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Effects of Average Childhood Dairy Intake on Adolescent Bone Health

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Abstract

Objective—To evaluate the effects of usual childhood dairy intake on adolescent bone health. Study design Dietary data collected in the Framingham Children's Study over twelve years were used to evaluate usual dairy consumption and adolescent bone health. Each child's average Food Pyramid servings were estimated from yearly sets of 3-day diet records. Bone mineral content (BMC) and area (BA) for total body and six regions (arms, legs, trunk, ribs, pelvis, and spine) at ages 15 to 17 years were the primary outcomes. Analysis of covariance was used to adjust for potential confounding by sex and physical activity, as well as age, height, body mass index and percent body fat at the time of the bone scan.

Results—Consuming ≥ 2 servings/day of dairy (versus less) was associated with significantly higher mean BMC and BA. Higher intakes of meats/other proteins (≥ 4 servings per/day) were also associated with higher mean BMC and BA values. Children with higher intakes of both dairy and meats/other proteins had the highest adjusted BMC (3090.1 gms), and children consuming less of each had the lowest BMC (2740.2 gms).

Conclusions—These prospective data provide evidence for a beneficial effect of childhood dairy consumption on adolescent bone health.

Keywords

diet; bone density; bone mineral content; prospective study; children

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The long-term effect of childhood dairy consumption on bone health is still debated. While calcium has been thought to underlie the beneficial effect of dairy on bone health, some question whether such an effect even exists. Most studies have shown at least short-term benefits of calcium supplementation (1-4), especially among children with very low baseline intakes. Among adolescents, the effects have been studied primarily in girls; most have also

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found beneficial effects, although to a lesser degree than generally found in younger girls (5-8).

Whether the effects of calcium supplementation last beyond the initial intervention period has been questioned by investigators re-evaluating studies of children participating in earlier supplementation trials. Follow-up periods have differed across trials and the findings have been inconsistent (9-11). Some investigators have suggested that when the intervention is stopped, children in the control group will eventually acquire levels of bone mass that are comparable to those of the supplemented group (12).

The effect of dairy on bone health in children and adolescents has been studied less often than calcium but most prospective studies and clinical trials have found that dairy intake is positively correlated with BMD or bone mass (13-16). One reviewer compared five such trials and concluded that when dairy served as the source of the calcium the beneficial effects on bone density were stronger than those seen with supplements alone (17).

Long-term trials of dairy intake throughout childhood would not be feasible. Therefore, previous trials have had relatively short intervention periods, ranging from about 12 to 24 months. Although these studies provide valuable data on dairy's effects on bone, it is not possible to extrapolate these effects to longer-term outcomes. However, the existence of short-term benefits suggests that a lifestyle with higher intakes of dairy (and calcium) may lead to higher peak bone mass during the period of bone accrual. Thus, dietary data from longitudinal studies of children are likely to provide the best available evidence for determining the long-term benefits of dairy consumption. The current study uses prospective data collected over twelve years in the Framingham Children's Study (FCS). The goal of the analysis is to evaluate the effects of average dairy intake throughout childhood on adolescent bone mineral content, area and density.

Methods

The FCS is a prospective study of diet, activity, and various physical and psychosocial risk factors among third and fourth generation descendents of the members of the original Framingham cohort. All subjects are caucasian. A total of 106 children (ages three to five years at baseline) and their parents were enrolled in 1987 and followed annually through 1999. Only one child per family was enrolled. The study was conducted with the full approval of the Institutional Review Board of the Boston University Medical Center and written informed consent procedures were strictly followed.

Dietary intake was assessed by means of multiple sets of three-day food diaries collected throughout the study. Four sets were collected during the first year and one or two sets in each subsequent year. The study nutritionist instructed each family in diary completion, including the estimation of portion sizes. During the early years of the study, parents completed all food diaries for the children and themselves. Beginning at about age ten, the child assisted in the collection of the dietary data, gradually assuming more responsibility. Food diary data were entered into the Nutrition Data System (NDS) of the University of Minnesota (18) for the calculation of mean intakes of macro- and micro-nutrients.

