CHAPTER 8

Minerals

KEY CONCEPTS

- The human body requires a variety of minerals to perform its numerous metabolic tasks.
- A mixed diet of varied foods and adequate energy value is the best source of the minerals that are necessary for health.
- Of the total amount of minerals that a person consumes, only a relatively limited amount is available to the body.

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Over the course of Earth's history, shifting oceans and plate tectonics have deposited minerals throughout its crust. These minerals move from rocks to soil to plants to animals and people. Not surprisingly, the mineral content of the human body is quite similar to that of Earth's crust.

In nutrition, we focus only on mineral elements: single atoms that are simple compared with vitamins, which are large, complex, organic compounds. However, minerals perform a wide variety of metabolic tasks that are essential to human life.

This chapter looks at minerals and shows how they differ from vitamins with regard to the variety of their tasks and in the amounts, which range from relatively large to exceedingly small, that are necessary to do those tasks.

NATURE OF BODY MINERALS

Most living matter is composed of four **elements**: hydrogen, carbon, nitrogen, and oxygen, which are the building blocks of life. The minerals that are necessary to human nutrition are elements widely distributed in nature. Of the 118 elements on the periodic table, 25 are essential to human life. These 25 elements, in varying amounts, perform a variety of metabolic functions.

Classes of Body Minerals

Minerals occur in varying amounts in the body. For example, a relatively large amount (approximately 2%) of our total body weight is calcium, most of which is in the bones. An adult who weighs 150 lb has approximately 3 lb of calcium in the body. Iron, on the other hand, is found in much smaller quantities. The same adult who weighs 150 lb has only approximately 0.11 oz of iron in his or her body. In both cases, the amount of each mineral is specific to its task.

The varying amounts of individual minerals in the body are the basis for classification into two main groups.

Major Minerals

The term *major* describes the amount of a mineral in the body and not its relative importance to human nutrition. **Major minerals** have a recommended intake of more than 100 mg/day. The seven major minerals are calcium,

element a single type of atom; a total of 118 elements have been identified, of which 94 occur naturally on Earth; elements cannot be broken down into smaller substances.

major minerals the group of minerals that are required by the body in amounts of more than 100 mg/day.

35. Ramanathan VS, Hensley G, French S, et al. Hypervitaminosis A inducing intra-hepatic cholestasis—a rare case report. *Exp Mol Pathol.* 2010;88(2):324-325.
36. Castano G, Etchart C, Sookoian S. Vitamin A toxicity in a physical culturist patient: a case report and review of the literature. *Ann Hepatol.* 2006;5(4):293-395.
37. Sheth A, Khurana R, Khurana V. Potential liver damage associated with over-the-counter vitamin supplements. *J Am Diet Assoc.* 2008;108(9):1536-1537.
38. Hasler CM, Brown AC. Position of the academy of nutrition of dietetics: functional foods. *J Am Diet Assoc.* 2009; 109(4):735-746.

FURTHER READING AND RESOURCES

For more information about the role of folic acid with regard to neural tube defects, see the following Web sites:

Centers for Disease Control and Prevention. www.cdc.gov/ncbddd/folicacid/index.html

Spina Bifida Association of America. www.sbaa.org

The following organizations and articles provide current information and guidelines regarding dietary recommendations for nutrient consumption:

Center for Science in the Public Interest. www.cspinet.org

Centers for Disease Control and Prevention, Fruit and Veggies Matter. www.fruitsandveggiesmatter.gov

Holick MF, Chen TC. Vitamin D deficiency: a worldwide problem with health consequences. *Am J Clin Nutr.* 2008;87(4):1080S-1086S.

Marra MV, Boyar AP. Position of the academy of nutrition of dietetics: nutrient supplementation. *J Am Diet Assoc.* 2009;109(12):2073-2085.

BOX 8-1 MAJOR MINERALS AND TRACE MINERALS IN HUMAN NUTRITION

Major Minerals*
- Calcium (Ca)
- Phosphorus (P)
- Sodium (Na)
- Potassium (K)
- Chloride (Cl)
- Magnesium (Mg)
- Sulfur (S)

Trace Minerals

Essential†
- Iron (Fe)
- Iodine (I)
- Zinc (Zn)
- Selenium (Se)
- Fluoride (Fl)
- Copper (Cu)
- Manganese (Mn)
- Chromium (Cr)
- Molybdenum (Mo)
- Cobalt (Co)
- Boron (B)
- Vanadium (V)
- Nickel (Ni)

Essentiality Unclear
- Silicon (Si)
- Tin (Sn)
- Cadmium (Cd)
- Arsenic (As)
- Aluminum (Al)

*Required intake of more than 100 mg/day.
†Required intake of less than 100 mg/day.

phosphorus, sodium, potassium, magnesium, chloride, and sulfur. Because the body cannot make any minerals, all minerals must be consumed in the foods that we eat.

Trace Minerals

The remaining 18 elements make up the group of **trace minerals**. These minerals are no less important to human nutrition than the major minerals; however, smaller amounts of them are in the body. Trace minerals have a recommended intake of less than 100 mg/day. Box 8-1 provides a list of all of the minerals that are essential to human nutrition.

Functions of Minerals

These simple single elements perform a wide variety of metabolic tasks in the body. They are involved in processes of building tissue as well as activating, regulating, transmitting, and controlling metabolic processes. For example, sodium and potassium are key players in water balance. Calcium and phosphorus are required for osteoclasts to build bone. Iron is critical to the oxygen carrier hemoglobin. Cobalt is at the active site of vitamin B_{12}. Thyroid peroxidase in thyroid cells uses iodine to make thyroid hormone, which in turn regulates the overall rate of body metabolism. Minerals are essential, and they are involved in most of the body's metabolic processes.

Mineral Metabolism

Mineral metabolism is usually controlled either at the point of intestinal absorption or at the point of tissue uptake.

Digestion

Minerals are absorbed and used in the body in their ionic forms, which means that they are carrying either a positive or negative electric charge. Unlike carbohydrates, proteins, and fats, minerals do not require a great deal of mechanical or chemical digestion before absorption occurs.

Absorption

The following general factors influence how much of a mineral is absorbed into the body from the gastrointestinal tract: (1) food form—minerals from animal sources are usually more readily absorbed than those from plant sources; (2) body need—more is absorbed if the body is deficient than if the body has enough; and (3) tissue health—if the absorbing intestinal surface is affected by disease, its absorptive capacity is greatly diminished.

The absorptive method for each mineral depends on its physical properties. Some minerals require active transport to be absorbed, whereas others enter the intestinal cells by diffusion. Compounds found in foods may also affect the absorptive efficiency. For example, the presence of fiber, phytate, or oxalate—all of which are found in a variety of whole grains, fruits, and vegetables—can bind certain minerals in the gastrointestinal tract, thereby inhibiting or limiting their absorption.

Transport

Minerals enter the portal blood circulation and travel throughout the body bound to plasma proteins or mineral-specific transport proteins (e.g., iron is bound to transferrin in the circulation).

trace minerals the group of elements that are required by the body in amounts of less than 100 mg/day.

Tissue Uptake

The uptake of some minerals into their target tissue is controlled by hormones, and excess minerals are excreted into the urine. For example, **thyroid-stimulating hormone (TSH)** controls the uptake of iodine from the blood by the *thyroid* gland depending on the amount that the thyroid gland needs to make the hormone thyroxine. When more thyroxine is needed, TSH stimulates the thyroid gland to take up iodine and the kidneys to excrete *less iodine* into the urine. When the thyroxine concentration is normal, less TSH is released from the anterior pituitary gland, thereby resulting in less iodine uptake by the thyroid gland and more excretion of iodine into the urine by the kidneys.

Occurrence in the Body

Body minerals are found in several forms in body tissues. The two basic forms in which minerals occur in the body are as free ions in body fluids (e.g., sodium in tissue fluids, which influence water balance) and as covalently bound minerals that may be combined with other minerals (e.g., calcium and phosphorus in hydroxyapatite) or with organic substances (e.g., iron that is bound to heme and globin to form the organic compound hemoglobin).

MAJOR MINERALS

Calcium

The intestinal absorption of dietary calcium depends on the food form (e.g., plant forms are sometimes bound to oxalate or phytate and thus are not readily available) and the interaction of three hormones (i.e., vitamin D, parathyroid hormone, and calcitonin [from the thyroid gland]) that directly control calcium's intestinal absorption and use, along with indirect control by the estrogens (i.e., sex hormones produced primarily by the ovaries).

Functions

After it has been absorbed, calcium has four basic functions in the body.

Bone and Tooth Formation. More than 99% of the body's calcium is found in the bones and teeth. Approximately 1% to 2% of adult body weight is calcium. When hydroxyapatite is removed from bone, the remaining tissue is a collagen matrix. If dietary calcium is insufficient during critical periods (e.g., the initial formation of the fetal skeleton, childhood growth, or the rapid growth of long bones during adolescence), then the construction of healthy bones is hindered. Teeth are calcified before they erupt from the gums; thus, insufficient dietary calcium later in life does not affect tooth structure as it does bone structure.

Blood Clotting. Calcium is essential for the formation of fibrin, which is the protein matrix of a blood clot.

Muscle and Nerve Action. Calcium ions are required for muscle contraction and the release of neurotransmitters from neuron synapses.

Metabolic Reactions. Calcium is necessary for many general metabolic functions in the body. Such functions include the intestinal absorption of vitamin B_{12}, the activation of the fat-splitting enzyme pancreatic lipase, and the secretion of insulin by the β cells of the pancreas. Calcium also interacts with the cell membrane proteins that govern the cell membrane's permeability to nutrients.

Requirements

The Dietary Reference Intake (DRI) for calcium should provide sufficient calcium nourishment for the body while recognizing that a lower intake may be adequate for many individuals. For all infants who are up to 6 months old, the Adequate Intake (AI) level is 200 mg/day; for infants who are 7 to 12 months old, the AI is 260 mg/day. Calcium needs increase during the growth years of childhood and adolescence, during which the Recommended Dietary Allowances (RDAs) are as follows: 1 to 3 years, 700 mg/day; 4 to 8 years, 1000 mg/day; and 9 to 18 years, 1300 mg/day. For both men and women between the ages of 19 to 50 years, the RDA for desirable calcium retention is 1000 mg/day, with a rise to 1200 mg/day for women who are more than 50 years old. During pregnancy and lactation, the RDA is currently set as being equal to the level for the general age group, as follows: 1300 mg/day for up to the age of 18 years and 1000 mg/day for ages 19 years old and older.[1]

Deficiency States

Various bone deformities may occur if sufficient dietary calcium is unavailable during growth years. The deficiency disease rickets is related to an inadequate level of vitamin D to support the intestinal absorption of calcium. A decrease of blood calcium concentration (i.e., **hypocalcemia**) relative to blood phosphorus concentration results in tetany, which is a condition that is characterized by

thyroid-stimulating hormone (TSH) an anterior pituitary hormone that regulates the activity of the thyroid gland; also known as *thyrotropin*.

hypocalcemia a serum calcium level that is below normal.

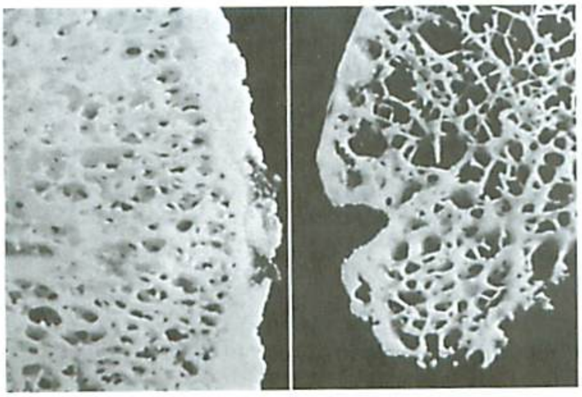


Figure 8-1 Osteoporosis. Normal bone *(left)* versus osteoporotic bone *(right)*. (Reprinted from Mahan LK, Escott-Stump S. *Krause's food & nutrition therapy*. 12th ed. Philadelphia: Saunders; 2008.)

muscle spasms. The most common calcium-related clinical issue today is **osteoporosis**. Osteoporosis is an abnormal decrease in bone density, especially in postmenopausal women, that is characterized by reduced bone mass, increased bone fragility, and a greater risk for the development of bone fractures (Figure 8-1). Such bone fractures are becoming more common among elderly men as well.[2] Each year in the United States, more than 1.5 million bone fractures and $17 to $20 billion in health care costs are linked to osteoporosis (see the Cultural Considerations box, "Bone Health in Gender and Ethnic Groups").[3]

Osteoporosis is not a primary calcium deficiency disease as such; rather, it results from a combination of factors that create chronic calcium deficiency. These factors include the following: (1) inadequate calcium intake; (2) poor intestinal calcium absorption related to deviations in the amounts of hormones that control calcium absorption and metabolism; and (3) a lack of physical activity, which stimulates muscle insertion into bones and significantly influences bone strength, shape, and mass. Insufficient physical activity contributes to the development of osteoporosis, and immobility after injury or disease can cause serious bone loss. Bone is a dynamic tissue, with both new bone formation and **resorption** occurring constantly. A portion of the skeleton is reabsorbed and replaced with new bone each year; this bone remodeling can affect up to 50% of total bone mass per year in young children and approximately 5% of bone mass in adults. Unfortunately, bone resorption often exceeds bone formation in postmenopausal women and in aging men. The interaction of factors in osteoporosis that result in bone calcium resorption outpacing bone calcium deposition are not fully understood. Increased calcium intake alone—be it via dietary calcium or supplemental calcium—does not prevent osteoporosis in susceptible adults or successfully treat diagnosed cases of osteoporosis. Therapies that reduce bone loss in osteoporosis include combinations of the various factors that are involved in the building of bones: dietary calcium, the active hormonal form of vitamin D, estrogens, and weight-bearing physical activity.

