American Academy of Pediatrics
DEDICATED TO THE HEALTH OF ALL CHILDREN™

CLINICAL REPORT

Optimizing Bone Health and Calcium Intakes of Infants, Children, and Adolescents

Guidance for the Clinician in Rendering Pediatric Care

Frank R. Greer, MD, Nancy F. Krebs, MD, and the Committee on Nutrition

ABSTRACT

Most older children and adolescents in the United States currently do not achieve the recommended intake of calcium. Maintaining adequate calcium intake during childhood and adolescence is necessary for the development of peak bone mass, which may be important in reducing the risk of fractures and osteoporosis later in life. Optimal calcium intake is especially relevant during adolescence, when most bone mineral accretion occurs. Because of the influence of the family's diet on the diet of children and adolescents, adequate calcium intake by all members of the family is important. Assessment of calcium intake can be performed in the physician's office. A well-rounded diet including low-fat dairy products, fruits, and vegetables and appropriate physical activity are important for achieving good bone health. Establishing these practices in childhood is important so that they will be followed throughout the life span.

OVERVIEW AND BACKGROUND

National survey data consistently show that most US children older than 8 years fail to achieve the recommended intake of calcium[1–4] (Fig 1). Maintaining adequate calcium intake during childhood and adolescence is necessary for the attainment of peak bone mass, which may be important in reducing the risk of fractures and osteoporosis later in life.[3,4]

Approximately 99% of total body calcium is found in the skeleton, with only small amounts found in the plasma and extravascular fluid. The primary need for dietary calcium is for bone mineral deposition. Hypocalcemia and calcium-deficiency rickets are uncommon in healthy infants, children, and adolescents. Overall calcium homeostasis is maintained by the actions of calcium-regulating hormones, which most notably include parathyroid hormone, calcitonin, and 1,25-dihydroxyvitamin D. Calcium is absorbed in the intestine by both passive and active processes, the active process being more important in situations in which dietary calcium intakes are suboptimal. The ability to respond to low calcium intakes is limited, however, and active absorption does not compensate for low intake. The active process requires vitamin D, which emphasizes the fact that good bone health requires satisfactory intakes of both calcium and vitamin D. The current recommended adequate vitamin D intake for all infants (including those who are breastfeeding), children, and adolescents is 200 IU per day (5.0 μg per day).[4,5]

Optimizing calcium intake is particularly important during adolescence. Peak calcium-accretion rate is attained at an average of 12.5 years of age in girls and

www.pediatrics.org/cgi/doi/10.1542/peds.2005-2822

doi:10.1542/peds.2005-2822

Key Words
bone mass, calcium, osteoporosis, fractures, diet

Abbreviation
NAS—National Academy of Sciences

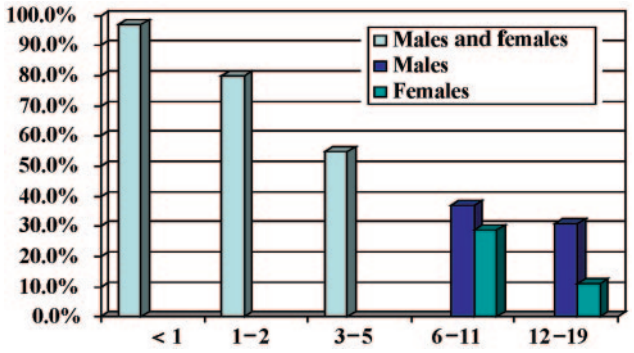

FIGURE 1
Percentage of children achieving the recommended daily adequate intake for calcium.[1–4]

14.0 years of age in boys.[6] During the 3- to 4-year period of increased bone mass acquisition that occurs during adolescence, 40% of total lifetime bone mass is accumulated. A recent review of controlled trials reported an increase in the bone mineral content in adolescents who have received calcium supplementation.[7] However, available data suggest that if calcium is supplemented for short time periods (ie, 1–2 years), there may be no long-term benefit in attaining and maintaining a maximum peak bone mass.[7] This emphasizes the importance of establishing dietary practices in childhood that promote adequate calcium intake throughout life. Unfortunately, long-term studies demonstrating the anticipated benefits of maintaining the recommended calcium intakes from childhood and adolescence throughout adulthood are not available. However, epidemiologic data, as reviewed by the National Academy of Sciences (NAS), support the prevailing view that maintaining such a diet will achieve optimal bone mass accretion in adolescence, thereby reducing the degree of osteoporosis in adulthood.[4]

