Nutritional Deficiencies in Children on Restricted Diets

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KEYWORDS

- Deficiencies • Restricted • Diets • Gluten
- Allergies • Vegetarian

Nutrient deficiencies in infants and children, commonly associated with poverty in developing countries, are caused by multiple factors, including maternal undernutrition; low-calorie, nutrient-poor complementary foods; and high incidence of infections. Estimates show that up to 40% of children less than 5 years of age living in poverty can be affected by protein energy malnutrition.[1] Specific micronutrient deficiencies considered major public health problems worldwide include those for iron, iodine, vitamin A, zinc, and selenium.[2] In the United States, such clinical nutrient deficiencies do not exist to the same degree, although diets may not always be optimal. The Feeding Infants and Toddlers Study, the first national study comparing nutrient intake of infants and toddlers with the new Dietary Reference Intakes (DRIs) concluded that healthy infants and toddlers in the United States had adequate intakes of most nutrients. However, there were inadequate intakes of vitamin E in 58% of toddlers from 12 to 24 months, low fat intakes for 29% of toddlers, low fiber intake, and high intake of vitamin A and zinc compared with recommended intake.[3] For children aged 2 to 11 years, the American Dietetic Association suggests potential inadequate dietary intake of vitamin E, folate, calcium, iron, magnesium, potassium, and fiber.[4] Finally, in adolescents, dietary deficiencies of vitamins A and C, calcium, iron, riboflavin, and thiamin have been noted.[5]

A review of the literature over the past 30 years demonstrates that clinical nutrient deficiencies in the United States are not absent, and particular pediatric populations may be at higher risk: children on medically prescribed diets, such as gluten-free, allergen-free, ketogenic, or tube feedings; and children on restricted diets because of developmental or behavioral disability and/or parent-selected dietary regimens. In contrast to deficiencies in developing countries, pediatric deficiencies in the United States are often not associated with poverty, but rather with caregiver nutritional

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ignorance, nutrition misinformation, fad diets, alternative nutrition therapies, and cultural preferences. This article reviews the importance of macro- and micronutrients for infants and children, and discusses the incidence and risks of nutrient deficiencies in both medically prescribed restricted diets and parent/child-selected restricted diets.

NUTRIENTS

Nutrients can be grouped into macronutrients of carbohydrates, protein, and fat, which supply calories, and micronutrients of vitamins and minerals. The DRIs have established recommended intakes for both macro- and micronutrients.[6] These include acceptable calorie reference ranges, the acceptable macronutrient distribution range, adequate intake, and recommended dietary allowances for essential vitamins and minerals.

Nutrient deficiencies result from inadequate nutrients in relation to biologic need. This imbalance can be caused by inadequate intake, impaired nutrient absorption, or increased nutrient need. Certain nutrient deficiencies can rapidly result in impaired growth, while other deficiencies deplete body stores initially, then tissue concentrations, and ultimately impair metabolic pathways, which lead to clinical symptoms. Deficiencies of macronutrients can be classified as marasmus (a primary calorie deficit), kwashiorkor (a primary protein deficit), and marasmic kwashiorkor (both a calorie and protein deficit). Calorie deficit is a primary nutrient deficiency. However, there can also be deficiencies or imbalances of the macronutrients: carbohydrates, protein, and fat. The acceptable macronutrient distribution range for children and adolescents is:

Carbohydrates: 45% to 65% of total calories
Protein: 5% to 20% for ages 1 to 3 and 10% to 30% for ages 4 and older
Fat: 30% to 40% for ages 1 to 3 and 25% to 35% for ages 4 and older

Specific micronutrient deficiencies that may be more frequently seen in restricted diets will be discussed in more detail and include those related to iron, zinc, calcium, vitamin D, and B vitamins.

Iron

Iron is a critical component of several proteins, including hemoglobin, myoglobin, cytochromes, and numerous enzymes. The largest portion of the body's iron is in the erythrocytic hemoglobin used in the transport of oxygen. The requirements are particularly elevated during periods of rapid growth. For this reason, cow's milk, which is a poor source of iron, is not recommended for use in infants under 1 year of age (under 9 months in Canada). Breast-feeding or the use of an iron-fortified formula should be continued until this time. Iron-fortified infant cereals can provide a significant amount of iron in the infant's diet once solid foods are started. During the growth spurt of preadolescence and adolescence, the need for iron can increase significantly. For females, the recommended dietary allowance for iron increases from 8 mg/d for 9- to 13-year-olds to 15 mg/d for 14- to 18-year-olds. For girls who have not started menstruating by this age, the requirement is approximately 10.5 mg/d.[7] For males, the recommended dietary allowance for iron increases from 8 mg/d for 9- to 13-year-olds to 11 mg/d for 14- to 18-year-olds.

The two forms of dietary iron are heme iron and nonheme iron. Heme iron is highly bioavailable. Sources of heme iron include beef, pork, lamb, chicken, turkey, fish, and shellfish. Nonheme iron is not as readily absorbed by the body and is found in beans, soybeans, eggs; whole-grain, iron-fortified, or iron-enriched foods such as rice, pasta, breads, and cereals; cooked spinach, nuts, seeds, and dried fruits. The absorption of nonheme iron can be enhanced if consumed with foods that contain vitamin C or with foods high in heme iron. In 2004, over 50% of the iron in the United States diet was from grain products. This was primarily due to the enrichment of flour with iron and the increased consumption of enriched grains and fortified ready-to-eat breakfast cereals. Meat, poultry, and fish were the secondary sources of iron, providing approximately 16%, followed by vegetables at 10%.[8]

The most common manifestation of an iron deficiency is iron deficiency anemia. According to the third National Health and Nutrition Examination Survey (1988–1994), iron deficiency and iron deficiency anemia are still relatively common in toddlers and adolescent girls. Nine percent of toddlers aged 1 to 2 years and 9% to 11% of adolescent girls were iron deficient. Of these, iron deficiency anemia was found in 3% and 2% respectively.[9]

Zinc

Zinc is critical for proper growth and development and is required for the senses of taste and smell. It also is a catalyst for approximately 100 enzymes, has a role in protein synthesis, and supports immune function. The recommended dietary allowance for zinc increases with age dramatically from 3 mg/d for the age range of 7 months to 3 years to a maximum of 11 mg/d for 14- to 18-year-old males.

