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Introduction to nutrition and oral health

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Nutrition is defined as the science of how the body utilizes food to meet requirements for development, growth, repair, and maintenance. There are six classes of nutrients found in foods: carbohydrates, fats, proteins, vitamins, minerals, and water. The first three are energy-producing nutrients; that is, they provide calories and enable the body to generate energy for carrying on its many functions. Although the latter three do not provide energy, they facilitate a variety of activities in the body.

The nutrient quantities that best support good health are based on recommendations of two national committees of nutrition experts. These committees, selected by the National Academy of Sciences and subject to approval by the National Research Council, are the Committee on Dietary Allowances and the Committee on Diet and Health. The former focuses on nutrient and energy needs and health maintenance; the latter concentrates on reducing risk of chronic diseases, dietary excesses, and deficiencies. Traditionally, the recommended dietary allowances (RDAs) generated by the Committee on Dietary Allowances have been used as a standard for energy and nutrient intakes. RDAs are established for energy (calories), protein, and many vitamins and minerals. RDAs are nutrient amounts in excess of what 98% of the population requires to maintain health; they are not minimum requirements or optimal intakes for all people. The exception is energy: calorie levels are set at the mean of a population's requirements in order to prevent excess calorie consumption. RDAs are most appropriately used as average daily energy and nutrient level intake estimates for healthy populations, through the consumption of a variety of foods [1].

Recently, the Food and Nutrition Board developed a broader measurement of nutrient intakes called Dietary Reference Intakes (Table 1). Research showed the importance of higher intakes of some nutrients for chronic disease prevention and performance. Also, there was substantial growth in

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Table 1
Dietary reference intakes by age group[a]

Age	Female	Male
14–18 years		
Calcium	1300	1300
Phosphorus	1250	1250
Magnesium	360	410
Vitamin D[b]	5	5
Fluoride	3	3
Thiamin	1	1.2
Riboflavin	1	1.3
Niacin	14	16
Vitamin B_6	1.2	1.3
Folate[c]	400	400
Vitamin B_{12}	2.4	2.4
Pantothenic acid	5	5
Biotin	25	25
Choline	400	550
Vitamin C	65	75
Vitamin E	15	15
Selenium	55	55
19–30 years		
Calcium	1000	1000
Phosphorus	700	700
Magnesium	310	400
Vitamin D[b]	5	5
Fluoride	3	4
Thiamin	1.1	1.2
Riboflavin	1.1	1.3
Niacin	14	16
Vitamin B_6	1.3	1.3
Folate[c]	400	400
Vitamin B_{12}	2.4	2.4
Pantothenic acid	5	5
Biotin	30	30
Choline	425	550
Vitamin C	75	90
Vitamin E	15	15
Selenium	55	55
31–50 years		
Calcium	1000	1000
Phosphorus	700	700
Magnesium	320	420
Vitamin D[b]	5	5
Fluoride	3	4
Thiamin	1.1	1.2
Riboflavin	1.1	1.3
Niacin	14	16
Vitamin B_6	1.3	1.3
Folate[c]	400	400
Vitamin B_{12}	2.4	2.4

Table 1 (*continued*)

Age	Female	Male
Pantothenic acid	5	5
Biotin	30	30
Choline	425	550
Vitamin C	75	90
Vitamin E	15	15
Selenium	55	55

[a] Values are given in milligrams.

[b] As cholecalciferol. 1 mg cholecalciferol = 40 IU vitamin D.

[c] As dietary folate equivalents (DFE). 1 DFE = 1 mg food folate = 0.6 mg of folic acid from fortified foods or as a supplement consumed with food. In view of evidence linking folate intake with neural tube defects in the fetus, it is recommended that all women capable of becoming pregnant consume 400 mg from supplements or fortified foods in addition to intake of food folate from a varied diet.

Data from The Grand Forks Human Nutrition Center. Available at: http://www.shs.unc.edu/library/articles/dietaryintakes.html#14, and The Grand Forks Human Nutrition Center Home Page. Available at: http://www.gfhnrc.ars.usda.gov/Default.htm.

food fortification and dietary supplement use. The existing RDAs did not adequately distinguish guidelines for populations and subgroups from those for individuals. Therefore, the Food and Nutrition Board incorporated the RDAs within the dietary reference intake concept to provide recommended intakes for varied circumstances. The Dietary Reference Intakes are actually composed from a set of four different reference values:

1. RDAs: the average daily dietary intake of a nutrient that is sufficient to meet the requirement of nearly all healthy people
2. Adequate intake: a level of a nutrient based on observed intakes of groups of healthy people when an RDA cannot be established
3. Tolerable upper intake level: the highest daily intake of a nutrient that is likely to pose no risk of toxicity for most healthy people
4. Estimated average requirement: the amount of a nutrient estimated to meet the requirement for half of all healthy people in a population

Standards such as the RDAs and Dietary Reference Intakes provide nutrient recommendations for various subgroups of the population: infants, children, males and females of varying ages, and states such as pregnancy or lactation [2].

Although determining specific nutrient needs on an individual basis is not routine, following the Diet and Health Guidelines for Americans (Box 1) provides a general framework for healthy eating for the majority of the population. A commonly used tool for planning a healthful diet is the food guide pyramid (Fig. 1). It is the pictorial representation of the United States Department of Agriculture's Daily Food Guide. It is user-friendly and offers people flexibility in planning a daily diet. Variations of the food guide pyramid exist for various populations such as the elderly, vegetarians, and people of different ethnicities.

