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# Nutrition and Periodontal Disease

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The role of diet in the etiology of dental caries is well established. The role of diet in the development and progression of periodontal disease, however, is less well understood. Recent studies have noted that as people lose teeth, there is a trend toward the presence of a poorer diet [1,2]. A person's diet can exert a topical or a systemic effect on the body and its tissues. Before tooth eruption, foods provide a nutritional or systemic effect during tooth development and in the maturation of dentine and enamel. After the tooth erupts, foods play a topical or dietary role in the maintenance of tooth structure. It is well known that the caries process can be modified through dietary (food selection and eating habit changes) rather than nutritional changes. For example, during growth and development, nutritional fluoride provides a systemic effect, making the tooth more resistant to decalcification by incorporation into the structure of the tooth. After the tooth has formed and erupted into the oral cavity, dietary fluoride provides a topical effect by modification of the surface layer of exposed enamel, cementum, and dentin. In this review, general concepts of nutrition are discussed first, followed by an overview of the current understanding of the relationship between nutrition and periodontal disease.

Nutrients can be considered major or minor as determined by the amounts consumed in our diets. Major nutrients are consumed in gram quantities. These include protein, carbohydrates, lipids, and water. Adults need approximately 0.8 g of protein per kilogram of body weight, whereas infants require 2.0 g of protein per kilogram of body weight to support their growth and development. Adults need about 130 g of carbohydrate per day to provide sufficient glucose for the brain and erythrocytes to function. In adults, about 20 to 30 g of essential fatty acids are needed daily for hormone

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production. Minor nutrients are required in milligram to microgram quantities and include vitamins and minerals.

The Food and Nutrition Board of the National Academy of Sciences has defined the quantitative intake of some nutrients [3]. The recommended dietary allowance (RDA) is defined as the amount of a nutrient that meets the needs of 97% to 98% of all people of a given age and sex. When there is insufficient information available to determine an average requirement for a specific nutrient, an adequate intake (AI) is assigned. This value is the amount that should be adequate to maintain a defined nutrition state. The current standards for the United States also apply to Canada because a committee of scientists from both countries established the values. The daily value (DV) is a generic standard developed by the Food and Drug Administration that can be used on food packaging without regard to age or sex differences. The DV is generally set at the highest nutrient recommendation and often exceeds the RDA or AI. The main purpose of the DV is to help provide a guide for nutrient content on food labels.

## Protein, carbohydrates, and lipids

Protein provides us with amino acids, the building blocks of our bodies. Protein is the most common substance in the body after water, making up about 50% of the body's dry weight. Proteins can be structural proteins such as collagen, a major organic component of bone, teeth, periodontal ligament, and muscle. Proteins also make up the enzymes, which are used to support bodily functions. When protein is eaten, it is broken down to its component amino acids, which can be used for protein synthesis and repair. Twenty-two amino acids are needed for protein synthesis, 9 of which are considered essential amino acids. These 9 essential amino acids—histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine—must be provided by the diet for protein synthesis to occur. Excess amino acids not used in protein synthesis or repair are used for energy. Protein provides 4 kcal of energy per gram. The RDA for protein for adults is 0.8 g of protein per day per kg body weight. Major sources of dietary protein are milk, meat, eggs, and legumes.

The main role of carbohydrates is to provide the body with energy. Carbohydrates are primarily used as a source of energy but they also aid in fat metabolism. Carbohydrates provide 4 kcal of energy per gram. Carbohydrates are found within the body as glycoprotein and glycosaminoglycans. They are essential for synthesis of the ground substance of the connective tissues, such as chondroiton, keratin, and dermatan sulfates. Glucose is also essential for erythrocyte and brain function. The body stores carbohydrates as glycogen (polysaccharides composed of $\alpha$-linked glucose molecules). Carbohydrates are protein sparing, in that when inadequate amounts of dietary carbohydrates are ingested, the body breaks down protein to provide glucose. The RDA for carbohydrate is 130 g/d for adults. Major sources of

carbohydrates are sugars and starches. Dietary fiber is also carbohydrate in nature, with soluble and insoluble forms. Diets high in fiber have been shown in some studies to lead to a decrease in intestinal disorders and several forms of colon cancer [4]. Wheat bran, a form of insoluble fiber, is composed of β-linked glucose molecules, which are not digestible by humans. Insoluble fiber helps retain fluid and provides bulk in the gastrointestinal system. Oat bran is a form of soluble fiber. Soluble fiber helps bind cholesterol molecules and can play a role in a cholesterol-lowering diet [5]. The AI for fiber for adults is 25 g/d for women and 38 g/d for men.

