Calcium, Dairy Products, and Bone Health in Children and Young Adults: A Reevaluation of the Evidence

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ABSTRACT. ***Objective.*** **Numerous nutrition policy statements recommend the consumption of 800 to 1500 mg of calcium largely from dairy products for osteoporosis prevention; however, the findings of epidemiologic and prospective studies have raised questions about the efficacy of the use of dairy products for the promotion of bone health. The objective of this study was to review existing literature on the effects of dairy products and total dietary calcium on bone integrity in children and young adults to assess whether evidence supports (1) current recommended calcium intake levels and (2) the suggestion that dairy products are better for promoting bone integrity than other calcium-containing food sources or supplements.**

Methods. **A Medline (National Library of Medicine, Bethesda, MD) search was conducted for studies published on the relationship between milk, dairy products, or calcium intake and bone mineralization or fracture risk in children and young adults (1–25 years). This search yielded 58 studies: 22 cross-sectional studies; 13 retrospective studies; 10 longitudinal prospective studies; and 13 randomized, controlled trials.**

Results. **Eleven of the studies did not control for weight, pubertal status, and exercise and were excluded. Ten studies were randomized, controlled trials of supplemental calcium, 9 of which showed modest positive benefits on bone mineralization in children and adolescents. Of the remaining 37 studies of dairy or unsupplemented dietary calcium intake, 27 studies found no relationship between dairy or dietary calcium intake and measures of bone health. In the remaining 9 reports, the effects on bone health are small and 3 were confounded by vitamin D intake from milk fortified with vitamin D. Therefore, in clinical, longitudinal, retrospective, and cross-sectional studies, neither increased consumption of dairy products, specifically, nor total dietary calcium consumption has shown even a modestly consistent benefit for child or young adult bone health.**

Conclusion. **Scant evidence supports nutrition guidelines focused specifically on increasing milk or other dairy product intake for promoting child and adolescent bone mineralization.** ***Pediatrics*** **2005;115:736–743;** ***bone health, bone mineral density, calcium, children and adolescents, dairy products.***

ABBREVIATIONS. BMD, bone mineral density; BMC, bone mineral content.

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Over the past 20 years, the National Institutes of Health, the National Academy of Sciences, and the US Department of Agriculture have made recommendations for calcium intake for children and adults for the intended purpose of osteoporosis prevention. Recommended intakes have escalated gradually, and dairy products have been promoted often in federal nutrition policy documents as a "preferred" calcium source.[1–5]

However, because the level of dairy product consumption in the United States is among the highest in the world, accounting for 72% of dietary calcium intake,[6] and osteoporosis and fracture rates are simultaneously high,[7,8] numerous researchers have called into question the effectiveness of nutrition policies aimed at osteoporosis prevention through dairy consumption.[9–13] Findings from recent epidemiologic and prospective studies in women,[14] children, and adolescents[15–18] also have raised questions about the efficacy of the use of dairy products and other calcium-containing foods for the promotion of bone health.

The World Health Organization's recommendations for preventing osteoporosis, published in 2003,[19] acknowledge this "calcium paradox" and recommend a minimum intake of 400 to 500 mg/day of calcium from all sources for individuals who live in countries with a high fracture incidence and are 50 years of age and older. Furthermore, the World Health Organization report concluded that "there is no case for global, population-based approaches." This report did not include a recommended minimum intake for children and adolescents. These findings contrast with European, UK, and other dairy-consuming nations' calcium recommendations (Table 1), including the US adequate intakes, which recommend between 800 and 1300 mg/day of calcium for all individuals in the United States across the lifespan.[3]

When designing studies to quantify the effect of the consumption of milk and dairy products on bone mineral density (BMD), bone mineral content (BMC), calcium balance, and, ultimately, peak bone mass, it is important to control for factors that may influence these indices of bone health.

Dietary protein, including that from dairy products, influences calcium balance. An adequate protein intake is important for supporting bone growth in children[20] and maintaining bone mass in older adults.[21,22] However, increasing intake of dietary protein, particularly animal protein, is associated with increased urinary calcium losses[23] that may

TABLE 1. Current Calcium Intake Requirements

	European Union 1993 Population Reference Intake, mg/d	UK 1991 Reference Nutrient Intake, mg/d	Australia 1991 Recommended Dietary Intake, mg/d	US and Canada 1997 Adequate Intake, mg/d
Infancy	400	525	300 (human) 500 (cow)	210–270
Childhood	400–550	350–550	530–800	500–800
Puberty and adolescence				
Boys	1000	1000	1000–1200	1300
Girls	800	800	800–1000	1300
Adulthood				
Male	700	800	800	1000
Female	700	800	800	1000
Pregnancy	700	700	1100	1000–1300
Lactation	1200	1250	1200	1000–1300
Later adulthood				
Men >65 y	700	700	800	1200
Postmenopausal women	700	700	1000	1200

Source: Report of the Joint Food and Agriculture Organization of the United Nations/World Food Organization of the United Nations Expert Consultation on Human Vitamin and Mineral Requirements, September 1998. Available at: ftp://ftp.fao.org/es/esn/nutrition/Vitrni/vitrni.html.

result in increased bone resorption[24] or increased fracture.[25] In metabolic studies, doubling protein intake produces an ~50% increase in urinary calcium.[26] Approximately 6 mg of dietary calcium is theoretically required to offset the urinary calcium loss associated with 1 g of protein.[27]

Dairy products may contain up to 20% of the recommended dietary allowance for sodium per serving. Sodium is an important determinant of urinary calcium excretion because the 2 minerals compete for resorption in the renal tubules.[28,29] For every 2300 mg of sodium excreted by the kidney, 40 to 60 mg of calcium also are lost (ie, every 100 mmol of sodium excreted leads to the excretion of ~1 mmol of calcium).[30] In 1 study, urinary calcium excretion was shown to be negatively associated with bone mineral density in 8- to 13-year-old girls,[29] but in another, salt intake was not associated with bone mass of prepubertal children.[31] The difference in the calcium:sodium ratio of the diets may be responsible for these differing findings.