Recent observational data support the possibility that low bone mass may be a contributing factor to fractures in children. A relationship between the adolescent growth spurt (corresponding to peak accrual rate of bone mass) and risk of fractures has been shown.[8,9] Wyshak and Frisch[10] were the first to report that high calcium intakes were associated with a protective effect against fractures in adolescent boys and girls. Goulding et al[11] reported lower bone mass at multiple sites in a group of 100 girls who were 3 to 15 years of age with distal forearm fractures compared with age-matched control girls. For the 11- to 15-year-old girls in this study, a lower calcium intake was reported for those with fractures compared with control subjects.[11] In addition, a 4-year follow-up of these same girls continued to show an increased rate of bone fractures in the group with lower calcium intake.[12] In boys between 3 and 19 years of age with distal forearm fractures, Goulding et al[13] also reported lower bone mass at multiple sites compared with age-matched control boys. These same investigators have also found an increased number of childhood fractures in children who avoided drinking milk.[14,15] Additional prospective studies on the relationship between calcium intake and fractures are needed before the magnitude of increased fracture risk at different calcium intake levels can be fully assessed. However, currently available evidence suggests that low calcium intakes may be an important risk factor for fractures.[10–15]

In addition to the calcium and vitamin D content of the general diet, other dietary factors are important to maximize retention of dietary calcium. Dietary substances that may decrease retention include alcohol, caffeine, oxalates, phytates (eg, in soy), and protein. The effect of dietary protein on calcium balance is complex. Although dietary protein increases urinary calcium excretion by increasing the total acid load from protein metabolism, recommended intakes of dietary calcium take into account the typical protein intake of the population.[16] Adjusting calcium intake on the basis of protein intake generally is not recommended for children and adolescents.[4] Dietary sodium is also an important factor in the renal excretion of calcium, because sodium and calcium share the same transport system in the proximal tubule.[16] Although there are some concerns about the negative effects of high salt consumption (eg, from salty snacks) on calcium excretion in children, current recommendations for calcium intakes in children do not vary on the basis of sodium intake.[4] There is also evidence that dietary intake of potassium and bicarbonate, largely obtained from fruits and vegetables, will decrease urinary calcium excretion, because potassium and bicarbonate can override the hypercalciuric effect of dietary sodium-chloride loading.[17] Thus, given the various aspects of the diet that influence bone health, good dietary practices that begin in childhood and are followed throughout the life span are important.

Weight-bearing exercise also plays a role in achieving maximal peak bone mass, but data to quantify the effect are limited. There is evidence that childhood and adolescence may represent an important period for achieving long-lasting skeletal benefits from regular exercise.[18,19] For example, Welten et al[20] showed that regular weight-bearing activity had a greater influence on peak bone mass than did dietary calcium intake in children. In general, studies support that moderate weight-bearing activity, such as running or jumping, has a more positive effect on bone mass than do non–weight-bearing activities such as swimming, which have minimal physical strain on bone.[21] It is still unclear whether a given level of calcium intake influences the degree of benefit derived from physical activity on bone mass or whether exercise alone, independent of calcium intake, improves bone mass.[18,19] Additional research is needed to examine the combined effects of calcium and exercise.

Although overweight and obesity are factors that have been associated with increased bone density, there

are data that support an increased incidence of fractures in children who are overweight.[10–12,14,15] This may be explained in part by recent observations that longitudinal calcium intake is negatively correlated with body fat percentage and BMI in children.[14,22,23] Overweight children also have lower bone mass and bone area (as measured by dual-energy x-ray absorptiometry) relative to their body weight than do children with healthy body weight, which may predispose overweight children to fractures.[24] Exercise, an important factor for optimizing bone health, is also important in the prevention of obesity,[25] and overweight children often have decreased physical activity compared with controls.[12]

RECOMMENDED INTAKES BY AGE GROUP

The calcium needs for different age groups depend on the varying physiologic requirements for calcium during development. Adequate calcium intakes are affected by many variable factors including age, gender, physical activity, and multiple dietary considerations. Genetic and ethnic variability are important also. The interactions of these factors make it impossible to recommend a single adequate calcium intake for all children.[4] The specific requirements for adequate calcium intake by infants, children, and adolescents were reviewed extensively by a panel of experts for the NAS Food and Nutrition Board in 1997.[4] A summary of their recommendations is shown in Table 1 and discussed in the following sections.

Infants

The optimal source of calcium during the first year of life is human milk. No evidence shows that exceeding the calcium intake of the exclusively breastfed term infant during the first 6 months of life (210 mg per day) or the intake of the breastfed infant supplemented with solid foods during the second 6 months of life (270 mg per day) is beneficial to achieving long-term increases in bone mineralization. Available data demonstrate that the bioavailability of calcium from human milk is greater than that from infant formulas (58% and 38%, respectively).[26] Thus, the concentration of calcium in infant formulas is increased relative to human milk to ensure at least comparable levels of calcium retention. Relatively greater calcium concentrations are found in specialized formulas, such as soy formulas and casein hydrolysates, to account for the lower bioavailability of the calcium. Research data are not available to justify the use of even higher levels of calcium in infant formula for term infants. Whole milk is not recommended for infants under 12 months of age, although yogurt and cheese can be introduced after 6 months. At present, calcium intake seems adequate in infants born at term in the United States (Fig 1), with most infants achieving almost 100% of the recommended adequate intake. This is not true in any other age group.