Food intake studies report that the average calcium intakes of females from adolescence through adulthood are generally well below the DRI. The period of life during which bone density reaches its peak is also the period of life where teenage girls are likely to experience the largest dietary calcium deficit.[4] Teenage girls consume 878 mg/day of calcium on average, whereas the recommended RDA is 1300 mg/day. Deficiencies during this critical period of bone development may have long-term negative outcomes with regard to overall bone strength and risk for osteoporosis.[5]

Toxicity Symptoms

The toxicity of calcium from food sources is unlikely. However, a Tolerable Upper Intake Level (UL) for calcium has been set at 2000 to 3000 mg/day (depending on age) as a result of the negative effects of excessive calcium supplementation over time. **Hypercalcemia** is associated with the calcification of soft tissue and the decreased intestinal absorption of several other minerals. Calcium can interfere with the intestinal absorption of iron, magnesium, phosphorus and zinc, thereby reducing the bioavailability of these essential nutrients.

Food Sources

Milk and milk products are the most important sources of readily available calcium. Milk that is used in cooking (e.g., in soups, sauces, or puddings) or in milk products such as yogurt, cheese, and ice cream is an excellent source of dietary calcium (Figure 8-2). Calcium-fortified tofu, fruit juices, and other food products (e.g., cereals, cereal bars) are also high in bioavailable calcium. In

osteoporosis an abnormal thinning of the bone that produces a porous, fragile, lattice-like bone tissue of enlarged spaces that are prone to fracture or deformity.

resorption the destruction, loss, or dissolution of a tissue or a part of a tissue by biochemical activity (e.g., the loss of bone, the loss of tooth dentin).

hypercalcemia a serum calcium level that is above normal.

CULTURAL CONSIDERATIONS

BONE HEALTH IN GENDER AND ETHNIC GROUPS

The World Health Organization defines osteopenia as a bone mineral density (BMD) of between 1 and 2.5 standard deviations below the mean of a reference group. Osteoporosis involves a BMD of 2.5 standard deviations or more below the mean of the reference group.

Osteoporosis affects a significant number of older Americans. Currently, 2% of men (0.8 million) and 10% of women (4.5 million) who are 50 years old or older are living with osteoporosis.[1] An additional 34.5 million Americans have osteopenia, which is a significant risk factor for osteoporosis.

Osteoporosis often is thought of as a "white woman's disease." However, this debilitating bone disease is prevalent in men and other ethnic groups as well. It is well established that there is a disparity between genders. The National Institutes of Health estimates that one out of every two women (compared with one in four men) who are 50 years old or older will have bone fractures at some point during their lives as a result of osteoporosis.[2] With regard to differences among ethnic groups, a recent study found that non-Hispanic black men and women had the highest BMD and the lowest risk for osteoporosis throughout life compared with other ethnic groups. The same researchers found that non-Hispanic white men and women had significantly higher BMDs than Mexican Americans.[3] The reasons for these observed differences by race are unclear; however, ethnicity, gender, and age are all well accepted as important factors when calculating the risk for osteoporosis, which is the most common form of bone disease.

Many factors are involved in BMD and the relative risk for the development of fragile bones, including body weight, physical activity, hormonal influences, and dietary intakes of several vitamins and minerals (not just calcium). Nutrition affects bone health by providing the materials that are needed for tissue deposition, maintenance, and repair. Overall bone strength is determined by BMD and the collagen matrix formation. Collagen, which is a structural protein, accounts for more than 20% of the dry weight of total bone mass and 90% of the organic bone matrix. Collagen degradation is associated with osteoporosis. As such, the vitamins and minerals that are critical for a strong collagen and bone matrix also are integral to overall bone health. A delicate balance of several nutrients is important for healthy bone building, including protein; vitamins C, D, and K; calcium; phosphorus; copper; magnesium; manganese; potassium; and zinc.

Osteoporosis is currently costing Americans more than $17 billion annually in direct medical costs. Coupled with the general trends of an aging population, this bone disease is a serious national concern. Because BMD reaches a peak mass by the average age of 30 years, the years before this are vital for developing healthy bones and preventing the onset of osteoporosis. Establishing peak bone mass ensures a greater reserve of bone mineral and collagen so that, as age-associated degradation ensues, effects are essentially postponed or abated altogether. A healthy diet following the MyPlate guidelines should provide all of the essential nutrients, and it is imperative during the first three decades of life to establish healthy bones.

For more information about osteoporosis please see the Web site of the National Institutes of Health Osteoporosis and Related Bone Diseases National Resource Center at www.niams.nih.gov/health_info/bone/osteoporosis/.

1. Looker AC, Melton LJ 3rd, Harris TB, et al. Prevalence and trends in low femur bone density among older US adults: NHANES 2005-2006 compared with NHANES III. *J Bone Miner Res.* 2010; 25:64-71.
2. National Institutes of Health Osteoporosis and Related Bone Diseases National Resource Center. *Osteoporosis in men* (website): www.niams.nih.gov/Health_Info/Bone/Osteoporosis/men.asp. Accessed October 8, 2011.
3. Looker AC, Melton LJ 3rd, Harris T, et al. Age, gender, and race/ethnic differences in total body and subregional bone density. *Osteoporos Int.* 2009; 20:1141-1149.

addition, several plants provide a natural source of this important mineral. Calcium in low-oxalate greens such as bok choy, broccoli, collard greens, kale, and turnip greens is absorbed and can be an important source of calcium for vegetarians. Oxalic acid is a compound that is found in plants such as spinach, rhubarb, Swiss chard, beet greens, and certain other vegetables and nuts that forms an insoluble salt with calcium (calcium oxalate), thus interfering with the intestinal absorption of calcium. Phytate, which is another plant compound that is found in grains such as wheat, can bind with calcium and interfere with its intestinal absorption. Table 8-1 lists food sources of calcium.

In addition to food sources, calcium intake from supplements is widespread. Surveys show that almost 6% of women in the United States specifically take calcium supplements, whereas 22% of the total population takes a multivitamin and mineral supplement that contains some calcium.[6] The bioavailability of calcium from supplements depends on the dose and whether it is taken with a meal. Calcium is best absorbed in doses of 500 mg or less and when taken with food rather than on an empty stomach (see the For Further Focus box, "Calcium From Food or Supplements: Which Is Better?").

Phosphorus

Functions

The phosphorus atom in nature is most commonly found in combination with four oxygen atoms to form the

Figure 8-2 Milk is the major food source of calcium. (Copyright Photos.com.)

TABLE 8-1 FOOD SOURCES OF CALCIUM

Item	Quantity	Amount (mg)
Bread, Cereal, Rice, and Pasta		
Corn muffin, commercially prepared	1 medium (113 g)	84
Cream of Wheat cereal, cooked	¾ cup	86
English muffin, plain, enriched	1 muffin (57 g)	93
Oatmeal, instant, fortified, prepared with water	¾ cup	98
Whole-grain cereal, Total	¾ cup	1000
Vegetables		
Collard greens, boiled	¾ cup	140
Spinach, boiled*	¾ cup	122
Fruits		
Orange juice, fortified with calcium and vitamin D	8 fl oz	351
Meat, Poultry, Fish, Dry Beans, Eggs, and Nuts		
Salmon, pink, canned, drained solids with bone	3 oz	235
Sardines, canned in oil, solids with bone	3 oz	325
Soybeans, boiled	½ cup	88
Tofu, raw, firm, prepared with calcium sulfate	½ cup	861
Milk and Dairy Products or Their Substitutes		
Cheese, mozzarella, part skim milk	1 oz	222
Milk, skim	8 fl oz	301
Milk, whole	8 fl oz	276
Soy milk	8 fl oz	93
Soy milk, calcium fortified	8 fl oz	368
Tofu yogurt	8 fl oz	309
Yogurt, plain, low fat	8 fl oz	448

*Low bioavailability.

Data from the U.S. Department of Agriculture, Agricultural Research Service: Nutrient Data Laboratory. *USDA nutrient database for standard reference* (website): www.ars.usda.gov/ba/bhnrc/ndl. Accessed October 2010.

phosphate molecule. Phosphorus and calcium (in the form of hydroxyapatite) are critical to bone formation. In addition, phosphorus functions in the following metabolic processes.

Bone and Tooth Formation. The calcification of bones and teeth depends on the deposition of hydroxyapatite $[Ca_{10}(PO_4)_6(OH)_2]$ by osteoblasts in bone's collagen matrix. The ratio of calcium to phosphorus in typical bone is approximately 1.5:1 by weight.

Energy Metabolism. Phosphorus in the form of phosphate (PO_4^{3-}) is necessary for the controlled oxidation of carbohydrate, fat, and protein to release the energy in their covalent bonds (as a component of thiamin pyrophosphate), and it captures energy for use in the body as a component of adenosine triphosphate. Phosphate is also involved in protein construction (as a component of RNA), cell function (as a component of cell enzymes activated by phosphorylation), and genetic inheritance (as a component of DNA).

Acid-Base Balance. Phosphate is an important chemical buffer that helps to maintain the pH homeostasis of body fluids.

Requirements

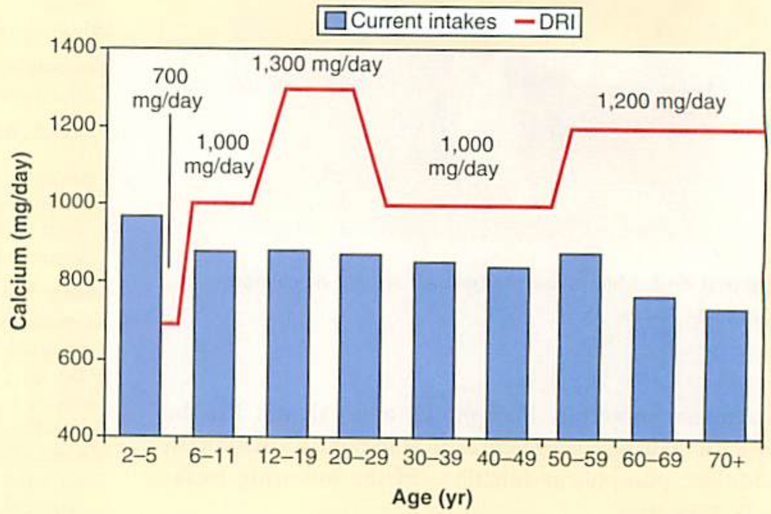
The typical American diet contains enough phosphorus to meet body needs. Surveys indicate that the mean daily phosphorus intake in the United States is approximately 1297 mg/day.[4] The AI level during the first 6 months of life is 100 mg/day, and, from the ages of 7 to 12 months, it is 275 mg/day. Healthy breast-fed infants receive adequate phosphorus. For children, the RDA varies with the stage of growth. Between the ages of 1 and 3 years, the RDA is 460 mg/day; between the ages of 4 and 8 years, it is 500 mg/day. From the ages of 9 to 18 years, which is a period of rapid bone growth, the RDA is 1250 mg/day. The established RDAs in the DRI guidelines for both men and women who are 19 years old and older is 700 mg/day, with no additional needs established for women who are pregnant or lactating.[7]

FOR FURTHER FOCUS

CALCIUM FROM FOOD OR SUPPLEMENTS: WHICH IS BETTER?

If only we could take a supplement to meet all of our nutrition needs, then we would not have to bother with eating healthy! Unfortunately, that is the type of thinking that fuels the continued search for the "magic pill." Good health is not a simple matter, and our bodies are no simple machines. They require lots of nutrients to function properly, and these must be provided by the diet. One of the major minerals that is needed by our body is calcium. According to the National Health and Nutrition Examination Study, relatively few women meet their Adequate Intakes for calcium through their diets. The graph below represents the average calcium intake for females by age group.

From the U.S. Department of Agriculture, Agricultural Research Service. *Nutrient intakes from food: mean amounts consumed per individual, by gender and age. What We Eat in America, NHANES 2007-2008* (website): www.ars.usda.gov/SP2UserFiles/Place/12355000/pdf/0708/Table_1_NIN_GEN_07.pdf. Accessed October 8, 2011; and Food and Nutrition Board, Institute of Medicine. *Dietary reference intakes for calcium, phosphorous, magnesium, vitamin D, and fluoride.* Washington, DC: National Academies Press; 1997.



A variety of factors influence our dietary intake of calcium. Over the past decade, Americans' food choices have changed in ways that directly affect calcium-rich food consumption. For example, Americans are replacing milk with soft drinks; they are eating out more often at restaurants; they seem to be perpetually dieting (and dairy products are often one of the first foods to go); and they are largely unaware of the healthy link between calcium-rich foods and health.