Vitamin D is essential for calcium uptake and bone development and remodeling.[32] The primary source of vitamin D is conversion in the skin, via exposure to UVB radiation, of 7-dehydrocholesterol to vitamin D_3, which then is metabolized sequentially in the liver and the kidney to its active form, 1,25-dihydroxyvitamin D. Few studies have investigated the effect of vitamin D intake, sun exposure, or vitamin D status on bone mineral in children and young adults. However, in a 3-year prospective study of Finnish girls who were aged 9 to 15 years, baseline concentration of serum 25-hydroxyvitamin D was associated positively with a 3-year change in BMD at the lumbar spine and femoral neck. Girls with hypovitaminosis D had a 4% lower BMD accumulation from baseline than did girls with normal vitamin D status.[33] Cow milk sold in the United States is supplemented with vitamin D precursors, although this is not generally true for other countries or for other dairy products. Studies that evaluate effects of US milk consumption on bone health, therefore may, be confounded by the presence of supplemental vitamin D.

Aside from these factors that influence the effect of milk and other dairy products on bone, body weight, pubertal status, and exercise levels must be controlled or accounted for in studies of bone integrity. Body weight has been shown to be a strong predictor of bone mineral content in children.[34,35] Dairy products are a major source of energy and fat, contributing 18% of total energy and 25% of total fat intake in the diets of children (2–18 years) in the United States.[36] Therefore, their impact on bone health may be mediated by their effect on body weight.[35]

Similarly, because pubertal status has a profound effect on bone turnover and calcium economy, it is also a predictor of bone mineralization.[34,37–39] Physical activity is also an important modulator of skeletal health.[34,38,40–46] Physical activity levels during ages 12 to 18 have been shown to exert a greater influence on later adult bone mineral density[15,17] and risk for hip fracture than does calcium intake during these ages.[47]

To assess the influence of milk and dairy products on bone integrity, we reviewed the published literature that addressed the effect of the consumption of dairy products and other calcium-containing foods or supplements on bone mineralization in children, adolescents, and young adults aged 1 to 25 years. To clarify this relationship, we asked the following questions:

1. Is there sufficient evidence to suggest that milk and other dairy products are better for promoting bone integrity than other calcium-containing food sources or calcium-containing supplements?
2. Is there sufficient evidence to support the current recommended adequate intake of 800 to 1300 mg/day of calcium in children and young adults?

METHODS

A Medline (National Library of Medicine, Bethesda, MD) search was conducted for studies published on the relationship between milk, dairy products, or total calcium intake and bone mineralization or fracture risk in children and teenagers using the key words "milk" or "dairy products" plus "bone," "bone density," or "osteoporosis," limiting the search to human studies, excluding infants, published in the English language for the period catalogued since 1966. Additional articles were identified from the bibliographies from these papers and from recent review articles.[9,48,49] We then reviewed these studies to identify those that addressed a relationship between milk, dairy products, or total calcium intake and bone mineralization or fracture risk in individuals ≤25 years (excluding infants). This search yielded 13 randomized, controlled trials; 10 longitudinal prospective studies; 13 retrospective studies; and 22 cross-sectional studies.

We identified the source of calcium (milk or dairy products specifically, total dietary calcium, or supplemental calcium) and noted whether total dietary protein, vitamin D intake or status, and sodium were reported or controlled. We also noted the age, gender, and race of the participants and excluded studies that did not control for body weight (or BMI), activity level, and pubertal status. Other factors that may also influence bone health, such as socioeconomic status, sunshine exposure, caffeine consumption, fruit and vegetable intake, potassium intake, and calcium load, were not addressed directly in this article.

Because bone density changes occur slowly,[50] we sought randomized, controlled trials and longitudinal prospective studies that were at least 1 year in length. Retrospective studies were limited to those that evaluated bone health during childhood or young adulthood.

RESULTS

Most studies were conducted with white preadolescent and adolescent girls. No randomized, controlled trials using milk or dairy products and few other studies have been conducted with boys, children <7 years old, or nonwhite girls.

Cross-Sectional Studies

Of 22 cross-sectional studies that addressed milk, dairy, or total calcium (including calcium from supplements) intake and bone health, 17 controlled for body weight, pubertal status, and activity level,[11,31,34,35,37–41,51–58] whereas 5 did not and were excluded.[59–63] Four of the 17 studies reported estimated dairy or milk intake specifically,[34,41,57,58] whereas the other 13 studies reported estimated total dietary calcium intake.

Among the 4 studies that reported only dairy or milk intake, 3 found no relationship between dairy intake and BMD. In 1 of these studies, 7- to 15-year-old Hutterite girls from South Dakota consumed milk that was fortified with vitamin D. However, the authors did not measure vitamin D intake.[57] In 2 studies (1 of Dutch boys and girls aged 7 to 11 years[41] and another of 10- to 26-year-old Australian female twin pairs[58]), milk was not supplemented with vitamin D, and no correlation between dairy intake and BMD was found. One study did find an effect of dairy intake: when studying Chinese adolescent girls (12–14 years) with mean calcium intake of 356 ± 97 mg/day, Du et al[34] found that milk intake and vitamin D intake both were significant predictors of total BMC but that total dietary calcium intake was not.

Of the 13 studies that investigated the relationship between total dietary calcium intake and BMD, 9 found no relationship between total dietary calcium intake and BMD or BMC.[11,31,35,37,40,51–53,55] In 1 of these studies, radial bone density was measured in young European adolescents and women from 6 countries across a wide range of mean calcium intakes (from 609 mg/day in Italy to 1267 mg/day in Finland). After adjustment for age, height, weight, bone area, and Tanner stage for girls or menstrual status for women, BMD did not differ significantly across quartiles of calcium intake for either adolescent girls or women.[11] The 4 remaining studies reported positive associations between dietary calcium intake and BMD. In 1, an association was found in French children and adolescents (aged 7–15 years) in the vertebral but not the femoral site.[38] A second, in 16-year-old girls from New Zealand, found the reverse: dietary calcium intake explained ~5% of the variability in femoral BMD but had no relationship with BMD in the lumbar spine.[56] The remaining 2 studies that identified positive associations included 2 US white populations: 8- to 18-year-old girls in Ohio and 6- to 18-year-old youths in Connecticut.[39,54] In the first of these studies, in addition to calcium intake, maturational age and chronological age were found to be significant predictors of vertebral BMD,[39] and in the second, weight and pubertal status were the main predictors of BMD.[54] However, in both studies, although the milk consumed by the subjects was fortified with vitamin D, vitamin D intake was not measured or controlled. Body weight,[34,35,37,38,40,51,53,54,57–59,61,63] physical activity level,[54,56,57] pubertal or menarchal status,[34,37–40,51,53,54,57] height,[40,51,53,54,56,57,59,61] and age[39,40,51,53,54,57,59,61] were the most consistent predictors of BMD in the children and adolescents in these cross-sectional studies.

