium, and zinc, it is reasonable to assume that some people could have subclinical deficiencies of selenium and magnesium because surveys suggest that dietary intake is below recommended levels (Ford and Mokdad, 2003). These data must be interpreted cautiously, however, because prolonged low dietary intake is suggestive but not predictive of a subclinical deficiency. Increased absorption or decreased excretion may offset low intake. For several of the trace minerals, the amount contained in food is not known; thus, dietary intake cannot be estimated and no conclusions about potential subclinical deficiencies can be made solely from dietary analysis.

Clinical mineral deficiencies negatively affect performance and undermine the athlete's health. Subclinical deficiencies are never desirable because they could theoretically impair an athlete's ability to train or perform. As is often said in sports, "the best defense is a good offense." The athlete's best defense against mineral deficiencies is an adequate intake of minerals daily through the consumption of nutrient-dense foods in sufficient quantities to meet caloric needs.

MINERAL TOXICITIES

For most of human history food was the only source of minerals. Very small amounts of trace minerals are found in food so there was little risk of consuming toxic amounts from the diet. As medical research advanced, mineral deficiencies could be detected. When a deficiency was diagnosed, it was easily reversed either with a change in food intake or short-term mineral supplementation. Supplementation was monitored as part of the medical treatment and toxic levels could be avoided. The scientific focus was on one of two points on the continuum—deficiency or toxicity.

In the last 20 years, especially in the United States, mineral supplementation by generally well-nourished individuals has increased. This has occurred because of research that has shown a relationship between various minerals and chronic diseases as well as increased advertising for mineral supplements. More foods are now fortified with minerals and more people are consuming supplements of a single mineral in amounts higher than would occur naturally from the consumption of food only. The scientific focus is now on three points on the continuum—deficiency, health benefits to well-nourished individuals, and toxicity (Fraga, 2005).

The distance between deficiency and toxicity has been fairly well defined; however, the difference between the amounts needed to prevent chronic diseases in the well-nourished individual and toxicity is poorly understood and hard to measure. The best advice for those who supplement with minerals, especially trace minerals, is to supplement carefully and monitor dosages to avoid potential toxicities. Fraga (2005) suggests that self-prescribed, poorly monitored intake of trace mineral supplements will put some people on the borderline of toxicity.

Table 9.6 lists the Tolerable Upper Intake Level that has been established for 14 of the minerals and the potential adverse affects associated with excess intake. For all of the nutrients except magnesium, the UL includes all foods, water, and supplements as mineral sources. In the case of magnesium, the established level is based on supplements only. To properly evaluate if an individual is approaching or exceeding the

Subclinical: Producing effects that are not detectable by usual clinical (medical) tests.

Osteoporosis: Disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture.

Estrogen: Female sex hormone.

Menopause: Period of time when menstruation diminishes and then ceases. Typically occurs around the age of 50.

Amenorrhea: Absence or suppression of menstruation.

Oligomenorrhea: Menstrual periods that are infrequent or sparse.

Osteopenia: Low bone mineral density. A risk factor for osteoporosis.

Table 9.6 Tolerable Upper Intake Level and Potential Toxic Effects of Minerals

Nutrient	Tolerable Upper Intake Level for Adult Males and Nonpregnant Females	Potential Toxic Effects
Calcium	2,500 mg	Kidney stone formation; hypercalcemia (high blood calcium) and renal (kidney) insufficiency; decreased absorption of other minerals
Phosphorus	4,000 mg (ages 19 to 70) 3,000 mg (ages 71 and above)	Impaired calcium regulation; calcification of the kidney; possible reduction of calcium absorption
Fluoride	10 mg	Fluorosis of the teeth and bones resulting in mottled teeth, fragile bones, and joint pain
Magnesium	350 mg (supplement sources only)	Diarrhea
Iron	45 mg	Gastrointestinal distress
Copper	10,000 mcg	Gastrointestinal distress; liver damage
Zinc	40 mg	Immunosuppression; decrease in high-density lipoproteins (HDL); impaired copper metabolism
Selenium	400 mcg	Selenosis resulting in brittle hair and nails, gastrointestinal distress, fatigue, impaired nervous system
Boron	20 mg	Low toxicity in humans; gastrointestinal distress associated with boron poisoning from accidental ingestion of large doses
Iodine	1,100 mcg	Thyroid-related medical problems
Manganese	11 mg	Elevated blood manganese levels; nervous tissue toxicity
Molybdenum	2,000 mcg	Minimal effects in humans; impaired growth and weight loss in laboratory animals
Nickel	1 mg	Low toxicity in humans; gastrointestinal distress associated with nickel poisoning from accidental ingestion of large doses
Vanadium	1.8 mg	Use vanadium with caution. There is no justification for adding vanadium to food

Legend: mg = milligram; mcg = microgram

Dietary Reference Intakes

UL, a nutritional analysis of the usual diet should be conducted to determine approximate mineral intake from food. The amounts consumed as supplements should be added to these estimates and the total intake compared to the UL. High-potency multimineral supplements can provide surprisingly high amounts of several minerals (see Spotlight on Supplements: Evaluating a High-Potency Multimineral Supplement Advertised to Athletes).

By now it should be clear that an adequate amount of each mineral is needed for proper biological function but that excessive amounts can be detrimental. Minerals are needed in every physiological system, but this chapter will focus on three that are vitally important for the athlete's health and performance—bone, blood, and immune system. Minerals involved in body fluids (e.g., sodium, potassium) are covered in detail in Chapter 7.

What's the point? Most athletes do not require more minerals than sedentary individuals and sufficient amounts can be obtained from food. Low calcium and iron intakes, which are more prevalent in females, may result in subclinical and clinical deficiencies. For those who consume a sufficient amount of minerals in food, consumption of large amounts of highly absorbable minerals found in supplements increases the risk for developing mineral toxicities.

The Roles of Minerals in Bone Formation

The strength and hardness of bones and lack of dimensional growth in adults may lead people to believe that bone has "finished growing" after adolescence and not

Evaluating a High-Potency Multimineral Supplement Advertised to Athletes

The following multimineral supplement is advertised as a "High absorbance formula for stressed people, athletes and body-builders, and cancer, AIDS, and HIV patients." The manufacturer recommends one tablet daily. Table 9.7 lists the dose found in the supplement for each mineral and compares it to the Dietary Reference Intake for a 22-year-old male. Information about the UL is also included.

This mineral supplement contains several minerals in amounts that are more than twice the DRI. Many male athletes who consume a sufficient amount of energy (kilocalories) are already obtaining the recommended amounts from food, and these doses will bring daily mineral intake several times higher than recommended. The supplement is advertised as being highly absorbable. Excessive or preferential absorption could result, although it is impossible to know how much of any mineral will be absorbed.

Five minerals contained in this supplement are of particular concern—magnesium, zinc, manganese, vanadium, and silica. The amount of magnesium exceeds the Tolerable Upper Intake Level established. The amount of zinc contained (22.5 mg) is higher than many nutrition professionals recommend. No more than 15 mg of supplemental zinc is generally recommended because high doses of zinc can interfere with iron and copper absorption and can suppress the immune system. This supplement provides 10 mg of manganese, 91 percent of the UL. When added to the amount consumed in food, intake of this nutrient could be high. It is not illegal to have high dosages in a supplement, even those that exceed the UL.

Although there is no UL for vanadium, the committee that established the UL noted that vanadium supplements should be used with caution (Institute of Medicine, 2001). The European Food Safety Authority (2004) concluded that vanadium is not an essential mineral for humans and noted that adverse effects on kidneys and reproduction have been reported in rats. The silica (silicon dioxide) in this supplement is extracted from horsetail herb and represents 20 to 50 percent of the estimated daily dietary intake of silicon. Although a UL has not been established, the Institute of Medicine also noted that silicon should not be added to food or supplements.

The label states that 2 mg of copper are contained in the supplement, but the DRI and UL are listed in micrograms, which makes it hard for the consumer to compare. Comparisons are unlikely, though, because mineral supplement labels do not require that the UL be listed.

It is curious that a supplement recommended to cancer, AIDS, and HIV-positive patients would also be recommended to athletes. Athletes are typically healthy individuals whose need for minerals is likely met by consuming amounts recommended by the DRI. Cancer and AIDS patients have wasting diseases that substantially affect nutrient intake and nutrient requirements. The use of the DRI is not appropriate with people who are ill because the DRI is established using data from healthy individuals. This supplement's advertising message was "more is better," but that conclusion is not necessarily true.

Table 9.7 Example of a High-Potency Multimineral Supplement

Mineral	Dose	DRI*	Dose Compared to DRI
Calcium	1,000 mg	1,000 mg	Equal
Iron	18 mg	8 mg	2.25 times greater
Iodine	150 mcg	150 mg	Equal
Magnesium	500 mg	400 mg	1.25 times greater; exceeds the UL (350 mg)
Zinc	22.5 mg	11 mg	2 times greater
Selenium	50 mcg	55 mcg	10% less
Copper	2 mg**	900 mcg	2.2 times greater
Manganese	10 mg	2.3 mg	4 times greater
Chromium	100 mcg	35 mcg	2.8 times greater
Molybdenum	10 mcg	45 mcg	Less than 25%
Potassium	99 mg	4,700 mg	Less than 2%
Vanadium	2 mcg	Not established	UL not established; use vanadium supplements with caution
Silica (horsetail herb)	10 mg	Not established	UL not established but report states that silicon should not be added to food or supplements

Legend: DRI = Dietary Reference Intakes; mg = milligram; mcg = microgram; UL = Tolerable Upper Intake Level

*22-year-old male

**2 mg = 2,000 mcg

metabolically active in adulthood. Bone is a dynamic tissue that is biologically active throughout life. Increases in bone length and thickness are associated with growth in childhood and adolescence, but bone mineral content can increase until about age 35, when peak bone density is achieved. After that point bone mineral loss slowly begins and continues throughout life. Loss is accelerated in females when estrogen production substantially declines such as after menopause and throughout the course of **athletic amenorrhea.**

BONE-FORMING MINERALS

Bone growth is accomplished by the balanced activity of two different types of bone cells, **osteoblasts** and **osteoclasts,** and by cartilage cells, **chondrocytes.** Osteoblasts are the bone-forming cells. They produce an organic matrix that consists of collagen fibers and a gel-like material known as ground substance, which accumulates outside of these bone cells. Calcium phosphate salts crystallize within this matrix, giving bone its rigidity and strength. Osteoclasts are bone cells that dissolve this matrix and thus remove bone tissue. This is important during bone growth in areas such as the inner surface of the marrow cavity to prevent the bones from becoming too thick and heavy. Bone length is increased by osteoblasts laying down new bone tissue at the ends of the bone where the chrondrocytes have become calcified. Once the crystallized matrix has surrounded an osteoblast, it is considered a mature bone cell and is referred to as an osteocyte (Sherwood, 2007).