The main role of lipids is to provide energy, energy storage, and thermal insulation. The average diet in the United States provides about one third of all calories from fat. In a 2400-kcal diet, this amount is 800 kcal or about 100 g of lipid. The body requires two essential fatty acids: linoleic and linolenic acid. Fats are also needed for the body to absorb the fat-soluble vitamins A, D, E, and K. There is no RDA for lipids, but to meet AI recommendations, about 5% of our total energy must be obtained from plant oils. Lipids are a more concentrated source of energy than carbohydrates or proteins, providing 9 kcal of energy per gram.

## Vitamins

Vitamins are organic substances present in small quantities in food and are required for the body to maintain appropriate metabolic reactions. Vitamins are not made (or are made in inadequate amounts) by the body and must therefore be supplied by food or made from a provitamin. Vitamins are used in milligram to microgram quantities. Vitamins can be grouped as fat-soluble or water-soluble. Vitamins A, D, E, and K are fat-soluble, whereas the B vitamins and vitamin C are water-soluble. Except for vitamin K, fat-soluble vitamins are not readily excreted and can accumulate in the body. Excess amounts of the water-soluble vitamins are generally excreted by way of the kidneys; howver, vitamins $B_{12}$ and $B_6$ can accumulate in the body. The functions of the fat-soluble vitamins are reviewed first, followed by the B vitamins and vitamin C (Table 1).

Vitamin A, a fat-soluble vitamin, is required for vision, as a component of visual purple (essential for night vision), and for the maturation of epithelial tissues. Preformed vitamin A is present in foods (primarily animal fats and fish oils) as retinoids, which are toxic in high doses. Carotenoids are present in food and can be precursors of vitamin A, functioning as a provitamin. β-carotene is the main carotenoid found in foods. β-carotene is nontoxic in high doses and can function as an antioxidant. Preformed vitamin A does not function as an antioxidant. The RDA is 900 μg/d of retinol equivalents for men and 700 μg/d of retinol equivalents for women.

Vitamin D is a fat-soluble vitamin that can be considered a conditional vitamin—it can be obtained from the diet and synthesized in the body with adequate exposure to sunlight. In the northern latitudes, sunlight is often

Table 1
National Academy of Sciences recommended dietary allowances or adequate intakes of vitamins for men and women aged 19 to 50 years

| Vitamin | Men | Women |
|---|---|---|
| A | 900 μg/d | 700 μg/d |
| Thiamin ($B_1$) | 1.2 mg/d | 1.1 mg/d |
| Riboflavin ($B_2$) | 1.3 mg/d | 1.1 mg/d |
| Niacin | 16 mg/d | 14 mg/d |
| $B_6$ | 1.3 mg/d | 1.3 mg/d |
| Folate | 400 μg/d | 400 μg/d |
| $B_{12}$ | 2.4 μg/d | 2.4 μg/d |
| Panothenic acid | 5 mg/d[a] | 5 mg/d[a] |
| Biotin | 30 μg/d[a] | 30 μg/d[a] |
| C | 90 mg/d | 75 mg/d |
| D | 5 μg/d[a] | 5 μg/d[a] |
| E | 15 mg/d | 15 mg/d |
| K | 120 μg/d[a] | 120 μg/d[a] |

[a] Adequate intake.

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inadequate, especially during the winter months, necessitating the dietary intake of vitamin D. Vitamin D functions to maintain blood calcium levels and the metabolism of osseous tissues. Vitamin D enhances the absorption of calcium from the intestines. When levels of blood calcium are inadequate, there is inadequate calcification of the osseous tissues, resulting in rickets or osteomalacia. High doses of vitamin D can lead to toxicity. The AI for adults $<$51 years old is 5 μg/d, 10 μg/d for those aged 51 to 70 years, and 15 μg/d for those older than 70 years. A major source of dietary vitamin D is fortified milk.

Vitamin E is a fat-soluble vitamin whose primary role is to function as an antioxidant. It is composed of eight related compounds called tocopherols or tocotrienols. The most active form is α-tocopherol, which is incorporated into the lipid membrane of cells helping to quench free radicals, thus protecting the fatty acids in the lipid bilayer. The RDA for vitamin E is 15 mg/d. It has a much greater margin of safety than that observed for vitamins A and D. Most of the vitamin E in our diets comes from plant oils. Animal fats contain very little vitamin E.