Retrospective Studies

Of the 13 retrospective studies reviewed,[64–76] 6 did not control for ≥1 of the following factors and consequently were excluded: body weight, pubertal status, or physical activity.[64,67,68,71,72,74] Of the remaining 7 retrospective studies, 3 assessed effect of dairy calcium intake (and in some cases also total calcium intake) on indices of bone health in children or young adults,[65,70,76] and 4 focused solely on total dietary calcium intake.[66,69,73,75]

In the studies that assessed the relationship between dairy product intake and fracture risk in children, Petridou et al[70] found that dairy product intake had no association with susceptibility to bone fractures in school-aged children, and Wyshak and Frisch[76] found that high total calcium intake was associated with reduced fracture incidence, but there was no association with milk consumption alone and fracture risk in 8- to 16-year-olds.

In a retrospective study of participants who were involved for 6 school terms in a school milk supplementation trial on child growth from ages 7 to 9 years, BMC and BMD were tested 14 years posttreatment. The BMC and BMD of the intervention and control subjects were not significantly different for men or women (20–23 years) at any of the sites measured.[65]

Wang et al[73] addressed the influence of childhood total dietary calcium intake on bone density of young women (mean age: 21.8–23.3 years) who were living in the United States and had participated in the 10-year National Heart, Lung, and Blood Institute Growth and Health Study. Previous dietary calcium intake was estimated from eight 3-day food records collected over 10 years. In this study of 693 white and black women, young adult spine, femoral neck, and whole-body BMD was associated with calcium intake during midpuberty (mean age of midpuberty: 12 years for white women and 11.7 years for black women; $P < .05$ for all 3 sites) but not during prepuberty or postpuberty. Physical activity was found to have a general positive effect on BMD during prepuberty.[73]

Among the studies that assessed total dietary calcium, Goulding et al[66] showed that although low bone density was more common in girls and boys[75] with fractures than those without fractures, the calcium intake of cases and control subjects was similar (girls: 858 mg/day cases vs 829 mg/day control subjects; boys: 1136 mg/day cases vs 1278 mg/day control subjects) and did not predict fracture risk.[66,75] However, in both studies, a subset of the cases (girls aged 11–15 and boys aged 11–13) had decreased calcium intake compared with control subjects.[66,75] Parsons et al[69] investigated the effect of a macrobiotic diet in early life (from birth onward for a mean period of 6.2 ± 2.9 years) on bone mass in adolescence. They found that children who had consumed a macrobiotic diet during the first 6 years of life had a 3% lower BMC in adolescence compared with the control group, who, as children, did not consume a macrobiotic diet. However, current calcium intake was not found to be a significant predictor of BMC at any site in either gender, although the present calcium intake of children who had consumed a macrobiotic diet in early life was significantly lower than that of control subjects (macro boys: 660 mg/day of calcium; macro girls: 557 mg/day of calcium; control boys: 1064 mg/day of calcium; control girls: 1045 mg/day of calcium).[69]

Prospective Studies

Ten prospective studies, ranging from 1 to 14 years' duration, addressed the influence of dairy product intake and/or total dietary calcium intake on bone mineralization in children or young adults, while controlling for body weight and, when applicable, activity level and pubertal status.[15,17,18,42–45,77–79] Of these, only Kroger et al[18] estimated total calcium intake from current intake of dairy products. In this study of 65 healthy children and adolescents aged 7 to 20 years, 6 children had intakes of <800 mg/day of calcium; 18 consumed 800 to 1200 mg/day of calcium; and 41 had intakes >1200 mg/day. Dairy calcium intake did not correlate significantly with bone mass or bone density.[18]

The remaining 9 studies reported total calcium intake, not dairy intake. Of these, 4 were <3 years in length and had ≤3 measures of dietary calcium intake.[42–44,79] Calcium intake was not a significant predictor of BMD when weight, exercise, and smoking (where relevant) were controlled for in these 4 studies.

The remaining 5 studies measured dietary calcium intake on ≥4 occasions over ≥3 years to examine the association between dietary calcium intake and later bone health.[15,17,45,77,78] In a study of Finnish girls who were aged 9 to 15 years, mean calcium intake and BMD were measured at 6-month intervals over 3 years. No significant correlation was found between calcium intake and BMD at the end of this period.[78] Similarly, calcium intake of Dutch boys and girls during adolescence and childhood was not a significant predictor of lumbar spine BMD at age 17.[45] In 2 separate reports from the Penn State Young Women's Health Study in which Lloyd et al[15,17] collected 3-day food records every 6 months for 6 to 8 years (for a total of 33 and 39 records in 2000 and 2002, respectively), no association between calcium intake and BMD, bone mineral gain, or BMC for the total body, leg, and hip was found. In the remaining study, cumulative calcium intake from birth to 5 years was associated positively with BMD, as measured at 5 years; however, the current calcium intake of the 5-year-olds was not associated with BMD.[77] In these reports, body weight or weight gain,[43–45,77] height,[43,77] age,[44] pubertal status,[18] physical activity,[15,17,42–45] fitness level,[15,17] vitamin D status,[78] and sodium intake[43] were significant predictors of BMD.