Preterm infants, on the other hand, have higher calcium requirements than do term infants. These needs may be met by using human milk fortified with commercially available fortifiers or specially designed formulas for preterm infants with increased calcium and vitamin D concentrations.[27] After discharge from the hospital, there may be benefits to providing formula-fed preterm infants with special formulas that have higher calcium concentrations rather than those of routine cow's milk–based formulas for term infants.[28] The optimal calcium concentrations and length of time that such formulas should be used are unknown, and although increases in bone mineralization can be demonstrated in the short-term, long-term benefits have not been proven.

TABLE 1 **Recommendations for Adequate Dietary Calcium Intake in the United States[4]**

Age	Calcium Intake, mg/d (mmol/d)
0–6 mo[a]	210 (5.3)
7–12 mo[b]	270 (6.8)
1–3 y	500 (12.5)
4–8 y	800 (20.0)
9–18 y	1300 (32.5)
19–50 y	1000 (25)
50 to >70 y	1200 (30)

The Food and Nutrition Board of the NAS released recommended dietary allowances for calcium in 1997. The term "adequate intake" was applied to calcium recommendations. Application of the adequate intake is similar to that of the recommended dietary allowance. The American Academy of Pediatrics recommends that the NAS guidelines should be the primary guidelines used.

[a] The 1997 NAS report used data based on younger infants (0–6 months) who are fed human milk exclusively.

[b] The 1997 NAS report was based on the assumption that older infants (6 months to 1 y) would be consuming a diet of human milk and solid foods, which would be similar to that of formula-fed infants at this age.

Children 1 to 8 Years of Age

Few data are available concerning the calcium requirements of children between infancy and the onset of puberty. Total calcium retention for weight is relatively low in toddlers compared with other age groups. An intake of 500 mg per day is recommended between 1 and 3 years of age. The optimal intake increases as the onset of puberty approaches. Most available data indicate that calcium intake levels of approximately 800 mg per day are associated with adequate bone mineral accumulation in prepubertal children (4–8 years of age). The benefits of a higher intake in this age group have not been studied adequately.[4] Important in this age group is the development of dietary practices that will be associated with adequate calcium intake later in life.

Preadolescents and Adolescents 9 to 18 Years of Age

Most research in children regarding optimal calcium intakes has been directed toward 9- to 18-year-olds, with the preponderance of studies having been performed in females. The efficiency of calcium absorption is increased during puberty, and most bone mineralization occurs

during this period.[6,29,30] Data from studies of calcium balance suggest that for most healthy children in this age range, the maximum net calcium balance is achieved with an intake of approximately 1300 mg per day. At intakes above this level, almost all of the additional calcium is excreted and of no benefit. At intakes below this level, the skeleton may receive less calcium than it can use, and peak bone mass may not be achieved.[4,31–33] Virtually all the data used to establish this intake level are from white children. Few data are available from other racial groups. There are data indicating that compared with white adolescents, black adolescents use dietary calcium more efficiently and may achieve comparable peak bone masses with less calcium intake.[34]

Upper Intake Levels of Calcium

The tolerable upper intake levels of calcium in infants (0–12 months of age) is not known.[4] One study found no effect on infant iron status from calcium intakes of 1700 mg per day using calcium-fortified infant formula.[35] For children 1 through 18 years of age, the NAS has recommended a maximum calcium intake of 2500 mg per day.[4] Although data on calcium toxicity in this age group are limited, high calcium intake in small children may increase the risk of zinc and iron deficiency attributable to the adverse affect of calcium on the absorption of these minerals.[4]

BARRIERS TO ADEQUATE CALCIUM INTAKE

The proportion of children who achieve the recommended adequate calcium intake declines dramatically after the second year of life, reaching its nadir between the ages of 12 and 19 years (Fig 1). This nadir occurs during the period in which accumulation of bone mineral is at its peak and calcium requirement is highest (Table 1). Documented mean intakes in this age group are approximately 700 to 1000 mg per day, with values at the higher side of this range occurring in males.[2,4,6] A preoccupation with being thin is common among females in this age group, as is the misconception that all dairy foods are fattening. Children, adolescents, and parents may not be aware that low-fat milk contains at least as much calcium as whole milk. However, studies in adolescent females do not consistently find that dieting is associated with lower calcium intake.[36,37]

Suboptimal intakes of calcium in children and adolescents may be related to the replacement of milk intake by soft drinks and fruit juices and/or fruit drinks.[38–40] Soft-drink consumption peaks in adolescence, at which time milk intake is at its lowest level.[40] Only 10% of adolescent girls achieve the recommended adequate dietary intake of calcium of 1300 mg per day (Fig 1).