Eighty to 90 percent of the mineral content of bone consists of calcium and phosphorus incorporated into **hydroxyapatite** crystals, $Ca_5(PO_4)_3OH$. Fluoride is also incorporated, increasing the size of the crystal and making it less fragile. However, too much fluoride makes the crystal too large and brittle and fragility is increased. Magnesium is not integrated into the hydroxyapatite crystal, but it sits on the surface and helps to regulate bone metabolism (Ilich and Kerstetter, 2000).

In addition to the structural minerals, several minerals play indirect roles. Iron, zinc, and copper are part of various enzymes that are needed to synthesize collagen. Sodium interacts with calcium, and studies have shown that sodium in the form of salt (e.g., sodium chloride) increases the loss of calcium in the urine. What is not yet known is whether a habitually high intake of dietary sodium chloride (i.e., table salt) reduces the amount of calcium in the bone crystal, but this effect is biologically plausible (Ilich and Kerstetter, 2000).

Nutrients other than minerals are also critical to proper bone development. Vitamin D, a general term that includes several different chemical forms, is an important influence because one form functions as a **hormone** and helps to regulate calcium absorption and excretion. Vitamin K assists with incorporation of calcium into the hydroxyapatite crystal. While all the nutrients involved in bone formation are important, calcium is emphasized because it makes up a large proportion of the hydroxyapatite crystal. Bone is a reservoir for calcium that will be tapped to provide for critical metabolic functions if dietary calcium intake is habitually low, absorption is poor, or excretion is high.

BONE REMODELING

Throughout life bone is constantly remodeled as existing bone is resorbed (broken down) and new bone is formed. This process, known as bone turnover, involves osteoclasts (cells that resorb bone) and osteoblasts (cells that form bone). Osteoclastic activity is triggered by many factors, including mechanical force (physical activity), microfractures, and changes in hormone concentrations, such as **parathyroid hormone** (PTH) and **calcitriol** (1,25-dihydroxyvitamin D_3). Once resorption begins, osteoblasts migrate to the site of resorption to begin the process of new bone formation. In children and adolescents deposition outpaces resorption. In young adults the amount of bone formed typically equals the amount of bone resorbed, but as people age, osteoblastic activity does not equal osteoclastic activity. The result is a net loss in bone density (Kenny and Prestwood, 2000).

Skeletal mass consists of both cortical and trabecular bone. Approximately 80 percent of the skeleton is cortical bone, which is found in the shafts of the long bones and on the surface of the bones. In contrast, about 20 percent is trabecular bone, which is found at the ends of the long bones and below the surface. Cortical bone is compact and is laid down in concentric circles around Haversian systems (canals) that contain blood vessels, nerves, and other tissues. In contrast, trabecular bone is a series of interconnecting plates housing the bone marrow that is the source of blood cells. Trabecular bone has much greater surface volume and a higher rate of metabolic activity and turnover than cortical bone (Compston, 2001).

One to 2 percent of the entire skeletal mass in adults is being remodeled at all times, but 20 percent of the trabecular bone is being remodeled, underscoring its high turnover. In the adult skeleton, approximately 10,000 to 20,000 new remodeling sites become active each day. At any given time, approximately 1 million sites are being actively remodeled. Over 10 years' time an adult's entire skeleton will have been remodeled (Sherwood, 2007).

Once the bone remodeling process begins at a site, the time to completion is a function of age. In children the remodeling takes several weeks, while in young adults it takes about three months. In older adults the time between bone breakdown and complete restoration can be anywhere from six to 18 months (Heaney, 2001). Most of the remodeling time is spent in bone formation, not bone breakdown (Compston, 2001).

CALCIUM METABOLISM

Calcium metabolism is hormonally controlled both on the micro level (e.g., the amount of calcium in the blood) and on the macro level (e.g., the amount of calcium absorbed, distributed, and excreted). Two critical hormones are parathyroid hormone and calcitriol (a form of vitamin D). The regulation of calcium in the blood and extracellular fluid (ECF) is referred to as calcium homeostasis and is primarily under the control of PTH. Calcium balance describes the body's total absorption, distribution, and excretion of calcium and is regulated by PTH and calcitriol. Calcium homeostasis and calcium balance describe different aspects of calcium metabolism, although the two functions are related.

Normal blood calcium concentration is between 8.5 and 10.5 mg/dl, a small physiological range. This range is tightly regulated because calcium is a cellular messenger and enzyme regulator. Approximately half of the calcium in the blood is bound to proteins and cannot leave the blood **plasma.** The remaining half is unbound and can diffuse into the extracellular fluid. On average, the extracellular fluid contains approximately 1,000 mg of calcium. The amount of calcium in the ECF directly affects the function of the nerve and muscle cells, so it must be well controlled.

Homeostasis of plasma calcium occurs because calcium can be quickly moved into the ECF from a pool of calcium in the bone fluid. Bone fluid surrounds the membranes that connect osteoblasts with osteocytes. When blood calcium concentration decreases, PTH activates calcium pumps located in the membranes surrounding the bone fluid to quickly move calcium into the blood and restore homeostasis. Known as fast exchange, the calcium is coming from bone fluid, not from mineralized bone. PTH also stimulates the kidney to resorb more calcium (so it is not lost in urine) and activate calcitriol, a hormone that increases calcium absorption in the intestine. Thus, PTH is maintaining homeostasis via fast exchange but it is also influencing calcium balance by decreasing the loss of calcium in the urine and increasing the supply of calcium from food.

Under normal conditions, a sufficient amount of calcium is consumed daily (i.e., the DRI). Calcium balance is maintained by the interplay of calcium absorption and excretion. Calcium absorption and excretion can be increased or decreased to maintain balance. Part of calcium balance also involves bone. Normally, calcium is exchanged with bone at an equal rate. Of the nearly 1,000,000 mg (1,000 g) of calcium found in bone, approximately 550 mg is exchanged daily. Obviously, bone contains a large amount of calcium, which can be used to offset a long-term low calcium intake.

Figure 9.1 illustrates the numerous tissues and hormones associated with calcium regulation. In adults, the average absorption is approximately 30 percent of the calcium entering the GI tract via food. Thus, of a 1,000-mg daily intake of calcium only about 300 mg is absorbed. The amount absorbed is regulated by vitamin D and does vary. Absorption of calcium in adults in estimated to be between 10 and 50 percent and as high as 75 percent in children (Gropper, Smith, and Groff, 2005; Heaney, 2001). Absorption from calcium supplements also varies depending on the chemical composition (e.g., calcium carbonate, calcium citrate), but typically ranges from 25 to 40 percent. The body cannot compensate for low calcium intake by increasing absorption to 100 percent.

On average, approximately 300 mg is also lost through the urine and **secretions** from the extracellular fluid into the GI tract. Under normal conditions (i.e., adequate calcium intake) the amount of calcium excreted is equal to the amount absorbed and the body can maintain calcium homeostasis and calcium balance (Gropper, Smith, and Groff, 2005).

Unfortunately, many people do not consume a sufficient amount of calcium daily, which affects calcium balance. The body must maintain calcium homeostasis, but faced with low calcium intake, it cannot do so by only using fast exchange, the PTH-stimulated calcium pumping mechanism. A second mechanism, known as slow exchange, must be relied upon to make available the calcium needed. In slow exchange, PTH stimulates the dissolution of bone by increasing osteoclast activity and inhibiting osteoblast activity. The bone crystal, $Ca_5(PO_4)_3OH$, dissolves releasing both

Athletic amenorrhea: Absence or suppression of menstruation as a result of athletic training.

Osteoblast: Bone-forming cell.

Osteoclast: Bone-removing cell.

Chondrocyte: A cartilage cell.

Hydroxyapatite: The principal storage form of calcium and phosphorus in the bone.

Hormone: A chemical compound that has a regulatory or stimulatory effect.

Parathyroid hormone: A hormone produced in the parathyroid glands that helps to raise blood calcium by stimulating bone calcium resorption.

Calcitriol: 1,25-dihydroxyvitamin D_3, a hormonally active form of vitamin D.

Plasma: The fluid portion of blood.

Secretion: The process of releasing a substance to the cell's exterior.

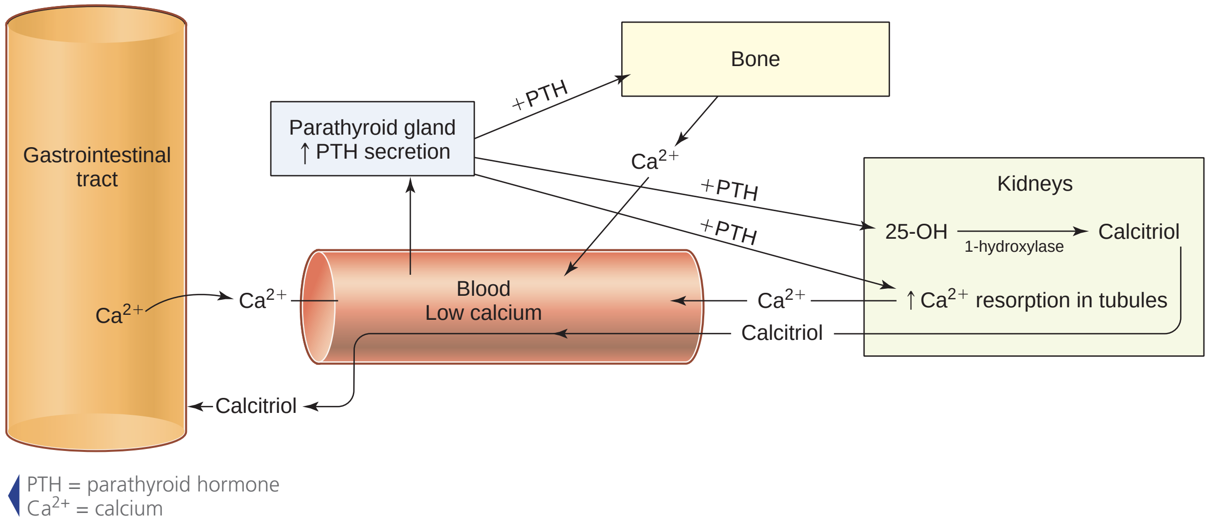

Figure 9.1 Calcium Regulation

Calcium homeostasis and balance are complex and involve the gastrointestinal tract, kidneys, bone, and blood. Two influential hormones are parathyroid hormone and calcitriol (a form of vitamin D).

Ca^{2+} (calcium) and PO_4^{3-} (phosphate). The calcium is used to maintain blood calcium within the normal range and the phosphate is typically excreted in the urine. Over time, this process undermines the integrity of the bone's structure because the mineral density of the bone is decreased (Sherwood, 2007).

PEAK BONE MINERAL DENSITY

Peak mineral density (PMD) refers to the highest bone mineral density achieved during one's lifetime. The largest amount of bone mineral is added during childhood and adolescence (45 percent of the total in each time period). Only 10 percent of bone density is accumulated between ages 20 and 35. Peak bone density of trabecular bone is achieved between the ages of 20 and 30, while cortical bone density peaks later, usually between ages 30 and 35.