Sources include meat (especially red meat), some seafood, poultry, eggs, cheese, milk, whole grains, and beans. In 2004, over 37% of the zinc in the American diet came from meats, fish, and poultry. This was followed by grain products and then dairy products at 25% and 16% respectively.[8]

Overt zinc deficiency as seen in acrodermatitis enteropathica is uncommon, but mild zinc deficiency can impair immune function, increase susceptibility to infection, and decrease ability to fight infection.[10] Signs and symptoms might include poor growth, poor appetite, altered immune function, hair loss, skin and eye lesions, and delayed puberty.[7]

Calcium

Calcium is needed for formation of bones and teeth, for muscle contractions, for blood vessel contraction and vasodilatation, for transmission of nerve impulses, and for hormone and enzyme secretion. More than 99% of total body calcium is found in the skeleton. Adequate intake of calcium during childhood and adolescence is necessary for accretion of peak bone mass. This may be important in reducing the risk of fractures and in prevention of osteoporosis later in life. The adequate intake levels for calcium increase throughout infancy and childhood. For children aged 1 to 3 years, the adequate intake is 500 mg/d. This increases to 800 mg/d for children aged 4 to 8 years, and to 1300 mg/d for 9- to 18-year-olds. Individual calcium needs are affected by the rate of growth, the degree of absorption, and the availability of other nutrients, including vitamin D and phosphorus, as well as calories and protein. Dietary substances that may decrease calcium retention include caffeine, excessive phosphorus intake, oxalic and phytic acids, and protein.[11]

Sources of calcium include dairy products; calcium-set tofu; calcium-fortified milk alternatives; such vegetables as Chinese cabbage, broccoli, and kale; and calcium-fortified fruit juices. In 2004, over 70% of the calcium in the American diet came from dairy products, primarily milk, cheese, and yogurt. These were followed by vegetables at 7%.[8] Calcium intake tends to be lower when carbonated drinks and fruit juices/drinks replace milk as a beverage.

Studies show that the percentage of children who meet the recommended adequate intake level declines with age, reaching its lowest point between the ages of 12 and 19.[12] Females in this age range have the lowest intake with only approximately 10% meeting the adequate intake level. They are followed by males at only 25%.[13]

Vitamin D

Vitamin D facilitates the intestinal absorption of calcium and phosphorus and plays a role in cellular metabolism. The adequate intake for vitamin D is 5 μg/d or 200 IU/d in the absence of exposure to sunlight. Recently, the American Academy of Pediatrics issued a recommendation that all infants and children, including adolescents, have a minimum daily intake of 400 IU of vitamin D beginning soon after birth.[14]

Sources include the diet and vitamin D synthesized in the skin with exposure to sunlight. Two dietary forms of vitamin D are vitamin D_2 (ergocalciferol) and vitamin D_3 (cholecalciferol). Vitamin D is naturally found in very few foods other than butter, cream, egg yolk, salmon, herring, and liver. However, almost all fluid milk is fortified with vitamin D as are many ready-to-eat cereals. Dairy foods, other than milk, may be good sources of calcium, but they are not always fortified with vitamin D.

Vitamin D deficiency may result in rickets, osteomalacia, and osteoporosis. Additionally, a number of recent studies have indicated that there is a high incidence of vitamin D insufficiency in the United States and Canada. Epidemiologic studies indicate that this may result in increased risk of various cancers.

B-Complex Vitamins

B-complex vitamins include thiamin, riboflavin, niacin, folate, B_6, and B_{12}. Thiamin, riboflavin, and niacin function as coenzymes in energy metabolism. Folate functions as a coenzyme in nucleic and amino acid metabolism. Vitamin B_6 plays a role in various metabolic reactions, especially in protein metabolism. Vitamin B_{12} is essential for blood formation and neurologic function. During periods of growth and the accompanying increased energy needs, the requirements for these nutrients also increase.

In 2004, grain products, especially enriched flours and fortified ready-to-eat cereals, provided the largest percentages of thiamin, riboflavin, niacin, and folate to the United States diet: 58%, 38%, 42%, and 70% respectively. Meat, fish, and poultry supplied over 75% of the B_{12} and 36% of the B_6. Meat alone was the next largest source of thiamin (16%), and meat and poultry combined equally to provide a total of 33% of the niacin. Milk products were a major secondary source of riboflavin (26%) and B_{12} (20%). The next largest sources of folate were vegetables and legumes. Vegetables were a secondary contributor to B_6 but half of this was from white potatoes.[8]

Much of the nutrient content of whole grains is in the outer husk and germ and is lost in the milling process. In the United States, wheat products and fortified cereals are enriched with thiamin, riboflavin, niacin, folate, and iron. Since January 1, 1998, all enriched cereal grains (eg, enriched bread, pasta, flour, breakfast cereal, and rice) have been required to be fortified with folate at 1.4 mg/kg of grain.[15]

RESTRICTED DIETS AND NUTRIENT DEFICIENCIES

Restricted diets in infants, children, and adolescents can increase risk of nutrient deficiencies. Some diets are medically necessary, such as the gluten-free diet for management of celiac disease, allergy-restricted diets, ketogenic diet for seizure management, and tube feedings for nutrition support. Other restricted diets are parent- or child-selected, such as vegetarian diets, milk alternatives, and diets frequently seen with developmental disabilities.