Primary lactose intolerance may be a problem for some populations. It is more common in children of African, Mexican, American Indian, and Asian descent than in white children.[41,42] Many children with lactose intolerance can drink small amounts of milk without discomfort, especially when accompanied by other foods. Intolerance of the consumption of 250 mL or less of milk is rarely seen in preadolescents, and the addition of small amounts of lactose-containing food to the diet may decrease the severity of lactose intolerance.[41] Other alternatives include the use of fermented dairy products such as hard cheese and yogurt, which may be tolerated better than milk. Lactose-free and low-lactose milks are available. Nondairy food products (such as certain vegetables) or calcium-supplemented foods (including calcium-fortified soy milk) may be used as other calcium sources, especially for vegetarians who do not consume dairy products (Table 2).

Parental intakes and practices influence their children's intakes. Maternal consumption of milk predicts the milk intake of young female children.[43] A recent study of adolescents shows that parents infrequently serve as role models for drinking milk, especially for older girls.[44] Thus, family dietary behavior should be considered when encouraging adolescents to drink milk.

DETERMINING ADEQUATE CALCIUM INTAKE IN CHILDREN AND ADOLESCENTS

More data are needed to establish the "optimal" level of calcium retention at different ages and determine the effects of development on calcium balance.[4] This is particularly true for children between 2 and 8 years of age. Multiple approaches are used to assess calcium requirements in children. These approaches include (1) measurement of calcium balance with various levels of calcium intake with or without use of calcium stable isotopes methodology,[32,33,45] (2) measurement of bone mineral content by dual-energy x-ray absorptiometry or other radiographic techniques in groups of children before and after calcium supplementation,[46,47] and (3) epidemiologic studies of the association of fracture incidence in children with bone mineral content or relating bone mass and/or fracture risk in adults to childhood calcium intake.[10–15,48,49] None of these approaches are useful in the office setting.

In the office setting, calcium intake and risk factors for suboptimal bone health can be assessed with the questions listed in Table 3 combined with the information shown in Table 2. Because family attitudes and behavior are important considerations, the questions should be asked of both the child and parent/guardian. In addition, family history should be explored for osteoporosis, because this will be very important in assessing the child's future risk and, thus, the urgency for achieving adequate calcium intake and bone health. This questionnaire should be administered at least 3 times during well-child visits (1) at 2 or 3 years of age, after the infant is no longer taking human milk or formula, (2) during

TABLE 2 **Approximate Calcium Contents of 1 Serving of Some Common Foods That Are Good Sources of Calcium**

Food	Serving Size	Calcium Content, mg	No. of Servings to Equal Calcium Content in 1 Cup of Low-Fat Milk
Dairy foods			
Whole milk	1 cup (244 g)	246	1.0
Low-fat (1%) milk	1 cup (244 g)	264	—
Nonfat milk	1 cup (245 g)	223	1.2
Yogurt, nonfat, fruit variety	6 oz (170 g)	258	1.0
Frozen yogurt, vanilla, soft serve	1/2 cup (72 g)	103	2.6
Cheese	1 1-oz slice (28 g)	202	1.3
Cheese, pasteurized, processed	1 3/4-oz slice (21 g)	144	1.8
Cheese, ricotta, part skim milk	1/2 cup (124 g)	337	0.7
Nondairy foods			
Salmon, sockeye canned, drained, with bones	3 oz (85 g)	203	1.3
Tofu, firm, prepared with calcium sulfate and magnesium chloride	1/2 cup (126 g)	204	1.3
White beans, cooked, boiled	1 cup (179 g)	161	1.6
Broccoli, cooked	1 cup, chopped (156 g)	62	4.3
Collards, cooked, boiled, drained	1 cup, chopped (190 g)	266	1.0
Baked beans, canned	1 cup (253 g)	127	2.1
Tomatoes, canned, stewed	1 cup (255 g)	87	3.0
Foods fortified with calcium			
Calcium-fortified orange juice	1 cup (240 mL)	300	0.9
Selected fortified breakfast cereals	3/4–1 cup (30 g)	100	2.6
Instant oatmeal, fortified, plain, prepared with water	1/2 cup (117 g)	65	4.1
English muffin, plain, enriched, with calcium propionate	1 muffin (57 g)	99	2.7
Calcium-fortified soy milk[a]	1 cup (240 mL)	200–500	0.5–1.3

Source: US Department of Agriculture, Agriculture Research Service. US Department of Agriculture Nutrient Data Laboratory. Available at: www.ars.usda.gov/main/site_main.htm?modecode=12354500. Accessed December 21, 2005.