Approximately 40 to 60 percent of peak bone density is genetically determined, although the exact genes are not known. Genetic factors could affect bone density capacity as well as the rate of bone deposition or resorption (Compston, 2001). To reach one's genetic potential for PMD, nutrient intake must be adequate. Although many nutrients are important in bone formation, the emphasis is put on consuming an adequate amount of calcium and vitamin D. A low calcium intake during childhood and adolescence can reduce peak bone mineral density by as much as 5 to 10 percent. This degree of peak mineral density deficit is associated with hip fracture in later life. As average life expectancy in the United States is approximately 78 years, obtaining peak bone mineral density is critical to long-term health (Centers for Disease Control and Prevention, 2004).

Physical activity or participation in sports or exercise programs has an important impact on the development of peak bone mineral density. Weight-bearing exercise or activity that exposes the body to repeated stress in excess of the normal effects of gravity is needed. This weight-bearing stress stimulates bone to increase bone mineral content over time. People who are physically active generally have greater bone mineral density than those who are sedentary. Exercise-related factors that influence peak bone density include the type, intensity, and frequency of exercise; age at which the activity is begun; and number of years that the exercise continues (Beck and Snow, 2003).

Studies in children have shown that jumping, hopping, and similar high-impact activities increase bone mineral content in the hip and spine and are safe for children to perform (Fuchs, Bauer, and Snow, 2001). A subsequent study showed that gains in bone density were sustained in the hip even after seven months of detraining (Fuchs and Snow, 2002). Childhood and adolescence are critical times for increasing bone mass and high-impact activities (e.g., jumping rope) and sports (e.g., gymnastics, volleyball, basketball) should be encouraged.

In young adults, high-impact activities and strength training such as power lifting increase bone mineral density to the greatest degree. Weight-bearing exercise at intensities of greater than 60 percent of $\dot{V}O_{2max}$ are more beneficial than weight-bearing activities performed at lower intensities. In contrast to children, bone-stimulating activities must be continued to maintain the gains made in bone density (Winters and Snow, 2000). Nonweight-bearing activities such as cycling or swimming do not stimulate gains in bone mineral

Table 9.8 Dietary Reference Intakes for Calcium and Vitamin D

Age Group (yr)	Calcium (mg)	Vitamin D (mcg)
0 to 0.5	210	5
0.5 to 1	270	5
1 to 3	500	5
4 to 8	800	5
9 to 18	1,300	5
19 to 50	1,000	5
51 to 70	1,200	10
71 and above	1,200	15

Legend: yr = year; mg = milligram; mcg = microgram

density (although these are good activities for cardiovascular fitness). Sedentary adults have lower bone mineral density than adults who are physically active. While high-impact activities have the greatest effect, weight-bearing activity, especially at higher intensities, is also beneficial. Predictably, more frequent activity has a greater effect than less frequent activity (Beck and Snow, 2003).

Recommended Dietary Intakes of Calcium and Vitamin D. Dietary intake of calcium throughout the life cycle is critical. The Dietary Reference Intakes for calcium and vitamin D for each age group are listed in Table 9.8. Calcium recommendations for infants and children increase proportionately to increasing growth. Between the ages of 9 and 18 recommended calcium intake is at its highest—1,300 mg daily. Recommendations remain relatively high throughout the life cycle. Males and nonpregnant females between the ages of 19 and 50 need 1,000 mg daily. After age 50, calcium recommendations are increased to 1,200 mg daily to help offset the loss of calcium from bone. The Tolerable Upper Intake Level for calcium is 2,500 mg daily and includes intake from food, water, and supplements.

In the United States daily calcium intakes for females peak at ages six to 11 when approximately 800 mg of calcium is consumed daily. The average dietary intake of calcium for adult women is approximately 650 mg daily, well below recommended amounts. Calcium supplements and calcium-fortified foods are consumed by some women, but consistently low calcium intakes across the life cycle are prevalent among women. Males consume approximately 925 mg daily after age nine (Morgan, 2001; Ilich and Kerstetter, 2000).

Vitamin D is a powerful regulator of calcium and phosphorus metabolism, so an adequate calcium intake should be accompanied by an adequate vitamin D intake. Vitamin D is found in a limited number of foods including fatty fish and fish oils. In industrialized countries, milk is fortified with vitamin D. Another important source is ultraviolet (UV) light. When the body is exposed to UV light (e.g., sunlight), a precursor to vitamin D in skin cells can be activated.

The Dietary Reference Intake for vitamin D is 5 mcg (200 IU) for infants, children, adolescents, and adults up to age 50. The DRI increases to 10 mcg (400 IU) for ages 50 to 69 years and to 15 mcg (600 IU) for those older than 70 years (see Table 9.8) These recommendations reflect expected reduced exposure to sunlight and a decreased conversion rate of the vitamin D precursor to the active form of vitamin D as people age. Heaney (2003), one of the world's authorities on osteoporosis, suggests that 15 mcg is too low for most elderly people and recommends 25 mcg (1,000 IU) daily for an elderly person diagnosed with osteoporosis.

Vitamin D is a fat-soluble vitamin and excessive intake could result in hypervitaminosis D, hypercalcemia (high blood calcium levels), and toxicity, although the prevalence is rare. The Tolerable Upper Intake Level is 50 mcg (2,000 IU). This level would not likely be achievable from food alone but could result from excessive vitamin D supplementation.

Vitamin D deficiency is prevalent in the older adult population. In the United States, men and women ages 50 and above have an average vitamin D intake of approximately 8 mcg (320 IU). Of this 8 mcg, approximately 5 mcg (200 IU) is obtained from food sources both fortified and naturally occurring. Exposure to UV light at all ages varies according to latitude, choice of clothing, and use of sunscreen and could be deficient (Grant and Holick, 2005).

Calcium receives most of the attention for bone formation, but bone crystal is calcium phosphate. Phosphorus is widely found in food, and 85 percent of women and almost 95 percent of men consume an adequate amount. The women with low phosphorus intakes are usually elderly. If these women take high-dose calcium supplements, the calcium may bind with the small amount of phosphorus found in the food (Heaney, 2004).

Concern has been raised about high dietary phosphorus intake due to the consumption of carbonated soft drinks, which contain phosphoric acid. At the present time the scientific research does not support an association between high phosphorus intake and osteoporosis (Heaney, 2004). However, children and adolescents are consuming more soft drinks than in the past and consumption of soda does displace milk consumption, an excellent source of calcium (Bowman, 2002). A low calcium intake by children and adolescents is a serious concern for the future bone health of the next generation of adults.

LOSS OF BONE CALCIUM

Unfortunately, many people do not consume sufficient calcium. Low dietary calcium intake results in lower contributions of calcium into the pool. For example, the average daily calcium intake for adult females is 650 mg. Assuming absorption of 30 percent, a 650-mg daily intake would likely result in 195 mg of calcium being absorbed or 65 percent of that absorbed if the recommended calcium intake of 1,000 mg was consumed (195 mg ÷ 300 mg = 65 percent). However, in adult women with low vitamin D concentrations (due to poor intake, absorption, and/or conversion to an active form), calcium absorption may be very low—approximately 10 percent—for both food and supplements. Heaney (2001) estimates that of a 750-mg calcium supplement, only 75 mg will be absorbed. Of that 75 mg, approximately 36 mg are retained (much is lost in the urine) and available to offset bone resorption. Although calcium absorption does vary and absorption can increase to some degree when an individual is deficient, it is easy to see how low calcium and vitamin D intakes negatively affect bone health.

As explained earlier, the calcium concentration in extracellular fluid must remain stable, and bone provides the calcium (via slow exchange) that would normally be provided by the diet. Calcium from trabecular bone is easily resorbed because it has much greater surface area and higher metabolic activity, but losses from cortical bone also occur. Other factors, such as estrogen, also influence bone resorption, and some loss of bone is a natural consequence of aging.

Long-term calcium deficiency is a risk factor for osteoporosis, a disease of the skeletal system characterized by low bone mineral density and deterioration of the bone's microarchitecture. Osteoporotic bones are fragile and more prone to fractures, particularly in the spine (vertebrae), wrist, and hip. Assessing bone density and preventing and treating osteoporosis are discussed in more detail in Chapter 12.

Bone Loss Associated with Aging. Estimates of yearly bone loss for women between the ages of 18 and 50 years range from 0.5 to 1.5 percent per year. With the onset of menopause, estrogen deficiency results in a yearly bone loss of 1 to 2 percent, initially much of it from the vertebrae. In the decade after menopause, women can lose a total of 20 to 30 percent of bone density from trabecular bone and up to 5 to 10 percent from cortical bone (Ilich and Kerstetter, 2000). Older men lose bone density at a fairly constant rate of about 1 percent per year (Kenny and Prestwood, 2000).

Bone resorption increases with both age and estrogen deficiency. The most important mechanism appears to be the increase in the number of units that undergo remodeling. A second mechanism is the incomplete bone formation that occurs when bone resorption outpaces bone formation. Once the remodeling process is complete at a remodeling site, further modifications cannot be made. Thus, if a remodeling cycle is completed and formation did not equal resorption, then the bone loss in that remodeling unit is irreversible (Compston, 2001).

Preventing or Reducing Bone Loss Associated with Aging. During the period when peak bone mineral density can be attained, the emphasis is on adequate calcium intake and weight-bearing exercise. After this physiological period is complete, the goal is to prevent and then slow the loss of calcium from bone. This is also accomplished with adequate calcium intake and weight-bearing exercise. How effective is calcium intake in preventing loss of calcium from bone? Between the period of the attainment of peak bone mineral density and menopause, adequate calcium intake through diet or supplements helps to slow the loss of calcium by about 1 percent a year. Recall that bone loss during this period ranges from about 0.5 percent to 1.5 percent. A reasonable conclusion is that bone calcium loss is reduced or prevented in many middle-aged women, as well as men, if calcium intake is adequate.

In postmenopausal women, a meta-analysis of research studies suggests that two or more years of calcium supplementation have a small but positive effect on bone mineral density and some reduction in vertebral fractures. It is not known if supplementation reduces the incidence of nonvertebral fractures (Shea et al., 2004). When research is evaluated based on the number of years since menopause, studies of women in the early postmenopausal period (5 to 8 years after menopause) show that calcium supplementation has a small effect on slowing the loss of calcium from cortical bone but not trabecular bone. This effect appears to be greatest for the women who consumed the least amount of calcium in their diets prior to supplementation. Studies of women after the first postmenopausal decade (10 to 20 years after menopause) show that adequate calcium intake, either through food or supplementation, helps to slow the loss of calcium from bone.

In the third postmenopausal decade and beyond (studies of women ages 70 and above), calcium supplementation appears to be beneficial. Calcium deficiency, in both older men and women, can result in hyperparathyroidism. Recall that when blood calcium is low, parathyroid hormone is elevated, which stimulates bone resorption and normalizes the blood calcium concentration. Calcium deficiency may be a result of low calcium intake, vitamin D insufficiency, or both. It is common for women over 70 to have low calcium intakes, reduced vitamin D absorption and/or conversion, and increased parathyroid hormone concentrations. Calcium and vitamin D supplementation resolves the hyperparathyroidism, thus preventing the bone resorption that accompanies this medical condition (Morgan, 2001; Kenny and Prestwood, 2000).