Gluten-Free Diet and Celiac Disease

The cause of nutritional deficiencies seen in celiac disease may be twofold: a result of celiac disease, and/or a consequence of the gluten-free diet. The length of time that celiac disease has gone undiagnosed or untreated, the location and degree of damage to the small bowel, and the degree of malabsorption all have a bearing. Since the damage likely occurs in the proximal small bowel, deficiencies of iron, folate, and calcium may occur. Malabsorption of fat-soluble vitamins (A, D, E, and K), carbohydrates, fat, and other micronutrients may occur if more distal portions of the small intestine are affected. Deficiencies of Vitamins B_{12} and $B_{6,}$ as well as zinc, selenium, and copper have all been seen in celiac disease.[16–18]

After the diagnosis of celiac disease, it is important to ensure that the gluten-free diet is adequate in all nutrients. In an Italian study, the diet of adolescents with celiac disease was compared with the diet of healthy adolescents. The group with celiac disease was further divided into two groups: those who were compliant with the gluten-free diet (53%) and those who were not (47%). Investigators found the diets of all three groups tended to be high in protein and fat with a resulting lower intake of carbohydrates. Comparing the two groups with celiac disease, the compliant group had a significantly higher intake of protein and a significantly lower intake of carbohydrates. The reverse was true with regard to fiber intake. The investigators concluded that strict compliance with a gluten-free diet may further worsen the imbalance of the adolescent diet and may place this group at nutritional risk.[19]

A 2005 study reviewed the adequacy of 3-day food records of 47 adults with celiac disease. These adults were recruited from the readership of a number of celiac disease publications and may have been more knowledgeable about the gluten-free diet. None of the women in the group consumed the recommended amounts of fiber, iron, or calcium and the men did not consume enough fiber or calcium. This led the investigator to conclude that nutrition therapy for celiac disease should not just focus on the foods permitted or forbidden on the gluten-free diet, but should also stress the nutritional quality of the diet.[20]

In addition to the inadequacy based on food choices, the gluten-free alternatives may not provide the same level of nutrients found in the gluten-containing foods. This is particularly evident with the grain-containing foods. Many of the gluten-free grains do not inherently contain thiamin, riboflavin, niacin, folate, and iron, nor are they required to be enriched/fortified as are many of the gluten-containing grains. However, some manufacturers are opting to do so. Food labels need to be scrutinized for gluten-containing ingredients to avoid, as well as for the addition of thiamin, riboflavin, niacin, folate, and/or iron. (**Fig. 1**) The "Nutrition Facts" portion of the label will also give the "% Daily value," which can be used as a tool for comparing products.

Wheat alternatives that are better sources of nutrients include amaranth, buckwheat, millet, brown rice, quinoa, sorghum, teff, and wild rice. Beans, such as garbanzo, fava, navy, and great northern, are also being milled into flour and used in place of wheat flour. Choosing grains and flours that are more nutritionally dense helps improve the quality of the diet. **Table 1** contains a comparison of enriched white flour to some of the gluten-free alternatives. However, most of these grains cannot compare with enriched white flour as sources of B vitamins. Therefore, a gluten-free multivitamin seems to be a prudent recommendation for patients with celiac disease.

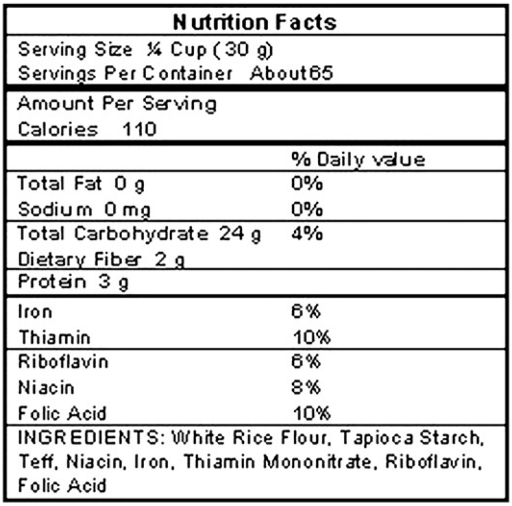
Nutrition Facts
Serving Size ¼ Cup (30 g)
Servings Per Container About 65
Amount Per Serving
Calories 110
% Daily value
Total Fat 0 g 0%
Sodium 0 mg 0%
Total Carbohydrate 24 g 4%
Dietary Fiber 2 g
Protein 3 g
Iron 6%
Thiamin 10%
Riboflavin 6%
Niacin 8%
Folic Acid 10%
INGREDIENTS: White Rice Flour, Tapioca Starch, Teff, Niacin, Iron, Thiamin Mononitrate, Riboflavin, Folic Acid

Fig. 1. Food label with "Nutrition Facts" and "% Daily value."