The child's average daily servings of dairy as defined by the USDA's Food Guide Pyramid (19) were estimated by combining FCS food diary data with the Food Pyramid serving database using the technical files of the USDA's Continuing Survey of Food Intake by Individuals (CSFII) (20). CSFII food codes were linked with NDS food codes whenever possible. When information on composite foods was insufficient to make an exact match, nutrient content data along with recipe and ingredient information were compared to determine the appropriate food servings for each food component. The USDA dairy group consists of milk, yogurt, and cheese; one serving is defined as a cup of milk or yogurt, 1.5 ounces of natural cheese or 2.0 ounces of processed cheese. For other cheeses (e.g., cottage cheese, cream cheese), a serving is defined as the amount of the food that provides about the same amount of calcium as a cup of milk. To estimate average servings of dairy per day over all years, we first estimated average intake at each age and then took the average intake over all ages during the exposure period of interest. The exposure period for the dietary variables ended during the cycle prior to the time of the bone scan.

Bone mineral content (BMC), BMD and bone area (BA) were assessed in the final year of the study when the children were 15-17 years of age using a Lunar DPX-L scanner (Lunar Corporation, Madison, Wisconsin). The scan was carried out by experienced technicians from the Framingham Osteoporosis Study (21). Subjects were scanned in **a** supine position with arms against the side of the body, palms facing down. The results of all scans were analyzed with the Lunar IQ program, software version 4.6b. The scanner provided estimates for both bone and soft tissue variables for the total body and specific regions (i.e., arms, legs, trunk, ribs, pelvis and spine). The same quality control procedures as were used in the adult Framingham Study were used with the children. When outliers were detected, the scans were re-analyzed after checking all of the measures that had been entered into the software program. Some input errors were able to be corrected in this fashion and other errors (e.g., resulting from significant artifact or incorrect positioning of the subject) led to exclusion of the data for that subject.

Total body BMC was estimated (in grams) by continuous scanner sampling across all body areas, with the output calibrated against standards for known BMC to correct for systematic errors. BMD is expressed as grams per centimeter squared of BA. Since the use of BMD may lead to overestimation of the dietary effects for children with larger bones, BMC is used here as the primary outcome of interest with BA as a secondary outcome (22). To allow for comparison with previously published results, however, the effects of dairy on total BMD are given as well. Finally, BMC and BA were measured for the six individual regions. Of the 106 families who enrolled in the study, 84 had complete and usable data at the end of the study as well as a DXA scan.

Data on potential confounding factors included the following: (a) mother's age, education level, and child's age and sex (baseline variables); (b) child's physical activity (Caltrac counts per hour), television viewing (hours per day), and energy intake (kilocalories per day) (average from each annual exam visit during the exposure period); (c) change in child's height throughout childhood as well as maximum height velocity and the age at maximum height velocity; (d) child's age, height, height z-score, weight, weight z-score, body mass index (BMI), BMI z-score and percent body fat (measured at the time of the bone scan); and (e) pubertal development (Tanner) stage and age at menarche for the girls.

Physical activity was assessed during each exam cycle on multiple days with the same electronic motion sensor (Caltrac accelerometer; Muscle Dynamics, Torrance, CA) (23). A questionnaire was used to ascertain the number of hours of television watched per day on weekdays and schooldays. Duplicate height and weight measures were taken without shoes (and in light clothing) at each annual visit using a standard counterbalance scale with a measuring bar. The child's attained height at the time of the bone scan was examined as a potential confounder as well as the change in height, estimated as both height velocity (change in height from one exam to the next divided by time between exams) and slope (average yearly change in height using all measures from baseline through exam 11). Since maximum height velocity and age at the time of maximum velocity are correlated with maturational development during adolescence, we considered both of these variables as potential confounders. BMI was calculated for each exam as the child's weight (in kilograms) divided by height in meters, squared. The z-scores for height, weight, and BMI were estimated using available CDC standards (24). Percent body fat (by region and in total) was measured as a part of the DXA scan and was calculated as grams of fat divided by the sum of soft tissue and BMC.