Adequate calcium intake via calcium-containing foods or supplements after age 35 is a prudent approach and may help to slow the loss of calcium from bone in some cases, but it is limited in its effectiveness by the effects of aging on bone remodeling. Calcium intake is not the sole influence on bone mineral density; thus, food or supplemental calcium cannot be expected to offset all of the various factors that cause a decline in BMD. The important point is the need for prevention; after age 35 even a sufficient calcium intake cannot compensate for a relatively low amount of calcium in bone since peak bone mineral density is achieved in childhood, adolescence, and young adulthood.

Results of exercise studies have been mixed, but high-intensity weight-bearing activity and resistance training generally maintains or increases bone mineral density in postmenopausal women. However, these activities must be safe for older women to perform, and those who have been diagnosed with osteoporosis should discuss with their physicians the most appropriate types of exercise. Unfortunately, low-intensity weight-bearing activities, such as walking, do not put enough stress on the bone to positively impact bone density, although there are many other benefits to walking. Any exercise by older women that increases muscle strength and stability is beneficial for the prevention of falls, which cause ~90 percent of hip fractures and ~50 percent of vertebral fractures (Beck and Snow, 2003).

Bone Loss Associated with Lack of Estrogen. Estrogen deficiency is known to be a powerful factor in bone loss. Estrogen affects osteoclast number and activity, with a decrease in estrogen being associated with an increase in osteoclast proliferation and activity (Compston, 2001). The lifespan of the osteoclast appears to increase with estrogen deficiency (Seeman, 2002). Estrogen deficiency may also be associated with increased erosion depth in trabecular bone. Erosion depth affects bone strength (Compston, 2001).

Estrogen deficiency is generally associated with menopause when estrogen production naturally and substantially declines. However, estrogen deficiency can also be present in adolescent and young adult female athletes. Amenorrhea or oligomenorrhea (absent or irregular menstruation, respectively) in young female athletes can be a result of consistently low energy intake coupled with high energy expenditure (known as energy drain), inadequate nutrient intake, and the increase in exposure to stress hormones such as **epinephrine, norepinephrine,** and **cortisol** that accompanies intense training. Distance runners, ballerinas, and gymnasts are at greatest risk for delaying the onset of menstruation, experiencing irregular menstruation, or developing amenorrhea (Gordon, 2000). Some, but not all, of these athletes have eating disorders. Low bone mineral density, amenorrhea, and low energy intake, especially precipitated by disordered eating, are three interrelated factors known as the Female Athlete Triad. Each of these factors is discussed in depth in Chapter 13.

The acquired estrogen deficiency described above predisposes these young women to a failure to achieve peak bone mineral density, the loss of calcium from bone, a greater incidence of stress fractures, osteopenia (low bone mineral density), and osteoporosis (De Souza and Williams, 2005). Therein lies the danger of assuming that estrogen deficiency is only associated with age.

Two sports, distance running and gymnastics, have a high prevalence of athletes with low estrogen concentrations and/or amenorrhea. Distance runners often have significantly lower bone mineral density when compared to age-matched controls (see Chapter 13 for a review of specific studies). Gymnasts, however, have above-normal bone mineral density even when estrogen concentration and menstrual status are abnormal. The high-impact training associated with gymnastics seems to offset the negative effects on bone density associated with amenorrhea. Although amenorrhea is not a normal or desirable condition, the differences in bone density between highly trained distance runners and gymnasts highlight the substantial effect of high-impact exercise on bone mineral density (Beck and Snow, 2003).

DIETARY STRATEGIES FOR ADEQUATE CONSUMPTION OF BONE-RELATED MINERALS

It has been documented in dietary surveys that many adults, including some athletes, do not consume sufficient calcium. While calcium is not the only mineral associated with bone health, it is the one that receives the most attention.

Calcium. Milk and milk products are excellent sources of calcium. An 8-oz (240 ml) glass of milk contains approximately 300 mg, so three to four glasses a day would meet the recommended calcium intake for adults of all ages. One 8-oz cup of yogurt also contains approximately 300 mg of calcium. Athletes who are trying to limit fat and/or caloric intake often choose nonfat versions of these foods. Other dairy products, such as 1½ oz of cheese, contain the equivalent amount of calcium found in 8 oz of nonfat milk but their fat contents are higher.

Many adolescents and adults cannot digest lactose (milk sugar) because they lack sufficient lactase, the enzyme needed for lactose breakdown. They may wish

Epinephrine: Adrenaline. Primary blood pressure raising hormone.

Norepinephrine: Noradrenaline. Hormone and neurotransmitter.

Cortisol: A hormone that is elevated under conditions of physiological (e.g., exercise) or psychological stress. Has anti-inflammatory and immunosuppressive effects.

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Milk and milk products are excellent sources of calcium.

© Felicia Martinez/PhotoEdit

Those with lactose intolerance may use some of the products shown, which allows them to include calcium-dense dairy foods in their diets.

to use lactase tablets, which provide the enzyme, or consume lactase-treated milk and milk products, which predigest the lactose. Some people have moderately reduced lactase production and can tolerate milk products that have been fermented, which reduces the lactose content. Examples of such products include yogurt and aged cheeses such as Parmesan, cheddar, and Gouda. These strategies help lactose-intolerant individuals to include some calcium-dense dairy foods in their diets.

Although milk and milk products contain a relatively large amount of calcium, calcium is not found exclusively in dairy foods. It is more difficult, but not impossible, to consume enough naturally occurring, nondairy calcium-containing foods. The difficulty is a result of a lack of concentrated sources of calcium and the need to consume a wide variety of foods. For example, 1 cup of cooked broccoli has about 100 mg of calcium, one-third the amount of an 8-oz glass of milk. Other vegetable sources of calcium include Brussels sprouts, collard greens, green cabbage, kale, kohlrabi, mustard greens, and turnip greens. Calcium is also found in some fish, beans, grains, and nuts in varying amounts. Table 9.9 lists the calcium content of some nondairy sources. Eaten over the course of a day, the foods in the amounts listed in the table would total 1,051 mg of calcium.

Table 9.9 Nondairy Sources of Calcium

Food and Amount	Calcium (mg)
2 pancakes	176
1 cup blackberries	46
1 whole wheat English muffin	175
2 T peanut butter	12
2 figs	54
8 oz San Pellegrino mineral water	50
4 oz canned salmon	240
1 cup broccoli	94
1 oz almonds	74
½ cup cooked acorn squash	54
1 mixed grain roll	24
1 medium orange	52

Legend: mg = milligram; T = tablespoon; oz = ounce

Together these foods total 1,051 mg of calcium.

Some foods are calcium fortified. Soy milk, rice milk, and orange juice are beverages that *may* be fortified with calcium. Even when calcium is added the amount can vary among brands, so the label must be checked to determine the calcium content. A common level of fortification for soy milk is 300 to 350 mg in an 8-oz glass, approximately the same amount of calcium found in dairy milk. However, the form of calcium added may not be as well absorbed, so 300 mg of calcium from soy milk may only be the equivalent of 225 mg of calcium found in cow's milk (Heaney et al., 2000).

Tofu (soy bean curd) can be processed with either calcium sulfate or calcium chloride. Tofu that has been processed using these compounds contains approximately 110 mg of calcium in a ½-cup (3-oz) serving. Many other foods have calcium added, including breakfast cereals and sports bars. It may not be immediately clear how many milligrams of calcium are contained because calcium may be listed as a percentage. This percentage is calculated using the Daily Value (DV) for calcium, 1,000 mg. For example, if the label on an energy bar states that it contains 2 percent

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Dark green vegetables are good nondairy sources of calcium.

© David Young-Wolff/PhotoEdit

Soy milk and rice drinks are often fortified with calcium.

of the DV for calcium, there are 20 mg of calcium in that bar (1,000 mg × 0.02 = 20 mg).

Calcium is a critical nutrient for all people of all ages. Milk was once accepted as the ideal beverage for children, but milk consumption is declining in children due, in part, to increased soda and juice consumption. Milk consumption often declines further during adolescence and adulthood. There is no one food that must be consumed or dietary pattern that must be followed in order for calcium needs to be met. However, each person needs to consume an adequate amount, and some or all of the following strategies may be used to obtain sufficient calcium daily.

Consume:

- milk and milk products
- lactase-treated products or lactase tablets
- fermented milk products such as yogurt or aged cheeses
- calcium-containing vegetables such as cabbage, broccoli, greens
- calcium-fortified products such as orange juice, soy milk, cereal, sports bars
- calcium supplements

Phosphorus, Fluoride, and Magnesium. Phosphorus is so abundant in food and the percentage absorbed is so high that deficiencies are unlikely to occur. Fluoride is typically obtained by infants and children through the use of fluoridated vitamins and by adults through the consumption of fluoridated water. The fluoride content of tap water is available to consumers by contacting their local water agency. Magnesium is found in green leafy vegetables, nuts, seeds, and beans and legumes, such as soybeans, kidney beans, pinto beans, and lentils. It is found naturally in whole grains (e.g., wheat germ, brown rice) but is lost in the processing when grains are highly refined (e.g., white bread, white rice). Drinking water is described as "hard" if it contains minerals; one of the minerals found in hard water is magnesium.

What's the point? Adequate nutrient intake, in particular calcium and vitamin D, and weight-bearing exercise are necessary throughout life for bone health. Calcium supplementation in mid and later life has some benefit, but cannot completely offset the calcium loss from bone that accompanies aging. Athletic amenorrhea is detrimental to bone health and performance.

The Roles of Minerals in Blood Formation

A favorite adage among endurance athletes is "oxygen is everything." It is no wonder that athletes, particularly endurance athletes, look at training and nutrition strategies that result in optimal oxygen delivery. The nutrient most associated with oxygen is iron.

BLOOD-FORMING MINERALS

Blood consists of three types of cells—**erythrocytes** (red blood cells), **leukocytes** (white blood cells), and **platelets.** This section will focus only on erythrocytes, the blood cells whose primary function is the transport

Erythrocyte: Red blood cell.

Leukocyte: White blood cell.

Platelet: A cell found in the blood that assists with blood clotting.