[a] Native soy milk contains 10 mg of calcium per cup (240 mL).

TABLE 3 **Assessing Calcium Intake**

How many times a day do you (or does your child) drink white or flavored milks? (whole, 2%, 1%, or skim milk)
How often do you (or does your child) eat cheese, yogurt, yogurt drinks, or other dairy products?
How often do you (or does your child) drink sweetened drinks (soft drinks, fruit drinks, fruitades, etc)?
Do you (or does your child) drink calcium-fortified juices or eat any other calcium-fortified foods such as cereal or bread? How often?
Do you (or does your child) eat any of the following: broccoli, beans, cooked greens (eg, collards, turnip greens, kale), or tofu?
Do you (or does your child) take any calcium supplements including those containing vitamins ?
How many times a week do you (or does your child) participate in vigorous weight-bearing physical activity?
Have you (or has your child) had any bone fractures?
Is there a family history of osteoporosis?
Was your child born prematurely?

preadolescence (8–9 years of age), and (3) during early adolescence, when peak accumulation of calcium occurs.

Although the easiest way to achieve adequate calcium intake is to consume 3 servings of dairy products per day (4 servings per day for adolescents), healthy dietary practices are based on the overall pattern of food intake over an extended period of time, not on the intake of a single meal or a single day.

ADVICE FOR ACHIEVING RECOMMENDED CALCIUM INTAKE AND OPTIMIZING BONE HEALTH

Inadequate calcium intake in a child or adolescent is a family problem. If the parent is not achieving the recommended calcium intake, it is unlikely that the child is achieving the recommended intake.[43,44] The adequate calcium intake for adults between 19 and 50 years of age is 1000 mg per day (Table 1).

Knowledge of dietary calcium sources is important for increasing the intake of calcium-rich foods. Table 2 shows typical amounts of calcium for some common food sources. The largest source of dietary calcium for most persons is milk and other dairy products, which accounts for 72% of the calcium in the US food supply.[50] Sixty-five percent of the dietary calcium intake in children in the United States is supplied by dairy products.[51] Drinking three 8-oz glasses of milk per day (or the equivalent; see Table 2) will achieve the recommended adequate intake of calcium in children 4 to 8 years of age, and four 8- to 10-oz glasses of milk (or the equivalent) will provide the adequate calcium intake for adolescents. Yogurt and cheese are also good sources of calcium. Flavored milks, cheeses, and yogurt brands containing reduced fat or no fat and modest amounts of added sweeteners (both caloric and noncaloric) are generally recommended. It is important to note that there is relatively little difference in the calcium

content of reduced-fat dairy products compared with whole milk–derived products.

Although dairy products are the most common calcium-dense foods in Western diets, there are no long-term follow-up data that demonstrate that they are superior to other sources of calcium in promoting bone health. Alternative sources of calcium are important for children and adolescents who do not drink milk (Table 2). Most vegetables contain calcium, although at relatively low density. Thus, large servings are needed to equal the total intake achieved with typical servings of dairy products (Table 2). The bioavailability of calcium from green vegetables generally is high, especially if the oxalate content is low, as in broccoli and collard greens (Table 2). In spinach, the high oxalate content makes the bioavailability of calcium very poor.[52,53] Some high-phytate foods such as whole bran cereals and soy foods also may have poor bioavailability of calcium.[52,53]

Several products have been introduced that are fortified with calcium. Orange and apple juice may be fortified to achieve a calcium concentration similar to that of milk. Limited studies of the bioavailability of the calcium in juice suggest that it is at least comparable to that of milk.[54] Breakfast cereals also are frequently fortified with minerals, including calcium, and this form has been shown to be very bioavailable.[55] A soy beverage, unless fortified with calcium, is not a good source, because the bioavailability of calcium is low.[56] If one relies on calcium-fortified foods or nondairy foods that are low in vitamin D, then another source of vitamin D is needed to provide the adequate intake of 200 IU per day (5.0 μg per day).[4,5] Orange juice can also be fortified with vitamin D in addition to calcium.

Calcium intakes on food labels are indicated as a percentage of the "daily value" in each serving. This daily value is currently set at 1000 mg per day, which is the adult requirement (up to 50 years of age). Therefore, it is important to instruct families about reading and interpreting food labels, because they may not be appropriate for the age of their children.

For children and adolescents who cannot or will not consume adequate amounts of calcium from preferred dietary sources, the use of calcium supplements should be considered. Although the bioavailability of calcium varies in supplements, it may be comparable to or greater than that in dairy products.[57] The most commonly available products contain calcium carbonate and supply 300 to 600 mg of elemental calcium per tablet. Some mineral supplements also contain vitamin D. Decisions about their use must be made on an individual basis, keeping in mind the usual dietary habits of the person, any individual risk factors for osteoporosis, and the likelihood that the use of the supplement will be maintained. If achieving the adequate calcium intake is a significant problem, then consultation with a registered dietitian should be sought.