Randomized, Controlled Trials

Of 13 randomized, controlled trials with children and adolescents that addressed the relationship between dairy product consumption or calcium supplementation on BMD in children and adolescents, 12 had at least a 1-year treatment period. Of these 12 longer-term studies, 3 tested the effects of added milk or dairy products[80,81] or both dairy products and calcium supplements[82] on bone density. Nine tested the effect of adding calcium supplements alone to the diet.[83–91]

Each of the 3 trials that tested milk or dairy products was conducted with white girls who were aged 11 to 18 years and whose mean baseline calcium intakes ranged from 725 to 900 mg/day. Only the study by Chan et al[80] measured vitamin D intake and serum vitamin D levels, assessed exercise levels, matched subjects for pubertal status (all began at a sexual staging of 2), assessed protein and dietary calcium intake and calcium to protein ratio, and controlled for body weight. In this study, calcium intake of 11-year-old girls increased from 728 mg/day of calcium to 1437 mg/day of calcium over a period of 1 year, through the use of additional servings of dairy products. At the end of the year, mean BMC and lumbar spine BMD were not significantly different between the groups of girls. An increased rate of gain in total BMC (14.2% vs 7.6%; $P < .001$) and BMD at the lumbar spine (22.8% vs 12.9%; $P < .001$) but not at femoral neck or radius was observed in the supplemented group compared with the control group.[80]

In the other 2 randomized, controlled trials, neither vitamin D nor protein intakes were controlled or accounted for. In a 2-year trial of calcium supplementation (as either dairy products or calcium carbonate tablets) that doubled calcium intake in adolescent girls (1640 mg/day of calcium treatment; 750 mg/day of calcium control), Matkovic et al[82] found no differences in bone density or change in bone density over time with either treatment. Cadogan et al[81] treated 12-year-old girls with a daily pint of milk for 18 months. At the end of this period, differences in final bone density between the groups were not reported. However, the total increase in bone density was slightly greater in the treated group as compared with the control group (9.6% vs 8.5%; $P = .017$).

In 10 trials that assessed the effects of supplemental calcium (300–1000 mg/day as calcium-fortified or enriched foods, calcium carbonate, or calcium citrate maleate), 9 showed a 1% to 6% increase in BMD or BMC at ≥1 bone sites measured over a period of 6 months to 3 years,[83–91] whereas 1 showed no effect.[82] Body weight was reported in each of these trials, and the authors found no significant difference in body weight or body weight change between the treated individuals and control subjects over these periods of time. Only 2 of these trials included both exercise and pubertal status in their analyses. In one, a positive effect on BMD was noted during 3 years of supplementation in prepubertal twin pairs but not pubertal or postpubertal adolescents,[85] and in the other, supplemented twins showed no additional increment in BMD beyond that observed during the first 6 months of supplementation.[90] Only 1 of these 10 trials reported an increase in BMD that persisted 12 months posttreatment.[83]

DISCUSSION

A positive relationship between dairy product consumption and measures of bone health in children or young adults was reported in 1 of 4 cross-sectional studies; in 0 of 3 retrospective studies; in 0 of 1 prospective study; and in 2 of 3 randomized, controlled trials. Only 1 of these randomized clinical trials adequately controlled for vitamin D intake, and it showed no significant effect of dairy products on BMD, although a change in the rate of gain was observed. Among the studies that reported total dietary calcium intake rather than specifically dairy intake, a positive relationship between calcium intake and measures of bone health in children and young adults was noted in 4 of 13 cross-sectional studies, 2 of 4 retrospective studies, and 1 of 9 prospective studies. No randomized, controlled trials addressed this topic. Nine of the 10 controlled trials of calcium supplementation showed a positive relationship with BMD or BMC.

Therefore, of the 37 studies of dairy or unsupplemented dietary calcium intake (ranging from a mean of 160 to 2000 mg/day) that in some way controlled for weight, pubertal status, and exercise in children, adolescents, and young adults, 27 studies found no relationship between dairy or dietary calcium intake and measures of bone health. In the remaining 9 reports, the effects on bone health are small. Three were confounded by vitamin D intake from milk that was fortified with vitamin D, 6 found positive relationships in some measures but not others, and 1 found an effect of increasing dietary calcium intake on BMD or BMC when habitual calcium intake was <400 mg/day.

Physical activity seems to be the primary modifiable stimulus for increased bone growth and development in adolescents. Findings of the Penn State Young Women's Health Study[17] indicate that <5% of the variance in adolescent bone gain and later peak bone mass in 6 bone measures could be accounted for by calcium intake during adolescence. In contrast, physical activity patterns in adolescence accounted for between 10% and 22% of adult bone variance. Similarly, in a study of Hutterite female individuals, physical activity levels from ages 15 years to young adulthood seemed to be the strongest predictor of BMC in adults.[57] Although other studies found no interaction between moderate physical activity and BMD,[92] adolescent subjects who participated in weight-bearing exercise programs generally show increased BMDs compared with sedentary subjects.[15,17,73,93]

Calcium intake, turnover, and absorption and excretion rates determine the availability of calcium for bone growth and development. During infancy and adolescence, the need for calcium and the rate of absorption are higher than during other ages.[94] Rates of urinary calcium excretion vary with age and pubertal status, with obligatory losses increasing from ~40 mg/day in young children to ~80 mg/day just before puberty, then rising further postpuberty to adult levels of ~160 mg/day.[95] Female adolescents have been shown to have both higher net absorption and lower urinary and fecal calcium excretion than young adults.[96] In female adolescents,[97] as well as adults,[98] calcium absorption is influenced by the total calcium load consumed with absorption ranging from 64% at the lowest loads (15 mg) to 28.6% at the highest loads (500 mg).

In addition to age, pubertal status, and dietary calcium load, several other factors influence calcium balance. Calcium absorption is modulated by the food source,[27] form of the calcium salt,[99] the presence of inhibitory factors in foods such as phytates or oxalates,[100,101] and vitamin D status.[32] In addition, obligatory urinary calcium losses are modified by the potential renal acid load of the diet, total dietary protein (particularly animal protein),[102] dietary sodium content,[30,101] dietary potassium content,[103] and possibly caffeine intake and smoking.

Factors that affect calcium balance, including dietary calcium intake, likely play a role in bone development, at least under some conditions. In the study in which mean habitual dietary calcium intake was <400 mg/day, dietary calcium consumption above this level was associated with greater bone mineralization than lower levels.[34] In addition, 9 of the 10 randomized, controlled trials that tested the effects of supplemental calcium (300–1000 mg/day) on BMC and BMD in children and adolescents reported a small but significant association (1%–6% increase in BMD or BMC). However, the effect seems to be transient. In the 10 calcium supplementation trials that studied children and adolescents and were at least 1 year in duration, only 2 reported an increase in BMD that persisted 12 months posttreatment.[83,91] As in most studies, in the Penn State Young Women's Health Study, the 6% increase in BMD observed during the supplementation period (from 12 to 16 years of age) did not persist into late adolescence.[17] Slemenda et al[104] and others[48,50] have suggested that calcium supplementation may transiently increase BMD by reducing the rate of bone remodeling.