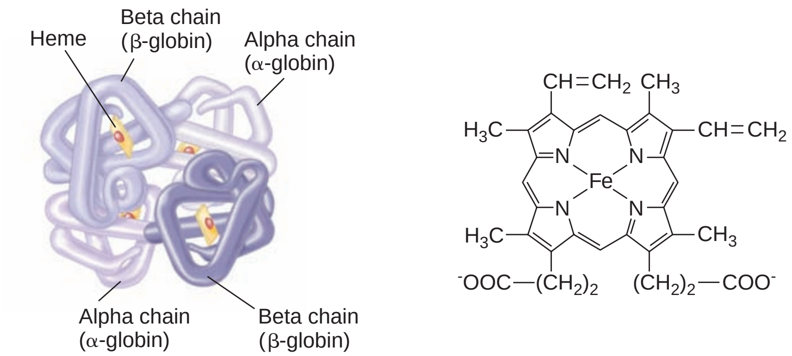

Figure 9.2 Simplified Hemoglobin and Heme Molecules

Hemoglobin consists of four polypeptide chains and four heme molecules. The iron in each heme molecule forms six bonds—four with nitrogen, one with globin (protein chain), and one with oxygen.

of oxygen. Secondary functions include carbon dioxide and nitric oxide transport. Simply stated, oxygen must be picked up from the lungs and transported to cells. Conversely, carbon dioxide must be picked up from cells and transported to the lungs. Both of these processes depend on hemoglobin, which transports 98.5 percent of the oxygen (1.5 percent is dissolved in the blood) and 30 percent of the carbon dioxide (60 percent is transported as bicarbonate and 10 percent is dissolved in blood) (Sherwood, 2007).

Hemoglobin (**heme** = iron, globin = protein) is an iron-containing protein found in the red blood cells that can bind oxygen (see Figure 9.2). At the center of the heme portion of the molecule is iron (Fe). This iron atom forms six bonds, four with nitrogen (to maintain the molecule's ring structure), one with the amino acids in the protein portion of the molecule (globin), and one with oxygen. There are four heme molecules in each molecule of hemoglobin; thus, a fully saturated hemoglobin molecule can carry four molecules of oxygen. Each red blood cell (RBC) contains more than 250 million molecules of hemoglobin. There are approximately 30 trillion red blood cells, so it is easy to see that the body has a phenomenal capacity for oxygen transport (Sherwood, 2007).

To transport oxygen throughout the body in the necessary amounts, blood must have a carrier or binding mechanism. Oxygen must bind to this carrier easily and rapidly in the lungs, remain bound as it is distributed throughout the body, yet release easily from the carrier so oxygen can be removed from the blood at sites in the body where the oxygen is needed. Iron-containing hemoglobin has unique properties that allow it to be an ideal oxygen carrier in the blood.

In areas of the body where oxygen levels are high (high **partial pressures** of oxygen), such as the lungs, hemoglobin has a high affinity for oxygen and is able to bind it readily. This is important for the fast and complete diffusion of oxygen from the lungs into the blood flowing through the pulmonary circulation. Under most circumstances, both at rest and for most people during exercise, there is nearly 100 percent saturation of oxygen on the hemoglobin molecules in the blood that passes through the pulmonary circulation. This is reflected in a common clinical test, the O_2-Hb saturation percentage, usually measured with a pulse oximeter or by the more invasive blood gas analysis.

Hemoglobin molecules have a unique ability to change their binding affinity for oxygen in areas of the body that contain less oxygen, in other words, when the partial pressure of oxygen is reduced. When the oxygen-laden blood arrives at tissues in the body that need oxygen, such as exercising muscle, the environment that has a lower partial pressure of oxygen results in hemoglobin reducing its binding affinity for oxygen, which allows the red blood cells to release oxygen molecules for transport into the cells. Iron-containing hemoglobin is critical to the effective uptake and delivery of oxygen to all tissues in the body. This process must continue constantly at rest, but is put under particular stress during exercise when oxygen demands can be dramatically increased.

Sufficient oxygen-carrying capacity is critical for all athletes, but especially endurance athletes. One measure of normal oxygen-carrying capacity is **hematocrit,** which is the amount of red blood cells expressed as a percentage of the total volume of blood plasma (the liquid portion of the blood). Normal hematocrit is approximately 42 percent for women and 45 percent for men. The general term *anemia* refers to a reduced oxygen-carrying capacity and is reflected in a hematocrit of approximately 30 percent. Another measure is the concentration of hemoglobin in the blood, which averages about 15 g/dl (dl = deciliter, or 100 milliliters) in males and slightly less, 14 g/dl, in females. Anemias

Table 9.10 Nutritional and Nonnutritional Anemias

Nutritional Anemias	Nonnutritional Anemias
Iron deficiency anemia	Aplastic anemia (RBC production depressed)
Vitamin B_{12} deficiency anemia	Hemolytic anemia (RBCs are destroyed)
Folate deficiency anemia	Sickle cell anemia (RBCs are abnormally shaped)
Anemia can result from a deficiency of any nutrient needed for RBC production (e.g., zinc, copper)	

Legend: RBC = red blood cell

can be caused by nutritional or nonnutritional factors as shown in Table 9.10.

Nutritional anemias are a result of a nutrient deficiency due to low intake or poor absorption. Some are vitamin-related (e.g., vitamin B_{12} or folic acid), but the most prevalent nutritional anemia is due to iron deficiency. Having sufficient iron stores by consuming an adequate amount of iron daily can prevent iron-deficiency anemia. Approximately 25 percent of the body's iron is found in storage in the liver, spleen, and bone marrow and this stored iron can be released and transported for incorporation into hemoglobin. On average, a well-nourished adult male has about 800 to 1,000 mg of stored iron. A well-nourished adult female has considerably less but still has sufficient stores to support normal red blood cell formation. With near-maximum iron stores, an adult male could sustain normal hemoglobin synthesis for about two years while consuming an iron-poor diet (Shah, 2004).

However, not all adults have excellent iron stores. Some may also experience higher-than-normal iron losses (e.g., large losses of blood via menstruation, small daily losses as a result of GI bleeding), low iron absorption, and low iron intake. These factors, singly or in combination, may tax an already low supply of stored iron. When iron stores are depleted and iron intake is low, then red blood cell production is negatively affected. Iron-deficiency anemia results in a decreased number of red blood cells, smaller cells, and a lower concentration of hemoglobin per cell. This results in less hemoglobin being available to transport oxygen. Not surprisingly, a common symptom associated with iron-deficiency anemia is fatigue.

Normal hemoglobin synthesis is also dependent on copper, another of the microminerals. Iron is stored in its ferrous form (Fe^{2+}) but must be converted to its ferric form (Fe^{3+}) to be transported in the blood. This conversion requires a copper-containing enzyme, ceruloplasmin. Humans can develop an anemia that is a result of a long-term copper deficiency. Excessive zinc interferes with copper absorption and can be one of the causes of this kind of anemia.

Myoglobin is an iron-containing protein found in muscle fibers that functions very similarly to hemoglobin, only in skeletal muscle. Myoglobin binds small amounts of oxygen within the muscle to provide a small reservoir for rapid increases in oxygen utilization. The body doesn't "store" oxygen per se, but myoglobin acts as an oxygen buffer when demand is increased until oxygen delivery from the blood can be increased. Myoglobin also facilitates the transfer of oxygen molecules from the red blood cells in the blood, through the muscle cells, and into the mitochondria. Highly aerobic tissues such as slow twitch (Type I) and intermediate (IIa) muscle fibers contain a higher concentration of myoglobin. Because aerobic exercise training stimulates the oxidative energy system, a common adaptation is an increase in myoglobin concentration in muscle, which helps increase the body's aerobic capacity.

Measuring the Progression of Iron Deficiency. Iron is unique among minerals in that there are a variety of blood tests that can detect normal and reduced stores and physiological function. These tests measure the amount of iron in red blood cells and estimate the level of iron storage. The most common measures are hemoglobin, hematocrit, and **serum** ferritin. When these values are within the recommended ranges, iron status is considered to be normal and red blood cell production is adequate. Normal laboratory values are listed in Table 9.11.

When iron intake is poor, iron status declines over time. Iron stores become depleted and this can be detected by measuring ferritin. **Ferritin** is the protein that stores iron in tissues (predominantly in the liver). The amount of ferritin circulating in the blood reflects the amount stored, so this blood test is a good indicator of iron storage. The normal values range from 12 to 300 ng/ml for males and 12 to 150 ng/ml for females. As the amount of storage iron declines, the amount of

Heme: Iron. Also refers to a form of iron that is well absorbed.

Partial pressure: The pressure exerted by one gas within a mixture of gases.

Hematocrit: The percentage of the volume of blood that is composed of red blood cells.

Serum: The fluid that separates from clotted blood. Similar to plasma but without the clotting agents.

Ferritin: Iron-containing storage protein.

Table 9.11 Iron-Related Blood Tests

Blood Test	Normal Values*	Explanation
Hematocrit	40.7 to 50.3% (males) 36.1 to 44.3% (females)	Measures the proportion of red blood cells in blood plasma. Values vary with altitude.
Hemoglobin	13.8 to 17.2 g/dl (males) 12.1 to 15.1 g/dl (females)	Measures the iron-containing protein in red blood cells. Values vary with altitude.
Ferritin	12 to 300 ng/ml (males) 12 to 150 ng/ml (females)	Indicates amount of iron stored.
Serum iron	60 to 170 mcg/dl	Measures the amount of iron in transferrin. Normally 30% of the available sites are carrying iron.
Transferrin saturation	20 to 50%	Indicates that there is not enough iron to fill the available sites.
Total iron binding capacity (TIBC)	240 to 450 mcg/dl	Indirect measure of transferrin.

Legend: g/dl = grams per deciliter; ng/ml = nanograms per milliliter; mcg/dl = micrograms per deciliter

*Normal values may vary by laboratory.

ferritin in the blood declines; so although the absolute value is important, repeated blood tests over time (e.g., every six months) also indicate if stores are declining. For example, an endurance athlete may have a complete blood count (CBC) two times a year for two years. The four consecutive ferritin tests are all within the normal range—120, 110, 85, and 63 ng/ml—but these "normal" values also suggest that iron stores are declining. In a moderate subclinical iron deficiency, hemoglobin and hematocrit values are in the normal range because iron-deficiency anemia develops slowly even after iron depletion. This subclinical deficiency is referred to as iron deficiency without anemia.

Hemoglobin measures the iron-containing protein found in red blood cells. Values below the normal range may indicate iron-deficiency anemia, a recognized disease, or false (runner's) anemia, which is not a true anemia. Normal hemoglobin values are 13.8 to 17.2 g/dl for males and 12.1 to 15.1 g/dl for females. Those who live or train at higher altitudes generally have hemoglobin concentrations nearer the upper end of the normal range. Values below 13.8 and 12.1 g/dl, for males and females respectively, are usually indicative of iron-deficiency anemia, but false anemia should be ruled out. In iron-deficiency anemia the body lacks the iron it needs to produce a normal amount of red blood cells. Hematocrit is also reduced because it is a measure of the proportion of red blood cells in blood plasma. In false (runner's) amemia, the slightly decreased hemoglobin value is due to plasma volume expansion associated with endurance training.