Vitamin K is required for blood clotting. The ''K'' is derived from the Danish word *koagulation*. Vitamin K is needed for the carboxylation of glutamic acid to allow for the synthesis of seven clotting factors produced in the liver. The drug warfarin (Coumadin) is a vitamin K antagonist that functions by inhibiting the production of the clotting factors. Vitamin K is also needed for the production of osteonectin and ''matrix gla protein,'' which are present in bone [6]. The vitamin K–mediated carboxylation of glutamic acid to γ-carboxyglutamic acid results in calcium-binding function by these proteins. Low levels of vitamin K have been associated with

decreased bone density measurements. Vitamin K can be obtained from the diet, but there is also a significant amount produced by intestinal bacteria. The AI for vitamin K is 90 μg/d for women and 120 μg/d for men.

Vitamin B complex is a group of related substances that are involved in energy production from carbohydrate and fats, in red blood cell formation, and in protein and amino acid metabolism. In the early twentieth century, the deficiency disease beriberi was cured by "vitamin B," which was later found to be a complex of many vitamins. As vitamin B complex was isolated, the individual vitamins were assigned numbers. $B_1$ was named thiamine, $B_2$ riboflavin, and so forth. Except for vitamins $B_6$ and $B_{12}$, most B vitamins are presently designated by their chemical names. Because the level of B vitamins is reduced during the refining of grains, flour has been supplemented with thiamin, riboflavin, and niacin since the 1940s to approximate the levels seen in whole grains. Folate was added in 1998.

Thiamin ($B_1$) has a primary role in energy production. It is required for the metabolism of carbohydrates and branched-chain amino acids. The classic disease of thiamin deficiency is beriberi. This nutritional disease affects the muscular, nervous, cardiovascular, and gastrointestinal systems. It can develop in 7 to 10 days from eating a diet that is severely deficient in thiamin. The RDA for thiamin is 1.1 mg/d for women and 1.2 mg/d for men. Fortified bread, pork, and orange juice are major sources of thiamin.

Riboflavin ($B_2$) is also important for energy production. It is involved in redox reactions within the body. There is no known primary deficiency disease associated with riboflavin. A riboflavin deficiency often results in an oral presentation of glossitis, angular cheilosis, or stomatitis [7]. The RDA for riboflavin is 1.1 mg/d for women and 1.3 mg/d for men. Milk is a major source of riboflavin.

Niacin is present in food as two forms, niacin (nicotinic acid) and niacinamide (nicotinamide). Niacin is involved in over 200 cellular pathways, primarily those responsible for energy production and synthesis and metabolism of fatty acids. In addition to being available from food, niacin can also be synthesized from tryptophan. The primary deficiency disease of niacin is pellagra, which has symptoms including dermatitis, dementia, and diarrhea. About 10,000 people died annually from pellagra in the United States during the earlier parts of the twentieth century. The enrichment of refined flour with niacin in the early 1940s led to the disappearance of pellagra in the United States. Niacin can also be used to moderate elevated cholesterol levels. Pharmacologic doses of niacin (50–100 times the RDA) can lower low-density lipoprotein cholesterol and raise high-density lipoprotein cholesterol. Adverse effects of these higher doses include flushing and itching of the skin, nausea, and possible liver damage. The RDA for niacin is 14 mg/d for women and 16 mg/d for men.

Pantothenic acid is part of coenzyme A. This enzyme is required for ATP production from protein, carbohydrates, lipids, and alcohol. The AI for pantothenic acid is 5 mg/d.

Biotin is an essential cofactor for different carboxylase enzymes. Three of these carboxylases are involved with amino acid metabolism and energy production. A fourth enzyme is involved in fatty acid synthesis. In addition to food, intestinal bacteria help provide biotin. The AI for biotin is 30 μg/d.

Vitamin $B_6$ consists of three compounds: pyridoxal, pyridoxine, and pyridoxamine. Vitamin $B_6$ is involved in over 100 cellular reactions. It is needed for amino acid, lipid, and homocysteine metabolism and for the synthesis of heme. Vitamin $B_6$ is also required for the conversion of tryptophan to niacin. Vitamin $B_6$ has also been used to treat carpal tunnel syndrome, with varying results [8,9]. The RDA of vitamin $B_6$ for adults is 1.3 to 1.7 mg/d. Vitamin $B_6$ is stored in the body, and long-term use of higher doses (>200 mg/d) has been shown to lead to irreversible nerve damage.