Statistical Analysis

The primary exposure of interest for these analyses was the child's average daily servings of dairy per day throughout childhood. Based on a sensitivity analysis and power considerations, two servings of dairy per day was chosen to define lower vs. higher dairy intake (i.e., <2 servings vs. ≥2 servings/day). Analysis of covariance models (in Proc GLM, SAS version 9.1) were used to estimate the child's adjusted mean BMC, BA and BMD associated with dairy consumption. Each bone outcome was examined separately as a result of strong inter-correlations between outcomes (i.e., BMC, BA, BMD). Results are presented for total and region-specific bone outcomes, adjusting for body size and other potential confounding variables.

All potential confounders were examined singly and in combination. Only those variables that changed the effect estimates by ten percent or more were retained in the final model. Many of the variables related to body size were highly collinear and therefore not included simultaneously in the models. For example, the Pearson correlation between weight and BMI was 0.87. In general, the variable that was the strongest confounder was retained in the final model. The child's final attained height was a stronger confounder than was height velocity, age at the time of maximum height velocity, or yearly change in height, leading us to keep attained height in the models. Maternal age and education level led to no confounding and were dropped from the models. The child's TV viewing time was collinear with physical activity and led to no confounding. It was therefore dropped along with energy intake and Tanner Stage which also led to no confounding of the estimates. Age at menarche was considered as a potential confounder among girls; the results with and without this variable were virtually identical. Therefore, the potential confounding factors that were retained in the final models included sex and mean physical activity level (Caltrac counts per hour) during the exposure period as well as age, height, BMI and percent body fat (from DXA) at the time of the bone scan.

Results

Table I provides descriptive data for the children according to their usual childhood dairy consumption. The means for most baseline variables in Table I were adjusted for the child's sex and baseline age using a general linear model to estimate least squares means. Mean values at the time of the bone scan were adjusted for sex and age at the time of the scan. Children consuming two or more servings of dairy per day were, on average, slightly more active and watched less television than those consuming less. They consumed fewer vegetables but otherwise their food intake patterns were similar. Higher dairy intake was associated with greater caloric consumption as well as higher intakes of many beneficial micronutrients. At the time of the bone scan, children consuming two or more servings of dairy per day were taller and heavier but had a lower BMI than those consuming less.

Table II shows the mean BMC, BA and BMD levels associated with dairy intake after adjusting for sex, activity level throughout childhood and age, height, BMI, and percent body fat at the time of the bone scan. Consuming two or more dairy servings per day was associated with significantly higher bone mass, area and density. Overall, children who consumed two or more servings of dairy per day throughout childhood had a mean BMC level that was 175 gm higher than that of children consuming less (p=0.009). When we examined dairy intake at different age periods instead of average dairy throughout childhood, the effects were weaker. Intake at 13-17 years of age was a stronger predictor of bone health than was intake at earlier ages. For example, consuming two or more servings of dairy per day at 13-17 years of age was associated with an adolescent BMC that was 113 gm higher than that of lower dairy consumers (p=0.063). Higher dairy intake at 3-6 years of age was only associated with a BMC that was 29 gm higher (p=0.612) than that of children with lower intakes, and the effects at 7-11 years of age were intermediate. Thus, the strongest predictor of bone health was mean dairy intake during all childhood years preceding the bone scan.

The combined effects of dairy and foods in other USDA food groups are also explored in Table II. For each combined exposure, children were classified into one of the following categories: high/high, high/low, low/high and low/low. For example, for the dairy/meat cross-classification, a child who was classified as “high/high” had higher intakes of dairy (two or more servings) and higher intakes of meats and other non-dairy proteins (four or more servings).

Children having high intakes in both dairy and meat/other non-dairy proteins had the highest level of BMC (3090.1 gms), and those with low intakes of both foods had the lowest BMC levels (2740.2 gms). A higher dairy intake alone (high/low) was slightly more beneficial to BMC (2914.0 gms) than was a higher intake of meats and other proteins alone (low/high) (BMC=2854.9 gms). In each cross-classification, children with higher intakes in both of the selected food groups had the highest BMC levels and those with lower intakes in both food groups had the lowest BMC levels. Another consistent finding throughout Table II was that dairy intake, whether alone or in combination with other dietary factors, had a strong beneficial effect on all bone outcomes.