Results from calcium supplementation trials are generally not mirrored in studies that use dairy products or total dietary calcium intake. Dairy products contain nutrients, including protein, sodium, and, in some cases, supplemental vitamin D, all of which influence calcium balance and bone mineralization and alter or negate the effect of dairy calcium in the body's mineral economy. Animal protein and sodium, in particular, tend to increase calcium excretion. According to calculations by Weaver et al,[27] even with the calciuric effect of protein and sodium, dairy product consumption should result in a positive calcium balance and, presumably, a positive effect on bone mineralization. However, in clinical, longitudinal, retrospective, and cross-sectional studies, neither increased consumption of dairy products, specifically, nor total dietary calcium consumption has shown even a modestly consistent benefit for child or adolescent bone health.

Recent reviews of the effect of dairy product and calcium consumption on bone health have highlighted these factors that affect calcium balance and bone mineral accrual and have presented conflicting conclusions. Weinsier and Krumdieck[9] reviewed 57 papers that evaluated the effect of dairy product consumption on bone health across the lifespan and concluded that the "body of evidence appears inadequate to support a recommendation for daily intake of dairy foods to promote bone health in the general US population." In contrast, Heaney's[49] review cited 139 studies that examined the relationship between calcium (including supplemental sources) intake and bone status of children and adults and concluded that the evidence supports a role for calcium, especially from dairy products, in bone health.

In a review that focused on determinants of bone health, specifically in children and adolescents, Bachrach[105] noted that it is unknown whether any short-term effects of dietary or supplemental calcium intervention in childhood or adolescence will translate into clinically meaningful reductions of osteoporosis risk in later life. Finally, a detailed recent review of the role of calcium in bone health during childhood observed that increases in BMD (observed primarily in cortical bone) related to higher calcium intakes were most apparent for children with relatively low baseline calcium intakes and did not persist beyond the treatment period.[48]

The vast majority of controlled studies of dairy supplementation[17,42,58,59,66,71,76,80] or total dietary calcium intake[10,14,16,32,36,38,41,43–46,52–54,56,67,70,75–77] show that, although very low calcium intakes (eg, <400 mg/day) may be harmful to bone development as shown in a few studies,[35,69] increases in dairy or total dietary calcium intake (>400–500 mg/day) are not correlated with or a predictor of BMD or fracture rate in children or adolescents.

We found no evidence to support the notion that milk is a preferred source of calcium. Indeed, only a minority of studies on dietary factors in bone health specifically examined dairy products. Although the conclusion of the 1994 National Institutes of Health consensus statement on optimal calcium intake[2] does not explicitly state that cow milk is the preferred source of calcium, it has been interpreted widely by government and industry as doing so. For example, the National Institute of Child Health and Human Development has selected low-fat or fat-free milk as the best source of calcium for its "Milk Matters" campaign because it has a high calcium content and the calcium can be absorbed easily by the body.[106] Although milk and other dairy products are reliable sources of calcium, many factors affect the availability and retention of the calcium from these products. For example, the calcium in dairy products is not as well absorbed as that in many dark green leafy vegetables but has an absorption fraction similar to that of calcium supplements, calcium-enriched beverages, calcium-set tofu, sweet potatoes, and beans.[27] Dairy products contain protein and sodium, and some dairy products, especially processed cheeses, clearly increase the urinary excretion of calcium as a result of their increased sodium, sulfur-containing amino acid, and phosphorus content.[26] Although dairy products tend to contain more calcium in absolute amounts than calcium-rich plant foods, when absorption fraction is taken into account, the amount of plant food needed to get the same amount of absorbable calcium is modest. For example, 1 cup of cooked kale or turnip greens, 2 packets of instant oats, two-thirds cup of tofu, or 1⅔ cups of broccoli provide the same amount of absorbable calcium as 1 cup of cow milk (as would 1 cup of fortified orange juice, soy milk, or Basic 4 cereal).

Many of the studies that have been used to set recommended levels of calcium intake are short-term calcium balance trials or longer-term calcium supplementation trials that last 1 to 3 years. Most evidence that is available from longer-term studies that evaluated the effect of childhood consumption of dairy or calcium on BMD or BMC have not supported the hypothesis that a positive calcium balance translates into increases in BMD, and, in many cases, confounders have not been controlled for adequately. Furthermore, it has not been demonstrated that if, in fact, increases in bone mass occur as a result of calcium consumption, then these increases will persist into adulthood or simply beyond the treatment period.

Currently, available evidence does not support nutrition guidelines focused specifically on increasing milk or other dairy product intake for promoting child and adolescent bone mineralization. Data regarding the effect of dairy product intake on bone mineralization in boys, children who are <7 years old, and nonwhite preadolescent and adolescent girls are scarce.

REFERENCES

1. National Institutes of Health. *Consensus Development Conference Statement. Osteoporosis Prevention, Diagnosis, and Therapy*. Bethesda, MD: National Institutes of Health; 2000:27–29
2. National Institutes of Health. Consensus Development Panel on Optimal Calcium Intake. NIH Consensus Conference: optimal calcium intake. *JAMA*. 1994;272:1942–1948
3. Institute of Medicine. *Dietary Reference Intakes for Calcium, Phosphorous, Magnesium, Vitamin D, and Fluoride*. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board. Washington, DC: National Academy Press; 1997
4. US Department of Agriculture. *The Food Guide Pyramid*. Hyattsville,