Folate is also called folic acid and folacin. It is involved in DNA synthesis and amino acid metabolism. It has a close relationship with vitamin $B_{12}$, which is needed for regeneration of a folate coenzyme. When folate levels are low, DNA synthesis is impaired. This impairment can lead to an inability of erythrocyte precursor cells to divide, leading to megloblastic anemia with large immature blood cells noted. This form of anemia is also observed with a vitamin $B_{12}$ deficiency. Neural tube defects may arise during early pregnancy if maternal folate levels are low. It is estimated that 70% of neural tube defects could be prevented if all women entered pregnancy with optimal levels of folate [10]. Flour has been fortified with folate since 1998. The RDA for folate is 400 μg/d. The level of folate in nonprescription vitamins is limited to 400 μg/d by the Food and Drug Administration because high doses of folate could mask the anemia associated with a vitamin $B_{12}$ deficiency.

Vitamin $B_{12}$ is also known as cyanocobalamin. Vitamin $B_{12}$ is not found in plant foods but found only in foods from animal sources. To obtain adequate levels of vitamin $B_{12}$, strict vegetarians must eat eggs or dairy products, eat foods fortified with vitamin $B_{12}$, or take supplemental vitamins. Vitamin $B_{12}$ is needed for folate and homocysteine metabolism. It is associated with enzymes that transfer carbon units and is involved in proper functioning of the nervous system. The primary disease associated with vitamin $B_{12}$ deficiency is pernicious anemia. This disease is due to a genetic defect that leads to deficient absorption of vitamin $B_{12}$ from the small intestine. In pernicious anemia, patients present not only with a megaloblastic (macrocytic) anemia similar to that observed with folate deficiency but also with neurologic symptoms that without treatment, could lead to death within 2 to 5 years. Early signs of $B_{12}$ deficiency are numbness of the extremities and difficulty walking. People who frequently eat meat can maintain stores of vitamin $B_{12}$ that could last for 5 years. The RDA for vitamin $B_{12}$ is 2.4 μg/d for adults. Because absorption of vitamin $B_{12}$ generally declines as people age, high-dose oral supplementation or monthly injections may be required to maintain adequate stores.

Vitamin C is also known as ascorbic acid. It was named for its ability to cure scurvy. All plants and most animals synthesize ascorbic acid. Only humans, nonhuman primates, and a few other animals do not make ascorbic acid. Vitamin C is involved in many cellular functions. It is needed for the hydroxylation of proline and lysine during collagen production and functions as an antioxidant. The classic vitamin C deficiency disease is scurvy, a hemorrhagic disease, which presents with muscle weakness, lethargy, diffuse tissue bleeding, painful and swollen joints, ecchymoses, increased fractures, poor wound healing, gingivitis, and loss of integrity of the periodontal ligament. In 1753, Dr. James Lind, a Royal Navy surgeon, performed an experiment with British sailors who had symptoms of scurvy. He studied six groups of sailors. For each group, he added different components to the typical ship's diet: (1) cider; (2) vinegar; (3) sulfuric acid, ethanol, ginger, cinnamon; (4) sea water; (5) garlic, mustard, and herbs; and (6) two oranges and a lemon. Those receiving the oranges and lemon recovered in about 1 week and those receiving cider recovered after more than 2 weeks. There was no improvement seen with the other four supplement regimens [11]. Finally, in 1795, more than 40 years after Lind's discovery, rations for British sailors were made to include citrus fruits.

The RDA for vitamin C is 75 mg/d for women and 90 mg/d for men, with an additional 35 mg/d for smokers. The additional 35 mg/d for smokers is thought to counter the oxidative effects of smoking. Average body stores of vitamin C are 1 to 2 g.

## Water

The average human contains about 40 L of water, with about 25 L of intracellular water and about 15 L of extracellular water. About 75% by weight of a newborn baby is water, whereas adult men are about 60% and adult women are about 50% water. Water acts as a solvent and reactive medium for cellular function in the body. A person can live about 8 weeks without food but only days without water because the human body cannot conserve, store, or synthesize water as it can for some of the other nutrients.

## Minerals

Minerals make up about 4% of body weight. Important minerals are found in the skeleton and in enzymes, hormones, and vitamins. Minerals help provide structure for bones and teeth and maintain normal heart rhythm, muscle contraction, nerve conduction, and acid-base balance. They can be integral parts of enzymes and hormones. Minerals are classified as major minerals (nutritional need $>100$ mg/d) or trace minerals (nutritional need $<100$ mg/d). The major minerals are sodium, potassium, calcium, magnesium, phosphorus, and sulfur. The trace minerals are iron, zinc, iodine, selenium, fluoride, copper, cobalt, chromium, manganese, and molybdenum.