Table III focuses on dairy's effects on region-specific bone outcomes. Here, the consumption of two or more servings per day throughout the childhood years led to higher BMC levels by the time of adolescence in all individual regions, but especially in the arms, legs, trunk, ribs and pelvis.

Discussion

This study provides longitudinal evidence that childhood dairy intake directly affects adolescent bone health. The effects of dairy in this study were not restricted to appendicular bone as has been suggested in some previous studies (25). Instead, these beneficial effects were seen across various regions, including weight-bearing and non-weight-bearing appendicular bone as well as axial bone. The beneficial effects of dairy on total body bone health were strengthened by diets that were higher in meats and other non-dairy proteins.

Peak bone mass is acquired during adolescence. Although genetics may account for 75% of peak bone mass, diet and activity are crucial modifiable contributors (26). Dairy is the primary source of calcium in the diets of American children. Even though the USDA recommends three or more servings of dairy per day for children aged nine years and older, we used two servings per day here to define higher and lower levels of intake; this exposure variable reflects average intake over several years, ranging from preschool age to adolescence. There were too few children consuming three or more servings per day throughout childhood to evaluate this higher cutpoint.

Earlier studies of calcium effects on bone mass have yielded conflicting results. The calcium content of bone is determined by a tightly regulated system in which adequate dietary calcium is essential. It is possible that above some threshold, additional calcium provides no additional benefit. As noted in a review by Wosje and Specker, results may also vary from study to study due to methodologic difference such as the use of varying referent groups, failure to include a clear control group, narrow ranges of intake, or the use of bone measurements from different sites (27). Although reviews have shown that calcium intake may have beneficial short-term effects on bone health, some have concluded that these short-term effects do not persist over time (25). This longitudinal study therefore provides important information about the effects of longer-term patterns of intake on peak bone mass.

In the United States, dairy is a key dietary source of vitamin D, a nutrient that is essential to efficient intestinal absorption of calcium. While the majority of dairy consumed is in the form of fluid milk throughout childhood and adolescence, this is particularly true during the childhood and early adolescent years (28). Thus, children who consume more dairy will not only take in more calcium, but more vitamin D as well. Dairy proteins may also play a role. Whey, the principal dairy protein, may affect the acquisition of bone by increasing osteoblastic activity and reducing the osteoclastic process (29). Whey protein has also been shown to suppress bone resorption (30). Thus, it is possible that this dairy protein could provide beneficial effects on bone mineralization in children.

In this study, the combined intakes of dairy, meats and other protein source foods were associated with a higher BMC, BMD and bone area. Historically, higher intakes of dietary protein in adults have been believed to lead to increased bone resorption and increased fracture risk (31-33). However, many epidemiologic studies and clinical trials have found that higher protein intakes were associated with less bone loss and a reduced risk of hip fracture (21, 34-36). The consumption of animal protein, particularly milk, stimulates the production and action of insulin-like growth factor-1 (IGF-1) which promotes greater linear growth in children (34, 37-38). Thus, IGF-1 may support bone formation and help to offset the renal loss of calcium that may be associated with protein intake.

Dawson-Hughes concluded that protein intake has more favorable effects on bone when dietary calcium requirements are met (39). Spencer et al suggest that the beneficial effects of abundant dietary protein on calcium balance may be attributable to its phosphorus content (40). Thus, the effects of dietary proteins on bone health may depend on total nutrient composition of the protein food sources (32). Just as calcium in dairy may offset the potential leeching of calcium associated with high protein intakes, the high potassium content of plant proteins seems to offset any negative protein effects and decrease urinary calcium losses. The intakes of two or more servings of dairy combined with higher intakes of fruits and vegetables in this study led to higher bone mass. This too could be attributable to the vitamin and mineral content of fruits and vegetables (e.g., potassium) that are important to bone health.

