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

Amy Joy Lanou, PhD*; Susan E. Berkow, PhD, CN‡; and Neal D. Barnard, MD*

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 un-supplemented 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 children²⁰ and maintaining bone mass in older adults.^{21,22} However, increasing intake of dietary protein, particularly animal protein, is associated with increased urinary calcium losses²³ 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/Vitni/vitni.html>.

result in increased bone resorption²⁴ 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 D₃, 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 pe-

riod 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 years⁴¹ and another of 10- to 26-year-old Australian female twin pairs⁵⁸), 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 al³⁴ 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 $\sim 5\%$ 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 al⁷⁰ found that dairy product intake had no association with susceptibility to bone fractures in school-aged children, and Wyshak and Frisch⁷⁶ 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 al⁷³ 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 al⁶⁶ showed that although low bone density was more common in girls and boys⁷⁵ 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 al⁶⁹ 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 al¹⁸ 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 intake⁴³ 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 supplements⁸² 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 al⁸⁰ 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 al⁸² found no differences in bone density or change in bone density over time with either treatment. Cadogan et al⁸¹ 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 Study¹⁷ 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 al¹⁰⁴ 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 Krumdieck⁹ 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's⁴⁹ 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, Bachrach¹⁰⁵ 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 intake² 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 1 2/3 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.

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