MD: Human Nutrition Information Service; 1996 [Home and Garden Bull. No. 252]
5. US Department of Agriculture and US Department of Health and Human Services. *Nutrition and Your Health: Dietary Guidelines for Americans*. 5th ed. Washington, DC: US Department of Agriculture and US Department of Health and Human Services; 2000 [Home and Garden Bull. No 232]
6. Gerrior S. Nutrient *Content of the US Food Supply. Home Economics Research Report no. 53*. Washington, DC: United States Department of Agriculture, Center of Nutrition Policy and Promotion; 2001
7. Abelow BJ, Holford TR, Insogna KL. Cross-cultural association between dietary animal protein and hip fracture: a hypothesis. *Calcif Tissue Int.* 1992;50:14–18
8. Report of a Joint Food and Agriculture Organization of the United Nations/World Food Organization of the United Nations Expert Consultation. Human vitamin and mineral requirements. Bangkok, Thailand; September 1998. Available at: ftp://ftp.fao.org/es/esn/nutrition/Vitrni/vitrni.html
9. Weinsier RL, Krumdieck CL. Dairy foods and bone health: examination of the evidence. *Am J Clin Nutr.* 2000;72:681–689
10. Hegsted DM. Fractures, calcium, and the modern diet. *Am J Clin Nutr.* 2001;74:571–573
11. Kardinaal AF, Ando S, Charles P, et al. Dietary calcium and bone density in adolescent girls and young women in Europe. *J Bone Miner Res.* 1999;14:583–592
12. Seppa K. Bone density and milk. Consider fat as well as calcium intake. *BMJ.* 1994;308:1566
13. Avenell A. Bone density and milk. Exercise and body size influence bone density. *BMJ.* 1994;308:1566
14. Feskanich D, Willett WC, Colditz GA. Calcium, vitamin D, milk consumption, and hip fractures: a prospective study among postmenopausal women. *Am J Clin Nutr.* 2003;77:504–511
15. Lloyd T, Chinchilli VM, Johnson-Rollings N, Kieselhorst K, Eggli DF, Marcus R. Adult female hip bone density reflects teenage sports-exercise patterns but not teenage calcium intake. *Pediatrics.* 2000;106:40–44
16. Lloyd T, Taylor DS. Calcium intake and peak bone mass. *J Am Med Womens Assoc.* 2001;56:49–52, 72
17. Lloyd T, Beck TJ, Lin HM, et al. Modifiable determinants of bone status in young women. *Bone.* 2002;30:416–421
18. Kröger H, Kotaniemi A, Kröger L, Alhava E. Development of bone mass and bone density of the spine and femoral neck—a prospective study of 65 children and adolescents. *Bone Miner.* 1993;23:171–182
19. Joint Food and Agriculture Organization of the United Nations/World Food Organization of the United Nations Expert Consultation on Diet, Nutrition, and the Prevention of Chronic Diseases. WHO Technical Report Series 916. Geneva, Switzerland: World Health Organization; 2003. Available at: www.who.int/hpr/NPH/docs/who_fao_expert_report.pdf
20. Cromer B, Harel Z. Adolescents: at increased risk for osteoporosis? *Clin Pediatr (Phila).* 2000;39:565–574
21. Hannan MT, Tucker KL, Dawson-Hughes B, Cupples LA, Felson DT, Kiel DP. Effect of dietary protein on bone loss in elderly men and women: the Framingham Osteoporosis Study. *J Bone Miner Res.* 2000;15:2504–2512
22. Promislow JH, Goodman-Gruen D, Slymen DJ, Barrett-Connor E. Protein consumption and bone mineral density in the elderly: the Rancho Bernardo Study. *Am J Epidemiol.* 2002;155:636–644
23. Breslau NA, Brinkley L, Hill KD, Pak CY. Relationship of animal protein-rich diet to kidney stone formation and calcium metabolism. *J Clin Endocrinol Metab.* 1988;66:140–146
24. Barzel US, Massey LK. Excess dietary protein can adversely affect bone. *J Nutr.* 1998;128:1051–1053
25. Frassetto L, Morris RC Jr, Sellmeyer DE, Todd K, Sebastian A. Diet, evolution and aging—the pathophysiologic effects of the post-agricultural inversion of the potassium-to-sodium and base-to-chloride ratios in the human diet. *Eur J Nutr.* 2001;40:200–213
26. Heaney RP, Recker RR. Effects of nitrogen, phosphorus, and caffeine on calcium balance in women. *J Lab Clin Med.* 1982;99:46–55
27. Weaver CM, Proulx WR, Heaney R. Choices for achieving adequate dietary calcium with a vegetarian diet. *Am J Clin Nutr.* 1999;70:543S–548S
28. Nordin BE. Calcium and osteoporosis. *Nutrition.* 1997;13:664–686
29. Matkovic V, Ilich JZ, Andon MB, et al. Urinary calcium, sodium, and bone mass of young females. *Am J Clin Nutr.* 1995;62:417–425
30. Nordin BE, Need AG, Morris HA, Horowitz M. The nature and significance of the relationship between urinary sodium and urinary calcium in women. *J Nutr.* 1993;123:1615–1622