The FCS has a number of important strengths but one of the most important ones is the availability of detailed dietary data collected over many years during childhood. This enabled us to classify the children more accurately with respect to their usual pattern of dietary intake. Also, detailed covariate information was collected over the years, giving us better control of possible confounding by other factors such as age, body size and physical activity. It is possible that higher dairy consumption simply reflects a healthier lifestyle in general. Thus the ability to control confounding by such factors as physical activity level is particularly important. The multiple years of replicate data on activity using an electronic motion sensor is an important strength of the study. The most notable weakness of the FCS is its sample size which yields limited power for stratified analyses. We attempted to examine the effects of meeting USDA Dietary Guideline recommendations for dairy intake. However, because only 16.7% of children in this sample at 9-17 years of age met the guidelines for dairy (and only 12% met the guidelines for calcium), there was inadequate power to address questions associated with the effects of meeting the Dietary Guidelines.

The findings of this study confirm the importance of a diet rich in dairy and other protein sources on adolescent bone mass. Many previous studies have examined shorter-term nutrient effects, most notably calcium effects, in clinical trials. Although these studies have aided in understanding of the potential mechanism of dairy's beneficial effects, they do not provide the sufficient evidence of longer-term effects. The data from the FCS add to our knowledge and understanding of the longer-term effects of dietary patterns on bone health in growing children.

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References

1. Johnston CC, Miller JZ, Slemenda CW, Reister TK, Hui S, Christian JC, et al. Calcium supplementation and increases in bone mineral density in children. N Engl J Med. 1992; 327:82–7. [PubMed: 1603140]
2. Nowson CA, Green RM, Hopper JL, Sherwin AJ, Young D, Kaymakci B, et al. A co-twin study of the effect of calcium supplementation on bone density during adolescence. Osteoporos Int. 1997; 7:219–25. [PubMed: 9205634]
3. Lee WTK, Leung SS, Wang SH, Xu YC, Zeng WP, Lau J, et al. Double-blind, controlled calcium supplementation and bone mineral accretion in children accustomed to a low-calcium diet. Am J Clin Nutr. 1994; 60:744–50. [PubMed: 7619105]
4. Bonjour J-P, Carrie A-L, Ferrari S, Clavien H, Slosman D, Theintz G, et al. Calcium-enriched foods and bone mass growth in prepubertal girls: a randomized, double-blind, placebo-controlled trial. J Clin Invest. 1997; 99:1287–94. [PubMed: 9077538]
5. Lloyd T, Andon MB, Rollings N, Martel JK, Landis JR, Demers LM, et al. Calcium supplementation and bone mineral density in adolescent girls. JAMA. 1993; 270:841–4. [PubMed: 8340983]
6. 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; 77:985–92. [PubMed: 12663301]
7. Mølgaard C, Thomsen BL, Michaelsen KF. Effect of habitual dietary calcium intake on calcium supplementation in 12-14-y-old girls. Am J Clin Nutr. 2004; 80:1422–7. [PubMed: 15531696]
8. Matkovic V, Goel PK, Badenhop-Stevens NE, Landoll JD, Li B, Ilich JZ, et al. Calcium supplementation and bone mineral density in females from childhood to young adulthood: a randomized controlled trial. Am J Clin Nutr. 2005; 81:175–88. [PubMed: 15640478]
9. Lee WTK, Leung SSF, Leung DMY, Cheng JCY. A follow-up on the effects of calcium-supplement withdrawal and puberty on bone acquisition of children. Am J Clin Nutr. 1996; 64:71–7. [PubMed: 8669418]
10. Bonjour J-P, Chevalley T, Ammann P, Slosman D, Rizzoli R. Gain in bone mineral mass in prepubertal girls 3-5 years after discontinuation of calcium supplementation: a follow-up study. Lancet. 2001; 358:1208–12. [PubMed: 11675056]
11. Dodiuk-Gad RP, Rozen GS, Rennert G, Rennert HS, Ish-Shalom S. Sustained effect of short-term calcium supplementation on bone mass in adolescent girls with low calcium intake. Am J Clin Nutr. 2005; 81:168–74. [PubMed: 15640477]
12. Abrams S. Calcium supplementation during childhood: long-term effects on bone mineralization. Nutr Rev. 2005; 63:251–5. [PubMed: 16121479]
13. Chan GM, Hoffman K, McMurry M. Effects of dairy products on bone and body composition in pubertal girls. J Pediatr. 1995; 126:551–6. [PubMed: 7699532]
14. Cadogan J, Eastell R, Jones N, Barker ME. Milk intake and bone mineral acquisition in adolescent girls: randomised, controlled intervention trial. BMJ. 1997; 315:1255–60. [PubMed: 9390050]
15. Merrilees MJ, Smart EJ, Gilchrist NL, Frampton C, Turner JG, Hooke E, et al. Effects of dairy food supplements on bone mineral density in teenage girls. Eur J Nutr. 2000; 39:256–62. [PubMed: 11395985]
16. Fiorito LM, Mitchell DC, Smiciklas-Wright H, Birch LL. Girls calcium intake is associated with bone mineral content during middle childhood. J Nutr. 2006; 136:1281–6. [PubMed: 16614417]
17. Kerstetter JE. Do dairy products improve bone density in adolescent girls? Nutr Rev. 1995; 53:328–32. [PubMed: 8643216]