Box 1. Diet and health guidelines for Americans

Aim for a healthy weight.
Be physically active each day.
Let the Food Guide Pyramid guide your good choices.
Choose a variety of grains daily, especially whole grains.
Choose a variety of fruits and vegetables daily.
Keep food safe to eat.
Choose a diet low in saturated fat and cholesterol and moderate in total fat.
Choose beverages and foods to moderate your intake of sugars.
Choose and prepare foods with less salt.
If you drink alcoholic beverages, do so in moderation.

(*Adapted from* 1995 US Department of Agriculture US Department of Health and Human Services. 4th edition. Available at: http://www.hoptechno.com/dietary.htm; with permission.)

The Nutrition Labeling and Education Act of 1990 produced major changes in the way consumers are informed about the nutritional contents of foods they purchase. Labels must state the name of the product, manufacturer, packer or distributor, net contents, ingredients in decreasing predominance by weight, serving size, servings per container, and the quantities of specific nutrients [3]. A basic understanding of food labels and serving sizes is useful in utilizing a tool such as the food guide pyramid. The following illustrates that serving sizes are standardized measures of food portions. The nutrition facts panel on commercial food items reveals much to the astute consumer.

Beyond showing serving size and servings per container, total energy (kcal), food energy from fat (kcal), total fat (grams), saturated fat (grams), cholesterol (mg), sodium (mg), total carbohydrate including starch, sugar, and fiber (g), and protein (g) are listed. Also, vitamin A, vitamin C, iron, and calcium contents must be provided compared with a standard for these nutrients. This labeling information makes it possible for the consumer to compare products for various nutrients and calories and, it is hoped, make the most healthful choice.

In addition, the percent daily value enables consumers to estimate how a specific food item fits into their total daily intake. It is based on a 2000 kcal/day diet and consumers must raise or lower their estimate depending on whether they consume more or less than 2000 kcal/day. For example, a moderately active woman, teenage girl, or sedentary man typifies the 2000 kcal/day diet. An active teenage boy may consume many more calories per day and, therefore, the percent daily value for a given nutrient for this individual would have to be adjusted lower as it will represent a smaller

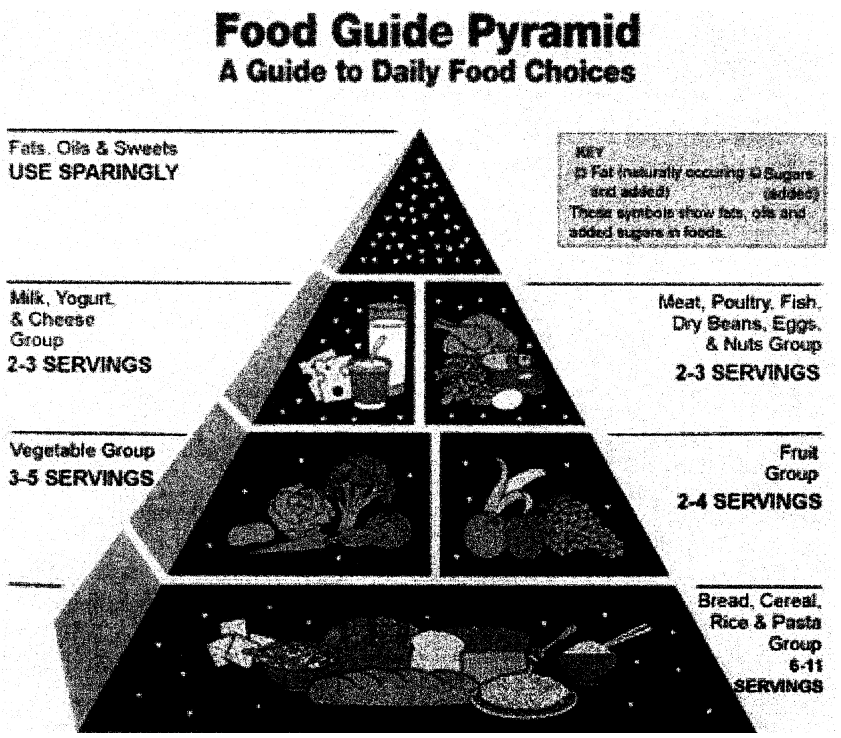

Fig. 1. Food guide pyramid.

percentage of the higher calorie diet. The percent daily value can also help people compare food items. For example, if a person interested in reducing fat intake finds a sandwich spread to contain 50% of a day's total fat intake compared with a similar sandwich spread that contains 20% of a day's total fat intake, then they may choose the latter item by quickly and easily comparing the food label's percent daily value.

The nutrients

Carbohydrates

Carbohydrates describe a varied class of nutrients that are a major source of energy within the human diet. The average adult stores about 300 g of carbohydrate in the liver and muscle tissue as glycogen. Carbohydrate's main function is to provide fuel to the body; central nervous system tissue in particular relies on carbohydrate for proper functioning. Carbohydrates provide 4 kcal/g. Consuming adequate amounts of carbohydrate also allows protein to be used for tissue anabolism and its other major metabolic functions and not as an energy source; in this way, carbohydrate is said to "spare protein." Without carbohydrate, fat metabolism is incomplete and

results in the formation of intermediate metabolites called ketone bodies. When these substances accumulate in the blood, a potentially fatal situation known as metabolic ketoacidosis may occur. This is not dissimilar from ketoacidosis of extended fasting or uncontrolled insulin-dependent diabetes mellitus. The formation of structural components of the body such as cartilage, nervous tissue, and bone are dependent on carbohydrate. In addition, the chemical structures needed for the formation of nonessential amino acids within the body require carbohydrate [4].