*Major minerals*

Sodium is the major cation in extracellular fluid; it is the key electrolyte. Sodium helps maintain fluid balance in the body and plays an essential role in nerve conduction. Almost all dietary sodium is absorbed in the intestinal tract. The average person has 250 g of salt (sodium chloride) in their body, 125 g in extracellular fluid, 90 g in mineralized tissues, and less than 30 g in intracellular fluid. The Food and Nutrition Board has set 500 mg/d as a minimum requirement for sodium, but this is presently being evaluated [12]. The DV for sodium is 2400 mg/d. The typical daily adult intake is 3–7 g (Table 2).

Potassium is the major cation in intracellular fluid. It is involved in many of the same functions as sodium, but intracellularly. It has been associated with decreased blood pressure and risk of stroke. Potassium deficiency is more likely than sodium deficiency because we do not usually add potassium to our foods. A low potassium plasma level can be life threatening, presenting with muscle cramps, confusion, and an irregular heartbeat. A deficiency may be seen with the use of diuretics that waste potassium. The minimum requirement for potassium is set at 2 g/d, whereas the DV is 3.5 g/d.

Calcium is a major mineral. The body contains about 1200 g of calcium (about 40% of the total body mineral), of which about 99% is in the skeleton. Bone is about 50% mineral, 20% protein, 5% fat, and about 25% water. Most of the mineral is present as hydroxyapatite. Calcium plays a major role in nerve conduction and blood clotting. Calcium is in equilibrium between bone, extracellular water, and soft tissue, with about

Table 2
National Academy of Sciences recommended dietary allowances or adequate intakes of minerals for men and women aged 19 to 50 years

| Mineral | Men | Women |
|---|---|---|
| Calcium | 1000 mg/d[a] | 1000 mg/d[a] |
| Chromium | 35 μg/d[a] | 25 μg/d[a] |
| Copper | 900 μg/d | 900 μg/d |
| Fluoride | 3.8 mg/d[a] | 3.1 mg/d[a] |
| Iodine | 150 μg/d | 150 μg/d |
| Iron | 8 mg/d | 18 mg/d |
| Magnesium | 400–420 mg/d | 310–320 mg/d |
| Manganese | 2.3 mg/d[a] | 1.8 mg/d[a] |
| Molybdenum | 45 μg/d | 45 μg/d |
| Phosphorous | 700 mg/d | 700 mg/d |
| Selenium | 55 μg/d | 55 μg/d |
| Zinc | 11 mg/d | 8 mg/d |

[a] Adequate intake.

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0.7 g absorbed and redeposited daily. Calcium is regulated by parathyroid hormone, calcitonin, and vitamin D. The AI for adults is 1000 to 1200 mg/d.

Phosphorus is found in all plant and animal cells. A primary dietary deficiency of phosphorous is not known. About 600 to 900 g of phosphorus is present in bone in hydroxyapatite. It was once thought that phosphate intake could influence calcium absorption, but it is now known that phosphate intake has little consequence for calcium absorption at normal levels of intake. The RDA for phosphorous is 700 mg/d, and the DV is 1000 mg/d.

Magnesium is present in all tissues. The average person has about 25 g, with most stored in bone and about 25% found in soft tissues. After potassium, magnesium is the second most prominent intracellular cation. It is concentrated in mitochondria and involved in energy transfer. In plants, it is found in chloroplasts. The RDA for magnesium is 310 mg/d for women and 400 mg/d in men.

Sulfur is found mainly in proteins. It is present in the amino acids methionine and cysteine, and the active sites of coenzyme A and glutathione contain sulfur residues. Sulfur is present in heparin and chondroitin sulfates. The vitamins thiamin and biotin contain sulfur, and vitamin D may be present as a sulfate salt. There is no RDA for sulfur because most sulfur in the diet is derived from protein.

### *Trace minerals*

The trace minerals are iron, zinc, iodine, selenium, fluoride, copper, cobalt, chromium, manganese, and molybdenum. Trace minerals are those with a daily nutritional need less than 100 mg. The total amount of trace minerals in the body is about 15 g.

Iron is important as a functional component of hemoglobin and it aids immune function. The typical person has about 4 g of iron: 2.5 g in hemoglobin, 0.3 g in myoglobin and cytochromes, and about 1 g in iron stores (ferritin). Most iron is used to make red blood cells in the bone marrow. Iron deficiency leads to anemia, which is seen more in women during their reproductive years and in children due to their rapid growth. Typical iron intake is about 10 mg/d, but only about 10% is absorbed. Meat (heme) iron is better absorbed than vegetable (nonheme) iron. Absorption is increased with vitamin C, in the presence of meat, and from gastric acidity. The RDA is 18 mg/d for adult women and 8 mg/d for men.