18. Schakel SF, Sievert YA, Buzzard IM. Sources of data for developing and maintaining a nutrient data base. J Am Diet Assoc. 1988; 88:1268–71. [PubMed: 3171020]
19. U.S. Department of Agriculture. The Food Guide Pyramid. Home and Garden Bulletin Number 252. 1992.
20. US Department of Agriculture. Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1989-1991. US GPO; Washington, DC: 1995. NFS Report No. 91-2
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; 15:2504–12. [PubMed: 11127216]
22. Heaney RP. Bone mineral content, not bone mineral density, is the correct bone measure for growth studies. Am J Clin Nutr. 2003; 78:350–1. [PubMed: 12885724]
23. Sallis JF, Buono MJ, Roby JJ, Carlson D, Nelson JA. The Caltrac accelerometer as a physical activity monitor for school-age children. Med Sci Sports Exerc. 1990; 22:698–703. [PubMed: 2233210]
24. Kuczmarski RJ, Ogden CL, Guo SS, Grummer-Strawn LM, Flegal KM, Mei Z, et al. CDC growth charts for the United States: Methods and Development. Vital Health Stat. 2002 11 (246) National Center for Health Statistics.
25. Vatanparast H, Whiting SJ. Calcium supplementation trials and bone mass development in children, adolescents, and young adults. Nutr Rev. 2006; 64:204–9. [PubMed: 16673756]
26. Heaney RP, Abrams S, Dawson-Hughes B, Looker A, Marcus R, Matkovic V, et al. Peak bone mass. Osteoporos Int. 2000; 11:985–1009. [PubMed: 11256898]
27. Wosje KS, Specker BL. Role of calcium in bone health during childhood. Nutr Rev. 2000; 58:253–68. [PubMed: 11060996]
28. Kranz S, Lin P-J, Wagstaff DA. Children's dairy intake in the United States: too little, too fat? J Pediatr. 2007; 151:642–6. [PubMed: 18035145]
29. Cornish J, Callon KE, Naot D, Palmano KP, Banovic T, Bava U, et al. Lactoferrin is a potent regulator of bone cell activity and increases bone formation in vivo. Endocrinol. 2004; 145:4366–74.
30. Toba Y, Takada Y, Yamamura J, Tanaka M, Matsuoka Y, Kawakami H, et al. Milk basic protein: a novel protective function of milk against osteoporosis. Bone. 2000; 27:403–8. [PubMed: 10962352]
31. Barzel US, Massey LK. Excess dietary protein can adversely affect bone. J Nutr. 1998; 128:1051–3. [PubMed: 9614169]
32. Massey LK. Dietary animal and plant protein and human bone health: a whole foods approach. J Nutr. 2003; 133:862S–5S. [PubMed: 12612170]
33. Feskanich D, Willett WC, Stampfer MJ, Colditz GA. Protein consumption and bone fractures in women. Am J Epidemiol. 1996; 143:472–9. [PubMed: 8610662]
34. Rizzoli R, Bonjour JP. Dietary protein and bone health. J Bone Miner Res. 2004; 19:527–31. [PubMed: 15005837]
35. Munger RG, Cerhan JR, Chiu BC. Prospective study of dietary protein intake and risk of hip fracture in postmenopausal women. Am J Clin Nutr. 1999; 69:147–52. [PubMed: 9925137]
36. 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; 155:636–44. [PubMed: 11914191]
37. Hoppe C, Udam TR, Lauritzen L, Molgaard C, Juul A, Michaelsen KF. Animal protein intake, serum insulin-like growth factor I, and growth in healthy 2.5-y-old Danish children. Am J Clin Nutr. 2004; 80:447–52. [PubMed: 15277169]
38. 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; 76:675–80. [PubMed: 12198017]
39. Dawson-Hughes B. Interaction of dietary calcium and protein in bone health in humans. Am J Clin Nutr. 2003; 133:852S–54S.