Carbohydrates are most commonly classified as simple (sugars) or complex (starches, fibers). Simple sugars (monosaccharides) represent single carbohydrate units such as glucose, fructose, and galactose. Disaccharides are formed by the bonding of two monosaccharides. For example, sucrose, the sugar most commonly associated with dental caries, is composed of glucose and fructose. Polysaccharides such as starch and fiber are composed of many monosaccharide units. Starches are derived from plant foods—mainly grains, legumes, and some vegetables and fruits. Ultimately, the digestive process breaks down the long chains of starch to glucose. Fiber is similar to starch in that it is composed of long strands of simple sugars; however, unlike starch, fiber cannot be degraded by human digestive enzymes. Fiber passes through the body without providing calories or nutrients; however, it does provide beneficial effects for the digestive tract and a framework for gut bacterial fermentation processes. Dietary fibers come in two forms: soluble and insoluble. Sometimes, both forms may be found within the same food item. For example, an apple contains insoluble fiber in the skin, whereas the pulpy interior provides the soluble fiber. Fiber may be found in whole grains, nuts, seeds, vegetables, and fruits. Dietary fiber provides notable health benefits such as preventing constipation, reducing blood cholesterol, and helping to stabilize blood glucose levels. In addition, consuming the recommended 20 g to 35 g of fiber-containing foods per day may decrease the amount of less nutritious foods in the diet. High-fiber foods tend to leave a person feeling satiated and less likely to overconsume calories [5].

Recommendations for a healthy diet suggest that 55% to 60% of total energy intake comes from carbohydrate, especially from complex carbohydrates such as whole grains, vegetables, and fruits. These forms of carbohydrate are nutrient dense; that is, they provide many nutrients for the calories they generate. Although carbohydrates in general have received a ''bad rap'' in recent years, for the average healthy person, a diet containing an abundance of complex carbohydrates along with an occasional simple sugar is in accordance with dietary guidelines for health maintenance.

Sugar, legally defined as sucrose, has been accused of causing hyperactivity, criminal behavior, obesity, and a host of other maladies. Although research has not proven such accusations, an abundance of refined sugars in the diet can contribute to dental caries and nutrient displacement. This can deplete the body's reserves of nutrients and result in

nutrient imbalances that may affect proper development, wound healing, and immune response [6]. Processed, cooked starchy foods, especially when combined with refined sugars (eg, donut, pastry, snack/potato chips, crackers) also can contribute to dental caries and plaque formation, thereby contributing to the development of periodontal disease. It is recommended that when highly processed simple sugars and starchy foods are consumed, they should be consumed sparingly and with meals to decrease caries and periodontal disease risk [6,7].

Today, many processed foods utilize various forms of sugar such as sucrose, fructose, high-fructose corn syrup, honey, molasses, maltose, and others. Consumers are advised to read product labels and choose foods with less added sugar. Interestingly, honey is currently being investigated for use in dentistry as an antibacterial agent. Although considered as cariogenic as sucrose, the beneficial properties of certain honeys (antioxidant, anti-inflammatory, antimicrobial) may outweigh the risks. Further research into this area needs to be done to determine honey's usefulness in oral health [8].

Alternative sweeteners such as sugar alcohols (eg, sorbitol, xylitol), aspartame, saccharin, sucralose, and acesulfame K are also available in food products; they do not contribute to dental caries and may be useful as sugar substitutes in various food items. Xylitol in chewing-gum form was shown to inhibit *Streptotcoccus mutans* activity and has been applied as part of a caries control regimen [9]. In addition, xylitol stimulates saliva production and the bicarbonate ions generated help neutralize plaque acids [10]. Sugar alcohols are not perfect, however. For example, some sugar alcohols like xylitol may produce diarrhea when consumed excessively. Aspartame should not be consumed by persons with phenylketonuria because their bodies cannot metabolize excess phenylalanine, a component of the sweetener [4].

Lipids

In recent years, dietary lipids have come under scrutiny. Mainstream nutrition has proposed that fats in the diet may contribute to obesity and heart disease and possibly other chronic diseases such as cancer. This concept is currently being revisited and it is hoped that new research in this area will clarify the role of dietary fat on health.

Dr. Bloch's article, elsewhere in this issue, discusses some of the new concepts related to the fat and carbohydrate content of the diet. Despite the controversy surrounding dietary lipids, the fact remains that a certain amount is important to maintaining adequate health. Dietary lipids are a great source of energy. They provide 9 kcals/g—more than twice the amount generated by carbohydrates or proteins. Fat, stored as adipose tissue in the body, serves to protect internal organs, regulate temperature, and store energy for times of famine. Dietary fat is a source of the fat-soluble vitamins (A, D, E, K) and two vital fatty acids (linoleic acid, linolenic acid). Fats serve as components of various body materials

including adipose tissue, nervous tissue, hormones and prostaglandins, cholesterol, and cellular components (phospholipids) [11]. In addition, fats give foods palatability and the consumer a sense of satiety when eating them [12].

Dietary lipids are divided into fats and oils; fats are generally solids at room temperature, whereas oils are liquids. Dietary lipids are often classified by their chemical structures as triglycerides, phospholipids, and sterols. Over 90% of dietary fat is in the form of triglycerides; these are glycerol molecules to which one, two, or three fatty acids are attached. The fatty acid structures vary (eg, the length of the fatty acid chain or its level of saturation), which affects the characteristics of the triglyceride. Saturation refers to the number of hydrogen atoms attached to the carbon skeleton of the fatty acid. If a fatty acid can acquire bonds with more hydrogen atoms, then it is termed unsaturated. Double bonds connect the unsaturated carbons. Saturated fats have no double bonds, monounsaturated fats have one double bond, and polyunsaturated fats have two or more double bonds [11].