Allergy Diets

In 2007, approximately 4% of United States children under the age of 18 had a food allergy. Ninety percent of food allergies are caused by reaction to cow's milk, eggs, peanuts, tree nuts, wheat, soy, fish, and shellfish.[21] The mainstay of allergy treatment is the elimination of the offending protein. However, a food-avoidance diet can have

Table 1
Comparison of enriched white flour and alternative grains

Grain (100 g)	Fiber (g)	Calcium (mg)	Iron (mg)	Zinc (mg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)	Folate (µg)
Wheat flour, white, all-purpose, enriched, unbleached	3	15	4.6	0.7	0.8	0.5	5.9	183
Rice flour, brown	5[a]	11	2.0	2.5[a]	0.4	0.1	6.3	16
Teff, uncooked	8[a]	180[a]	7.6[a]	3.6[a]	0.4	0.3	3.4	NA
Amaranth, uncooked	7[a]	159[a]	7.6[a]	2.9[a]	0.1	0.2	0.9	82
Buckwheat flour, whole-groat	10[a]	41[a]	4.1	3.1[a]	0.4	0.2	6.2[a]	54
Millet, raw	9[a]	8	3.0	1.7[a]	0.4	0.3	4.7	85
Quinoa, uncooked	7	47[a]	4.6[a]	3.1[a]	0.4	0.3	1.5	184[a]
Sorghum	6[a]	28[a]	4.4	NA	0.2	0.1	2.9	NA
Tapioca, pearl, dry	1	20[a]	1.6	0.1	0.0	0.0	0.0	4
Rice flour, white	2	10	0.4	0.8[a]	0.1	0.0	2.6	4
Potato flour	6[a]	65[a]	1.4	0.5	0.2	0.1	3.5	25

Abbreviation: NA, not available.
[a] Values equal to or exceeding those of enriched white flour.
Data from USDA National Data Laboratory. National Nutrient Database for Standard Reference. Available at: http://www.nal.usda.gov/fnic/foodcomp/search. Accessed March 19, 2009; with permission.

the potential risk of being nutritionally inadequate, especially if more than one food is being eliminated. It is recommended that reliable allergy testing be completed by an allergist before placing the child on a restricted diet.

Elimination of even one of the eight most common food allergens, especially dairy or wheat, can have a major impact on the adequacy of the diet. Individually, the elimination of soy, eggs, peanuts, tree nuts, fish, or shellfish should not compromise the nutritional quality of the child's diet. However, as the number of foods eliminated increases, so does the risk of nutrient inadequacy. Also, as the previous section showed, the removal of wheat-containing products does have a negative effect on a number of nutrients. Equally, the elimination of dairy products, which are the major source of calcium and vitamin D in the diet, can alter the level of these nutrients significantly.

Inadequate growth and nutritional deficiencies are more likely to occur in children who are allergic to cow's milk and in children with allergy to more than two foods.[22,23] A study of 34 children with known food allergy showed the nutrients most likely to be negatively affected are calcium, vitamin D, vitamin E, and zinc.[24]

If dairy products must be eliminated, calcium and vitamin D must be replaced by an alternative source. Additionally, other sources of protein, riboflavin, phosphorus, fat, and calories (if the child is under 24 months of age) may need to be included. For the infant, soy-based, hydrolyzed, or elemental infant formulas supply all the nutrients needed for growth, provided that the infant consumes an adequate amount. For a toddler and older child, a milk-free formula or such beverages as soymilk, which are fortified with calcium and vitamin D, should be used.

In a review of the diets of 127 United States children (9–18 years of age) who were not consuming dairy products, only 1 of the subjects had a calcium intake of 1300 mg/d or more, which is the adequate intake for this age group.[13] The investigators concluded that an intake of 1.5 servings of a calcium-fortified citrus juice resulted in a more adequate intake of calcium.

With the elimination of an offending food and potential loss of nutrients, suitable substitute foods that provide comparable nutrients must be identified. **Table 2** provides a reference for identifying critical nutrients provided by specific foods or food groups, and for substituting alternate foods to minimize risk of deficiencies.

Ketogenic Diet

The ketogenic diet is a high-fat diet used in the treatment of intractable seizures and for certain metabolic disorders, such as pyruvate dehydrogenase complex deficiency and glucose transporter type 1 deficiency.[32] The ketogenic diet has been shown to be

Table 2
Restricted diets and affected food groups

Restricted Diet	Primary Food Group(s) Affected
Gluten-free diet	Grains
Milk allergy	Dairy
Wheat allergy	Grains
Ketogenic	Grains, dairy, fruits, vegetables
Vegetarian	Protein, dairy
Macrobiotic	Protein, dairy, fruits, vegetables
Milk alternative	Dairy, protein, fat
Gluten-free, casein-free	Grains, dairy

effective in some infants[33] and children.[34] The diet provides 70% to 90% of calories from fat, with the remaining calories provided by protein and carbohydrates. This macronutrient distribution differs significantly from the recommended acceptable macronutrient distribution range noted previously. The restrictive nature of the diet raises the risk of growth retardation and micronutrient deficiency when not appropriately supplemented. A study by Couch and colleagues[34] demonstrated stable height and weight for age percentiles after 6 months on the diet. However, a study by Williams and colleagues[35] demonstrated that, after 1.2 years on the diet, 86% of study participants had a decrease in their height-for-age percentile. Adequate micronutrient intake is also a concern. Zupec-Kania and Spellman[36] report inadequate micronutrient intake of 19 known essential micronutrients on a 4:1 ketogenic diet despite using nutrient-dense foods. They concluded that the ketogenic diet requires careful vitamin and mineral supplementation for nutrient adequacy.

Tube Feedings

Children with developmental disabilities have a higher risk of feeding difficulty, inadequate intake, and nutritional problems due to a variety of reasons, including oral motor and swallowing difficulty, altered nutritional needs, altered nutrient absorption and metabolism, drug-nutrient interactions, delay in feeding skills, altered appetite and thirst, and extended feeding times. Advances in medical technology, however, now allow for provision of nutrition support by nasogastric, gastrostomy, and jejunostomy feeding tubes, selecting from an increasing variety of formulas developed for various medical needs. For most infants and children, these formulas can provide adequate nutrition, thus preventing nutrient deficiency.[37] However, two situations that can increase the risk of nutrient deficiencies are (1) low volume of formula provided and (2) the use of home-blenderized tube feeding.