Iron Deficiency, Iron-Deficiency Anemia, and Performance. It is known that iron-deficiency anemia impairs performance. When iron-deficiency anemia is present, $\dot{V}O_{2max}$ (i.e., aerobic capacity) declines and subsequently increases with iron supplementation. The reduction in $\dot{V}O_{2max}$ is a result of impaired oxygen transport. Studies have documented that $\dot{V}O_{2max}$ can decline between 10 to 50 percent and reflects the severity of the anemia. Aerobic capacity does not seem to decline in people with an iron deficiency that has not progressed to anemia because oxygen transport is normal (Haas and Brownlie, 2001). Recall that those with iron deficiency without anemia (i.e., subclinical iron deficiency) have normal hemoglobin and hematocrit concentrations.

Iron-deficiency anemia also affects endurance capacity or the length of time until exhaustion at a given workload. This is different from aerobic capacity because endurance capacity depends on both oxygen transport and oxygen utilization. The role of iron in oxygen transport has been explained, but iron also plays a role in oxygen utilization because some oxidative enzymes contain iron.

Energy is produced either as heat or ATP from the flow of hydrogen molecules and electrons down the electron transport chain located in cell mitochondria. As part of this metabolic pathway, iron is oxidized and reduced so that the transfer of electrons can proceed. A decrease in iron-containing compounds would negatively affect oxygen utilization. Studies have documented that iron-deficiency anemia reduces endurance capacity. Studies in animals suggest that iron deficiency without anemia also affects endurance capacity, but this has not been documented in human studies. A prudent approach is to maintain normal iron status to avoid any potential problems with endurance capacity (Haas and Brownlie, 2001).

Prevalence of Iron Deficiency and Iron-Deficiency Anemia in Athletes. The prevalence of iron deficiency and iron-deficiency anemia in athletes is hard to determine. Most adult male athletes can easily meet their need for iron (8 mg daily) through diet, so the prevalence of iron-deficiency anemia is low in males. It is occasionally seen in male endurance runners and male athletes who routinely take medications that relieve pain but also induce bleeding (e.g., **aspirin, Ibuprofen**).

Some adolescent male athletes may experience iron-deficiency anemia if they lack both sufficient kilocalories and iron-containing foods in their diet. The demand for iron resulting from rapid growth during adolescence, including an expanding blood volume, can outstrip the intake of iron. Still, the prevalence is low partly because very demanding periods of physiological growth favor iron absorption.

Female athletes who are menstruating are at risk for manifesting iron-deficiency anemia. The loss of menstrual blood, thus the loss of iron, requires that iron be resupplied. This *can* be accomplished through diet alone, although the need for iron is relatively high (18 mg). Many factors may result in a poor dietary iron intake. Low caloric intake, low or absent animal protein intake, or high intake of iron inhibitors (e.g., fiber) can result in an insufficient supply of dietary iron (Beard and Tobin, 2000). Some female athletes may also have an appreciable loss of iron in sweat, feces, and urine due to the stress of heavy training.

While any female athlete may be at risk, iron-deficiency anemia is most prevalent in female distance runners, gymnasts, and other athletes who have a restricted eating style. These athletes tend to have a low caloric intake compared to their energy output and therefore a low iron intake. The energy imbalance may be substantial and is due to a high energy expenditure from a heavy training volume and a commensurate inadequate intake of energy, often in the belief that losing weight and being a lower percentage of body fat will aid performance. In addition to inadequate total energy intake, these athletes often choose high-carbohydrate, low-fat, low-protein diets that are also low in iron. Some prefer to be vegetarians, and iron found in plant sources is not as well absorbed as that found in animal foods (Beard and Tobin, 2000).

Regardless of the estimated prevalence in the general athletic population or the specific sport, each athlete should have iron status periodically assessed. This is easily accomplished with a CBC and serum ferritin as part of a yearly physical. Those who are known to be at greatest risk—female, vegetarian, low-energy intake athletes—should have their iron status assessed more frequently, often two times a year. All athletes can be proactive in avoiding declines in iron status by consuming sufficient dietary iron daily.

Christina Micek

Iron is found in many foods, but often in small amounts. Adequate dietary iron intake is associated with adequate energy intake.

DIETARY STRATEGIES FOR ADEQUATE CONSUMPTION OF BLOOD-RELATED MINERALS

Sufficient dietary iron intake is correlated with adequate energy intake. Although there are a few foods that are excellent sources of iron (e.g., oysters, clams) and some foods that contain moderate amounts (e.g., meat, dried beans, green leafy vegetables), many foods contain only small amounts. This wide distribution of small amounts of iron in food means that iron intake generally increases as caloric intake increases.

The average adult diet in the United States contains 6 to 7 mg of iron for every 1,000 kcal consumed (Beard and Tobin, 2000). Most males, especially male athletes, consume over 2,000 kcal daily. Even without emphasizing iron-rich foods in their diets, males are likely to consume at least 12 mg daily, more than the 8 mg recommended. Adequate dietary intake is one reason that males rarely manifest iron-deficiency anemia.

It is easy to see why women are at much greater risk for iron deficiency. If a woman consumed 2,000 kcal daily, then her likely intake of 12 to 14 mg of iron would be less than the recommended 18 mg. But many females, including female athletes, restrict caloric intake. A female athlete who is trying to attain or maintain a low percentage of body fat and restricts energy intake to 1,500 kcal daily would be expected to consume only 9 mg of iron daily, half the recommended amount. Females who prefer a dairy-based diet and consume high levels of milk, yogurt, and cheese also tend to have a low iron

Aspirin: Medication used to relieve pain, reduce inflammation, and lower fever. Active ingredient is salicylic acid.

Ibuprofen: Medication used to relieve pain, reduce inflammation, and lower fever.

intake since milk and milk products are relatively poor sources of iron compared to beans, grains, nuts, vegetables, and meat, poultry, and fish.

In addition to the amount of iron consumed, the form of iron is a factor because it affects absorption. Iron is found in one of two forms in food—heme or **nonheme.** Heme iron, which is found in animal foods, is well absorbed. Absorption is estimated to be 15 to 35 percent of the heme iron consumed. In contrast, nonheme iron, which is found in plant foods, has much lower absorption, in the range of 2 to 20 percent. The presence of ascorbic acid (vitamin C) enhances the absorption of both heme and nonheme iron. A compound found in meat, fish and poultry, known as MFP factor, enhances heme iron absorption. Nonheme sources of iron (e.g., grains, vegetables) may contain iron absorption inhibitors such phytates and oxalates.

How can athletes best use this information to plan a diet that is adequate in iron? Athletes should focus first on obtaining sufficient energy (kilocalories). Those who have low or marginal energy intakes should focus on including iron-rich foods in their diets. Increasing intake of iron-dense foods helps to provide more iron while not substantially increasing caloric intake. Vegetarian athletes, who do not consume the more absorbable heme iron or MFP factor, need to focus on the quantity of iron consumed as well as ensuring that a variety of plant foods are eaten. The focus on variety helps to modulate the intake of compounds that are known to inhibit iron absorption. Consuming vitamin-C-containing foods at the same meal can also be beneficial.

Table 9.12 lists iron-containing foods. The table has been subdivided into heme and nonheme sources. Foods are then listed in descending order according to the amount of iron contained. Choosing foods nearer the top of each category is recommended for athletes who are at risk for iron-deficiency anemia.

Although it receives less attention, an adequate copper intake is also important. Excellent sources of copper include seafood, nuts, and seeds. Copper is also found in whole grains, dried beans, and some green leafy vegetables. Most nutrient analysis programs do not include the copper content of foods in the database, so it is difficult to assess dietary intake. The DRI is 900 mcg for adults and the average intake by U.S. adults is more than 1,000 mcg.

What's the point? Low dietary iron intake may lead to iron-deficiency anemia, which has a negative effect on training, performance, and health. Iron supplementation can slowly help to build back iron stores. Menstruating females who restrict caloric intake are at the greatest risk for developing iron-deficiency anemia.

Table 9.12 Iron-Containing Foods

Food	Iron (mg)
Heme Sources	
3 oz steamed clams	26.6
5 steamed oysters	5 to 16.5
3 oz beef liver	5.3
3 oz beef	3
1 cup tuna fish	2.4
3 oz dark meat chicken	1.3
3 oz light meat chicken	1.1
3 oz halibut	0.9
3 oz pork loin	0.8
Nonheme Sources	
1 cup cereal (iron added, amount depends on the brand)	2 to 16
1 cup instant oatmeal (iron added)	10
1 cup soy beans	8.8
1 cup lentils	6.6
1 cup pinto beans	4.2
½ cup spinach, cooked from fresh	3.2
½ cup spinach, cooked from frozen	1.4
1 cup soy milk	1.4
½ cup tofu	1.3
1½ oz raisins	0.87
1 slice bread (iron added)	0.8
1 egg, white and yolk	0.72

Legend: mg = milligram; oz = ounce

The Roles of Minerals in the Immune System

Intense training and prolonged exercise is immunosuppressive. In other words, heavy training, especially for endurance athletes, depresses the immune system. Many endurance athletes have frequent infections, particularly upper respiratory infections, during periods of intense or prolonged training, which then undermines their ability to maintain training and negatively affects performance. The two nutritional factors most associated with proper immune system function are adequate protein and total energy intakes. However, several minerals are also involved (e.g., zinc, magnesium, selenium) and inadequate intake of these minerals impairs immune response. Conversely, excessive levels of some minerals (e.g., zinc, iron) can impair the immune system.

MINERALS AND IMMUNE SYSTEM FUNCTION

The immune system is the body's defense against disease. Effective immunity relies upon a system of tissues and organs that are supported by adequate nutrition; nearly every tissue is involved. The skin serves as a physical barrier, hairlike projections known as cilia and mucosal secretions guard against invasion via the respiratory tract, and the GI tract can kill microorganisms with hydrochloric acid, digestive enzymes, and other secretions. These are examples of nonspecific immunity, the body's first line of defense against potentially harmful microorganisms. Another form of nonspecific resistance is inflammation, which involves the release of chemicals from phagocytic cells that destroy microbes.

While nonspecific immunity is important, the body must have more specific ways to fight disease. This is known as acquired immunity, a special immune system response that forms antibodies and activates lymphocytes (white blood cells). Acquired immunity cannot occur until a specific microorganism has invaded the body (now called an antigen) and the immune system forms antibodies in response. Each antigen (microorganism) has a unique protein or large polysaccharide that the body can detect and remember. When reexposed to that specific antigen, the antibody response is rapid (within a few hours) and potent (circulating for months rather than weeks). All antibodies are immunoglobulins, compounds that are made of several polypeptide (protein) chains.

Regulation of the immune system is the responsibility of the cytokines. Cytokines are protein-containing compounds that are released in response to chronic inflammation, infections, and other disease processes. Interleukins (IL) and interferon (INF) are examples of regulatory cytokines (Guyton and Hall, 2005). Detailed information about the immune system can be found in any physiology or medical physiology textbook.

The effect of exercise on the immune system follows the "too much of a good thing may be harmful" theory. Considering just one outcome of immune function, upper respiratory tract infections (URTI), the results of a number of studies show that moderate exercise bolsters immune function as evidenced by lower risk for or incidence of URTI. However, people involved in more rigorous or prolonged exercise, such as marathon running or prolonged running training, have a greatly increased risk for upper respiratory tract infections (Nieman, 1994).