40. Spencer H, Kramer L, Osis D. Do protein and phosphorus cause calcium loss? J Nutr. 1988; 118:657–60. [PubMed: 3286844]

Table 1

Characteristics of children according to usual dairy intake throughout childhood

Characteristics	Dairy (≥ 2 servings) (n=49)	Dairy (< 2 servings) (n=35)	*p value*
	(mean ± s.e.)		
Baseline Data *			
Baseline Age	4.0 ± 0.69	4.0 ± 0.85	*0.8601*
Baseline Height	40.6 ± 0.27	40.0 ± 0.32	*0.1594*
Baseline BMI	16.0 ± 0.18	16.5 ± 0.22	*0.1119*
Measures of Activity and Inactivity****			
Activity (caltrac counts/hour)	10.8 ± 0.25	10.0 ± 0.30	*0.0630*
TV (hours/day)	2.1 ± 0.12	2.3 ± 0.15	*0.2143*
Food Intakes (servings per day)*			
Dairy	2.6 ± 0.08	1.6 ± 0.09	<*.0001*
Fruit	1.8 ± 0.15	1.9 ± 0.18	*0.7460*
Vegetables	1.7 ± 0.11	2.0 ± 0.13	*0.2094*
Grains	6.8 ± 0.17	6.7 ± 0.21	*0.7796*
Meat / Other Non-Dairy Proteins	3.6 ± 0.15	3.5 ± 0.19	*0.7756*
Nutrient Intakes (per day)*			
Energy (kilocalories)	1974.2 ± 35.5	1799.0 ± 43.6	*0.0059*
Calcium (mg)	1036.6 ± 24.7	747.8 ± 30.3	<*.0001*
Magnesium (mg)	237.2 ± 5.6	203.2 ± 6.9	*0.0008*
Phosphorus (mg)	1249.8 ± 25.3	1002.6 ± 31.1	<*.0001*
Potassium (mg)	2275.9 ± 56.9	1985.5 ± 69.8	*0.0044*
Zinc (mg)	9.2 ± 0.24	8.1 ± 0.29	*0.0087*
Vitamin D (μg)	6.9 ± 0.24	4.3 ± 0.29	<*.0001*
Height Velocity			
Maximum height velocity (inches/year)	3.2 ± 0.76	3.1 ± 0.72	*0.5848*
Age at maximum height velocity	12.4 ± 1.5	11.7 ± 1.5	*0.0172*
Characteristics at Time of Bone Scan*****			
Age	15.9 ± 0.79	16.0 ± 1.0	*0.9117*
Height	68.5 ± 0.42	66.6 ± 0.51	*0.0113*
Weight	153.5 ± 4.6	151.0 ± 5.7	*0.7559*
BMI	22.9 ± 0.68	23.8 ± 0.83	*0.4199*
Height z-scores	0.65 ± 0.89	0.21 ± 1.1	*0.0425*
Weight z-scores	0.91 ± 0.88	0.59 ± 0.93	*0.1157*
BMI z-scores	0.62 ± 0.92	0.52 ± 0.97	*0.6347*

* Baseline height and BMI adjusted for gender and baseline age.