Generally, the volume of tube feeding formula delivered for a specific infant or child is planned to match the energy expenditure, promoting acceptable weight gain and linear growth. Developmentally disabled children with low calorie expenditure receive a lower volume of formula to provide energy balance. This can result in inadequate micronutrient intake. Jones and colleagues[38] describe a 3-year-old boy with cerebral palsy, developmental delay, and seizure disorder. The boy, who was receiving a tube feeding volume matched to his energy needs, developed scurvy and deficiencies of vitamin A and zinc. This case highlights the need for careful evaluation of tube feeding not only for adequate calorie and macronutrient intake, but also for adequate micronutrient intake.

Although there are available an increasing number of nutritionally adequate formulas designed for various pediatric medical conditions, some families prefer to prepare their own home-blenderized tube feeding from foods available in their home. Such tube feedings can be nutritionally adequate. However, the use of home-blenderized tube feeding requires nutrition education for caregivers with regard to formula recipes, proper food safety techniques, nutrient balance, and appropriate supplementation. Ongoing nutrient analysis of formula recipes as well as monitoring of the child's growth and nutritional status must be provided. Major concerns include not only adequate calorie, protein, and fat intake, but also macronutrient balance, adequate micronutrient intake, and adequate intake of sodium, other electrolytes, and fluid.

Vegetarian Diets

Carefully planned and monitored vegetarian diets can provide adequate nutrients for infants and children, according to the American Academy of Pediatrics,[32] the American Dietetic Association, and the Dietitians of Canada.[39] However, due to the critical nutrient needs in infancy and childhood, and to the restrictive aspects of some forms of vegetarianism, nutrients of concern whose adequacy needs to be assured include calories; protein; fat; vitamins A, D, and B_{12}; and the minerals iron, zinc, and calcium. Careful attention must be given especially to vegan diets that avoid all meat, fish, poultry, eggs, and dairy.

Calories

Calorie needs may not be met because of early satiety with the high bulk and fiber content and at times lower calorie density of vegetarian diets, especially in children less than 5 years of age.[40] Texture modifications, regularly scheduled snacks, and the inclusion of healthy fats can help to provide adequate calories for growth.

Protein

Protein intake from vegetarian diets focuses on the amino acid composition and the lower digestibility of the plant foods. Dietary protein provides amino acids, which are categorized into three groups: essential amino acids, which cannot be synthesized by humans and must be obtained from foods; nonessential amino acids, which can be synthesized by humans; and conditionally essential amino acids, which under certain circumstances, such as growth or illness, become essential. Animal foods are the best source of essential amino acids, while plant foods are often lacking in one or more essential amino acids: legumes and fruits are low in methionine and cysteine; cereals are low in threonine, and all plant foods are lower than animal foods in lysine.[32] Including a variety of plant foods helps balance the amino acid composition and optimizes protein intake. This concept of complementary proteins underscores the importance of including a variety of plant foods within a single day or even within a period of several hours to optimize protein intake.[41] To allow for the amino acid composition and the lower digestibility of plant foods, it has been recommended that protein intake be increased 30% to 35% for infants, 20% to 30% for children 2 to 6 years old, and 15% to 20% for children over 6.[41] When a variety of plant foods are carefully selected and calorie intake is adequate, vegetarian diets can meet protein needs of infants and children.

Fat

Fat intake is a concern especially for vegan infants and young children, for whom adequate fat is critical not only for energy but also for brain development, and to provide the essential fatty acids: linoleic (18:2 ω 6) and alpha-linolenic (18:3 ω 3). It is recommended that diets of breast-feeding vegan mothers and vegan children include sources of alpha-linolenic acid, such as canola oil, soy, flax, and walnuts, to enhance conversion of alpha-linolenic to docosahexanoic acid and eicosapentanoic acid, both of which are low in vegan diets.[41,42]

Vitamin A

Vitamin A intake may be a concern only for vegans, since preformed vitamin A is found only in animal foods, and vegans depend on beta-carotene and other carotenoids, which are converted to vitamin A. Three servings per day of deep yellow or orange vegetables or fruits are recommended.[39]

Vitamin D

Vitamin D deficiency and nutritional rickets has been associated with unsupplemented breast-feeding and strict vegetarian diets.[43] Lacto-ovo-vegetarian diets can provide adequate vitamin D from cow's milk. Vegan diets require vitamin D from fortified soy or rice milk, breakfast cereals, or supplements.

Vitamin B_{12} (cobalamin)

Vitamin B_{12} (cobalamin) adequacy is a concern primarily for vegan diets. Dairy products and eggs eaten regularly provide adequate vitamin B_{12} for lacto-ovo-vegetarians. However, vegan diets, especially the more processed and hygienic diets in developed countries, cannot be relied upon to provide adequate B_{12}, and should be supplemented with either B_{12} supplements, or B_{12}-fortified foods, such as certain brands of soy milk, breakfast cereals, meat analogs, or nutritional yeast grown on a vitamin B_{12} medium. Weiss and colleagues[44] describe a 6-month-old breast-fed female diagnosed with severe vitamin B_{12} deficiency with neurologic sequelae associated with a maternal strict vegetarian diet. Therefore, vitamin B_{12} supplementation for pregnant and breast-feeding vegan mothers is recommended.

Iron

Iron deficiency for children on vegetarian diets is a concern for two reasons: (1) iron from plants is nonheme iron, which is less well absorbed than the heme iron found in animal products, and (2) many plant foods contain phytates, which bind with iron, decreasing its bioavailability. To compensate for these differences, the DRI recommends an 80% increase in dietary iron intake for vegetarians. In addition, iron absorption can be enhanced by combining a vitamin C–rich food with an iron-containing food, or by using special food preparation methods, such as leavening whole grain breads with yeast, to reduce the phytate content.[45]

Zinc

Zinc intake from vegetarian diets, especially vegan diets, is also a concern for infants and children due to the lower zinc content in plant foods, and the phytate content, which binds zinc, making it less available for absorption. The DRI recommends a 50% increase in dietary zinc intake for strict vegetarians.