31. Jones G, Riley MD, Whiting S. Association between urinary potassium, urinary sodium, current diet, and bone density in prepubertal children. *Am J Clin Nutr.* 2001;73:839–844
32. Holick MF. Vitamin D and bone health. *J Nutr.* 1996;126:1159S–1164S
33. Lehtonen-Veromaa M, Mottonen T, Nuotio I, Irjala K, Viikari J. The effect of conventional vitamin D(2) supplementation on serum 25(OH)D concentration is weak among peripubertal Finnish girls: a 3-y prospective study. *Eur J Clin Nutr.* 2002;56:431–437
34. Du XQ, Greenfield H, Fraser DR, Ge KY, Liu ZH, He W. Milk consumption and bone mineral content in Chinese adolescent girls. *Bone.* 2002;30:521–528
35. Moro M, van der Meulen MC, Kiratli BJ, Marcus R, Bachrach LK, Carter DR. Body mass is the primary determinant of midfemoral bone acquisition during adolescent growth. *Bone.* 1996;19:519–526
36. Subar AF, Krebs-Smith SM, Cook A, Kahle LL. Dietary sources of nutrients among US children, 1989–1991. *Pediatrics.* 1998;102:913–923
37. Maggiolini M, Bonofiglio D, Giorno A, et al. The effect of dietary calcium intake on bone mineral density in healthy adolescent girls and young women in southern Italy. *Int J Epidemiol.* 1999;28:479–484
38. Ruiz JC, Mandel C, Garabedian M. Influence of spontaneous calcium intake and physical exercise on the vertebral and femoral bone mineral density of children and adolescents. *J Bone Miner Res.* 1995;10:675–682
39. Sentipal JM, Wardlaw GM, Mahan J, Matkovic V. Influence of calcium intake and growth indexes on vertebral bone mineral density in young females. *Am J Clin Nutr.* 1991;54:425–428
40. Uusi-Rasi K, Haapasalo H, Kannus P, et al. Determinants of bone mineralization in 8 to 20 year old Finnish females. *Eur J Clin Nutr.* 1997;51:54–59
41. VandenBergh MF, DeMan SA, Witteman JC, Hofman A, Trouerbach WT, Grobbee DE. Physical activity, calcium intake, and bone mineral content in children in the Netherlands. *J Epidemiol Community Health.* 1995;49:299–304
42. Bass S, Pearce G, Bradney M, et al. Exercise before puberty may confer residual benefits in bone density in adulthood: studies in active prepubertal and retired female gymnasts. *J Bone Miner Res.* 1998;13:500–507
43. Gunnes M, Lehmann EH. Physical activity and dietary constituents as predictors of forearm cortical and trabecular bone gain in healthy children and adolescents: a prospective study. *Acta Paediatr.* 1996;85:19–25
44. Valimaki MJ, Karkkainen M, Lamberg-Allardt C, et al. Exercise, smoking, and calcium intake during adolescence and early adulthood as determinants of peak bone mass. Cardiovascular Risk in Young Finns Study Group. *BMJ.* 1994;309:230–235
45. 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
46. Hara S, Yanagi H, Amagai H, Endoh K, Tsuchiya S, Tomura S. Effect of physical activity during teenage years, based on type of sport and duration of exercise, on bone mineral density of young, premenopausal Japanese women. *Calcif Tissue Int.* 2001;68:23–30
47. Nieves JW, Grisso JA, Kelsey JL. A case-control study of hip fracture: evaluation of selected dietary variables and teenage physical activity. *Osteoporos Int.* 1992;2:122–127
48. Wosje KS, Specker BL. Role of calcium in bone health during childhood. *Nutr Rev.* 2000;58:253–268
49. Heaney RP. Calcium, dairy products and osteoporosis. *J Am Coll Nutr.* 2000;19:83S–99S
50. Heany RP. The bone-remodeling transient: implications for the interpretation of clinical studies of bone mass change. *J Bone Miner Res.* 1994;9:1515–1523
51. Bonofiglio D, Maggiolini M, Marsico S, et al. Critical years and stages of puberty for radial bone mass apposition during adolescence. *Horm Metab Res.* 1999;31:478–482
52. Bonofiglio D, Maggiolini M, Catalano S, et al. Parathyroid hormone is elevated but bone markers and density are normal in young female subjects who consume inadequate dietary calcium. *Br J Nutr.* 2000;84:111–116
53. Katzman DK, Bachrach LK, Carter DR, Marcus R. Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. *J Clin Endocrinol Metab.* 1991;73:1332–1339
54. Rubin K, Gendreau P, Sarfarazi M, Mendola R, Dalsky G. Predictors of axial and peripheral bone mineral density in healthy children and adolescents, with special attention to the role of puberty. *J Pediatr.* 1993;123:863–870
55. Taha W, Chin D, Silverberg AI, Lashiker L, Khateeb N, Anhalt H. Reduced spinal bone mineral density in adolescents of an Ultra-