Triglycerides in foods generally are a mixture of these fats but often contain more of one type. For example, butter contains mostly saturated fat but also has some monounsaturated and, to a lesser extent, polyunsaturated fat. Saturated fats are predominately found in animal products such as meats and dairy foods. Monounsaturated fats are generally found in plant products such as olive oil and peanuts. Polyunsaturated fats are also plant derived; examples include corn oil, soybean oil, and sunflower oil. There are some notable exceptions: coconut, palm, and palm kernel oil are mostly saturated, whereas fish oils contain mostly polyunsaturated fats [11].

Polyunsaturated fats may be further classified as omega-3 fats or omega-6 fats. Omega-3 polyunsaturated fats have their first double bond at the third carbon from the methyl end of the molecule. These fats include linolenic acid, and research indicates they may have healthful benefits. Population studies indicate that omega-3 fatty acids may decrease cholesterol and cardiac disease risk by lowering blood pressure and preventing blood clots. Main sources of omega-3 fats include fish and fish oils. Omega-6 fats are so named because their first double bond is at the sixth carbon from the methyl end. They include the essential fatty acid linoleic acid and are found mainly in vegetables and meats. The average American diet is generally much higher in omega-6 fatty acids compared with omega-3 fatty acids [13].

Fats should form at least 3% of the daily calories (kcal) in order to maintain health and prevent fatty acid deficiencies. Stated differently, the average adult requires about 1 tablespoon of polyunsaturated fats daily to provide enough linoleic acid for health. Diet and Health Guidelines suggest that fats comprise $\leq$30% of total calories (kcal) consumed per day, intake of saturated fats should be 10% or less, and dietary cholesterol limited to less than 300 mg. For someone consuming 2000 kcal/day, this amounts to 80 g of fat. This equates roughly to the amount of fat in a 10 oz prime rib or

T-bone steak [11]. Consumers are advised to look at labels and be aware of the fat content of foods they consume. Many times, diets do not need to be drastically altered to significantly reduce fat intake. Simply trimming the fat from meats or removing the skin from poultry and broiling or baking instead of frying can reduce fat content significantly. Choosing smaller portions of higher fat foods may also be helpful.

In recent years, fat substitutes have come on the market. For example, Simplesse (CP Kelco US Inc., Wilmington, DE) is a fat substitute made from milk protein and egg whites. It is used in dairy and oil-based products to provide the "mouth feel" of fat, without the calories. Olestra (Proctor and Gamble), a sucrose-based synthetic fat, is frequently used in fat-free foods. Because it is not digested or absorbed, it does not contribute calories [14].

Fats are important to oral health from the standpoint that phospholipids are a structural component of cell membranes, tooth enamel, and dentin. Fats are involved in the initiation of calcification and mineralization of teeth and bones. In addition, research indicates that high-fat foods tend to be inhibitory towards dental caries. Small quantities of nuts and cheeses, for example, can be good between-meal snack foods or even as "dessert" substitutes for patients concerned with dental caries [14]. Dentists need to be aware that the average American consumes in excess of 40% of daily calories from fat. Although the role of fat in health and disease is being debated in nutrition circles and the medical community, it is important to remember that cardiovascular disease is still the leading cause of death in the United States. Therefore, it is prudent to advise patients to have their lipid profiles and blood cholesterol monitored annually. In addition, patients may be consuming fish oil supplements for possible health benefits of omega-3 fatty acids; indiscriminate use should be avoided because these supplements may be contaminated with pesticides or heavy metals and may have a negative effect on the blood glucose levels of diabetics. In addition, these products may produce an anticoagulatory effect, rendering the patient more prone to postoperative bleeding and retarded wound healing following an oral surgical procedure [14].

The oral health care provider should be aware that some patients concerned about fat content of their diet may drastically reduce fat intake, with potential consequences. These patients may present with sensitivity to cold, dry skin, dull hair, and gaunt appearance. The dentist should inquire about the diet of such patients and suggest referral to a physician if severe fat restriction is suspected. Infants and children in the first 2 years of life should not have dietary fat restrictions because this may contribute to failure to thrive.

Proteins

Dietary proteins are composed of amino acids, all of which have the same basic structure that includes a central carbon atom with hydrogen, an amino

group, an acid group, and a side group. The uniqueness of the side group gives each amino acid different characteristics. The body can synthesize most amino acids, but there are some that the body cannot manufacture and these are termed essential amino acids. The essential aminio acids are histidine, leucine, isoleucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. These essential amino acids must be obtained through dietary means.

Dietary proteins are ultimately degraded to their component amino acids that enter an amino acid pool from which the body can obtain building materials. One of the main functions of proteins is in the building, repair, and replacement of body tissues. Proteins also function as enzymes, hormones, regulators of fluid and acid-base balance, transport molecules (eg, hemoglobin), and antibodies. Like carbohydrates, proteins provide 4 kcal/g; however, this is not their primary function [15].

Although inadequate dietary protein is a problem in many developing countries around the world, most Americans consume significantly more than recommended [16]. The RDA for protein is 0.8 g/kg; thus, an adult 150 lb man would meet the RDA with about 54 g of protein per day. This amount can be obtained by consuming, for example, two 3 oz roasted chicken wings [17]. In addition, it is recommended that protein not account for more than 15% to 20% of daily calories (kcal) [16]. An estimate for a serving size of protein is roughly the size of a deck of cards.

Along with protein quantity in the diet, protein quality is also a factor for consideration. Proteins of poor quality provide an unbalanced supply of amino acids so the body cannot completely utilize all of them. Complete proteins contain all the essential amino acids; these are the highest quality. Generally, animal products contain complete proteins; plant foods may be limited in one or more amino acids. For years, eggs were used as a reference for high-quality protein [15]. Soy, however, is a complete protein that has received much notice in recent years and has replaced beef to a greater extent than ever before in government-supported school lunch programs in the United States [18].