Calcium

Calcium intake is a concern for vegans because the high oxalate content of certain vegetables, such as greens and broccoli, can inhibit absorption of calcium from foods. Calcium-enriched foods or supplements should be encouraged.

Special considerations for vegetarian infants

The American Academy of Pediatrics recommends vitamin D supplements for all breast-fed infants soon after birth and a source of iron by 6 months of age. In addition, breast-fed infants of mothers who do not include vitamin B_{12}–fortified foods or supplements regularly in their diet require a vitamin B_{12} supplement.[39] Finally, adequate zinc intake should be provided when complementary foods are introduced.

Macrobiotic Diets

Macrobiotic diets, which are based on eating ''in harmony with one's local environment,''[42] can be considered one subset of vegetarian diets. These diets can significantly vary in practice, but most rely heavily on brown rice, sea vegetables, root vegetables, and beans, with moderate intake of fruits, nuts, and seeds; and usual avoidance of meats, dairy foods, tropical fruits, potatoes, and processed sweeteners.[46] Several studies have identified serious concerns in macrobiotic infants and children: growth retardation;[47–49] kwashiorkor, marasmus, and rickets;[50] dietary deficiencies of calories, protein, calcium, vitamin D, riboflavin, and vitamin B_{12};[51,52] vitamin D deficiency rickets;[53] severe megaloblastic anemia with neurologic sequelae;[44] and iron deficiency anemia due to low iron availability from plant foods.[49] Dietary modifications of a macrobiotic diet to improve nutrient intake include (1) increased fat as a source of calories; (2) adequate protein for growth; (3) adequate sources of calcium and vitamin D, such as fortified soymilk products; and (4) a reliable source of vitamin B_{12} from foods or supplement.

Milk Alternatives

Years of research and monitoring infant growth and nutritional status support breast milk as the optimum source of nutrition for infants, with complementary foods introduced at 6 months. When breast-feeding is not possible or requires supplementation, iron-fortified infant formula is recommended. When infants do not tolerate standard cow's milk–based formulas, nutritionally appropriate alternatives are available, such as soy formula, hypoallergenic formulas, and elemental formulas. For infants, cow's milk and goat's milk are inappropriate because of the their high renal solute load, high protein load, and inadequate micronutrients of iron, zinc, vitamin E, vitamin C, and folic acid.

Serious health consequences can result when alternative milk substitutes replace breast milk or formula. A review of the literature demonstrates that an alarming number of infants and toddlers develop serious nutritional deficiencies when caregivers discontinued breast milk or formula. Milk substitutes include nondairy creamers, which are extremely low in protein; vitamins A, C, B_1, and B_2; niacin; calcium; iron;[25] unfortified goat's milk, which is low in folic acid; or rice milk, which is low in protein, fat, and, when unfortified, low in vitamins A and D and in calcium. **Table 3** identifies 19 case reports of infants and toddlers developing kwashiorkor or severe protein energy malnutrition from using a nutritionally inferior milk alternative.[25–31] Rickets has also been noted in unsupplemented breast-feeding and with early transition to non–vitamin D–fortified beverages.[31,43] Severe iodine and carnitine deficiencies and osteopenia were described in a 7.5-month-old transitioned at 2.5 months of age from breast milk to an almond extract in water.[54] These case reports demonstrate the existence in affluent countries of severe nutrient deficiencies not associated with poverty, but rather with nutritional ignorance, suspected milk intolerance, cultural diets, and trends toward health food alternatives. It is critical for pediatric providers to carefully review infant and toddler feeding histories for early identification of inappropriate feeding practices.

Developmental and Behavioral Disabilities and Restricted Diets

Some of the more challenging feeding problems present in children with pervasive development delay (PDD) and/or autism spectrum disorder (ASD). These problems include refusal of certain food textures, color, and food presentation; a need for specific utensils; delayed feeding skills; and disruptive mealtime behaviors. The result is often mild to severe food selectivity. Schreck and colleagues[55] compared eating habits of autistic children with typically developing children, finding that 72% of the autistic group accepted approximately 50% of the food variety in most food groups with the exception of starches. Ahearn[56] also demonstrated food selectivity, and categorized the patterns of acceptance as complete food refusal, overly selective acceptance of primarily starch foods and some fruits, moderately selective acceptance, texture selectivity, and high overall acceptance. In 17 children with ASD, Cornish reports 7 ate 20 or more different foods, 7 ate 10 to 19 foods, and 3 ate fewer than 8 different foods.[57]

Severe food selectivity can result in nutrient deficiency, as demonstrated in the case report by Tamura and colleagues,[58] in which a previously healthy 5-year-old boy developed scurvy secondary to a 5-month self-restricted diet of biscuits, Pop-Tarts, cheese pizza, and water, while refusing fruits, vegetables, juices, and a vitamin-mineral