Zinc. Zinc is necessary for proper cellular function because of its role as a constituent/cofactor in more than 200 enzyme systems. It has wide-reaching effects on DNA, RNA, and cellular functions; thus many different types of immune system cells are affected when zinc is deficient or excessive. Zinc deficiency results in damaged skin cells and gastrointestinal cells, both of which are involved with nonspecific immunity. Examples of ways that zinc deficiency negatively affects specific immunity include decreased production and function of lymphocytes. An excessive zinc intake also decreases lymphocyte response and inhibits copper absorption. A copper deficiency is also immunosuppressive (Shankar and Prasad, 1998).

The Dietary Reference Intake for zinc is 8 mg for females and 11 mg for males. The Tolerable Upper Intake Level is 40 mg. The median (50th percentile) intake for adults in the United States is 9 mg for women and 13 mg for men, so clearly zinc requirements can be met through diet alone. Those who meet the DRI for zinc tend to consume sufficient kilocalories and animal foods such as red meat and milk (Institute of Medicine, 2001).

Unfortunately, it is estimated that up to 90 percent of endurance athletes do not meet the DRI for zinc. Many endurance athletes limit red meat intake and consume high-carbohydrate, relatively low protein diets (Micheletti, Rossi, and Rufini, 2001). This puts them at risk for subclinical zinc deficiencies and makes zinc supplementation attractive. But supplemental zinc can interfere with the absorption of other nutrients, especially iron and copper, and can suppress the immune system. Since caution is warranted, no more than 15 mg of supplemental zinc daily is recommended.

Recurring infections are the bane of many endurance athletes. Researchers have studied the effect of zinc supplements on prevention of upper respiratory tract infections and treatment of colds. The study results have been mixed and the evidence in support of zinc supplement use to prevent colds and infections is limited. Gleeson, Nieman, and Pedersen (2004) recommend that endurance athletes monitor their zinc status. This can be done by assessing dietary zinc intake and through a specialized blood test. Given poor intake, higher-than-normal losses in sweat and urine, and evidence of altered zinc status, low-dose zinc supplementation would be appropriate.

Selenium. At least 20 selenium-containing proteins are involved in cellular metabolism; thus selenium is an

Nonheme: A form of iron with a lower rate of absorption (see heme).

essential nutrient. Its exact roles in the immune system are not known, but depressed immunity is associated with selenium deficiency. When selenium is deficient there is less proliferation of lymphocytes, immunoglobin production is decreased, and the ability to kill pathogens is reduced (Arthur, McKenzie, and Beckett, 2003). It does not appear that athletes are selenium deficient (Speich, Pineau, and Ballereau, 2001). Food sources of selenium include meat, fish, poultry, whole grains, and nuts.

Iron. Iron has already been discussed in detail due to its role in oxygen transport. Iron also plays a role in the proper functioning of the immune system. Most studies suggest that individuals with iron deficiency are at a greater risk for infection. Iron is necessary for proper cellular function and a deficiency can affect the iron-containing enzymes of immune cells. Iron also helps to regulate the cytokines (Beard, 2001). Excess iron can impair immune system function (Gleeson, Nieman, and Pedersen, 2004).

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A nutritious diet contains adequate kilocalories and a variety of foods, such as those shown here. This dietary pattern is likely to provide sufficient carbohydrates, proteins, fats, vitamins, and minerals.

The Adequate Intake of All Minerals

At first glance, it may seem as if obtaining the proper intake of the 21 known essential minerals would be difficult. Fortunately, it is not necessary to measure and track the intake of all the macro- and microminerals in the diet. Because minerals are found in small amounts in many different foods, the best way to ensure adequate mineral status is to: 1) consume adequate kilocalories daily, 2) eat a variety of nutritious foods that have been minimally processed, and 3) consume an adequate amount of calcium and iron from food. Calcium and iron, when obtained from naturally occurring food sources, are fairly good predictors of the intake of the other minerals. In other words, when calcium and iron intake from food is adequate then the intake of the remaining 19 essential minerals is likely to be adequate.

In a nutshell, a nutritious diet contains a variety of fruits, vegetables, whole grains, beans and legumes, lean sources of proteins, heart-healthy fats, and a sufficient, but not excessive amount of energy. This dietary pattern is consistent with adequate mineral intake. This same pattern also provides athletes the

THE EXPERTS IN. . .

Mineral Research

Robert P. Heaney, M.D., is one of the world's experts in bone biology and calcium nutrition. His research has elucidated the physiology of calcium and helped to establish calcium requirements, such as the Dietary Reference Intakes. Much of his research has been conducted in postmenopausal, osteoporotic women, resulting in a better understanding of the causes and potential treatments of low bone mineral density. Christine M. Snow, Ph.D., is director of the Bone Research Laboratory at Oregon State University. Her research interest is the role of exercise in attaining and maintaining peak bone mass, particularly the effect of high-impact exercise on bone density in children.

John L. Beard, Ph.D., is an expert in iron metabolism. His research has focused on problems associated with iron deficiency and he has an interest in food-based strategies to help eliminate iron-deficiency-related diseases. Henry C. Lukaski supervises the Applied Physiology Laboratory at the Grand Forks Human Nutrition Research Center. The focus of his research is trace minerals, particularly iron, copper, and zinc, and their metabolism under extreme conditions such as exercise and low environmental temperatures. His work has helped to establish the amount of trace minerals needed by athletes and the benefits and potential harms of inadequate, adequate, and excessive trace minerals from dietary and/or supplement sources. Exercise scientists and sports nutritionists use the research findings of these and other scientists to better understand the metabolism of minerals and as the basis for making recommendations to athletes and nonathletes.

2 fried eggs
2 pieces of white toast w/1 T butter
2 slices bacon
8 oz coffee w/1 T each cream, sugar
Ham & cheese sandwich
1-oz bag potato chips
16-oz soft drink
3 Oreo cookies
Cheeseburger
Medium fries
16-oz soft drink
½ cup chocolate ice cream

Figure 9.3 An Example of a High-Fat, High-Sugar, Low-Fiber Diet
Legend: T = tablespoon; oz = ounce

1 cup oatmeal
1 slice whole wheat toast
1 T peanut butter
8 oz nonfat milk
8 oz orange juice
8 oz black coffee
1.5 cups lentil soup
Large (1.5 cups) green salad
1 oz avocado (~ ⅕ of an avocado)
2 T oil & vinegar dressing
2 whole wheat rolls
8 oz nonfat milk
1 banana
6 oz chicken breast
1½ cups brown rice
1 cup broccoli
1 slice whole wheat bread w/1 tsp *transfree* margarine
1 cup strawberries
Water
1 cup nonfat frozen yogurt
¼ cup dry-roasted sunflower seeds

Figure 9.4 An Example of a Nutrient-Dense, Whole-Foods Diet
Legend: T = tablespoon; oz = ounce

carbohydrates, proteins, and fats needed to support training and competition.

OBTAINING MINERALS FROM FOOD

Two diets that were discussed in Chapter 8 are repeated here in Figures 9.3 and 9.4. One is a high-fat, high-sugar, low-fiber dietary pattern that is low in most, but not all, vitamins for a 20-year-old male. The other diet emphasizes fruits and vegetables, legumes, nuts, and whole-grain, less processed foods. This whole foods diet meets the recommended daily intakes for all of the vitamins. How well do these diets fare when mineral content is analyzed? Tables 9.13 and 9.14 reveal the answers.

Table 9.13 Mineral Intake of a High-Saturated-Fat, High-Sugar, Low-Fiber Diet Compared to the DRI

Mineral	Intake	DRI*	% of DRI
Calcium	509 mg	1,000 mg	51
Iron	12.25 mg	8 mg	156
Magnesium	61 mg	400 mg	15
Zinc	3.5 mg	11 mg	32

Legend: DRI = Dietary Reference Intakes; mg = milligram
*20-year-old male

Table 9.14 Mineral Intake of a Nutrient-Dense, Whole-Foods Diet Compared to the DRI

Mineral	Intake	DRI*	% of DRI
Calcium	1,145 mg	1,000 mg	114
Iron	20.39 mg	8 mg	255
Magnesium	629 mg	400 mg	157
Zinc	16 mg	11 mg	148

Legend: DRI = Dietary Reference Intakes; mg = milligram***
*20-year-old male

Four minerals were analyzed—calcium, iron, magnesium, and zinc. Other than sodium and potassium (covered in Chapter 7), these four minerals are the only ones included in most nutrient analysis programs. The high-fat, high-sugar, low-fiber diet contains ~2,500 kcal, yet three of the four minerals assessed are low because of a lack of nutrient-dense foods. Magnesium and zinc intake are particularly low, 15 percent and 32 percent, respectively, and calcium intake is approximately 50 percent of the amount recommended for a 20 year old.

Contrast that with the nutrient-dense, whole-foods diet. This diet has approximately the same amount of energy (kilocalories), but substantially more minerals. The nutrient-dense diet provides more than 100 percent of the DRI for calcium, iron, magnesium, and zinc. In the case of iron, the diet provides 20 mg, which meets the DRI for both adult males (8 mg) and 19- to 50-year-old females (18 mg). The food with the highest iron content is lentil soup, which contains 4 mg. The remainder of the iron is gathered from the variety of foods included in this diet. With the exception of margarine and oil, all of the foods contributed iron, although no one food except the soup had more than 2 mg. An athlete consuming this dietary pattern could reasonably assume that the other minerals not analyzed are also adequate.

CONSUMING MINERAL-FORTIFIED FOODS OR A MULTIMINERAL SUPPLEMENT

By now it should be clear that adequate mineral intake can be achieved from food alone. However, this requires that a variety of nutrient-dense foods are consumed and, realistically, many people simply do not eat that way. They may wish to consume foods that have been highly fortified or enriched with minerals. Cereal is one product that has minerals added, and more mineral-fortified foods, such as energy bars, are being manufactured, in part, because people are known to consume mineral-poor diets.

Multimineral supplements are also sold. Earlier in the chapter, a supplement advertised as "high potency" was evaluated (see Spotlight on Supplements: Evaluating a High-Potency Multimineral Supplement Advertised to Athletes). But what about a mineral supplement that is not "high potency"? Another example of a product that is advertised to athletes is shown in Table 9.15. This supplement is advertised as a way to obtain the various minerals that may be missing from an athlete's usual diet. Notice that one mineral, magnesium, exceeds the Tolerable Upper Intake Level. The amount of zinc contained is 30 mg, twice as high as the 15-mg dose that is often recommended. Given that the average male consumes 13 mg of zinc daily, total zinc intake would likely exceed the UL if a male athlete consumed this supplement. This supplement also contains iron. Iron supplementation is generally not recommended for males because the risk of iron overload is greater than the risk of iron-deficiency anemia. About five of every 1,000 people in the United States, mostly Caucasian males, carry two copies of the abnormal gene responsible for overabsorption of iron, which can lead to excessive iron storage in tissues. These individuals should never take iron supplements. Before consuming any multimineral supplement, consumers should carefully check the dose of all the minerals contained.