Zinc is a cofactor for over 50 enzymes (eg, carbonic anhydrase, alkaline phosphatase, alcohol dehydrogenase, and superoxide dismutase). About 2 g of zinc is stored in the body, with most present in bone. A zinc deficiency can lead to small stature, mild anemia, and impaired wound healing. Good sources of zinc are meats, whole grains, and legumes. The RDA is 8 mg/d for women and 11 mg/d for adult men.

Iodine was first discovered in 1811 and used to treat goiter in 1820. Iodine is present in thyroxine and triiodothyronine and helps maintain an appropriate metabolism. Body stores are about 20 to 50 mg, with about 8 mg being concentrated in the thyroid. A major source of iodine in the diet is from iodized salt. The RDA for iodine is 150 μg/d.

Fluoride functions to decrease the solubility of calcified tissues. Teeth having fluorapatite crystals have an increased resistance to decalcification. In some studies, fluoride has been shown to increase bone density, and is sometimes used to treat osteoporosis [13]. The fluoride present in saliva can help promote remineralization of enamel. The AI of fluoride is 3.1 mg/d for adult women and 3.8 mg/d for adult men.

Selenium can function as an antioxidant like vitamins C and E and β-carotene. Selenium is present in the glutathione peroxidase system and helps minimize oxidative damage to lipid membranes. This enzyme system may help to spare vitamin E. The RDA for selenium is 55 μg/d for adult men and women.

Copper and iron are required for the formation of hemoglobin. Copper is stored bound to ceruloplasmin, a copper-dependent ferroxidase that helps to oxidize iron. Ceruloplasmin is required for optimal use of ferritin. Copper is found in two members of the superoxide dismutase family, which help quench superoxide free radicals. The RDA for copper is 900 μg/d.

Chromium is present in all tissues, but the total body content is low (<6 mg). It helps maintain normal sugar and fat metabolism. Chromium plays a role in the uptake of glucose into cells, possibly through a chromium-binding protein, which may upregulate insulin receptors. A chromium deficiency can lead to increased serum cholesterol levels and poor glucose tolerance. The AI for chromium is 25 μg/d for women and 35 μg/d for men. The DV is 120 μg/d. Good sources of this element are brewers yeast, liver, cheese, and whole grains.

Manganese is a cofactor for enzymes involved in the synthesis of proteoglycans. Some manganese-containing enzymes are present in mitochondria. The AI of manganese is 1.8 mg/d for women and 2.3 mg/d for men.

Molybdenum is a constituent of xanthine oxidase, aldehyde oxidase, and sulfite oxidase. No deficiency disorder has been recognized. The RDA for adults is 45 μg/d and the DV is 75 μg/d.

Five ultratrace minerals may have a role in human nutrition, but there are no RDA or AI values for them [12]. These ultratrace minerals include boron, nickel, silicon, arsenic, and vanadium [14]. Boron appears to interact with calcium and magnesium and to have a role in ion transport within cellular membranes. Nickel may function as a cofactor in amino acid and fatty acid metabolism. Silicon may play a role in bone metabolism with the organic bony matrix in some animals, but no conclusive evidence is available for humans. Arsenic is probably involved in the metabolism of methionine and in some nucleic acid synthesis. Vanadium may have a role in insulin metabolism.

## Role of nutrition in periodontal disease

Periodontal diseases are a group of bacterial inflammatory disorders that result in destruction of the supporting tissues of the teeth. They include chronic periodontitis, aggressive periodontitis, and necrotizing ulcerative gingivitis and periodontitis. Periodontal diseases result from bacterial infections. Therapy to reduce oral microbial levels can reduce gingivitis and stabilize periodontitis. Although dietary components play a major role in the pathogenesis of dental caries, diet plays primarily a modifying role in the progression of periodontal disease. A periodontal lesion is essentially a wound, and sufficient host resources must be available for optimal healing. The effect of nutrition on the immune system and its role in periodontal disease has been recently reviewed [15,16]. Neiva et al [17] recently reviewed the literature on the use of specific nutrients to prevent or treat periodontal diseases. These investigators concluded that although the treatment of periodontal disease by nutritional supplementation has minimal side effects, the data on its efficacy are limited.