Table 3
Case reports of kwashiorkor related to milk alternatives

Age	Dietary Manipulation	Rationale for Dietary Change	References
3 mo	High-fat, low-protein nondairy creamer	Suspected intolerance to milk	25
4 mo	Rice Dream milk and Poly Vi Sol	Colic, feeding problems	26
5 mo	Juice, cereal, applesauce	Parental belief child did not need milk	26
5 mo	Brown rice emulsion, black strap molasses, chlorophyll, acidophilus extract, flaxseed oil, vitamins	Vegan family; chronic constipation	26
5.5 mo	High-fat, low-protein nondairy creamer	Suspected intolerance to milk	25
7 mo	High-fat, low-protein nondairy creamer for 1.5 mo with small amounts of cereal, fruits, vegetables	Suspected intolerance to milk and soy	25
7 mo	Rice Dream, small amounts of baby food, iron supplement	Formula intolerance noted at 2 mo of age; changed to rice beverage	27
8 mo	Rice flour, water, and baby food	Vomiting; perceived formula dislike	26
8 mo	Goat's milk, juice, herbal tea, graphite tablets, yogurt	Atopic dermatitis	26
8 mo	Cream soda supplemented with calcium powder; occasional strained vegetables and fruits	Physician prescribed because of diagnosed milk intolerance with vomiting; infant had been breast-fed for 1 mo, then fed cow's milk for 2 wk	28
8 mo	Daily intake: 8 jars baby food (primarily fruit) and 8 oz Similac formula	Nutritional ignorance	26
9 mo	Barley, water and cinnamon emulsion, foods	Chronic vomiting; milk protein allergy	26
11 mo	Potatoes and juice	Nutritional ignorance	26
14 mo	Rice Dream, vegetables, meat	Breast-fed for 8 mo; did not tolerate formula; started on rice beverage	27
17 mo	Rice milk, first-stage infant foods	Breast-fed for 4 months; hypoallergenic formula until 8 months of age; soy formula until 12 months of age; then enriched rice milk and restricted variety of foods because of eczema	29
17 mo	Rice milk; small amounts of baby foods or solid foods without meat	Chronic atopic dermatitis and positive radioallergosorbent test to multiple foods	30
18 mo	High-fat, low-protein nondairy creamer	Suspected intolerance to milk	25
22 mo	Plantains, lentils, other vegetables	Suspected allergy to milk with pulmonary congestion and diarrhea	26
22 mo	Rice milk with poor intake of solids	Breast-fed for 13 mo; then changed to rice milk because of chronic eczema and perceived milk intolerance	31

supplement. However, there are conflicting reports on the nutritional consequences of the food selectivity seen with PDD/ASD. Raiten and Massaro[59] analyzed food diaries of 40 autistic children and determined that their diets were nutritionally adequate. Williams and colleagues[60] presented the results of 100 surveys sent to families of children with ASD, reporting that although two thirds reported picky eating behaviors, over half reported adequate nutritional intake. On the other hand, Cornish's dietary analysis of 17 children ages 42 to 117 months with ASD demonstrated inadequate intakes for vitamins C, D, and B_6; riboflavin; niacin; calcium; and zinc in 53% of the children.[57] Finally, Bowers' review[61] of 26 food records demonstrated adequate intakes for energy and protein, but inadequate intake of micronutrients. These conflicting reports raise several thoughts:

- It seems clear that this population demonstrates a higher incidence of food selectivity than typically developing children.
- The selectivity is highly variable.
- Appetite appears to be less of a problem and, when these children are allowed their preferred foods, adequate energy intake is often achieved.
- Inadequate micronutrient intake may be associated less with selectivity within a specific food group than with complete avoidance of one or more food groups.
- Some preferred foods eaten in large amounts and more readily available fortified foods can become sources of nutrients lacking due to avoidance of other foods.

However, food selectivity can be associated with nutrient deficiency, especially when foods become limited to fewer than 20, when complete food groups are omitted, and when selectivity involves children less than the age of 5 years. Often, a complete multivitamin-mineral supplement can address some of these concerns. However, the child with texture selectivity is often unwilling to accept these supplements, increasing the risk of deficiency.

Gluten-Free, Casein-Free Diet

The self-restricted diet noted in children with PDD/ASD can be complicated by the addition of a gluten-free, casein-free diet (GFCF), an elimination diet that has become a popular alternative therapy for this population. The diet is based on several proposed theories. These include:

- The theory that opioid excess leads to altered central nervous system activity
- The immune dysfunction theory, which suggests that gluten and/or casein act as proinflammatory stimuli in the gastrointestinal mucosa
- The theory of decreased peptidase activity contributing to abnormal leaky gut[62]

Though these theories carry some possible rationale for the elimination diet, there is limited published literature of trials addressing the efficacy of these diets, and many of the studies are considered flawed.[62] Elder's double-blind repeated-measures crossover study[63] of 13 children and young adults ages 2 to 26 years with ASD comparing a regular diet and a GFCF diet showed no statistically significant differences in autism symptoms, although many parents chose to continue the diet.

The question then becomes what harm can there be in the use of this GFCF diet. First, eliminating gluten and casein requires major changes in food choices from the grain and dairy groups. The nutrients at risk are those mentioned earlier in this article in the discussion of celiac disease and milk allergy. Second, imposing this diet on a child who has self-restricted to a limited variety of foods increases the risk of nutrient deficiency. Third, the GFCF diet requires additional resources for purchasing alternative grains and dairy substitutes, some of which are not fortified. This increases the need for supplements, which are often difficult for the child with PDD/ASD to accept because of texture aversion.

Limited studies have been published comparing nutritional status of children on the GFCF diet with those on unrestricted diets. Cornish reported on nutrient analysis of 37 food records, 8 following a GFCF diet and 29 following the child's self-selected diet, finding no significant differences in energy, protein, and micronutrient intakes between the two groups.[64] However, individual children in both groups had inadequate intake of specific micronutrients, demonstrating the individual food selectivity that occurs with this population. Arnold and colleagues[65] demonstrated lower plasma levels of essential amino acids in children with ASD on GFCF diets when compared with those autistic children on unrestricted diets and those children with developmental disabilities other than ASD; and Hediger and colleagues[66] demonstrated potential negative impact of the GFCF diet on bone development. With these cautions in mind, a nutritionally adequate GFCF diet can still be provided, but it requires caregiver education, monitoring of patient growth and nutrient intake, and individualization.