The consumption of plant foods alone (such as is done by vegetarians) was once regarded as having inadequate protein quality. With planning, however, vegetarians may choose foods in such a way as to combine a food having a certain array of amino acids with another food containing a complementary array of amino acids. By combining proteins, the vegetarian can obtain protein quality greater than either food alone can provide. Examples of this mutual supplementation technique include rice and beans, cereal and milk, tofu and stir-fried vegetables, and peanut butter on whole-grain bread [15].

Protein foods generally are not cariogenic, although they may be high in fat. Excessive consumption should be avoided; however, small amounts of nuts, seeds, dried beans and peas, boiled eggs, or hard cheeses, for example, make for nutritious snacks with low cariogenicity. Patients, especially older

adults, may be unable to consume enough protein in their diet if they have ill-fitting dentures, are edentulous, experience gustatory changes associated with aging and/or medications, or have limited funds or inaccessibility to a grocery. Inadequate dietary protein may predispose such persons to decreased immune function, impaired wound healing, and oral infections [16].

Water

Water is an essential nutrient for life through which all body processes occur. Nutrients and waste products are transported throughout the body by water. Water serves the body as a solvent, lubricant, shock absorber, temperature regulator, blood volume regulator, and structural component of numerous molecules, and participates in a variety of chemical reactions within the body. About 60% of an adult human body and an even greater percentage of a child's is composed of water. Water within the body is basically intracellular or extracellular. Intracellular fluid accounts for two thirds of body water and is high in phosphate and potassium. The remainder is extracellular fluid that includes interstitial fluid (high in sodium and chloride), plasma, and structural water such as in bones and skin [19].

The average adult requires 2000 ml to 3000 ml of water daily (7–12 cups). Pregnancy and lactation further increase fluid needs. The main sources of water include beverages and foods. Many meats and cheeses are composed of up to 50% water, whereas fruits and vegetables may be up to 95% water. Water is also produced by the body during metabolism. Losses of water can occur from urination, defecation, perspiration, and respiration. The body tightly controls water balance such that homeostasis needed for life is maintained. Thirst is the primary regulator of water intake in response to changes sensed by the mouth, hypothalamus, and nerves. The kidneys respond to higher blood sodium levels by stimulating the pituitary gland to secrete antidiuretic hormone, which causes the kidneys to excrete less water. The kidneys respond to reduced blood flow by releasing rennin, which stimulates activation of angiotensin and, in turn, causes blood vessels to constrict, raising blood pressure and stimulating the adrenal glands to secrete aldosterone. This hormone directs the kidneys to retain more sodium and water and causes blood volume to increase [19,20]. Unfortunately, by the time thirst is sensed, the person may already be somewhat dehydrated. In addition, this mechanism depends on a person's ability and willingness to respond to the sensation and obtain fluids.

Fluid volume excess can result in body water moving into interstitial compartments, which can produce peripheral edema. Congestive heart failure, renal failure, liver disease, and steroid use can predispose a person to sodium retention and ultimately fluid volume excess. Prolonged dehydration and excessive vomiting, diarrhea, perspiration, and polyuria may result in fluid volume deficit. People may experience light-headedness, disorientation, extreme thirst, nausea, unusual drowsiness, and oral signs and symptoms.

The oral mucosa is very sensitive to fluid volume. Xerostomia, dry, shrunken, fissured tongue or mucous membranes, and dry skin may be noted in patients presenting with fluid volume deficit. In addition, a patient who has experienced rapid weight loss or whose denture suddenly feels loose may be experiencing a fluid volume deficit. The dentist should inquire about medications being taken and dietary and fluid intake in such patients. Patients experiencing edema may note their denture fits tightly and may present with mucosal irritations related to changes in fit of the prosthesis. Patients should be encouraged to consume adequate daily water. Water should be recommended over other beverages like coffee or tea because caffeine is a diuretic. Sodas, juices, and concentrated sports drinks that contain salt, sugars, and other chemicals must be diluted as they enter the bloodstream, which causes fluid to be removed from the cells (furthering dehydration) and also triggers the thirst mechanism. Patients on high-protein diets require a much higher daily water intake to eliminate the waste products associated with protein metabolism [19–21].

Obtaining drinking water that is free from harmful microbiologic and environmental contaminants, pesticides, and additives is an important issue today. In the United States, drinking water mainly comes from surface or groundwater sources. Surface water from lakes, reservoirs, rivers, and so forth supplies most major metropolitan areas and can be easily contaminated with agricultural chemicals, industrial wastes, and other environmental pollutants. It can be cleansed to some degree by fresh rain, sunlight, plants, and microorganisms within it. Groundwater, which is usually obtained by tapping underground aquifers through pump systems, is more slowly contaminated than surface water. It is, however, more difficult to remove contaminants from these sources. In addition, because well water is not routinely treated or disinfected, users are at a greater risk of drinking contaminated water. Municipal water treatment centers seek to remove contaminants to acceptable EPA-defined levels and disinfect the water supply by the addition of chlorine. Even clean source water may become contaminated by the time it reaches the home through dirt, bacteria, asbestos, or lead within plumbing systems. Because many people are concerned about the quality of their drinking water, home treatments and alternate water sources and have become popular [22].