Table 9.15 Example of a Multimineral Supplement

Mineral	Amount	% of DV	UL*
Calcium	1,000 mg	100	2,500 mg
Magnesium	500 mg	125	350 mg
Zinc	30 mg	200	40 mg
Manganese	10 mg	500	11 mg
Iron	10 mg	55	45 mg
Copper	2 mg	100	10 mg
Iodine	150 mcg	100	1,100 mcg
Selenium	200 mcg	285	400 mcg
Chromium	200 mcg	167	Not established
Molybdenum	500 mcg	667	2,000 mcg

Legend: DV = Daily Value; UL = Tolerable Upper Intake Level; mg = milligram; mcg = microgram

*The UL for minerals is based on the intake all food (fortified and nonfortified), water, and supplements except for magnesium, which is based on supplements only.

The biggest question about multiple minerals being added to food or taken as supplements is whether the minerals are well absorbed. Multimineral supplements contain too many minerals to test so this remains an unanswered question. A 2005 review article of iron and zinc supplementation together found that zinc reduced, but did not completely block, iron absorption (Fischer Walker et al., 2005). More studies are needed

KEEPING IT IN PERSPECTIVE

Minerals as Building Blocks

Remember the story of the Three Little Pigs? The first pig built his house out of straw, the second pig out of sticks, and the third pig out of bricks. The straw and stick houses were built quickly and the pigs had time to play while the third pig built his house of bricks. But the houses made of straw and sticks were not well constructed and could not withstand the huffing and puffing of the big, bad wolf.

Consuming minerals in proper balance is like building a house of bricks. The most obvious analogy is with calcium and the other bone-forming nutrients. These minerals help the bones to be dense and strong and to better withstand the loss of bone calcium that accompanies aging. Many minerals are also involved in the proper function of the immune system, which must withstand pathological microorganisms and other sources of harm on a daily basis over a lifetime. A low or unbalanced mineral diet over a long period of time is like a house of straw or sticks. Consuming enough minerals is like building and living in a house of bricks. You will be glad you did when the big, bad wolf (e.g., aging and disease) comes huffing and puffing at your door.

to determine both the potential benefits and harms associated with multiple mineral supplements.

Supplementing with Individual Minerals. Many people adopt a "food first, supplements second" philosophy. They try to obtain all of their nutrients from food if possible, but consume supplements when dietary intake is habitually low. The most frequently supplemented individual minerals are calcium and iron. Females are more likely than males to have insufficient habitual intake, increased avenues of loss, or both, potentially necessitating supplements. If both iron and calcium are supplemented, these supplements should be taken at different times if possible to reduce competition for absorption.

If a physician diagnoses iron-deficiency anemia, the appropriate treatment is iron supplementation. High doses of ferrous sulfate (325 mg of which 65 mg is iron) are often recommended. Because this form and quantity can cause GI upset, adjustments may need to be made in the supplement's dose or type. Despite high supplemental doses, the restoration of depleted iron stores is a slow process that takes three to six months. Iron supplementation should be discontinued (or started) only after consultation with a physician.

Obtaining calcium from food sources is advised, but supplemental calcium is generally absorbed as well as calcium from milk. The best absorption occurs when supplemental calcium is consumed as a 400- to 500-mg dose. The Tolerable Upper Intake Level is 2,500 mg, so supplemental calcium of up to 1,500 mg daily is probably safe for most people, although the exact amount will depend on dietary intake.

Athletes may self-prescribe other individual mineral supplements (e.g., zinc, chromium, magnesium) because they are concerned that dietary intake may be low. Although a single supplement may provide more than enough of that particular mineral, there are concerns that a single supplement, especially one containing a high dose, may be detrimental to the absorption of other nutrients. A prudent approach is to take no more than the DRI in supplement form. However, low-dose single mineral supplements are often hard to find so individual mineral supplements may need to be taken every other day or every third day to reduce exposure.

Sometimes supplements are advertised as having a higher **bioavailability** than food or another brand of supplements. The term *bioavailability* is often used interchangeably with the term absorption, but technically, bioavailability refers to absorption, utilization,

Bioavailability: The degree to which a substance is absorbed, utilized, and retained in the body.

SPOTLIGHT ON SUPPLEMENTS

How Beneficial Is Chromium Supplementation for Athletes?

Chromium is a mineral supplement sometimes taken by athletes for the purpose of increasing muscle mass and decreasing body fat. Bodybuilders and other strength athletes are frequent users. The most common supplement form is chromium picolinate. The picolinate, which makes the compound extremely stable, increases gastrointestinal absorption of the chromium. An important point is that chromium picolinate is not absorbed in the same manner as dietary chromium. It appears that chromium picolinate supplements can result in an increase in free radical (oxidant) production. More research is needed to determine if there is a long-term effect, but athletes should be aware of this possibility (Vincent, 2000).

Chromium seems to enhance insulin sensitivity by increasing the number of insulin receptors (Speich, Pineau, and Ballereau, 2001). Enhanced insulin sensitivity would improve glucose utilization. Insulin also has anabolic properties, and enhanced sensitivity could promote amino acid uptake into muscle cells. Uptake of amino acids is known to stimulate protein synthesis.

Animal studies and early studies in humans suggested that muscle mass was increased and body fat was decreased with chromium supplementation. In humans, the changes were small but significant, ~1.8 kg (~4 lb) increase in muscle mass and ~3.4 kg (~7.5 lb) decrease in body fat. Subsequent studies, with stricter methodology including better measurements of body composition, did not replicate these early results. Most studies use daily doses of chromium supplements of 200 to 400 mcg (Lukaski, 1999).

The Dietary Reference Intakes for adults range from 20 to 35 mcg daily depending on age and gender. The average daily dietary intake of chromium is approximately 25 mcg for adult females and 33 mcg for adult males. If sufficient kilocalories (energy) are consumed, a chromium deficiency would not be expected. No Tolerable Upper Intake Level has been established. Chromium supplementation of 50 to 200 micrograms daily seems to be safe. The effects of higher daily intakes are not known, but there is some suspicion that iron absorption may be decreased and that accumulated chromium in the body can damage DNA (Lukaski, 2000).

and retention. Bioavailability should be thought of as a point on a continuum. The goal should be adequate bioavailability, not poor or excess bioavailability. If bioavailability is too low, absorption or utilization would likely be poor. But excess bioavailability can be a problem, too, due to excess absorption, a high blood concentration of that mineral, and substantially reduced absorption of other minerals that use the same absorption pathways.

An example is supplemental chromium, which may be sold as chromium picolinate. The picolinate makes the compound very stable and the chromium is absorbed in much higher amounts than would be absorbed from food. Excess chromium could cause damage to cells, so highly bioavailable chromium is not as beneficial as it may sound. Chromium supplements, which are popular with athletes, are featured in the Spotlight on Supplements: How Beneficial Is Chromium Supplementation for Athletes?

What's the point? Consumption of a variety of nutrient-dense foods and sufficient caloric intake are associated with an adequate intake of minerals. Supplementation may be beneficial to provide minerals missing from the diet. Dose and extent of absorption are important issues to consider when choosing a mineral supplement.

Summary

More than 20 **minerals** are needed for the proper functioning of the body. Dietary calcium, zinc, and magnesium intakes tend to be low for both men and women in the general population. Dietary iron intake may also be low for women. Athletes' intakes of these, as well as other minerals, are likely to be low if energy intake is restricted.

Adequate calcium intake and weight-bearing exercise is needed throughout life so that peak bone mineral density is achieved and loss of calcium from bone is prevented or slowed. Bone loss is accelerated by a lack of **estrogen.** A lack of estrogen is usually associated with **menopause** but may also be present in some adolescent and young adult female athletes, putting them at great risk for low bone mineral density and fractures. Milk and milk products are concentrated sources of calcium, but calcium is found in a variety of nondairy products, although typically in lower amounts.

Iron is closely linked to athletic performance because depleted iron stores lead to iron-deficiency **anemia,** resulting in a reduced oxygen-carrying capacity of the red blood cells. Oxidative capacity at the cellular level is reduced and performance is impaired, particularly for the endurance athlete. With such clear impacts on performance, preventing iron-deficiency anemia is important for athletes. Several minerals are also involved in maintaining a healthy immune system, including iron, zinc, and selenium.

The best ways to ensure adequate mineral status is to consume enough kilocalories daily and to eat a variety of nutritious foods that have been minimally processed. While all minerals are important, there is an emphasis on obtaining adequate amounts of calcium and iron in the diet. When dietary intake of these two minerals is adequate, the intake of other minerals is likely to be adequate.

Because dietary mineral intake is low for many people, including athletes, there is much interest in taking mineral supplements. Dose is very important because large amounts of one mineral can hamper the absorption of other minerals. Large doses can also increase the risk for toxicities. Supplementation with minerals should be done thoughtfully to avoid potential problems. Mineral deficiency diseases, such as iron-deficiency anemia, are successfully treated with mineral supplementation.

Post-Test Reassessing Current Knowledge of Minerals

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

1. The basic functions of minerals include building body tissues, regulating physiological processes, and providing energy.
2. In general, the body absorbs a high percentage of the minerals consumed.
3. In most cases, exercise does not increase mineral requirements above what is recommended for healthy, lightly active individuals.
4. If dietary calcium is inadequate over a long period of time, the body maintains its blood calcium concentration by reabsorbing skeletal calcium.
5. Iron-deficiency anemia has a negative impact on performance.

Review Questions

1. Compare and contrast minerals with vitamins. How are minerals similar to vitamins? Different from vitamins?
2. Explain the physiological and performance effects of mineral intakes that are too low or excessive.

3. Explain absorption problems associated with minerals found in food and supplements.
4. Are the requirements for minerals increased for athletes?
5. Do sedentary adults consume enough minerals? Do athletes? Explain.
6. Describe some of the potential toxic effects associated with consumption of minerals in excess of the Tolerable Upper Intake Level.
7. Explain the differences between a clinical and subclinical mineral deficiency, using either calcium or iron as an example.
8. Name the bone-forming minerals and explain why each is important for normal physiological function.
9. Briefly describe the roles of minerals and hormones in maintaining calcium homeostasis and calcium balance, including their roles in absorption, excretion, deposition, and resorption.
10. What effect does exercise have on attaining peak bone density and maintaining bone density across the life cycle?
11. How does iron deficiency, with and without anemia, affect athletic performance?
12. Explain the roles of minerals in proper immune function. Describe problems associated with both deficiencies and excesses.
13. How do athletes know if they are getting enough of all the minerals? What general dietary principles are associated with adequate mineral intake?
14. Are mineral supplements helpful or harmful to athletes? If so, in which ways?
15. What are the pros and cons of consuming a multimineral supplement daily?

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