SUMMARY OF KEY POINTS

1. Pediatricians can actively promote bone health and support the goal of achieving adequate calcium intakes by children and adolescents by promoting the recommended adequate intakes of the Food and Nutrition Board of the NAS[4] (Table 1). The prevention of future osteoporosis and the possibility of a decreased risk of fractures in childhood and adolescence should be discussed with patients and families as potential benefits for achieving these goals.
2. Physical activity, primarily weight-bearing exercise, is encouraged as part of an overall healthy bone program.
3. Currently, the average dietary intake of calcium by children and adolescents (Fig 1) is well below the recommended levels of adequate intake (Table 1). Information regarding calcium content of various foods should be given to patients and families for whom calcium intake seems inadequate. A registered dietitian may be consulted for a more thorough assessment of diet and to make the necessary recommendations to improve calcium.
4. Inadequate calcium intake by the child or adolescent is a family issue. Adequate intake of dietary calcium should be encouraged for all family members (Table 1).
5. In the office setting, calcium intake can be assessed periodically with a simple questionnaire. Suggested ages for screening are 2 to 3 years of age, after the transition from human milk or formula; 8 to 9 years of age during preadolescence; and again during adolescence, when the peak rate of bone mass accretion occurs. Targeted questions are suggested (see Table 3) to assess calcium intake, general diet, and lifestyle practices relevant to bone health.
6. The most common sources of calcium in the Western diet are milk and other dairy products. Whole milk is not recommended until after 12 months of age, although yogurt and cheese can be introduced after 6 months. Low-fat dairy products including skim milk and low-fat yogurts are good sources of calcium. Nondairy calcium-rich foods are the next preferred source, although the calcium in soy products has low bioavailability. Calcium supplements are another alternative source, but these products do not offer the benefits of other associated nutrients, and compliance may be a problem. Most people can achieve the recommended dietary intake of calcium by eating 3 age-appropriate servings of dairy products per day (4 servings per day for adolescents) or the equivalent.
7. The diet of all infants (including those who are breastfeeding[58]), children, and adolescents should include the recommended adequate intakes of vitamin

D (200 IU [5.0 μg] or 500 mL of vitamin D–fortified formula or milk per day[4,5]) as well as fruits and vegetables that are sources of potassium and bicarbonate, which may improve calcium retention.