Vitamin/Mineral Supplementation

Depending on the situation, a vitamin and/or mineral supplement may be necessary to provide the nutrient(s) lacking in one of these diets. Clinicians must be aware of the great variations in the number of nutrients, the form of the nutrients, the amount of the nutrients, and the recommended dose in various supplements. The word *complete* to describe the pediatric multivitamin/mineral indicates that a wide variety of both vitamins and minerals are contained; it does not mean that the product contains 100% of the recommended dietary allowance for each nutrient. These authors reviewed nine vitamin and vitamin/mineral supplements designed for children: four chewable complete, one chewable with only vitamins, three gummy-type, and one liquid. The number of nutrients in these products ranged from 10 to 22. Likewise, there was a wide range of nutrient content—from 0 to 1.5 mg of thiamin, 0 to 400 μg of folic acid, and 0 to 18 mg of iron, for example. The form of vitamin A and vitamin D also varied. In general, the gummy-type products tended to have a fewer number of nutrients and lower amounts of most nutrients than the complete chewable-type. The four chewable complete products all contained iron and calcium, while none of the gummy-types did; three of the former also contained significantly more zinc than did the latter. These products do contain labeling similar to that for food (see **Fig. 1**) so that a comparison of products can be easily done paying close attention to those nutrients deemed to be lacking. Note that the daily value for calcium is based on 1000 mg. Therefore, if using labeling as a guide to intake, 9- to 18-year-olds need 130% of the daily value.

SUMMARY

Nutrient deficiencies exist. However, they may be the result of medically necessary diets or parent/child-selected diets rather than poverty. A diet history should be done on a regular basis and unusual eating habits, omission of food groups, and actual or perceived food allergies should trigger a more in-depth assessment of the child's nutritional status. Once the restricted diet is recognized, **Table 2** can help to determine which food groups are affected. **Table 4** can then help the clinician identify the affected nutrients and offer alternative food sources to provide these nutrients. Growth should be monitored because poor growth may be related to poor nutrition. Consideration should be given to the need for appropriate nutritional supplements. Lastly,

Table 4
Sources of nutrients—food groups and alternative sources

Food Group	Nutrient	Alternative Sources
Grains: breads, cereal, rice, pasta	Thiamin	Allowable grains,[a] allowable ready-to-eat cereals,[b] pork, ham
	Riboflavin	Milk and milk products, allowable grains,[a] allowable ready-to-eat cereals,[b] organ meats
	Niacin	Meat, fish, poultry, allowable grains,[a] allowable ready-to-eat cereals[b]
	Folate	Allowable grains,[a] allowable ready-to-eat cereals,[b] dark leafy vegetables, lentils, legumes
	Iron	Meat and poultry, allowable grains,[a] allowable ready-to-eat cereals,[b] eggs, legumes, lentils, spinach, raisins
	Magnesium	Green leafy vegetables, allowable whole grains, nuts and seeds, legumes, fish, meat, fruits, other vegetables
	Selenium	Organ meats, meats, seafood, allowable grains and cereals, nuts
Dairy: milk, yogurt, cheese	Calcium	Calcium-fortified milk alternatives and juices, dark green leafy vegetables, tofu, legumes, fish with bones (eg, sardines, herring)
	Protein	Meat, poultry, fish, eggs, meat substitutes, legumes, nuts, seeds
	Vitamin A	Liver, fish, dark green and deep yellow fruits and leafy vegetables
	Vitamin D	Vitamin D–fortified milk alternatives, juices and cereals, fish oils, fatty fish (salmon, tuna, sardines, mackerel), egg yolk
	Riboflavin	Enriched grains, fortified ready-to-eat cereals,[b] organ meats
	Phosphorus	Meat, fish, poultry, eggs, lentils, legumes, nuts, seeds
	Vitamin B_{12}	Meat, fish, vitamin B_{12}–fortified milk alternatives, fortified ready-to-eat cereals[b]
Protein: meats, poultry, fish, eggs, nuts, beans	Protein	Cheese, milk, yogurt, meat substitutes, legumes, nuts, seeds
	Iron	Whole grains and enriched grain products,[a] fortified ready-to-eat cereals,[b] legumes, lentils, spinach, raisins
	Zinc	Lentils, legumes, whole grains, fortified ready-to-eat cereals, milk and milk products, nuts
	Selenium	Grains and cereals, nuts
	Thiamin	Whole grains,[a] enriched grains, ready-to-eat cereals[b]
	Riboflavin	Milk and milk products, enriched grains, ready-to-eat cereals[b]
	Vitamin B_6	Fortified ready-to-eat cereals,[b] fortified soy-based meat alternatives, enriched grains, white potatoes, starchy vegetables
	Vitamin B_{12}	Milk, vitamin B_{12}–fortified milk alternatives, fortified ready-to-eat cereals[b]
	Niacin	Whole grains,[a] enriched grains, ready-to-eat cereals[b]

[a] See Table 1 for alternative grains that are high in this nutrient or allowable grains that are enriched/or fortified with this nutrient.
[b] Check food label for "% Daily value."

Data from Standing Committee on the Scientific Evaluation of Dietary Reference Intakes and its Panel on Folate, Other B Vitamins, and Choline and Subcommittee on Upper Reference Levels of Nutrients, Food and Nutrition Board, Institute of Medicine. Dietary reference intakes for thiamin, riboflavin, niacin, vitamin B6, folate, vitamin 2, pantothenic acid, biotin, and choline. Washington (DC): The National Academies Press; 1998; and United States Department of Agriculture. USDA national nutrient database for standard reference, release 21. 2009;2009(3/19).

referral to a registered dietitian knowledgeable about infant, childhood, and adolescent nutrition should be done for those clients with very restricted diets, poor growth, and/or poor nutritional status.

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