Protein and other nutrients are needed to provide adequate host defenses. The periodontal defenses include cell-mediated immunity, antibody or humoral immunity, the complement system, and innate immunity. The crevicular and junctional epithelium provide an epithelial barrier function. This epithelial surface provides a major defensive barrier to invasion by antigens, noxious products, and bacteria. It undergoes a rapid turnover and is therefore dependent on sufficient protein, zinc, folic acid, iron, vitamin A, and vitamin C. When patients are undernourished, their nutritionally deficient status could result in a reversible loss of barrier function.

Calcium is the major mineral present in osseous tissues. Deficiency can lead to a decrease in serum calcium, resulting in mobilization from host tissues. Calcium is needed for normal bone metabolism, with an interplay between the osteoblasts, osteocytes, and osteoclasts. Calcium homeostasis is controlled by parathyroid hormone and calcitonin.

Dietary calcium has long been a candidate to modulate periodontal disease. Animal and human studies of calcium intake, bone mineral density, and tooth loss provide a rationale for hypothesizing that low dietary intake of calcium is a risk factor for periodontal disease. A recent epidemiologic study by Nishida et al [18] suggested that low dietary intake of calcium results in more severe periodontal disease. In this study, data from the Third National Health and Nutrition Examination Survey (NHANES III) were analyzed. Low levels of dietary calcium were found to be associated with periodontal disease in young men and women and in older men. Further studies are needed to better define the role of calcium in periodontal disease and to determine the extent to which calcium supplementation can modulate periodontal disease and tooth loss.

Excess vitamin A can lead to gingival pathology. In a case report, a 20-year-old woman presented with gingival erosions, ulcerations, bleeding,

swelling, and a loss of keratinization. Headache, dry mouth, and loss of hair were also noted. She reported a history of taking 200,000 IU of vitamin A daily for 6 months to reduce acne. When the vitamin supplementation was stopped, gingival improvement was noted within 1 week. At 2 months, the appearance of the oral tissues was found to be normal [19]. This case report has excellent clinical photographs.

Several studies and case reports have evaluated the role of vitamin C in periodontitis. Vitamin C has long been a candidate for modulating periodontal disease. Studies of scorbutic gingivitis and the effects of vitamin C on extracellular matrix and immunologic and inflammatory responses provide a rationale for hypothesizing that vitamin C is a risk factor for periodontal disease. Collagen is a major component of the periodontium, being one of the major proteins in the gingival connective tissues and bone. For collagen maturation to occur, adequate vitamin C must be available within the body for the hydroxylation of lysine and proline.

Vogel et al [20] evaluated the role of megadoses of vitamin C on polymorphonuclear chemotaxis and on the progression of experimental gingivitis. Four months of daily vitamin C (500 mg three times a day) supplementation resulted in a significant increase in plasma ascorbate levels but did not increase host resistance during 4 weeks of experimental gingivitis as evaluated by clinical parameters, by polymorphonuclear chemotaxis, and by changes in crevicular fluid enzyme levels.

Leggott et al [21] evaluated the effect of controlled ascorbic acid depletion and supplementation on periodontal health. Eleven men ate a diet low in vitamin C (<5 mg/d) and received supplementation of 60 mg/d during weeks 1 and 2; 0 mg/d during weeks 3, 4, 5, and 6; 600 mg/d during weeks 7, 8, 9, and 10; and 0 mg/d during weeks 11, 12, 13, and 14. Ascorbic acid depletion, with good oral hygiene, led to a decrease in plasma ascorbate levels and an increase in gingival inflammation and bleeding but did not result in severe periodontal disease or changes in pocket depth. This study showed that a vitamin C deficiency influenced the early stages of gingival inflammation but did not lead to a loss of attachment during the time frame of this study.

A diet low in vitamin C can lead to the development of scurvy. In one case report, a 48-year-old man presented with the sudden development of scurvy. His gingiva was bright red, inflamed, and edematous. Acute leukemia and diabetes were ruled out. He was screened for a vitamin deficiency, and a low plasma level of ascorbic acid was determined. After completing a 5-day diet history, nutritional analysis revealed deficiencies in several nutrients. A typical daily diet for this patient was coffee, a peanut butter sandwich, tuna noodle casserole, and one-half case of beer. His average daily consumption of vitamin C was less than 1 mg/d. Treatment consisted of vitamin C and vitamin B complex supplementation, a diversified diet, and periodontal scaling and root planing. His general health and his periodontal condition showed rapid improvement [22]. Excellent photos are presented showing the progression of disease.