Health organizations such as the National Institutes of Health, the Academy of Nutrition and Dietetics, the American Medical Association, and the National Academy of Sciences agree that the best source of calcium is dairy products. The primary reason for this is because, unlike calcium supplements, calcium-rich foods supply the body with other beneficial nutrients as well, including protein; vitamins A, B_{12}, and D (if fortified); magnesium; potassium; riboflavin; niacin; and phosphorus. Some nondairy foods naturally contain calcium, including salmon with bones, dried beans, turnip greens, mustard greens, kale, tofu, and broccoli. Most people find that meeting the Dietary Reference Intake for calcium exclusively from nondairy foods can be difficult, because the relative amount of calcium in these foods is significantly less than that found in dairy products. For example, half a cup of chopped kale has 47 mg of calcium, whereas 8 oz of skim milk contains 302 mg. In addition, many vegetables contain phytates and oxalates that form insoluble complexes with calcium and thus, decrease their bioavailability to the body.

Keller and colleagues analyzed the consumer cost and bioavailability of calcium from major sources. They found that Total cereal was the least expensive food source of calcium, with fluid milk and calcium-fortified orange juice being the next least expensive.[1] Calcium from supplements may be found in a variety of forms, including calcium carbonate, citrate, phosphate, lactate, and gluconate. The amount of calcium absorbed into the body from these sources varies considerably. Of the calcium supplements, calcium carbonate in a chewable form (e.g., Tums) or supplement provides the least expensive and most bioavailable source of calcium, with a 34% absorption fraction.[1]

The best way to improve one's overall diet is to consume a variety of foods that are high in calcium, preferably from dairy or fortified dairy substitute sources. However, calcium-fortified foods and supplements may be necessary for some people to meet their recommended intake of calcium. Calcium is best absorbed in doses of 500 mg or less at a time.

Regardless of where your calcium comes from, take a moment to consider the overall value of your diet, and assess whether improvements are warranted.

For more information about the fortification of calcium in the American food supply, please see Rafferty K, Walters G, Heaney RP. Calcium fortificants: overview and strategies for improving calcium nutriture of the U.S. population. *J Food Sci.* 2007; 72:R152-R158.

1. Keller JL, Lanou A, Barnard ND. The consumer cost of calcium from food and supplements. *J Am Diet Assoc.* 2002; 102(11): 1669-1671.

Deficiency States

Phosphate (the dietary form of phosphorus) is widely distributed in foods; thus, a deficiency is rare. A person must be completely deprived of food for an extended period to develop a dietary phosphorus deficiency. The only evidence of deficiency has been among people who consumed large amounts of antacids that contained aluminum hydroxide. The aluminum (Al^{3+}) binds with phosphate, thereby making the phosphate unavailable for intestinal absorption. Phosphorus deficiency (i.e., **hypophosphatemia**) results in bone loss; it is characterized by weakness, loss of appetite, fatigue, and pain.

Toxicity Symptoms

A toxicity of phosphorus (i.e., **hyperphosphatemia**) from food intake is equally rare. However, if phosphorus intake is significantly higher than calcium intake for a long period, bone resorption may occur. The DRI guidelines list the UL for phosphorus at 4 g/day for people between the ages of 9 and 70 years.[7]

Food Sources

Phosphorus is part of all living tissue, and it is found in all animal and plant cells; therefore, phosphorus is sufficient in the natural food supply of virtually all animals. High-protein foods are particularly rich in phosphorus, so milk and milk products, meat, fish, and eggs are the primary sources of phosphorus in the average diet. The bioavailability of phosphorus from plant seeds (e.g., cereal grains, beans, peas, other legumes, nuts) is much lower, because these foods contain phytic acid, which is a storage form of phosphorus in seeds that humans cannot directly digest. However, intestinal bacteria can make up to 50% of phosphorus from phytic acid available for intestinal absorption. Table 8-2 outlines some main food sources of phosphorus.

TABLE 8-2 FOOD SOURCES OF PHOSPHORUS

Item	Quantity	Amount (mg)
Vegetables		
Potato, baked, with skin	1 medium (173 g)	121
Meat, Poultry, Fish, Dry Beans, Eggs, and Nuts		
Almonds, roasted	1 oz (22 nuts)	139
Bacon, fried	3 medium slices	128
Beef, ground, 70% lean, pan browned	3 oz	172
Beef liver, pan fried	3 oz	412
Beef top round, lean, broiled	3 oz	173
Chicken, dark meat, roasted, without skin	3 oz	152
Chicken, white meat, roasted, without skin	3 oz	184
Chickpeas (garbanzo beans), boiled	½ cup	138
Clams, cooked, moist heat	3 oz	287
Cod, cooked, dry heat	3 oz	117
Crab, Alaskan king, cooked, moist heat	3 oz	238
Halibut, cooked, dry heat	3 oz	242
Ham, sliced, regular (11% fat)	3 oz	130
Lentils, boiled	½ cup	178
Lobster, cooked, moist heat	3 oz	157
Pinto beans, boiled	½ cup	126
Sirloin steak, lean, broiled	3 oz	184
Soybeans, boiled	½ cup	211
Tofu, raw, firm, prepared with calcium sulfate	½ cup	152
Trout, rainbow, cooked, dry heat	3 oz	226
Tuna, light, canned in water, drained solids	3 oz	139
Milk and Dairy Products		
Cheese, cheddar	1 oz	145
Cheese, mozzarella, part skim milk	1 oz	131
Cottage cheese, 1% milk fat	½ cup	151
Milk, 1% fat	8 fl oz	232
Yogurt, plain, low fat	8 fl oz	353

The food group that is composed of bread, cereal, rice, and pasta is not an important source of phosphorus. Whole-grain products are higher in phosphorus than are refined grain products, but the phosphorus, in the form of phytate, is not bioavailable to humans.
Data from the U.S. Department of Agriculture, Agricultural Research Service: Nutrient Data Laboratory. *USDA nutrient database for standard reference* (website): www.ars.usda.gov/ba/bhnrc/ndl. Accessed October 2010.

hypophosphatemia a serum phosphorus level that is below normal.

hyperphosphatemia a serum phosphorus level that is above normal.

Sodium

Sodium is one of the most plentiful minerals in the body. Approximately 120 g (4.2 oz) is present in an adult body.

Functions

The main function of sodium is the maintenance of body water balance, which is discussed further in Chapter 9. Sodium also has important tasks in muscle action and nutrient absorption.

Water Balance. Ionized sodium concentration is the major influence on the volume of body water outside of the cells (i.e., extracellular) (Figure 8-3). Variations in sodium concentration largely control the movement of water across biologic membranes by osmosis. Sodium is

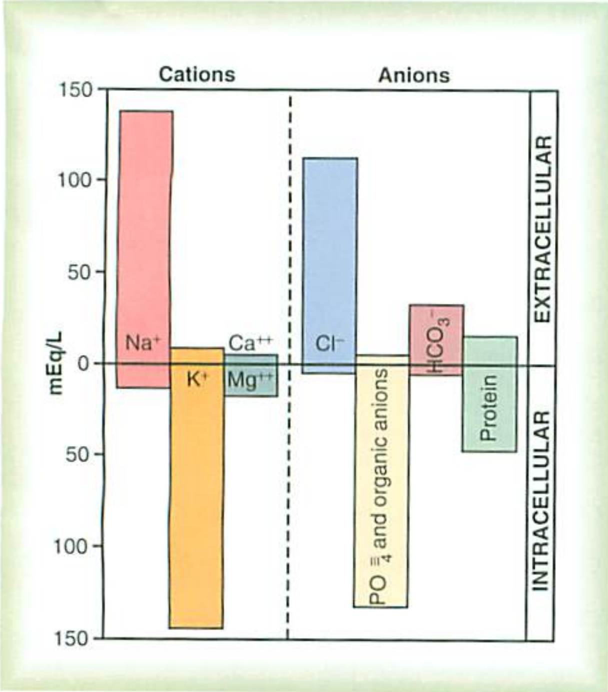


Figure 8-3 The ionic composition of the major body fluid compartments. (Reprinted from Guyton AC, Hall JE. *Textbook of medical physiology*. 12th ed. Philadelphia: Saunders; 2006.)

also an integral part of the digestive juices that are secreted into the gastrointestinal tract, most of which are reabsorbed by the intestinal cells.

Muscle Action. Sodium and potassium ions are necessary for the normal response of stimulated neurons, the transmission of nerve impulses to muscles, and the contraction of muscle fibers.

Nutrient Absorption. Sodium-dependent glucose transporters, which are a vital part of intestinal cells, allow for the passage of glucose and galactose from the intestinal lumen into the intestinal cells.

Requirements

The body is able to function on various amounts of dietary sodium through mechanisms that have been designed to conserve or excrete the mineral as needed. For that reason, no specific RDA for sodium exists. Individual sodium needs vary greatly depending on growth stage, sweat loss, and medical conditions (e.g., diarrhea, vomiting). The DRI standards include an AI for the three major electrolytes that are needed to maintain body fluid balance: sodium, chloride, and potassium. A sodium intake of 1.5 g/day should be adequate for healthy people who are not excessively losing sodium through extended exercise and sweating. Adults between the ages of 50 and 70 years have a slightly reduced AI (1.3 g/day) that corresponds with decreased energy intake. The AI for individuals who are more than 71 years old is 1.2 g/day.[8]

Deficiency States

Sodium deficiencies are rare, because the body's need is low, and individual intake is typically high. An exception is during heavy sweating, such as by those who are engaged in heavy labor or strenuous physical exercise in a hot environment for an extended period of time (i.e., more than 2 hours). Commercial sports drinks, which replace sodium, glucose, and fluid, may be useful to restore losses. Although sweat is relatively low in sodium, drinking too much plain water during extended strenuous exercise can dilute blood sodium concentration and exacerbate sodium deficiency complications (see Chapter 16). Sodium deficiency (i.e., **hyponatremia**) can result in acid-base imbalances and muscle cramping.

Toxicity Symptoms

The sodium content of the average American diet, which contains a high amount of processed foods, usually far exceeds the recommended intake range. The National Health and Nutrition Examination Survey (NHANES) of 2007 to 2008 revealed that men consume an average of 4043 mg/day of sodium and that women have an average intake of 2884 mg/day.[4] Excessive sodium intake has been linked to hypertension in individuals who are salt sensitive (i.e., approximately 25% of hypertensive patients).[9] However, for most people with healthy kidneys and adequate water intake, the kidneys excrete excess sodium in the urine. The acute excessive intake of sodium chloride (i.e., table salt) causes the accumulation of sodium in the blood (i.e., **hypernatremia**) and extracellular spaces. This sodium can pull water out of cells into the extracellular space by osmosis, thereby causing edema. The current DRIs set the UL for sodium intake at 2.3 g/day but state that some individuals may have a much lower tolerance.[8]

Food Sources

Common table salt as used in cooking, seasoning, and processing foods is the main dietary source of sodium.

hyponatremia a serum sodium level that is below normal.

hypernatremia a serum sodium level that is above normal.

Sodium occurs naturally in foods, and it is generally most prevalent in foods of animal origin. Enough sodium is found in natural food sources to meet the body's needs. When food manufacturers add salt and other sodium compounds to processed foods as a preservative, sodium intake dramatically increases. For example, cured ham has approximately 20 times more sodium than raw pork. Natural unprocessed food sources of sodium include animal products such as milk, meat, and eggs and vegetables such as carrots, beets, leafy greens, and celery (see the Evolve site for the sodium and potassium content of foods and Appendix C for salt-free seasoning guides).

Potassium

The adult body contains approximately 270 g (9.5 oz) of potassium, which is nearly twice the amount of sodium.

Functions

Potassium is involved with sodium in the maintenance of the body water balance, and it also has many other metabolic functions.

Water Balance. Potassium is the major electrolyte inside cells (i.e., intracellular). Its osmotic effect holds water inside the cells and counterbalances the osmotic effect of sodium, which draws water out of the cells and into the extracellular fluid (see Figure 8-3).

Metabolic Reactions. Potassium plays a role in energy production, the conversion of blood glucose into stored glycogen, and the synthesis of muscle protein.

Muscle Action. Potassium ions also play a role in nerve impulse transmission to stimulate muscle action. Along with magnesium and sodium, potassium acts as a muscle relaxant that opposes the stimulating effect of calcium, which allows for muscle contraction. The heart muscle is sensitive to potassium levels; therefore, blood potassium concentration is regulated within narrow tolerances.

Insulin Release. Potassium is necessary for the release of insulin from pancreatic β cells in response to rising blood glucose concentrations.

Blood Pressure. Sodium is one of the main dietary factors that is associated with hypertension; however, hypertension may be more related to the sodium and potassium ratio (this is a molar ratio as opposed to a mass ratio) than to the amount of dietary sodium alone. A potassium intake that is equal to the sodium intake may help to prevent the development of hypertension; such is the basis for the Dietary Approaches to Stop Hypertension (DASH) diet (see www.nhlbi.nih.gov/hbp/prevent/h_eating/h_e_dash.htm for more information).