REFERENCES

1. US Department of Agriculture, Agricultural Research Service. Data tables: results from USDA's 1994–96 Continuing Survey of Food Intakes by Individuals and 1994–96 Diet and Knowledge Survey. 1999. Available at: www.ars.usda.gov/services/docs.htm?docid=7760. Accessed December 21, 2005
2. Suitor CW, Gleason PM. Using dietary reference intake-based methods to estimate the prevalence of inadequate nutrient intake among school-aged children. *J Am Diet Assoc.* 2002:102:530–536
3. NIH Consensus conference. Optimal calcium intake. NIH Consensus Development Panel on Optimal Calcium Intake. *JAMA.* 1994;272:1942–1948
4. Institute of Medicine, Food and Nutrition Board. *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. Washington, DC: National Academy Press; 1997
5. Gartner LM, Greer FR; American Academy of Pediatrics, Section on Breastfeeding and Committee on Nutrition. Prevention of rickets and vitamin D deficiency. *Pediatrics.* 2003;111:908–910
6. Bailey DA, Martin AD, McKay HA, Whiting S, Mirwald R. Calcium accretion in girls and boys during puberty: a longitudinal analysis. *J Bone Miner Res.* 2000;15:2245–2250
7. Wosje KS, Specker BL. Role of calcium in bone health during childhood. *Nutr Rev.* 2000;58:253–268
8. Bailey DA, Wedge JH, McCulloch RG, Martin AD, Bernharson SC. Epidemiology of fractures of the distal end of the radius in children as associated with growth. *J Bone Joint Surg Am.* 1989;71:1225–1231
9. Parfitt AM. The two faces of growth: benefits and risks to bone integrity. *Osteoporos Int.* 1994;4:382–398
10. Wyshak G, Frisch RE. Carbonated beverages, dietary calcium, the dietary calcium/phosphorus ratio, and bone fractures in girls and boys. *J Adolesc Health.* 1994;15:210–215
11. Goulding A, Cannan R, Williams SM, Gold EJ, Taylor RW, Lewis-Barned NJ. Bone mineral density in girls with forearm fractures. *J Bone Miner Res.* 1998;13:143–148
12. Goulding A, Jones LE, Taylor RW, Manning PJ, Williams SM. More broken bones: a 4-year double cohort study of young girls with and without distal forearm fractures. *J Bone Miner Res.* 2000;15:2011–2018
13. Goulding A, Jones IE, Taylor RW, Williams SM, Manning PJ. Bone mineral density and body composition in boys with distal forearm fractures: a dual-energy x-ray absorptiometry study. *J Pediatr.* 2001;139:509–515
14. Black RE, Williams SM, Jones IE, Goulding A. Children who avoid drinking cow milk have low dietary calcium intakes and poor bone health. *Am J Clin Nutr.* 2002;76:675–680
15. Goulding A, Rockell JE, Black RE, Grant AM, Jones IE, Williams SM. Children who avoid drinking cow's milk are at increased risk for prepubertal bone fractures. *J Am Diet Assoc.* 2004;104:250–253
16. Weaver CM, Proulx WR, Heaney R. Choices for achieving adequate dietary calcium with a vegetarian diet. *Am J Clin Nutr.* 1999;70(3 suppl):543S–548S
17. Morris RC, Frassetto LA, Schmidlin O, Forman A, Sebastian A. Expression of osteoporosis as determined by diet-disordered electrolyte and acid-base metabolism. In: Burckhardt P, Dawson-Hughes B, Heaney RP, eds. *Nutritional Aspects of Osteoporosis*. San Diego, CA: Academic Press; 2001:357–378
18. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the University of Saskatchewan bone mineral accrual study. *J Bone Miner Res.* 1999;14:1672–1679
19. Weaver CM. Calcium requirements of physically active people. *Am J Clin Nutr.* 2000;72(2 suppl):579S–584S
20. Welten DC, Kemper HC, Post GB, et al. Weight-bearing activity during youth is a more important factor for peak bone mass than calcium intake. *J Bone Miner Res.* 1994;9:1089–1096
21. Cromer B, Harel Z. Adolescents: at increased risk for osteoporosis? *Clin Pediatr (Phila).* 2000;39:565–574
22. Carruth BR, Skinner JD. The role of dietary calcium and other nutrients in moderating body fat in preschool children. *Int J Obes Relat Metab Disord.* 2001;25:559–566
23. Skinner JD, Bounds W, Carruth BR, Ziegler P. Longitudinal calcium intake is negatively related to children's body fat indexes. *J Am Diet Assoc.* 2003;103:1626–1631
24. Goulding A, Taylor RW, Jones IE, McAuley KA, Manning PJ, Williams SM. Overweight and obese children have low bone mass and area for their weight. *Int J Obes Relat Metab Disord.* 2000;24:627–632
25. American Academy of Pediatrics, Committee on Nutrition. Prevention of pediatric overweight and obesity. *Pediatrics.* 2003;112:424–430
26. Fomon SJ, Nelson SE. Calcium, phosphorus, magnesium, and sulfur. In: Fomon SJ. *Nutrition of Normal Infants*. St Louis, MO: Mosby-Year Book, Inc; 1993:192–218
27. Schanler RJ, Abrams SA. Postnatal attainment of intrauterine macromineral accretion rates in low birth weight infants fed fortified human milk. *J Pediatr.* 1995;126:441–447
28. Bishop NJ, King FJ, Lucas A. Increased bone mineral content of preterm infants fed with a nutrient enriched formula after discharge from hospital. *Arch Dis Child.* 1993;68:573–578
29. Ellis KJ, Abrams SA, Wong WW. Body composition in a young multiethnic female population. *Am J Clin Nutr.* 1997;65:724–731
30. Abrams SA, Grusak MA, Stuff J, O'Brien KO. Calcium and magnesium balance in 9–14-y-old children. *Am J Clin Nutr.* 1997;66:1172–1177