Cessation of chronic vitamin C intake can also result in oral scurvy. In this case report, a 49-year-old man presented with "sore gums." His gingiva showed the presence of petechial hemorrhages, crevicular bleeding, and mucosal ulcerations. He reported a daily intake of 1 g of vitamin C for 1 year, which was stopped about 10 days previously. Taking 1 g of vitamin C for 2 weeks allowed for the regression of the lesions. He stopped for 1 week and the lesions returned. He was gradually reduced to 100 mg/d over a 7-week period and remained free of oral symptoms [23]. This condition is known as rebound or conditional scurvy.

Nishida et al [24] evaluated the effect of dietary intake of vitamin C and the presence of periodontal disease. Dietary intake of vitamin C showed a weak but statistically significant relationship to periodontal disease in current and former smokers as measured by clinical attachment. The greatest clinical effect on periodontal tissues was shown in smokers who took the lowest levels of vitamin C.

Low serum levels of vitamin D have been linked with a loss of periodontal attachment. NHANES III data from over 11,000 subjects were analyzed for serum vitamin D levels and attachment loss [25]. In subjects less than 50 years of age, there was no significant association noted between vitamin D levels and attachment loss. In patients 50 years or older, serum vitamin D levels were inversely associated with attachment loss for men and women. It was concluded that the increased risk for periodontal disease might be attributable to low levels of vitamin D, which would reduce bone mineral density, or to an immunomodulatory effect.

Intake of tomato products has also been shown to be associated with a reduced risk of congestive heart failure in patients with periodontitis [26]. Data from NHANES III were evaluated for monthly tomato consumption, serum lycopene (a phytochemical found in tomatoes) levels, and congestive heart failure. Subjects with periodontitis have an increased risk of congestive heart failure, and increased tomato consumption appears to reduce this risk.

## Herbal and nutritional supplements

Various herbal and nutritional supplements have been touted as being beneficial for the prevention and treatment of periodontal disease. Few cross-sectional studies exist, however, and there are no randomized longitudinal studies. Coenzyme $Q_{10}$ is distributed throughout all human tissues. It is involved in the electron transport functions of the mitochondria. It has also been proposed as a modulator of periodontal disease. In vivo and in vitro reports in the literature suggest that patients with periodontal disease may have a deficiency of coenzyme $Q_{10}$ and that treatment with this coenzyme may improve a patient's periodontal disease status [27–33]. Most studies showed that in gingival biopsy samples, periodontally diseased tissues had lower levels of coenzyme $Q_{10}$ than periodontally healthy gingival tissues.

With only a limited number of reports in the literature, it is premature to recommend coenzyme $Q_{10}$ for the treatment of periodontal disease, although its use would appear to have a minimal risk of side effects.

In Africa, Asia, and the Middle East, some populations have long used chewing sticks to clean their teeth. The chewing stick, or miswak, is usually made from the *Salvadora persica* plant. These sticks are usually chewed and rubbed against the teeth to remove plaque. Use of the miswak generally was equivalent to and sometimes better than the use of a toothbrush in reducing plaque and gingivitis scores [34,35]. The miswak has also been shown to have a selective antimicrobial effect against various oral microorganisms [34,36–38]. This effect is attributable to the natural antimicrobial agents that the plant uses to fight microbial infection. In response to chewing, these agents leach out from the miswak into the oral cavity and interact with the oral flora. Other plants have also been used as chewing sticks. The rural and urban people of Namibia use *Diospyros lycioides* for oral hygiene. This plant contains antimicrobial compounds that can inhibit the growth of *Streptococcus mutans*, *Porphyromonas gingivalis*, and *Prevotella intermedia* [39]. Other plant-derived agents used for oral hygiene practices include mango leaf in India [40] and *Massularia acuminata* and *Distemonanthus benthamianus* in Nigeria [41]. The polyphenols extracted from green tea have been shown to inhibit the metabolism of *Porphyromonas gingivalis*, leading to a reduction of toxic products [42]. Many other natural products have been used throughout the world in an attempt to improve the oral health of the resident population. Some are without merit but others have shown promise in the quest for better dental health.

## Clinical implications

Although it is reasonable to consume a nutritionally adequate diet to maintain host resistance and maintain the integrity of the periodontal tissues, insufficient evidence is available to justify treatment with vitamin and mineral supplementation in the adequately nourished individual. Periodontal disease is an infectious disease caused by bacterial infection and can be treated and prevented by the elimination of bacterial plaque in the adequately nourished individual. In patients who have inadequate nutrition, it may be reasonable to suggest a vitamin or mineral supplement.

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