Requirements

As with sodium, the present DRI guidelines do not have an RDA for potassium, although potassium is essential in the diet. The AI of potassium is 4.7 g/day for all adults.[8] The National Research Council recommends an increase in potassium intake through the increased consumption of fruits and vegetables. The average American diet provides significantly less potassium than the established AI, with a median daily intake of 2 to 3 g/day.[4] The *Dietary Guidelines for Americans* committee identified potassium as a key nutrient that is lacking in the typical American diet, which led to the recommendation to increase the daily intake of fruits, vegetables, whole grains, and dairy products.[10]

Deficiency States

Symptoms of potassium deficiency are well defined but seldom related to inadequate dietary intake. Potassium deficiency (i.e., **hypokalemia**) is more likely to develop during clinical situations such as prolonged vomiting or diarrhea, the use of diuretics, severe malnutrition, or surgery. Hypokalemia also is a concern while a person is using antihypertensive medications, particularly diuretics that cause urinary potassium loss. Characteristic symptoms of potassium deficiency include heart muscle weakness with possible cardiac arrest, respiratory muscle weakness with breathing difficulties, poor intestinal muscle tone with resulting bloating, and overall muscle weakness.

Toxicity Symptoms

As with sodium, the kidneys normally excrete excess potassium so that toxicity does not occur. However, if oral potassium intake is excessive or if intravenous potassium is given that causes **hyperkalemia**, the heart muscle can weaken to the point at which it stops beating. A UL has not been established for potassium from food sources.

Food Sources

Potassium is an essential part of all living cells; thus, it is abundant in natural foods. The richest dietary sources of potassium are unprocessed foods: fruits such as oranges and bananas, vegetables such as broccoli and leafy green

hypokalemia a serum potassium level that is below normal.

hyperkalemia a serum potassium level that is above normal.

vegetables, fresh meats, whole grains, and milk products. Those who eat large amounts of fruits and vegetables have a high potassium intake. Plant sources of potassium are highly water soluble; therefore, much of the potassium is lost when fruits and vegetables are boiled or blanched (unless the water is retained). Table 8-3 lists food sources of potassium.

Chloride

Chloride is the chemical form of chlorine in the human body. Chloride accounts for approximately 3% of the body's total mineral content, and it is widely distributed throughout body tissues.

Functions

Chloride is predominantly found in the extracellular fluid compartments, where it helps to maintain the water and acid-base balances (see Figure 8-3). Its two significant functions involve digestion and respiration.

Digestion. Chloride (Cl^-) is one element of the hydrochloric acid (HCl) that is secreted in the gastric juices. The action of gastric enzymes requires that stomach fluids have a specific acid concentration (i.e., a pH of approximately 1.0).

Respiration. Carbon dioxide, which is a by-product of cellular metabolism, is transported by red blood cells (RBCs) to the lungs, where it is expelled during respiration. Within the RBCs, the enzyme carbonic anhydrase combines carbon dioxide (CO_2) with water (H_2O) to form carbonic acid (H_2CO_3). Carbonic acid then dissociates into a bicarbonate ion (HCO_3^-) and a proton (H^+). Bicarbonate ions move out of the RBCs and into the plasma, and chloride ions (Cl^-) move into the RBCs and out of the plasma, thereby maintaining the balance of negative charges on either side of the RBC membrane. The exchange of a bicarbonate ion with a chloride ion in the plasma is called the *chloride shift*.

Requirements

The AI for chloride for young adults is set at 2.3 g/day on the basis of a molecular equivalence to sodium.[8] Similar to sodium's AI, the need for chloride gradually declines after the age of 50 years.

Deficiency States

A dietary deficiency of chloride does not occur under normal circumstances. Because the normal intake and output of chloride from the body parallels that of sodium, conditions that lead to a sodium deficiency also can lead to a chloride deficiency. The primary reason for chloride deficiency is excessive loss through vomiting, which

TABLE 8-3 FOOD SOURCES OF POTASSIUM

Item	Quantity	Amount (mg)
Bread, Cereal, Rice, and Pasta		
Wheat germ, toasted cereal	¾ cup	803
Vegetables		
Avocado, raw	¼ medium	244
Brussels sprouts, boiled	½ cup	247
Potato, baked, with skin	1 medium (173 g)	926
Spinach, boiled	½ cup	419
Sweet potato, with skin, baked	1 medium (114 g)	542
Tomato, raw	1 medium	254
Fruits		
Banana	1 medium (118 g)	422
Dates, dried, pitted	¼ cup, chopped	292
Orange juice, fresh	8 fl oz	496
Orange, navel	1 medium (140 g)	232
Prunes, dried, pitted	½ cup (87 g)	637
Prune juice, canned	8 fl oz	707
Raisins, seedless	¼ cup	272
Meat, Poultry, Fish, Dry Beans, Eggs, and Nuts		
Beef liver, pan fried	3 oz	298
Beef top round, lean, broiled	3 oz	221
Chickpeas (garbanzo beans), boiled	½ cup	239
Clams, cooked, moist heat	3 oz	534
Crab, blue, cooked, moist heat	3 oz	275
Ground beef, 70% lean, pan browned	3 oz	279
Halibut, cooked, dry heat	3 oz	490
Ham, sliced, 11% fat	3 oz	244
Lentils, boiled	½ cup	365
Lima beans, boiled	½ cup	478
Pinto beans, boiled	½ cup	373
Salmon, cooked, dry heat	3 oz	352
Sirloin steak, lean, broiled	3 oz	348
Soybeans, boiled	½ cup	443
Milk and Dairy Products		
Milk, skim	8 fl oz	382
Milk, whole	8 fl oz	349
Yogurt, plain, low fat	8 fl oz	573
Sugar		
Molasses	1 Tbsp	293

Data from the U.S. Department of Agriculture, Agricultural Research Service: Nutrient Data Laboratory. *USDA nutrient database for standard reference* (website): www.ars.usda.gov/ba/bhnrc/ndl. Accessed October 2010.

results in metabolic alkalosis from disturbances in the acid-base balance (see Chapter 9).

Toxicity Symptoms

The only known dietary cause of chloride toxicity is as a result of severe dehydration, when the concentration of chloride is too great. No ULs are established for chloride.

Food Sources

Dietary chloride is almost entirely provided by sodium chloride, which is the chemical name of ordinary table salt. The kidneys efficiently reabsorb chloride when dietary intake is low.

Magnesium

An adult body contains 25 g (i.e., a little less than 1 oz) of magnesium on average. Sixty percent of this magnesium is present in the bones.

Functions

Magnesium has widespread metabolic functions, and it is found in *all* body cells. About 99% of body magnesium is intracellular, with the remaining 1% found in the extracellular space.

General Metabolism. Magnesium is a necessary cofactor for more than 300 enzymes that make use of nucleotide triphosphates (e.g., adenosine triphosphate) for activation or catalyzing reactions that produce energy, synthesize body compounds, or help to transport nutrients across cell membranes.

Protein Synthesis. Magnesium is a cofactor for enzymes that activate amino acids for protein synthesis and that synthesize and maintain DNA. When cells replicate, they must produce new proteins. The cell replication process requires magnesium to function correctly.

Muscle Action. Magnesium ions are involved in the conduction of nerve impulses that stimulate muscle contraction as part of magnesium adenosine triphosphate (MgATP). Calcium is pumped out of the myofibrillar spaces into the sarcoplasmic reticulum by pumps that require MgATP for energy.

Basal Metabolic Rate. MgATP is involved in the secretion of thyroxine, thus helping the body to maintain a normal metabolic rate and to adapt to cold temperatures.

Requirements

The DRI guidelines establish RDA amounts by age and gender. Requirements increase gradually with age. For those between the ages of 14 and 18 years, the RDA for magnesium is 410 mg/day for boys and 360 mg/day for girls. For those who are 19 to 30 years old, the RDA is 400 mg/day for men and 310 mg/day for women. For adults 31 years old and older, the RDA is 420 mg/day for men and 320 mg/day for women. The RDA is slightly higher during pregnancy.[7] The average American diet provides less magnesium than the established RDA, with a median daily intake of 334 mg/day for men and 258 mg/day for women.[4]

Deficiency States

A magnesium deficiency from a lack of dietary magnesium is quite rare among people who consume balanced diets. Symptoms of magnesium deficiency (i.e., **hypomagnesemia**) have been observed in clinical situations such as starvation, persistent vomiting or diarrhea with a loss of magnesium-rich gastrointestinal fluids, and most commonly as a result of renal disorders. Hypomagnesemia is also a symptom of various diseases that involve the cardiovascular and neuromuscular systems as well as in patients with diabetes mellitus, kidney disease, and alcoholism.[11] In severe cases, hypomagnesemia can be life threatening.[12] Deficiency symptoms include muscle weakness and cramps, hypertension, and blood vessel constriction in the heart and brain.

Toxicity Symptoms

Magnesium from food has not been observed to have adverse effects at high intake levels. Therefore, the DRI standards give a UL only for magnesium intake from supplements and pharmaceutical preparations. The UL from nonfood sources is 350 mg/day for people who are 9 years old and older; it is less for younger children.[7] Individuals who consume excessive amounts of magnesium from supplements or nonfood sources (e.g., medications) may experience nausea, vomiting, and diarrhea.

Food Sources

Although magnesium is relatively common in foods, the content is variable. Unprocessed foods have the highest concentrations of magnesium. Major food sources of magnesium include nuts, soybeans, cocoa, seafood, whole grains, dried beans and peas, and green vegetables. More than 80% of the magnesium in cereal grains is lost with the removal of the germ and outer layers. Significant

hypomagnesemia a serum magnesium level that is below normal.

amounts of magnesium may also be present in drinking water in regions that have hard water with a fairly high mineral content.

Sulfur

Functions

As part of the amino acids cysteine and methionine, sulfur is an essential part of protein structure, and it is present in all body cells. It participates in widespread metabolic and structural functions, and it is also a component of the vitamins thiamin and biotin.

Hair, Skin, and Nails. Disulfide bonds between cysteine residues in the protein keratin are essential to the structure of the hair, skin, and nails.

General Metabolic Functions. Sulfhydryl or thiol groups (i.e., sulfur that is covalently bonded to hydrogen) form high-energy bonds that make various metabolic reactions energetically favorable.

Vitamin Structure. Sulfur is a component of thiamin and biotin, which act as coenzymes in cell metabolism.

Collagen Structure. The disulfide bonding of cysteine residues is necessary for collagen superhelix formation, and it is therefore important in the building of connective tissue.

Requirements

Dietary requirements for sulfur are not stated as such, because sulfur is supplied by protein foods that contain the amino acids methionine and cysteine.

Deficiency States

Sulfur deficiency states have not been reported. Such conditions only relate to general protein malnutrition and the deficient intake of the sulfur-containing amino acids.

Toxicity Symptoms

Sulfur is unlikely to reach toxic concentrations in the body as a result of dietary intake; thus, no UL has been established.

Food Sources

A diet that contains adequate protein contains adequate sulfur. Sulfur is only available to the body as part of the amino acids methionine and cysteine and in the vitamins thiamin and biotin. Thus, animal protein foods are the main dietary sources of sulfur. Sulfur is widely available in meat, eggs, milk, cheese, legumes, and nuts.

Table 8-4 provides a summary of the major minerals.

TRACE MINERALS

Iron

Iron has the longest and best-described history of all of the micronutrients. The human body contains approximately 45 mg iron per kilogram of body weight. As with several other nutrients, iron is essential for life, but it can be toxic in excess. Thus, the body has developed exquisite systems for balancing iron intake and excretion and for efficiently transporting iron in and out of cells to maintain homeostasis. Iron is transported in the body bound to **transferrin**, and it is stored as **ferritin** in the liver, the spleen, and other tissues (Figure 8-4).

Functions

Iron serves as the functional part of hemoglobin, and it plays a role in the body's general metabolism.

Hemoglobin Synthesis. Approximately 70% of the body's iron is in hemoglobin within RBCs. Iron is a component of heme, which is the nonprotein part of hemoglobin. Hemoglobin carries oxygen to the cells, where it is used for oxidation and metabolism. Iron also is part of myoglobin, a protein that is found in muscle cells that is structurally and functionally analogous to hemoglobin in blood.

General Metabolism. Iron is necessary for glucose metabolism, antibody production, drug detoxification by the liver, collagen and purine synthesis, and the conversion of β-carotene to active vitamin A.

Requirements

Iron needs vary throughout life, depending on growth and development. The DRIs establish the recommended intakes of iron for children as follows: the AI for infants up to the age of 6 months is 0.27 mg/day; for the ages of 7 to 12 months, the RDA is 11 mg/day; for the ages of 1 to 3 years, the RDA is 7 mg/day; and for the ages of 4 to 8 years, the RDA is 10 mg/day. RDAs for iron for the age of 9 years old and older are between 8 and 11 mg/day for

transferrin a protein that binds and transports iron through the blood.

ferritin the storage form of iron.