31. Matkovic V, Ilich JZ. Calcium requirements for growth: are current recommendations adequate? *Nutr Rev.* 1993;51:171–180
32. Jackman LA, Millane SS, Martin BR, et al. Calcium retention in relation to calcium intake and postmenarcheal age in adolescent females. *Am J Clin Nutr.* 1997;66:327–333
33. Matkovic V, Heaney RP. Calcium balance during human growth: evidence for threshold behavior. *Am J Clin Nutr.* 1992; 55:992–996
34. Bryant RJ, Wastney ME, Martin BR, et al. Racial differences in bone turnover and calcium metabolism in adolescent females. *J Clin Endocrinol Metab.* 2003;88:1043–1047
35. Dalton MA, Sargent JD, O'Connor GT, Olmstead EM, Klein RZ. Calcium and phosphorus supplementation of iron-fortified infant formula: no effect on iron status of healthy full-term infants. *Am J Clin Nutr.* 1997;65:921–926
36. Barr SI. Dieting attitudes and behavior in urban high school students: implications for calcium intake. *J Adolesc Health.* 1995;16:458–464
37. Neumark-Sztainer D, Story M, Dixon LB, Renick MD, Blum RW. Correlates of inadequate consumption of dairy products among adolescents. *J Nutr Educ.* 1997;29:12–20
38. American Academy of Pediatrics, Committee on Nutrition. The use and misuse of fruit juice in pediatrics. *Pediatrics.* 2001;107: 1210–1213
39. Frary CD, Johnson RK, Wang MQ. Children and adolescents' choices of foods and beverages high in added sugars are associated with intakes of key nutrients and food groups. *J Adolesc Health.* 2004;34:56–63
40. Rampersaud GC, Bailey LB, Kauwell GP. National survey beverage consumption data for children and adolescents indicate the need to encourage a shift toward more nutritive beverages. *J Am Diet Assoc.* 2003;103:97–100
41. American Academy of Pediatrics, Committee on Nutrition. Carbohydrate and dietary fiber: lactose. In: Kleinman RE, ed. *Pediatric Nutrition Handbook*. 5th ed. Elk Grove Village, IL: American Academy of Pediatrics; 2003:250–252
42. American Academy of Pediatrics, Committee on Nutrition. Practical significance of lactose intolerance in children: supplement. *Pediatrics.* 1990;86:643–644
43. Fisher JO, Mitchell DC, Smiciklas-Wright H, Birch LL. Maternal milk consumption predicts the tradeoff between milk and soft drinks in young girls' diets. *J Nutr.* 2001;131:246–250
44. Auld G, Boushey CJ, Bock MA, et al. Perspectives on intake of calcium-rich foods among Asian, Hispanic, and white preadolescent and adolescent females. *J Nutr Educ Behav.* 2002;34: 242–251
45. Abrams SA, Stuff JE. Calcium metabolism in girls: current dietary intakes lead to low rates of calcium absorption and retention during puberty. *Am J Clin Nutr.* 1994;60:739–743
46. Lloyd T, Andon MB, Rollings N, et al. Calcium supplementation and bone mineral density in adolescent girls. *JAMA.* 1993; 270:841–844
47. Johnston CC Jr, Miller JZ, Slemenda CW, et al. Calcium supplementation and increases in bone mineral density in children. *N Engl J Med.* 1992;327:82–87
48. Kalkwarf HJ, Khoury JC, Lanphear BP. Milk intake during childhood and adolescence, adult bone density, and osteoporotic fractures in US women. *Am J Clin Nutr.* 2003;77:257–265
49. Sandler RB, Slemenda CW, LaPorte RE, et al. Postmenopausal bone density and milk consumption in childhood and adolescence. *Am J Clin Nutr.* 1985;42:270–274
50. Gerrior S, Bente L. *Nutrient Content of the US Food Supply 1909–97.* Washington DC: US Department of Agriculture, Center for Nutrition Policy and Promotion; 2001. Home Economics Research Report 54
51. Subar AF, Krebs-Smith SM, Cook A, Kahle LL. Dietary sources of nutrients among US children, 1989–1991. *Pediatrics.* 1998; 102:913–923
52. Weaver CM. Calcium bioavailability and its relation to osteoporosis. *Proc Soc Exp Biol Med.* 1992;200:157–160
53. Weaver CM, Plawecki KL. Dietary calcium: adequacy of a vegetarian diet. *Am J Clin Nutr.* 1994;59(suppl):1238S–1241S
54. Andon MB, Peacock M, Kanerva RL, De Castro JA. Calcium absorption from apple and orange juice fortified with calcium citrate malate (CCM). *J Am Coll Nutr.* 1996;15:313–316
55. Abrams SA, Griffin IJ, Davila P, Liang L. Calcium fortification of breakfast cereal enhances calcium absorption in children without affecting iron absorption. *J Pediatr.* 2001;139:522–526
56. Heaney RP, Dowell MS, Rafferty K, Bierman J. Bioavailability of the calcium in fortified soy imitation milk, with some observations on method. *Am J Clin Nutr.* 2000;71:1166–1169
57. Miller JZ, Smith DL, Flora L, Slemenda C, Jiang XY, Johnston CC Jr. Calcium absorption from calcium carbonate and a new form of calcium (CCM) in healthy male and female adolescents. *Am J Clin Nutr.* 1988;48:1291–1294
58. American Academy of Pediatrics, Section on Breastfeeding. Breastfeeding and the use of human milk. *Pediatrics.* 2005;115: 496–506

Optimizing Bone Health and Calcium Intakes of Infants, Children, and Adolescents

Frank R. Greer and Nancy F. Krebs

Pediatrics 2006;117;578
DOI: 10.1542/peds.2005-2822

PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Optimizing Bone Health and Calcium Intakes of Infants, Children, and Adolescents

Frank R. Greer and Nancy F. Krebs

Pediatrics 2006;117;578
DOI: 10.1542/peds.2005-2822