Boiling water is an inexpensive but time-consuming treatment that will kill microorganisms and remove some organic compounds; however, it may concentrate inorganic contaminants such as heavy metals. Filtration with granulated activated carbon is easy to use but can be expensive. It can remove some impurities, but bacterial growth can occur within the filters if they are not changed regularly. Reverse osmosis systems utilize a semi-permeable membrane that allows particles of a certain size to pass through and filters out larger particles. Distillation is an expensive, high-maintenance process that vaporizes source water in order to separate it from its contaminants. Ozonation involves ozone units that superoxygenate water

and reduce bacterial load with adequate time. It is expensive and does not eliminate other types of contaminants. Kinetic degradation fluxion resin is a technology limited to chlorine removal and more commonly used in commercial settings. Ultraviolet light systems are effective at killing bacteria, viruses, and some algae but do not eliminate harmful protozoa such as giardia or chemical impurities [23]. Some of the more useful systems mentioned also remove fluoride from the water supply. Patients concerned about their drinking water quality should have their water laboratory tested and, based on the findings, determine the best type of water treatment system for their particular contaminant situation. In addition, if children are in the home, then the available fluoride in the water or in the resulting treated water should be assessed.

The popularity of bottled water has risen in recent years because many people believe it is safer than tap water. Although bottled water is regulated nationally by the Food and Drug Administration, bottled water sold strictly within state borders is regulated locally by state and environmental agencies. An estimated 75% of bottled water comes from groundwater sources that have been disinfected with ozone. Other bottled waters that come from municipal sources may be treated with carbon filtration, reverse osmosis, or distillation. Interestingly, carbonated waters including seltzer, soda, and tonic waters are considered soft drinks and not waters [22–24].

Existing regulations do not require bottled waters to be purer than tap water. Contamination has been a problem with bottled waters. In 1991, the United States House Energy and Commerce Commission study found 31% of the sampled waters to exceed tap water limits for microbiologic contaminants. A study of bottled waters sold in California done in 1985 by the California Assembly Office of Research obtained similar findings. The fluoride content of bottled waters may also vary dramatically [23].

Consuming adequate amounts of water on a daily basis is important for health promotion. Water quality issues, however, will continue to be a relevant topic in the public forum for the foreseeable future. Patients who are immunocompromised, infants, children, and the elderly may be most susceptible to contaminants in drinking water. Patients should be advised to have their drinking water tested periodically and, based on the findings, determine the best course of action for their particular situation.

Vitamins

Vitamins are a group of essential nutrients required in very minute amounts to participate and regulate chemical reactions within the body. They are not energy-producing nutrients but enable energy to be released from carbohydrate, fat, and protein for proper body functioning. For example, many B vitamins act as coenzymes, which bind to protein enzymes and enable the enzymes' activity. Vitamins available from foods may be in an active or inactive form. The inactive precursor, or provitamin, is later

chemically altered to the active form of the vitamin [25]. Vitamins are organic compounds and, as such, can be destroyed. For example, prolonged heating may destroy almost half the thiamin in food, oxygen destroys vitamin C, and light causes loss of riboflavin in milk [26]. Nearly all foods contain vitamins. Sometimes, food processing destroys or removes them and they are replaced through the process of enrichment (eg, breads and cereals). Sometimes, vitamins are added to foods that may or may not have contained them originally (eg, vitamin D in milk). Enrichment and fortification are done to prevent nutrient deficiencies in the population [25].

Vitamins are generally classified as water soluble or fat soluble. Water-soluble vitamins include vitamin C and the B vitamins (thiamin, riboflavin, niacin, folate, vitamin B_6, vitamin B_{12}, biotin, and pantothenic acid). The fat-soluble vitamins include vitamins A, D, E, and K [25]. In general, water-soluble vitamins are easily absorbed into the bloodstream at the intestinal level and freely move about the cells. They are not stored to any large degree and need to be obtained from the diet on a regular basis. Fat-soluble vitamins first enter the lymph and then the blood where their transport is often dependent on protein carriers. They are stored in the liver and fatty tissues of the body, so depletion takes much longer than with the water-soluble vitamins. Toxicity, however, is more likely with fat-soluble vitamins, especially if the source is vitamin supplements rather than foodstuffs [26].

Composition of the diet and body conditions affect the bioavailability of vitamins. For example, persons on low-fat diets may have lower absorption of fat-soluble vitamins. Sometimes, the vitamins in foods (such as niacin in corn) are chemically bound to other compounds that hinder absorption. Some vitamins are easily absorbed by simple diffusion (eg, vitamin C). Others vitamins such as vitamin B_{12} must be bound to intrinsic factor (a gastric protein) before absorption can occur [25]. Table 2 summarizes water-soluble and fat-soluble vitamins [27].

Minerals

Minerals provide structural components for the body (eg, in the form of bones and teeth). They allow for nerve and muscle function, blood clotting, tissue growth and repair, and acid-base balance of body fluids, and act as cofactors for enzymes in chemical reactions within the body. Minerals are classified as major or trace minerals. Major minerals are needed from dietary sources in amounts greater than 100 mg/day. These include calcium, magnesium, phosphorus, potassium, sodium, chloride, and sulfur. Trace minerals (elements) are needed in lesser amounts and include fluoride, iron, zinc, selenium, chromium, copper, iodine, molybdenum, and manganese [21].