TABLE 8-4 SUMMARY OF MAJOR MINERALS

Mineral	Functions	Recommended Intake (Adults)	Deficiency	Tolerable Upper Intake Level (UL) and Toxicity	Sources
Calcium (Ca)	Bone and teeth formation; blood clotting; muscle contraction and relaxation; nerve transmission	Between the ages of 19 and 50 years, 1000 mg; between the ages of 51 and 70 years, 1200 mg in women and 1000 mg in men; 70 years old or older, 1000 mg	Tetany, rickets, osteoporosis	UL: 2500 mg Increases the risk of kidney stones and constipation; interferes with the absorption of other nutrients	Dairy products, fish bones, fortified orange juice and cereals, legumes, green leafy vegetables
Phosphorus (P)	Bone and tooth formation; energy metabolism; DNA and RNA; acid-base balance	700 mg	Unlikely, but can cause bone loss, loss of appetite, and weakness	UL: 4g Bone resorption (loss of calcium)	High-protein foods (e.g., meat, dairy), soft drinks
Sodium (Na)	Major extracellular fluid control; water balance; acid-base balance; muscle action; transmission of nerve impulse and resulting contraction	Adequate intake: between the ages of 19 and 50 years, 1.5 g; between the ages of 51 and 70 years, 1.3 g; 71 years old or older, 1.2 g	Fluid shifts, acid-base imbalance, cramping	UL: 2.3 g Hypertension in salt-sensitive people; edema	Table salt, processed foods (e.g., luncheon meats, salty snacks)
Potassium (K)	Major intracellular fluid control; acid-base balance; regulation of nerve impulse and muscle contraction; blood pressure regulation	Adequate intake: 14 years old or older, 4.7 g	Irregular heartbeat, difficulty breathing, muscle weakness	UL not set Cardiac arrest	Fresh fruits and vegetables, meats, whole grains
Chloride (Cl)	Acid-base balance (chloride shift); hydrochloric acid (digestion)	Adequate intake: between the ages of 19 and 50 years, 2.3 g; between the ages of 51 and 70 years, 2.0 g; 71 years old or older, 1.8 g	Hypochloremic alkalosis with prolonged vomiting or diarrhea	UL not set Toxicity unlikely	Table salt, processed foods
Magnesium (Mg)	Coenzyme in metabolism, muscle and nerve action; helps with thyroid hormone secretion	Men, 400 to 420 mg; women, 310 to 320 mg	Tremor, spasm, low serum level after gastrointestinal losses or renal losses from alcoholism, convulsions	UL 350 mg (from supplements) Nausea; vomiting; diarrhea	Whole grains, nuts, legumes, green vegetables, seafood, cocoa
Sulfur (S)	Essential constituent of cell protein, hair, skin, nails, vitamin, and collagen structure; high-energy sulfur bonds in energy metabolism	Diets that are adequate in protein contain adequate sulfur	Unlikely	UL not set Toxicity unlikely	Meat, eggs, cheese, milk, nuts, legumes

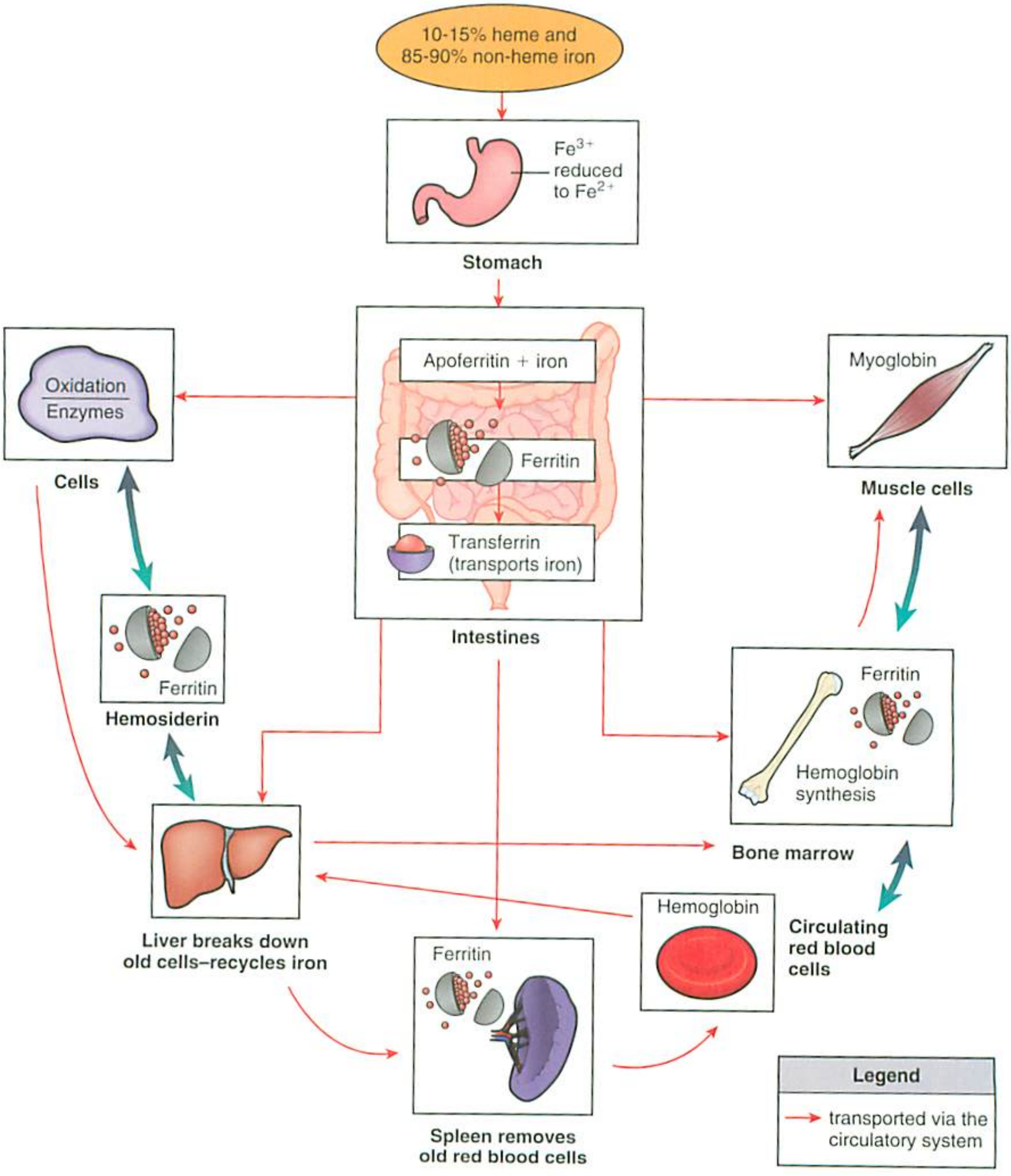


Figure 8-4 The absorption and metabolism of iron.

boys and between 8 and 18 mg/day for girls to accommodate growth spurts.[13] Women require more iron to cover the losses that occur during menstruation. Throughout pregnancy, a woman's RDA for iron increases to 27 mg/day. This increase usually requires an iron supplement, because neither the usual American diet nor the iron stores of many women can meet the increased iron demands of pregnancy. The average iron intake of women between the ages of 20 and 50 years is 13 mg/day, which is notably below the RDA.[4]

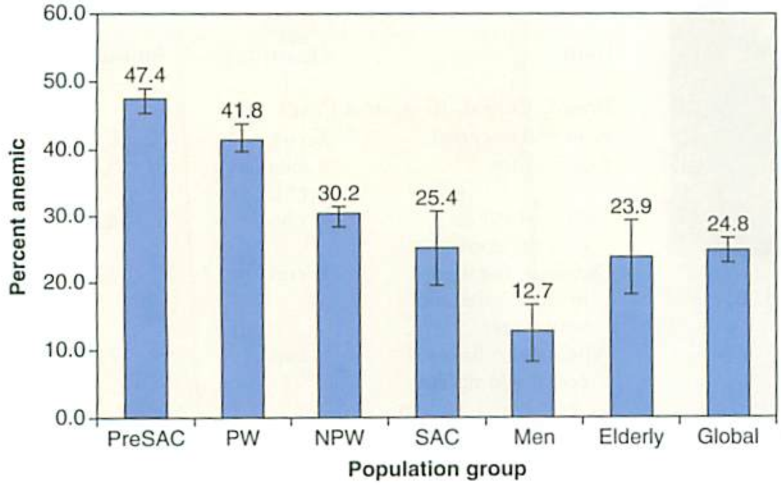


Figure 8-5 The global prevalence of anemia (%) and the number of individuals (in millions) affected in different population groups. *PreSAC,* Preschool-aged children (0 to 4.99 years old); *PW,* pregnant women; *NPW,* nonpregnant women (15 to 49.99 years old); *SAC,* school-aged children (5 to 14.99 years old); *Men* (15 to 59.99 years old); *Elderly* (includes men who are more than 60 years old and women who are more than 50 years old). (Reprinted from McLean E, Cogswell M, Egil I, et al. Worldwide prevalence of anaemia, WHO Vitamin and Mineral Nutrition Information System, 1993-2005. *Public Health Nutr.* 2009; 12(4):444-454.

Deficiency States

The major condition that indicates a deficiency of iron is **anemia**. Iron-deficiency anemia is usually evaluated biochemically by the percentage of packed RBCs (i.e., hematocrit), the RBC hemoglobin level, or the percentage of transferrin saturation. Iron-deficiency anemia is the most prevalent nutrition problem in the world today (Figure 8-5). The World Health Organization estimates that iron deficiency anemia affects 24.8% of the population worldwide, with a disproportionate prevalence seen among preschool-aged children and pregnant women.[14]

Iron-deficiency anemia may have several causes, including the following: (1) inadequate dietary iron intake; (2) excessive blood loss; (3) an inability to form hemoglobin as a result of a lack of factors such as vitamin B_{12} (i.e., pernicious anemia); (4) a lack of gastric hydrochloric acid, which liberates iron for intestinal absorption; (5) inhibitors of iron absorption (e.g., phytate, phosphate, tannin, oxalate); and (6) intestinal mucosal lesions that affect the absorptive surface area.

Toxicity Symptoms

Iron toxicity from a single large dose (20 to 60 mg per kilogram of body weight) can be fatal. The UL for iron is 45 g/day for adults.[13]

In the United States, iron overdose from supplements is one of the leading causes of poisoning among young children who are less than 6 years old. Symptoms include nausea, vomiting, and diarrhea. If these children are not immediately treated, several organ systems may be adversely affected, including the cardiovascular system, the central nervous system, the kidney, the liver, and the hematologic system.[15]

Chronic excessive iron intake through dietary supplements may impair the absorption of zinc, cause gastrointestinal upset, and increase the risk of the development of heart disease and cancer. Hemochromatosis, an iron overload disease, may result from five types of genetic mutations, but it is most commonly the result of a mutation in the hemochromatosis (*HFE*) gene.[16] The congenital disease is an autosomal recessive disorder that results in iron overload even though iron intake is within the normal range. This disorder affects 1 in 200 to 1 in 300 individuals of northern European descent.[17] Afflicted individuals absorb excessive amounts of iron from food; over time (usually between the ages of 40 and 60 years), the iron accumulation causes widespread organ damage. Treatment involves frequent bloodletting (i.e., therapeutic phlebotomy) to reestablish normal serum iron levels. If treatment begins before widespread damage occurs, patients may have a normal life expectancy.

Food Sources

The typical Western diet provides an average of 6 mg of iron per 1000 kcal of energy intake. Iron is widely distributed in the U.S. food supply, primarily in meat, eggs, vegetables, and fortified cereals (Figure 8-6). Liver and fortified cereal products are especially good sources. The body absorbs iron more easily when it is taken along with vitamin C. Iron in food occurs in two forms: heme and nonheme. Heme iron is the most efficiently absorbed form of dietary iron, but it contributes the least to the total iron intake. Heme iron is found in only 40% of the animal food sources and in no plant foods (Table 8-5). Nonheme iron is less efficiently absorbed, because it is more tightly bound in foods, yet most of our food sources

anemia a blood condition that is characterized by a decreased number of circulating red blood cells, decreased hemoglobin, or both.

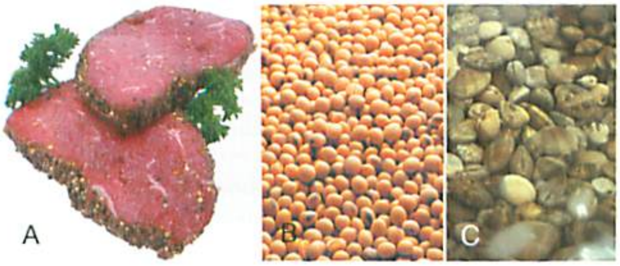


Figure 8-6 Food sources of dietary iron. **A,** Beef. **B,** Black-eyed peas. **C,** Oysters and clams. (Copyright JupiterImages Corporation.)

TABLE 8-5 CHARACTERISTICS OF THE HEME AND NONHEME PORTIONS OF DIETARY IRON

	Heme	Nonheme
Food sources	None in plant sources; 40% of iron in animal sources	All iron in plant sources; 60% of iron in animal sources
Absorption rate	Rapid; transported and absorbed intact	Slow; tightly bound in organic molecules

(i.e., 60% of the animal food sources and all the plant food sources) contain nonheme iron. To enhance the absorption of nonheme iron, food sources of vitamin C and moderate amounts of lean meats, fish, or poultry should be consumed in the same meal. Enriched and fortified cereal products are a good source of nonheme iron. Table 8-6 lists food sources of iron.

Iodine

The average adult body contains only 20 to 50 mg of iodine.