Orthodox Jewish community in Brooklyn. *Pediatrics*. 2001;107(5). Available at: www.pediatrics.org/cgi/content/full/107/5/e79
56. Turner JG, Gilchrist NL, Ayling EM, Hassall AJ, Hooke EA, Sadler WA. Factors affecting bone mineral density in high school girls. *N Z Med J.* 1992;105:95–96
57. Wosje KS, Binkley TL, Fahrenwald NL, Specker BL. High bone mass in a female Hutterite population. *J Bone Miner Res.* 2000;15:1429–1436
58. Young D, Hopper JL, Nowson CA, et al. Determinants of bone mass in 10- to 26-year-old females: a twin study. *J Bone Miner Res.* 1995;10: 558–567
59. Chan GM. Dietary calcium and bone mineral status of children and adolescents. *Am J Dis Child.* 1991;145:631–634
60. Kristinsson JO, Valdimarsson O, Steingrimsdottir L, Sigurdsson G. Relation between calcium intake, grip strength and bone mineral density in the forearms of girls aged 13 and 15. *J Intern Med.* 1994;236: 385–390
61. Kröger H, Kotaniemi A, Kroger L, Vainio P, Alhava E. Bone densitometry of the spine and femur in children by dual-energy x-ray absorptiometry. *Bone Miner.* 1992;17:75–85
62. Lee WT, Leung SS, Ng MY, et al. Bone mineral content of two populations of Chinese children with different calcium intakes. *Bone Miner.* 1993;23:195–206
63. Tsukahara N, Sato K, Ezawa I. Effects of physical characteristics and dietary habits on bone mineral density in adolescent girls. *J Nutr Sci Vitaminol (Tokyo).* 1997;43:643–655
64. 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
65. Fehily AM, Coles RJ, Evans WD, Elwood PC. Factors affecting bone density in young adults. *Am J Clin Nutr.* 1992;56:579–586
66. 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
67. Henderson RC, Hayes PR. Bone mineralization in children and adolescents with a milk allergy. *Bone Miner.* 1994;27:1–12
68. Infante D, Tormo R. Risk of inadequate bone mineralization in diseases involving long-term suppression of dairy products. *J Pediatr Gastroenterol Nutr.* 2000;30:310–313
69. Parsons TJ, van Dusseldorp M, van der Vliet M, van de Werken K, Schaafsma G, Van Staveren WA. Reduced bone mass in Dutch adolescents fed a macrobiotic diet in early life. *J Bone Miner Res.* 1997;12: 1486–1494
70. Petridou E, Karpathios T, Dessypris N, Simou E, Trichopoulos D. The role of dairy products and non alcoholic beverages in bone fractures among schoolage children. *Scand J Soc Med.* 1997;25:119–125
71. Pettifor JM, Moodley GP. Appendicular bone mass in children with a high prevalence of low dietary calcium intakes. *J Bone Miner Res.* 1997;12:1824–1832
72. Teegarden D, Lyle RM, Proulx WR, Johnston CC, Weaver CM. Previous milk consumption is associated with greater bone density in young women. *Am J Clin Nutr.* 1999;69:1014–1017
73. Wang MC, Crawford PB, Hudes M, Van Loan M, Siemering K, Bachrach LK. Diet in midpuberty and sedentary activity in prepuberty predict peak bone mass. *Am J Clin Nutr.* 2003;77:495–503
74. 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
75. 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
76. 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
77. Lee WT, Leung SS, Lui SS, Lau J. Relationship between long-term calcium intake and bone mineral content of children aged from birth to 5 years. *Br J Nutr.* 1993;70:235–248
78. Lehtonen-Veromaa MK, Mottonen TT, Nuotio IO, Irjala KM, Leino AE, Viikari JS. Vitamin D and attainment of peak bone mass among peripubertal Finnish girls: a 3-y prospective study. *Am J Clin Nutr.* 2002;76:1446–1453
79. Jones G, Riley MD, Dwyer T. Maternal diet during pregnancy is associated with bone mineral density in children: a longitudinal study. *Eur J Clin Nutr.* 2000;54:749–756
80. Chan GM, Hoffman K, McMurry M. Effects of dairy products on bone and body composition in pubertal girls. *J Pediatr.* 1995;126:551–556
81. Cadogan J, Eastell R, Jones N, Barker ME. Milk intake and bone mineral acquisition in adolescent girls: randomized, controlled intervention trial. *BMJ.* 1997;315:1255–1260
82. Matkovic V, Fontana D, Tominac C, Goel P, Chesnut CH III. Factors that influence peak bone mass formation: a study of calcium balance and the inheritance of bone mass in adolescent females. *Am J Clin Nutr.* 1990;52:878–888
83. Bonjour JP, Carrie AL, Ferrari S, et al. Calcium-enriched foods and bone mass growth in prepubertal girls: a randomized, double-blind, placebo-controlled trial. *J Clin Invest.* 1997;99:1287–1294
84. Dibba B, Prentice A, Ceesay M, Stirling DM, Cole TJ, Poskitt EM. Effect of calcium supplementation on bone mineral accretion in Gambian children accustomed to a low-calcium diet. *Am J Clin Nutr.* 2000;71: 544–549
85. 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
86. Lee WT, Leung SS, Wang SH, et al. Double-blind, controlled calcium supplementation and bone mineral accretion in children accustomed to a low-calcium diet. *Am J Clin Nutr.* 1994;60:744–750
87. Lee WT, Leung SS, Leung DM, Tsang HS, Lau J, Cheng JC. A randomized double-blind controlled calcium supplementation trial, and bone and height acquisition in children. *Br J Nutr.* 1995;74:125–139
88. Lloyd T, Andon MB, Rollings N, et al. Calcium supplementation and bone mineral density in adolescent girls. *JAMA.* 1993;270:841–844
89. Lloyd T, Martel JK, Rollings N, et al. The effect of calcium supplementation and Tanner stage on bone density, content and area in teenage women. *Osteoporos Int.* 1996;6:276–283
90. Nowson CA, Green RM, Hopper JL, et al. A co-twin study of the effect of calcium supplementation on bone density during adolescence. *Osteoporos Int.* 1997;7:219–225
91. Stear SJ, Prentice A, Jones SC, Cole TJ. Effect of a calcium and exercise intervention on the bone mineral status of 16–18-y-old adolescent girls. *Am J Clin Nutr.* 2003;77:985–992
92. Mazess RB, Barden HS. Bone density in premenopausal women: effects of age, dietary intake, physical activity, smoking, and birth-control pills. *Am J Clin Nutr.* 1991;53:132–142
93. Matkovic V. Calcium metabolism and calcium requirements during skeletal remodeling and consolidation of bone mass. *Am J Clin Nutr.* 1991;54:245S–260S
94. Peacock M. Calcium absorption efficiency and calcium requirements in children and adolescents. *Am J Clin Nutr.* 1991;54:261S–265S
95. Weaver CM, Martin BR, Plawecki KL, et al. Differences in calcium metabolism between adolescent and adult females. *Am J Clin Nutr.* 1995;61:577–581
96. O'Brien KO, Abrams SA, Liang LK, Ellis KJ, Gagel RF. Increased efficiency of calcium absorption during short periods of inadequate calcium intake in girls. *Am J Clin Nutr.* 1996;63:579–583
97. Heaney RP, Weaver CM, Fitzsimmons ML. Influence of calcium load on absorption fraction. *J Bone Miner Res.* 1990;5:1135–1138
98. Levenson DI, Bockman RS. A review of calcium preparations. *Nutr Rev.* 1994;52:221–232
99. Heaney RP, Weaver DM, Fitzsimmons ML. Soybean phytate content: effect on calcium absorption. *Am J Clin Nutr.* 1991;53:745–747
100. Weaver CM, Heaney RP, Nickel KP, Packard PI. Calcium bioavailability from high oxalate vegetables: Chinese vegetables, sweet potatoes and rhubarb. *J Food Sci.* 1997;62:524–525
101. Sellmeyer DE, Stone KL, Sebastian A, Cummings SR. A high ratio of dietary animal to vegetable protein increases the rate of bone loss and the risk of fracture in postmenopausal women. Study of Osteoporotic Fractures Research Group. *Am J Clin Nutr.* 2001;73:118–122
102. Massey LK. Dietary animal and plant protein and human bone health: a whole foods approach. *J Nutr.* 2003;133:862S–865S
103. Slemenda CC, Hui SL, Longcope C, Johnston CC Jr. Cigarette smoking, obesity, and bone mass. *J Bone Miner Res.* 1989;5:737–741
104. Slemenda CW, Peacock M, Hui S, Zhou L, Johnston CC. Reduced rates of skeletal remodeling are associated with increased bone mineral density during the development of peak skeletal mass. *J Bone Miner Res.* 1997;12:676–682
105. Bachrach LK. Acquisition of optimal bone mass in childhood and adolescence. *Trends Endocrinol.* 2001;12:22–28
106. Milk Matters. Calcium Education Campaign. National Institute of Child Health and Development; 2004. Available at: www.nichd.nih.gov/milk/milk.cfm