Main dietary mineral sources include both plant-based and animal-based foods. Unlike vitamins, minerals—as inorganic elements—are not as susceptible to destruction through storage, handling, or cooking practices. As with vitamins, however, some bioavailability issues exist. Some plant

Table 2
Vitamins

Vitamins	Actions	Sources	Deficiency
Fat soluble			
A[a]	Responsible for vision and growth; maintenance of mucous membranes, epithelium	Retinol in milk, fortified margarine, butter, cheese, egg yolk, liver, fatty fish. Beta-carotenes in milk, carrots, tomatoes, dark green vegetables	Reduced night vision; blindness through corneal damage; reduced resistance to infection
D[a]	Promotes calcium and phosphate absorption	Sunlight, fortified margarine, egg yolk, fortified cereals	Failure of bone calcification; rickets in children, osteomalacia in adults
E[a]	Antioxidant	Vegetables and their oils; seeds, nuts, whole grains	May occur in premature infants or in malabsorption syndromes
K[a]	Essential to the formation of blood-clotting proteins	Synthesized by gut microorganisms; dark green leafy vegetables	Increased clotting time
Water soluble			
C (ascorbic acid)[a]	Essential to collagen production—used in the structure of bone and connective tissues; aids wound healing and iron absorption	Fresh fruit/citrus fruits, red and green peppers, broccoli, snow peas, Brussels sprouts	Scurvy; poor wound healing and bleeding gums
B_1 (thiamin)	Coenzyme in carbohydrate metabolism	Lean pork, enriched breads/ cereals, legumes, seeds, nuts	Beri-beri; Wernicke Korsakoff syndrome in alcoholism
B_2 (riboflavin)[a]	Coenzyme in fat and protein, metabolism	Enriched and whole grains; meats, liver, eggs, dairy products, fish, poultry, dark leafy vegetables	Ariboflavinosis with glossitis, cheilitis, and seborrheic dermatitis
B_3 (niacin)[a]	Cofactor to enzymes involved in energy metabolism; glycolysis and TCA cycle	Meats, poultry, fish, whole and enriched breads and cereals, milk	Pellagra; toxicity leads to vasodilation, liver damage, gout, and arthritic symptoms
B_6 (pyridoxine)[a]	Coenzyme in energy metabolism; antibody and hemoglobin formation	Meat, poultry, fish, whole grains, fortified cereals, eggs	Altered nerve function

(*continued on next page*)

Table 2 (*continued*)

Vitamins	Actions	Sources	Deficiency
B_{12} (cobalamin)[a]	Transport/storage of folate; energy metabolism; blood cell and nerve formation	Animal foods; fortified cereals	Pernicious anemia
Folic acid (folate)[a]	Coenzyme metabolism; fetal neural tube formation	Green leafy vegetables, legumes, citrus fruits	Megaloblastic anemia

[a] These nutrients are associated with oral health promotion.
TCA, Tricarboxylic acid cycle.
Modified from PEWorld. Available at: www.peworld.org.

foods contain binders such as oxalates, tannins, or phytates that bind the minerals within them, rendering these minerals unavailable for digestion and absorption [21,24]. This is not a problem with minerals from animal-based foods. For example, beans are a good source of calcium, but calcium in milk is better absorbed. Table 3 summarizes the minerals [27].

Specific nutrients in oral tissues growth, development, and health

Growth, which begins at conception, is defined as an increase in size resulting from the multiplication and enlargement of cells and comprises three phases. Hyperplasia, the first phase, consists of rapid cell proliferation. The second phase, hyperplasia and hypertrophy, describes a decreased rate of cell proliferation, with a continued increase in cell size. The third phase, hypertrophy, involves the cessation of cell proliferation with ongoing increases in cell size. Biochemical changes occur to accompany the various growth phases. Development, like growth, begins at conception; however, unlike growth, it continues throughout one's life. Development includes many complex processes that allow the body to vary and adapt to changes during its life cycle [28,29].

Growth and development are affected by the nutritional environment. Diet can affect the process of cell replication and enlargement, thereby influencing tissue and organ growth. Many nutrients affect the enzymatic processes of the body and, therefore, enzymatic regulation is also influenced by the diet. In addition, the points at which a nutrient deficit occurs during the growth timeline can have just as important an impact as the type of nutrient deficit involved. These are often referred to as the ''critical periods'' of growth [28]. For example, permanent damage from decreased cell numbers for a particular tissue or organ may be the result of inadequate nutrition during a hyperplastic phase of growth. If the same deficit occurred during a hypertrophic phase, however, then it may be compensated for later, in the way of ''catch-up'' growth, when nutrition is adequate [29]. The

Table 3
Minerals

Mineral	Actions	Sources	Deficiency
Calcium[a]	Bone/tooth formation; blood clotting; nerve/muscle function; CNS; blood pressure	Milk-based foods, sardines with bones, green leafy vegetables, legumes	Reduced bone density
Phosphorus[a]	Bone/tooth formation; metabolism; acid-base balance	Dairy foods, eggs, meat, fish, poultry, legumes, whole grains	Rare
Magnesium[a]	Bone/tooth formation; nerve and muscle function; blood clotting; cofactor in metabolism	Whole grains, green leafy vegetables, hard water, meats, dairy products, fish	Associated with FVD: weakness, muscle twitching, convulsions
Potassium[a]	Fluid/electrolyte balance; muscle and nerve function; hormone release	Whole grains, vegetables, meats, legumes, dairy foods, fruits, unprocessed foods	Associated with FVD: weakness, confusion, arrhythmias
Chloride	Fluid/electrolyte balance; gastric digestive acid	Table salt, processed foods	Associated with FVD
Sulfur	Component of body proteins (eg, hair, cartilage, nails)	Protein foods: eggs, meats, fish, poultry, legumes	Associated with protein deficiency
Sodium	Electrolyte/fluid balance; nerve function; blood pressure; acid/base balance	Table salt, processed foods	Associated with FVD: headache, cramps, weakness, confusion, decreased appetite
Fluoride[a]	Bone/tooth formation; increases resistance to caries	Fluoridated water, tea, seafood, seaweed	Increased dental caries
Zinc[a]	Required for digestion, metabolism, wound healing, tissue growth and repair, reproduction	Protein foods; meats, fish, poultry, eggs, legumes	Retarded growth; taste/smell alterations; decreased immune function and wound healing; slow physical/sexual maturity
Iron[a]	Growth; immune system health; hemoglobin and myoglobin formation; energy production	Liver and other meats, fish, eggs, poultry, green vegetables, legumes, enriched breads and cereals	Microcytic anemia (women and children at risk)
Copper[a]	Coenzyme in antioxidant reactions and energy metabolism; iron use; wound healing; blood and nerve fiber production	Organ meats, seafood, green leafy vegetables, nuts, seeds, water from copper pipes	Bone demineralization and anemia