Functions

Iodine's basic function is as a component of **thyroxine (T_4)**, a hormone that is synthesized by the thyroid gland and that helps to control the basal metabolic rate. T_4 synthesis is ultimately controlled by the hypothalamus and the pituitary gland. The hypothalamus excretes **thyrotropin-releasing hormone (TRH)**. TRH, in turn, stimulates the release of TSH from the anterior pituitary gland. TSH controls the thyroid gland uptake of iodine from the bloodstream and the release of triiodothyronine (T_3) and T_4 into the circulation (Figure 8-7). Blood T_4 concentration determines how much TRH the hypothalamus releases and how much TSH the pituitary gland

TABLE 8-6 FOOD SOURCES OF IRON

Item	Quantity	Amount (mg)
Bread, Cereal, Rice, and Pasta		
Bran Flakes cereal	¾ cup	8.1
Bran muffin	1 medium (113 g)	4.75
Cream of Wheat, instant, cooked	¾ cup	8.98
Oatmeal, fortified, instant, prepared with water	¾ cup	7.26
Wheat Bran flakes cereal, Complete	¾ cup	17.98
Fruits and Vegetables		
Prune juice, canned	8 fl oz	3.02
Spinach, boiled, drained*	½ cup	3.21
Meat, Poultry, Fish, Dry Beans, Eggs, and Nuts		
Beef, ground, 70% lean, pan browned	3 oz	2.11
Beef liver, pan fried	3 oz	5.24
Beef top round, lean, broiled	3 oz	2.78
Chickpeas (garbanzo beans), boiled	½ cup	2.37
Clams, cooked, moist heat	3 oz	23.77
Lentils, boiled	½ cup	3.3
Lima beans, large, boiled	½ cup	6.74
Oysters, cooked, dry heat	3 oz	6.6
Shrimp, cooked, moist heat	3 oz	2.63
Soybeans, boiled	½ cup	4.42
Tofu, raw, firm, prepared with calcium sulfate	½ cup	2.03

*Low bioavailability

Data from the U.S. Department of Agriculture, Agricultural Research Service: Nutrient Data Laboratory. *USDA nutrient database for standard reference* (website): www.ars.usda.gov/ba/bhnrc/ndl. Accessed October 2010.

thyroxine (T_4) an iodine-dependent thyroid gland hormone that regulates the metabolic rate of the body.

thyrotropin-releasing hormone (TRH) a hormone that is secreted by the hypothalamus and that stimulates the release of thyroid-stimulating hormone by the pituitary.

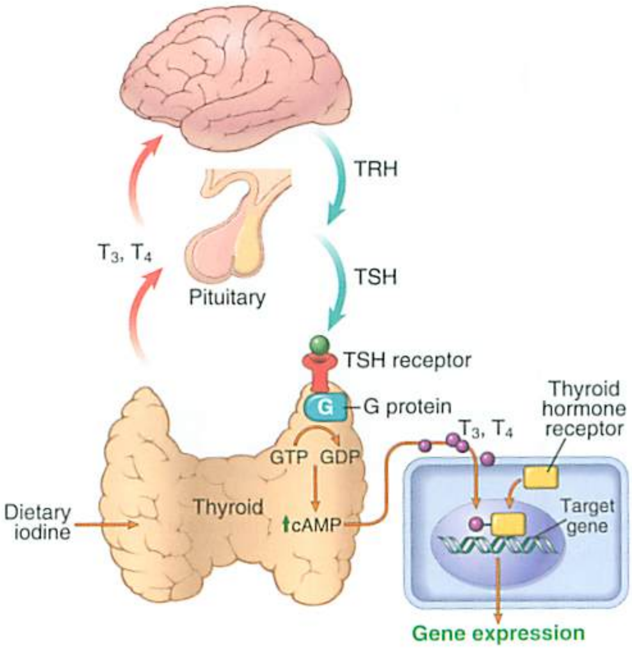


Figure 8-7 Uptake of iodine for triiodothyronine and thyroxine production. (Reprinted from Guyton AC, Hall JE. *Textbook of medical physiology*. 12th ed. Philadelphia: Saunders; 2006.)

releases. As blood T_4 concentration decreases, the hypothalamus and the pituitary gland are stimulated to release more TRH and TSH, respectively.

The transport form of iodine in the blood is called *serum protein-bound iodine.* T_3, T_4, and inorganic iodine are eventually disposed of by the liver in bile.

Requirements

The body's need for iodine has been extensively studied. To maintain desirable tissue levels of iodine, the adult body's minimal requirement is 50 to 75 mcg/day; therefore, to provide an extra margin of safety, the RDA is 150 mcg/day for all people who are 14 years of age and older; less is indicated for infants and children. During pregnancy, the need increases to 220 mcg/day; during lactation, it increases to 290 mcg/day.[13]

Deficiency States

The World Health Organization reports that iodine-deficiency disorders are the easiest and least expensive of all nutrient disorders to prevent; however, they remain the number one cause of preventable brain damage worldwide. Iodine-deficiency disorders are generally found in geographic locations with mountains or frequent flooding that result in poor soil iodine levels. Roughly 31% of the world's population has insufficient iodine intake; these individuals are at high risk for the following deficiency diseases.[18]

Goiter. Goiter is characterized by an enlargement of the thyroid gland (Figure 8-8). When the thyroid gland is starved for iodine, it cannot produce a normal amount of T_4. Because of a low blood T_4 concentration, the pituitary gland continues to release more TSH. These large amounts of TSH overstimulate the nonproductive thyroid gland, thereby causing its size to increase greatly. An iodine-starved thyroid gland may weigh 0.45 to 0.67 kg (1 to 1.5 lb) or more. Although the thyroid is one of the larger endocrine glands, it normally only weighs 10 to 20 g in an adult.

Cretinism. Cretinism is characterized by physical deformity, dwarfism, and mental retardation. This serious condition occurs among children who are born to mothers who had limited iodine intake during adolescence and pregnancy. During pregnancy, the mother's need for iodine takes precedence over the iodine needs of the developing child. Thus, the fetus suffers from iodine deficiency and continues to do so after birth. The physical and mental development of these children is severely impeded and irreversible.[19]

Impaired Mental and Physical Development. Iodine deficiency at any stage in life may result in mental impairment. Studies indicate that there is a significant reduction in the intelligence quotient of people with chronic and severe iodine deficiency. Iodine deficiency during the adolescent and teen years delays growth as well as the onset of puberty.[19,20]

Hypothyroidism. An adult form of hypothyroidism called *myxedema* occurs when a poorly functioning thyroid gland does not make enough T_4, thereby greatly reducing the basal metabolic rate. The symptoms of this condition are thin, coarse hair; dry skin; poor cold tolerance; weight gain; and a low, husky voice.

Hyperthyroidism. Hyperthyroidism is a condition in adults in which the overstimulated thyroid gland releases excessive T_4, thereby greatly increasing the basal metabolic rate. Hyperthyroidism is known as *Graves' disease* or *exophthalmic goiter* because of its prominent symptom of protruding eyeballs. Other symptoms include weight loss, hand tremors, general nervousness, increased appetite, and an intolerance of heat.

goiter an enlarged thyroid gland that is caused by a lack of enough available iodine to produce the thyroid hormone thyroxine.

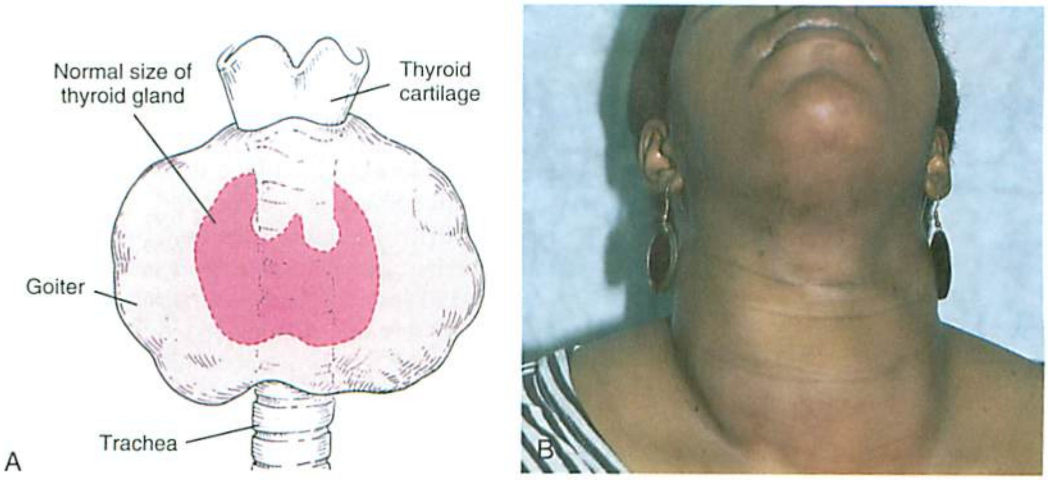


Figure 8-8 **A,** Illustration of a goiter. **B,** The extreme enlargement is a result of an extended duration of iodine deficiency. (**B,** Reprinted from Swartz MH. *Textbook of physical diagnosis.* 5th ed. Philadelphia: Saunders; 2006.)

Toxicity Symptoms

The incidental intake of iodine through supplementation or water contamination may result in toxicity. Excessive intake may cause iodine-excess goiter, autoimmune thyroiditis, hypothyroidism, elevated TSH, and ocular damage.[21]

Although the risk of iodine toxicity exists, the continued use of iodized salt is still widely practiced in several countries, including the United States. The risk for iodine deficiency far outweighs the small potential for iodine toxicity. The UL of iodine in healthy adults is 1100 mcg/day.[13]

Food Sources

The amount of iodine in natural food sources varies considerably depending on the iodine content of the soil in which the food was grown. Seafood consistently provides a good amount of iodine. However, the major reliable source of iodine in U.S. diets is iodized table salt, with each gram containing 76 mcg of iodine. Salt that is used in the preparation of processed food supplies iodine for those people who do not use table salt.

Zinc

Zinc is an essential trace mineral with wide clinical significance. The amount of zinc in the adult body is approximately 1.5 g (0.05 oz) in women and 2.5 g (0.09 oz) in men.

Functions

Zinc is especially important during growth periods such as pregnancy, lactation, infancy, childhood, and adolescence. Zinc is present in minute quantities in all body organs, tissues, fluids, and secretions. In these tissues, zinc participates in three different types of metabolic functions, as outlined in the following paragraphs.

Enzyme Constituent. Zinc's wide tissue distribution reflects its broad metabolic activity as an essential part of certain cell enzyme systems. More than 200 zinc-containing enzymes have been identified. Zinc's role in protein metabolism is associated with wound healing and healthy skin. Zinc greatly influences rapidly growing tissues, including those involved in fetal development during gestation.

Immune System. A considerable amount of protein-bound zinc is present in leukocytes (i.e., white blood cells). Zinc is integral in the health of the immune system as a result of its role in the synthesis of nucleic acids (DNA and RNA) and protein.[22] Zinc is also needed for lymphocyte transformation. Healthy lymphoid tissue, which gives rise to lymphocytes, is rich in zinc.

Other Functions. Zinc stabilizes the prohormone storage form of insulin in the pancreas. It is also involved in the protection of RBCs from oxidative damage and in taste and smell acuity.

Requirements

The DRIs establish an AI for infants of 2 to 3 mg/day during the first 3 years of life and of 5 mg/day for children between the ages of 4 and 8 years. The zinc requirement continues to rise until adulthood for both genders. Males who are 14 years old and older require 11 mg of zinc per day, whereas females need 8 mg/day, with the exception of 14- to 18-year-old girls, whose needs are slightly higher. Pregnant women require 11 mg/day to meet fetal growth needs and 12 mg/day for lactation. Pregnant or lactating girls who are younger than 18 years old require 2 mg/day more zinc than pregnant women older than 18 years old.[13] The average daily zinc intake for men and women in the United States is 14.4 mg and 9.9 mg, respectively.[4]

Deficiency States

Adequate zinc intake is imperative during periods of rapid tissue growth, such as childhood and adolescence. Stunted growth, especially in boys, has been observed in some populations in which dietary zinc intake is low.[23] Impaired taste and smell (i.e., hypogeusia and hyposmia, respectively) are improved with increased zinc intake if dietary zinc intake was previously inadequate. Zinc deficiency commonly causes poor wound healing, hair loss, diarrhea, skin irritation, and overall compromised immune function.[22] Patients with poor appetites, who subsist on marginal diets, or who have chronic wounds or illnesses with excessive tissue breakdown may be particularly vulnerable to developing zinc deficiency (see the For Further Focus box, "Zinc Barriers").

Acrodermatitis enteropathica (AE) is a rare autosomal recessive disorder that results in severe zinc deficiency and death if it is not treated. Patients with this condition are not able to absorb sufficient zinc from the gut. Classical symptoms of acrodermatitis enteropathica begin with skin lesions and progress to severely compromised immune function (Figure 8-9). This metabolic disorder is successfully treated with oral zinc supplements at high doses if it is diagnosed during infancy.

Figure 8-9 Skin lesions that are characteristic of severe zinc deficiency in a patient with acrodermatitis enteropathica. (Kumar V, Abbas AK, Fausto N. *Robbins and Cotran pathologic basis of disease*. 7th ed. Philadelphia: Saunders; 2005.)

FOR FURTHER FOCUS

ZINC BARRIERS

Are people eating more zinc but absorbing it less? Current trends toward a heart-healthy diet may be the reason why. Some Americans may be at risk for developing a zinc deficiency—not because they are avoiding zinc-rich foods but because they are choosing foods and supplements that reduce zinc's availability for absorption. Here are some examples:

- Animal foods, which are rich in readily available zinc, are consumed less by an increasingly cholesterol-conscious public.
- Dietary fiber may hinder absorption and create a negative zinc balance.
- Food processing may make zinc less available.
- Vitamin and mineral supplements may contain iron-to-zinc ratios of greater than 3 : 1 and thus, provide enough iron to inhibit zinc absorption.

Low levels of zinc can reduce the amount of protein that is available to carry iron and vitamin A to the target tissues. It can also reduce an individual's normal appetite and taste for certain foods.

The following suggestions may help to increase dietary zinc:

- Include some form of animal food (e.g., meat, milk, and eggs) or vegetarian-acceptable fortified food in the diet each day to ensure an adequate intake of zinc.
- Avoid the excessive use of alcohol.
- Avoid "crash" diets, which are typically low in micronutrients.

Signs of zinc deficiency are fairly rare in the United States, but they are becoming more apparent among at-risk people (e.g., older adults who are hospitalized with long-term chronic illnesses).[1] However, there is no need for the general public to take massive supplemental doses. These large doses may compete with other minerals (e.g., iron) and create other deficiency problems. Excess zinc can lead to nausea, abdominal pain, anemia, and immune system impairment. As with all other nutrients, too much of a good thing can sometimes be as bad as—or even worse than—too little.

1. Prasad AS. Impact of the discovery of human zinc deficiency on health. *J Am Coll Nutr.* 2009; 28(3):257-265.

Toxicity Symptoms

As with several other minerals, zinc toxicity from food sources alone is uncommon. However, prolonged supplementation that exceeds the recommended zinc intake can alter lymphocyte function and cause adverse symptoms such as nausea, vomiting, and epigastric pain.[24] The UL for zinc of 40 mg/day was established on the basis of the negative effects of excess zinc supplementation on copper metabolism.[13] Excessive zinc intake inhibits copper absorption, thereby resulting in a zinc-induced copper deficiency.

Food Sources

The greatest source of dietary zinc in the United States is meat, which supplies approximately 70% of the zinc that is consumed. Seafood (particularly oyster) is another excellent source of zinc. Legumes and whole grains are reasonable sources of zinc, but the zinc in these foods is less available for intestinal absorption as a result of phytate binding. A balanced diet usually meets adult needs for zinc. People who consume diets with little or no animal products and who have a high intake of phytate-rich unrefined grains may be at risk for developing marginal zinc deficiency.[25] Table 8-7 lists food sources of zinc.

TABLE 8-7 FOOD SOURCES OF ZINC

Item	Quantity	Amount (mg)
Bread, Cereal, Rice, and Pasta		
Bran Flakes cereal	¾ cup	1.5
Bran muffin	1 medium (113 g)	2.08
Wheat Bran flakes cereal, Complete	¾ cup	15.22
Meat, Poultry, Fish, Dry Beans, Eggs, and Nuts		
Almonds, roasted	1 oz	1
Beef, ground, 70% lean, pan browned	3 oz	5.06
Beef liver, pan fried	3 oz	4.45
Beef round top, lean, broiled	3 oz	3.83
Cashews, roasted	1 oz	1.59
Chicken, dark meat only, cooked, without skin	3 oz	1.81
Chickpeas (garbanzo beans), boiled	½ cup	1.25
Clams, cooked, moist heat	3 oz	2.32
Crab, Alaskan king, cooked, moist heat	3 oz	6.48
Ham, sliced, regular (11% fat)	3 oz	1.15
Lentils, boiled	½ cup	1.26
Lima beans, large, boiled	½ cup	2.68
Lobster, cooked, moist heat	3 oz	2.48
Oysters, cooked, dry heat	3 oz	38.4
Shrimp, cooked, moist heat	3 oz	1.33
Sirloin steak, lean, broiled	3 oz	4.84
Tofu, raw, firm, prepared with calcium sulfate	½ cup	1.05
Milk and Dairy Products		
Milk, skim	8 fl oz	1.03
Yogurt, plain, low fat	8 fl oz	2.18

Data from the U.S. Department of Agriculture, Agricultural Research Service: Nutrient Data Laboratory. *USDA nutrient database for standard reference* (website): www.ars.usda.gov/ba/bhnrc/ndl. Accessed October 2010.

Selenium

Functions

Selenium is present in all body tissues except adipose tissue. The highest concentrations of selenium are in the liver, kidneys, heart, and spleen. Selenium is an essential part of the antioxidant enzyme glutathione peroxidase, which protects the lipids in cell membranes from oxidative damage. An abundance of selenium may spare vitamin E to an extent, because both selenium and vitamin E protect against free radical damage. Selenium is also a component of many proteins in the body that are referred to as *selenoproteins*. One such selenoprotein is type 1 iodothyronine 5′ deiodinase, which is the enzyme that converts T_4 to T_3.

The DRI panel on antioxidants reviewed the current scientific research on selenium. The panel concluded that, although selenium intakes that are higher than the RDA may protect against cancer, further large-scale research is necessary to confirm such an effect.[26] However, several recent studies found no correlation between dietary selenium intake above recommended amounts and cancer prevention.[27,28]

Requirements

The recommendations for selenium intake are made by age group without specificity to gender. For both men and women who are 14 years old and older, the RDA is 55 mcg/day. The RDA decreases by age for children: it is 40 mcg/day for children who are 9 to 13 years old, 30 mcg/day for children who are 4 to 8 years old, and 20 mcg/day for children who are 1 to 3 years old. The DRI does not list an RDA for infants. On the basis of mean intakes of breast milk, an infant's observed AI level is 15 mcg/day for the first 6 months of life and 20 mcg/day from the ages of 7 to 12 months. The recommended selenium intake day during pregnancy is 60 mcg/day, and it is 70 mcg/day during lactation.[26]

Deficiency States

Inadequate selenium negatively alters immune function and increases the opportunity for oxidative stress, specifically within the thyroid gland. Selenium deficiency is generally only found in geographic areas with a poor soil content of selenium.[29] Research indicates that adequate selenium intake plays a role in preventing *Kashin-Bek disease* and *Keshan disease*. Kashin-Bek disease results in chronic arthritis and joint deformity. Keshan disease, which is named after the area in China where it was discovered, is a disease of the heart muscle that primarily affects young children and women of childbearing age and that can lead to heart failure as a result of cardiomyopathy (i.e., degeneration of the heart muscle).

Toxicity Symptoms

The most common symptom of selenium toxicity is hair loss, joint pain, nail discoloration and gastrointestinal upset (i.e., nausea, vomiting, and diarrhea). Most known cases of dietary selenium toxicity are in isolated regions of the world where the soil has extremely high levels of selenium. However, in 2008 a misformulated dietary supplement resulted in 201 cases of selenium poisoning in the United States, with symptoms that persisted for more than 3 months.[30] The UL for selenium is 400 mcg/day for people who are 14 years old and older.[26]

Food Sources

Most selenium in food is highly available for intestinal absorption. The amount of selenium in food depends on the quantity of selenium in the soil that is used to graze animals and grow plants. Seafood, kidney, and liver are consistently good sources of selenium. To a lesser extent, other meats also provide selenium. Grains and other seeds have variable selenium content, and fruits and vegetables generally contain little selenium. In the United States and Canada, the dietary intake of selenium can vary by the geographic region in which the fruits and vegetables are grown, but these local differences are mitigated by the national food distribution system. The average adult intake of selenium in the United States is 104.9 mcg/day.[4]

The following sections briefly review the remaining essential trace minerals.

Fluoride

Fluoride forms a strong bond with calcium; thus, it accumulates in calcified body tissues such as bones and teeth. Fluoride's main function in human nutrition is to prevent dental caries. Fluoride strengthens the ability of teeth to withstand the erosive effect of bacterial acids. To a great extent, the fluoridation of the public water supply (for which the optimal level is 1 ppm) is responsible for the remarkable decline in dental caries during recent decades. The use of fluoridated toothpaste (0.1% fluoride) and improved dental hygiene habits have also benefited dental health.

According to the DRI guidelines, research data are insufficient with regard to fluoride intake to support a specific RDA. Alternatively, the DRI lists observed AIs by age group. For adults who are 19 years old and older, the AI is 4 mg/day for men and 3 mg/day for women, with lower intakes for children. It is not recommended that fluoride intake increase during pregnancy and lactation. The DRI guidelines set the UL for fluoride at 10 mg/day for people who are 9 years old and older to avoid dental **fluorosis** (Figure 8-10).[7]

Fish, fish products, and tea contain the highest concentrations of fluoride. Cooking in fluoridated water raises the fluoride concentration in many foods. People who are using well water should periodically check the fluoride concentration of their water, because well water can contain excessively high natural sources of fluoride.

Copper

Copper has frequently been called the "iron twin," because both iron and copper are metabolized in much the same way, and both are components of cell enzymes. Both of these minerals are also involved in energy production and hemoglobin synthesis. Severe copper deficiency is rare, and it can be attributed to individual adaptation to somewhat lower intakes.

There are two severe inborn errors of metabolism that involve copper. The first is Menkes' disease, which is an X-linked genetic disease of copper metabolism that currently has no treatment or cure. Individuals who are affected with Menkes' disease progress through neurodegeneration and connective tissue deterioration, and they usually do not survive past childhood.[31] Wilson's disease is a rare autosomal recessive genetic disorder that causes an abnormally high storage of copper in the body. Without treatment, Wilson's disease can result in liver and nerve damage that leads to death. However, there are treatments for Wilson's disease that may stabilize or even reverse it.[32]

The adult RDA for dietary copper intake is 900 mcg/day. Pregnant and lactating women are recommended to increase their copper intake to 1 mg/day and 1.3 mg/day, respectively.[13] The average daily intake of dietary

fluorosis an excess intake of fluoride that causes the yellowing of teeth, white spots on the teeth, and the pitting or mottling of tooth enamel.

Figure 8-10 Fluorosis.

copper in the United States is 1.3 mg/day.[4] The UL for copper is 10 mg/day to avoid gastrointestinal upset and liver damage.[13] Copper is widely distributed in natural foods. Organ meats (especially liver), seafood, nuts, seeds, legumes, and grains are the richest food sources of copper.

Manganese

The adult body contains approximately 20 mg of manganese that is found primarily in the liver, pancreas, pituitary gland, and bones. Manganese functions like many other trace minerals: as a component of cell enzymes. Manganese-dependent enzymes catalyze many important metabolic reactions. In some magnesium-dependent enzymes, manganese may serve as a substitute for magnesium, depending on the availability of these two minerals. The intestinal absorption and bodily retention of manganese are associated with serum ferritin concentration.

Manganese deficiency has been documented in animal studies, but there are no known manganese deficiencies among humans who are consuming a free diet. Manganese toxicity occurs as an industrial occupation disease known as *inhalation toxicity* in miners and other workers who are exposed to manganese dust over long periods. The excess manganese accumulates in the liver and the central nervous system, thereby producing severe neuromuscular symptoms that are similar to those of Parkinson's disease. There is also a potential for manganese toxicity among patients who are receiving total parenteral nutrition, because the bioavailability is approximately 95% greater than if it is absorbed enterally. In addition, the normal elimination pathway is often impaired in these patients; thus, manganese accumulates in and damages the brain.[33] The UL from dietary sources is 11 mg/day for healthy adults.[13]

The DRIs estimate an AI of 2.3 mg/day for men and 1.8 mg/day for women who are older than 19 years of age. Needs gradually increase during and after childhood, and pregnant and lactating women need more manganese (2.0 mg/day and 2.6 mg/day, respectively).[13] The best food sources of manganese are of plant origin. Whole grains, cereal products, and teas are the richest food sources.

Chromium

The precise amount of chromium that is present in body tissues is uncertain, because analysis is difficult. Although large geographic variations occur, total body chromium is less than 6 mg. Chromium is an essential component of the organic complex glucose tolerance factor, which stimulates the action of insulin. Chromium supplements were previously thought to reduce insulin resistance (the cause of impaired glucose tolerance) and to improve lipid profiles for at-risk patients. However, a recent randomized double-blind study that examined the effects of chromium supplements in subjects with impaired glucose tolerance did not find significant improvements in glucose tolerance among those who took chromium compared with the control group.[34] For adults, the AI of chromium intake is 35 mcg/day for men and 25 mcg/day for women. Chromium needs gradually rise from infancy to adulthood and then decline after the age of 50 years. Pregnant and lactating women have an increased need of 30 mcg/day and 45 mcg/day, respectively. No UL has been established.[13] Brewer's yeast is a rich source of chromium, and most grains and cereal products contain significant amounts.