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Table 3 (*continued*)

Mineral	Actions	Sources	Deficiency
Iodine[a]	Thyroxin synthesis; regulates metabolism, growth, and development	Iodized salt, seafood	Goiter, tiredness, weight gain
Selenium[a]	Antioxidant; may be helpful in periodontal disease	Meats, fish, eggs, whole grains	Predisposition to heart disease
Chromium	Carbohydrate metabolism	Whole grains, cheese, meats, brewer's yeast	Possible cardiovascular disorders and insulin dysfunction
Molybdenum	Coenzyme	Whole grains, legumes, milk	Unknown
Manganese	Metabolic reaction participant	Whole grains, green leafy vegetables, legumes	Unknown

[a] These minerals are associated with oral health promotion.
CNS, central nervous system; FVD, fluid volume deficit.
Modified from PEWorld. Available at: www.peworld.org.

critical-period concept, which has been demonstrated in both animal and human models, reveals the importance of nutrition in allowing the body to attain its full growth and development potential. Oral tissues are no less susceptible to nutritional stresses that may affect a person's oral health and wellness throughout life.

Because tooth development begins in utero and extends into adult life, nutrition exerts a pre-eruptive and a posteruptive effect. Research with animals and human population studies have shown relationships between nutrient deficiencies during tooth development and tooth size, formation, eruption time, and caries susceptibility [28,29]. Protein deficiency in the form of protein energy malnutrition is more commonly seen in developing countries but can be found in lower socioeconomic groups in industrialized countries, in substance/alcohol abusers, and in those with eating disorders or chronic illness. Poor bone calcification, retarded centers of ossification, small teeth, delayed tooth eruption, retarded jaw growth, and crowded dentition have been related to protein deficiency during the critical growth periods [30,31]. Postnatal weight gain has been found to correlate positively with the age of first tooth eruption. In addition, a study of premature infants who required prolonged care involving oral intubation and nutrition experienced delayed tooth eruption compared with healthy premature infants [32,39].

Calcium, vitamin D, and phosphorus are essential for the formation of bones and teeth. Deficiencies of these nutrients during critical periods of growth have been shown to have dental implications such as retarded jaw, tooth, and condyle development, and reduced quality of tooth enamel and dentin [27,30,31,39]. Vitamin D and calcium deficiencies have also been found to result in generalized jaw bone resorption and loss of the periodontal ligament [27].

Vitamin C deficiency has been related to loss of connective tissue, gingival hemorrhage, and tooth mobility. These effects, however, are resultant to the infectious process and highly variable depending on the bacterial plaque present. Nonetheless, vitamin C deficiency has been found to increase the risk of periodontal disease among certain populations, including smokers and persons with diabetes [27,33,34]. Vitamin C is vital to collagen production for the formation of teeth and bone and also has antioxidant properties. As such, vitamin C is important in the healing of oral soft-tissue and hard-tissue wounds.

Animal studies have shown vitamin A and beta-carotene to be indispensable to the proper growth and development of periodontium, teeth, salivary glands, and oral epithelium. In humans, the teeth are less sensitive to vitamin A deficiency, although some studies suggest that it can exacerbate an existing periodontitis [27,35]. Vitamin A is also vital to the wound-healing process, for example, as it contributes to epithelialization, collagen formation, and immune response during the inflammatory stage of healing [36].

Nutrients such as vitamins A, C, and E and selenium have antioxidant properties, that is, the ability to scavenge free radicals and reactive oxygen molecules. These reactive species can cause cell damage by reacting with their membrane lipids, denaturing proteins, and altering nucleic acids. The antioxidant roles of these nutrients could provide health benefits to oral tissues; for example, recent studies suggest beta-carotene may have a role as a chemotherapeutic agent in oral cancer [36,37].

The nutritional state of a person is often manifested in oral tissues due to the rapid turnover of cells in this area and the bacterial onslaught the area receives. Healthy oral epithelium, for example, experiences a 3-day to 7-day cell turnover and acts as an effective barrier to toxins. Inadequate nutrition may cause the tissues to breakdown, become infected, and/or develop lesions. B-complex vitamin deficiency may manifest as a magenta, raw, fissured, smooth, or swollen tongue. Angular cheilitis, itchy eyes, and scaly dermatitis may also be evident. Patients with iron deficiency may present with tissue pallor, spoon shape nails, pale, atrophic tongue, pale conjunctivae, and sensitivity to cold [26,28,38,39].

Although this review has put some emphasis on the manifestations of nutrient deficiencies, the overconsumption of nutrients, usually by way of supplements, is just as important. The article by Dr. Rigassio Radler, elsewhere in this issue, reviews commonly used supplements and their effects. In either case, the oral health care provider should be aware of the role of nutrition in health and, specifically, in oral health and disease. Patients should be assessed for signs of nutrient imbalances and, if imbalances are suspected, then appropriate referrals should be made. The oral health care provider can aid patients' health and well-being by providing nutritional information as it relates to conditions pertinent to oral health and general health and, in so doing, improve the quality of life of the community in which the oral health care provider operates.

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