Molybdenum

Molybdenum is better absorbed than many minerals, and inadequate dietary intake is unlikely. The amount of molybdenum in the body is exceedingly small; it ranges from 0.1 to 1 mcg per gram of body tissue. Molybdenum is the functional catalytic component in several cell enzymes. For adults, the RDA of molybdenum is 45 mcg/day. Pregnant and lactating women need an additional 5 mcg/day. The National Academy of Sciences found it necessary to establish a UL of 2000 mcg/day for adults who are older than 19 years of age.[13] The amounts of molybdenum in foods vary considerably depending on the soil in which they are grown. Food sources include legumes, whole grains, milk, leafy vegetables, and organ meats.

Table 8-8 provides a summary of selected trace minerals.

Other Essential Trace Minerals

RDAs and AIs were not set for the remaining trace minerals: aluminum, arsenic, boron, nickel, silicon, tin, and vanadium. At the time of the 2002 DRIs, not enough data were available to establish such recommendations.[13] Most of these minerals are deemed essential to the nutrition of specific animals and probably are essential to human nutrition as well, although the complete process of their metabolism is not yet fully understood. Because these minerals occur in such small amounts, they are difficult to study, and dietary deficiency is highly unlikely.

The available research data regarding boron, nickel, and vanadium is sufficient to establish a tolerable UL level. The adult ULs for both boron and vanadium were set on the basis of data that were gathered from animal studies: for boron, the UL is 20 mg/day; for vanadium, it is 1.8 mg/day. The adult UL for arsenic was set at 1 mg/day.[13]

MINERAL SUPPLEMENTATION

The same principles that were discussed in Chapter 7 for vitamin supplementation apply to mineral supplementation as well. Special needs during growth periods and in clinical situations may require specific mineral supplements. Before taking supplements, potential nutrient-nutrient interactions and drug-nutrient interactions should be considered. Several situations can occur in which mineral bioavailability may be hindered (see the Drug-Nutrient Interaction box, "Mineral Depletion").

Life Cycle Needs

Mineral supplements may be needed during rapid growth periods throughout the life cycle.

DRUG-NUTRIENT INTERACTION

MINERAL DEPLETION

Medications interact with minerals through two major mechanisms: either by blocking absorption or by inducing renal excretion. The following are examples of common drug-nutrient interactions that specifically affect mineral status:

- *Diuretics:* People who require the long-term use of diuretic drugs for the treatment of hypertension may need to pay special attention to certain minerals that are also lost. The minerals that are usually excreted with excess water are sodium, potassium, magnesium, and zinc. The increased intake of foods that are high in these minerals is generally enough to regain homeostasis. Some diuretics (e.g., spironolactone) are potassium sparing and thus extra potassium should not need to be consumed.
- *Chelating agents:* Chelation therapy is used to remove excess metal ions from the body. Penicillamine is used to treat Wilson's disease (i.e., the excess accumulation of copper in the body) and rheumatoid arthritis and to prevent kidney stones. It attaches to zinc and copper, thereby blocking absorption and leading to the excretion and possible depletion of these essential minerals.
- *Antacids:* The acidic environment of the stomach is required for the absorption of many drugs and nutrients, including minerals. When this environment is altered as a result of the chronic use of antacids, mineral deficiencies can occur. Phosphate deficiency is a concern for individuals who are chronically using over-the-counter antacids. In extreme cases, hypercalcemia may result, and damage to soft tissues can occur.

TABLE 8-8 SUMMARY OF SELECTED TRACE ELEMENTS

Mineral	Functions	Recommended Intake (Adults)	Deficiency	Tolerable Upper Intake Level (UL) and Toxicity	Sources
Iron (Fe)	Hemoglobin and myoglobin formation; cellular oxidation of glucose; antibody production	Men, 8 mg; women between the ages of 19 and 50 years, 18 mg; women who are 50 years old or older, 8 mg	Anemia, pale skin, impaired immune function	UL: 45 mg Nausea; vomiting; diarrhea; liver, kidney, heart, and central nervous system damage; hemochromatosis (iron overload disease)	Liver, meats, egg yolk, whole grains, enriched bread and cereal, dark green vegetables, legumes, nuts
Iodine (I)	Synthesis of thyroxine, which regulates cell oxidation and basal metabolic rate	150 mcg	Goiter, cretinism, hypothyroidism, hyperthyroidism	UL: 1100 mcg Goiter	Iodized salt, seafood
Zinc (Zn)	Essential enzyme constituent; protein metabolism; storage of insulin; immune system; sexual maturation	Men, 11 mg; women, 8 mg	Impaired wound healing and taste and smell acuity, retarded sexual and physical development	UL: 40 mg Nausea; vomiting; decreased immune function; impaired copper absorption	Meat, seafood (especially oysters), eggs, milk, whole grains, legumes
Selenium (Se)	Forms glutathione peroxidase; spares vitamin E as an antioxidant; protects lipids in cell membrane	55 mcg	Impaired immune function, Keshan disease, heart muscle failure	UL: 400 mcg Brittleness of hair and nails; gastrointestinal upset	Seafood, kidney, liver, meats, whole grains
Fluoride (Fl)	Constituent of bone and teeth; prevents dental caries	Adequate Intake: men, 4 mg; women, 3 mg	Increased dental caries	UL: 10 mg Dental fluorosis	Fluoridated water, toothpaste
Copper (Cu)	Associated with iron in energy production, hemoglobin synthesis, iron absorption and transport, and nerve and immune function	900 mcg	Anemia, bone abnormalities	UL: 10 mg Toxicity disease (Wilson's disease, which results in liver and nerve conduction damage)	Liver, seafood, whole grains, legumes, nuts
Manganese (Mn)	Activates reactions in urea synthesis, energy metabolism, lipoprotein clearance, and the synthesis of fatty acids	Adequate Intake: men, 2.3 mg; women, 1.8 mg	Clinical deficiency present only with protein-energy malnutrition	UL: 11 mg Inhalation toxicity in miners, which results in neuromuscular disturbances	Cereals, whole grains, soybeans, legumes, nuts, tea, vegetables, fruits
Chromium (Cr)	Associated with glucose metabolism	Adequate Intake: men, 35 mcg; women, 25 mcg	Impaired glucose metabolism	UL not set Toxicity unlikely	Whole grains, cereal products, brewer's yeast
Molybdenum (Mo)	Constituent of many enzymes	45 mcg	Unlikely	UL: 2 mg Toxicity unlikely	Organ meats, milk, whole grains, leafy vegetables, legumes

Pregnancy and Lactation

Women require additional chromium, copper, iodine, iron, magnesium, manganese, molybdenum, selenium, and zinc to meet the demands of rapid fetal growth during pregnancy. DRIs remain elevated for several minerals throughout lactation to meet both mother and infant needs. Not all women will require dietary supplements to meet these increased needs, because they will be met with a healthy, balanced diet. However, some nutrients (e.g., iron) are regularly supplemented, because it is sometimes challenging to meet the DRI recommendations through dietary intake alone during this time.

Adolescence

Rapid bone growth during adolescence requires increased calcium and phosphorus. If an adolescent's diet provides insufficient calcium, the risk for bone-density problems (e.g., osteoporosis) during the later adult years is increased. Too little dietary calcium may lead to the resorption of calcium from bone to maintain an appropriate blood calcium concentration. With the major increases in soft-drink consumption coupled with the decreased milk consumption per capita in the United States, concern has increased about poor bone growth during these critical years.

Supplements that combine iron with folate may be indicated for adolescent girls as they begin their menstrual cycles.

Adulthood

Healthy adults who consume well-balanced and varied diets do not require mineral supplements. A well-rounded and varied diet in combination with adequate physical activity and exercise maintains optimal bone health in most adults. Some studies do indicate that supplemental calcium and vitamin D may improve bone health and reduce the risk of fracture among postmenopausal women.[35] However, at any adult age, calcium supplementation alone neither prevents nor successfully treats osteoporosis, the cause of which is not clear and involves multiple factors. Calcium supplements may be used as part of a treatment program together with vitamin D, estrogen, and increased physical activity.

Clinical Needs

People with certain clinical problems or those who are at high risk for developing such problems may require mineral supplements.

Iron-Deficiency Anemia

One of the most prevalent health problems encountered in population surveys is iron-deficiency anemia. The need for increased iron intake has long been established for pregnant and breast-feeding women.[13] The following high-risk groups also may need to supplement their diets: adolescent girls and women who are in their child-bearing years who consume poor diets; people who are food insecure (i.e., those who are not able to secure enough food on a consistent basis); alcohol-dependent individuals; vegetarians; and elderly people who consume poor diets.

Zinc Deficiency

The increased popularity of vegetarian diets has amplified concern about possible zinc deficiency because of the low zinc content of plant foods. The position statement of the Academy of Nutrition and Dietetics and the Dietitians of Canada regarding vegetarian diets indicates that zinc requirements for individuals who consume high phytate diets may exceed the current DRIs.[25] Signs of zinc deficiency are slow growth, impaired taste and smell, poor wound healing, and skin irritation; however, 3 to 24 weeks may pass before symptoms appear. Others who are at risk for zinc deficiency include alcohol-dependent individuals; people on long-term, low-calorie diets; and elderly people in long-term institutional care.

SUMMARY

- Minerals are elements that are widely distributed in foods. They are absorbed by the intestines and used in building body tissue; activating, regulating, and controlling metabolic processes; and transmitting neurologic messages.
- Minerals are classified in accordance with their relative amounts in the body. Major minerals are necessary in larger quantities than trace minerals, and they make up 60% to 80% of all of the inorganic material in the body. Trace minerals, which are necessary in quantities as small as a microgram, make up less than 1% of the body's inorganic material.
- RDAs have not been set for all minerals because of a lack of scientific data. However, AIs or ULs have been set for almost all essential minerals without RDAs.
- Mineral supplementation—along with vitamin supplementation—continues to be a hot topic of research. There are periods that occur throughout the life cycle and specific disease states that may warrant supplementation. However, in most situations, a balanced diet provides an adequate supply of all of the essential nutrients.

CRITICAL THINKING QUESTIONS

1. List the seven major minerals. Describe their functions and the problems created by dietary deficiency or excess.
2. List the trace minerals that are essential to human nutrition. Which ones have established RDAs? Which ones have suggested AIs? Why is establishing an RDA for every mineral difficult?
3. Considering the normal dietary supply of minerals, would you recommend the taking of a multimineral dietary supplement? If so, to whom and for what reasons?

CHAPTER CHALLENGE QUESTIONS

True-False

Write the correct statement for each statement that is false.

1. *True or False:* Most of the phosphorus in the diet is absorbed and used by the body for bone formation.
2. *True or False:* The typical adult consumption of sodium is approximately 10 times the amount that the body actually requires for metabolic balance.
3. *True or False:* Potassium is the major electrolyte that controls the water outside of cells.
4. *True or False:* Chloride is a necessary component of stomach fluids.
5. *True or False:* Copper has many metabolic functions, the most important of which is its role in T_4 synthesis.
6. *True or False:* A high intake of selenium has been proved to prevent cancer in almost everyone.
7. *True or False:* Iodine is associated with iron functions in the body and is called the "iron twin."

Multiple Choice

1. Overall calcium balance is mostly maintained by which two balanced regulatory agents?
   a. Vitamin A and thyroid hormone
   b. Ascorbic acid and growth hormone
   c. Vitamin D and parathyroid hormone
   d. Phosphorus and TSH
2. Optimal levels of body iron are controlled at the point of absorption, which is interrelated with a system of transport and storage. Which of the following statements correctly describes this iron-regulating process?
   a. The iron form in food requires an acid medium to reduce it to the form that is necessary for absorption.
   b. 70% to 90% of the iron that is ingested in food is absorbed.
   c. Vitamin C acts as a binding and carrying agent to transport and store iron.
   d. When RBCs are destroyed, the iron that is used to make the hemoglobin is excreted.
3. A known function of fluoride in human nutrition is dental health. Which of the following statements correctly describes this relationship?
   a. Small amounts of fluoride produce mottled, discolored teeth.
   b. Fluoridation of the public water supply in very small amounts helps to prevent dental caries.
   c. The topical application of fluoride is not effective on young teeth.
   d. Fluoride works with vitamin A to build strong teeth.

4. Cretinism is a disorder in children who are born to mothers who had a deficiency of which mineral during adolescence and pregnancy?
   a. Calcium
   b. Phosphorus
   c. Iron
   d. Iodine
5. Which mineral has the following functions: blood clotting, muscle and nerve action, and bone and teeth formation?
   a. Calcium
   b. Phosphorus
   c. Magnesium
   d. Chloride
6. Which of the following minerals is a trace mineral?
   a. Potassium
   b. Iron
   c. Chloride
   d. Sulfur

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

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FURTHER READING AND RESOURCES

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The following Web sites are good sources for information about certain minerals in the diets and their role in general health. You can also go to the National Heart, Lung, and Blood Institute Web site to learn about the role of sodium and hypertension and to read more about how to follow a low-sodium diet. Examine the American Dental Association Oral Health Topics for more information about the protective role of fluoride in dental hygiene.

American Dental Association. www.ada.org/fluoride.aspx

National Digestive Diseases Information Clearinghouse, hemochromatosis. http://digestive.niddk.nih.gov/ddiseases/pubs/hemochromatosis/

National Heart, Lung, and Blood Institute. www.nhlbi.nih.gov/hbp/prevent/sodium/sodium.htm

National Osteoporosis Foundation. www.nof.org