** Means (adjusted for age and gender) are estimated as an average during exposure period (from preschool to exam prior to bone scan)

*** Height, weight and BMI at time of bone scan adjusted for gender and age at time of bone scan.

Table 2

Combined effects of dairy and other factors on bone outcomes during adolescence

Intake Categories (3-17 Years)		Bone Mineral Content (gm)		Bone Area (cm^2)		Bone Mineral Density (gm/cm^2)	
	(n)	*(mean ± s.e.)**	*p-value*	*(mean ± s.e.)**	*p-value*	*(mean ± s.e.)**	*p-value*
Dairy †							
≥ 2 servings	49	2966.6 ± 36.7		2477.1 ± 15.0		1.19 ± 0.01	
< 2 servings	35	2791.6 ± 45.3		2412.8 ± 18.6		1.15 ± 0.01	
		p = 0.009		*p = 0.019*		*p = 0.022*	
Dairy / Meats & Other Proteins ‡							
High / High	19	3090.1 ± 57.3	*ref*	2503.2 ± 24.0	*ref*	1.22 ± 0.02	*ref*
High / Low	30	2914.0 ± 41.3	*0.010*	2468.2 ± 17.3	*0.213*	1.17 ± 0.01	*0.009*
Low / High	9	2854.9 ± 75.2	*0.021*	2456.5 ± 31.5	*0.267*	1.16 ± 0.02	*0.015*
Low / Low	26	2740.2 ± 51.5	*0.000*	2388.9 ± 21.6	*0.002*	1.14 ± 0.01	*0.001*
Dairy / Fruit & Vegetables ‡							
High / High	35	2985.8 ± 41.8	*ref*	2490.5 ± 16.8	*ref*	1.19 ± 0.01	*ref*
High / Low	14	2924.2 ± 63.0	*0.396*	2446.5 ± 25.4	*0.134*	1.18 ± 0.02	*0.457*
Low / High	22	2836.2 ± 52.9	*0.045*	2434.3 ± 21.3	*0.061*	1.16 ± 0.01	*0.083*
Low / Low	13	2710.0 ± 67.8	*0.002*	2373.5 ± 27.3	*0.001*	1.13 ± 0.02	*0.006*
Dairy / Grains ‡							
High / High	24	3008.7 ± 51.6	*ref*	2482.9 ± 20.9	*ref*	1.20 ± 0.01	*ref*
High / Low	25	2936.4 ± 47.9	*0.276*	2480.1 ± 19.3	*0.917*	1.18 ± 0.01	*0.200*
Low / High	9	2825.3 ± 77.9	*0.054*	2460.9 ± 31.5	*0.563*	1.14 ± 0.02	*0.025*
Low / Low	26	2770.1 ± 56.1	*0.007*	2388.0 ± 22.7	*0.008*	1.15 ± 0.01	*0.027*

*All models are adjusted for gender, physical activity (Caltrac counts/hour) and **age**, height, BMI, activity, and percent body fat (DXA) at the time of bone scan.

†Low Dairy: < 2 servings

‡Low Meat & Non-Dairy Proteins: <4 servings; Low Fruit & Vegetables: <3 servings: Low Grains: <7 servings

Table 3

Effect of dairy intake on region-specific bone outcomes during adolescence

Mean Dairy Intake (3-17 Years)		Arms	Legs	Trunk	Ribs	Pelvis	Spine
	(n)			*(mean ± s.e.)**			
				Bone Mineral Content (gm)			
Dairy ≥ 2 servings	49	334.5 ± 6.8	1089.9 ± 13.6	1069.3 ± 16.7	403.1 ± 8.4	399.1 ± 6.8	267.1 ± 5.1
Dairy < 2 servings	35	309.7 ± 8.4	1042.0 ± 16.9	982.4 ± 20.7	361.5 ± 10.4	368.3 ± 8.4	252.6 ± 6.3
p-value		*p=0.0456*	*p=0.0528*	*p=0.0047*	*p=0.0070*	*p=0.0130*	*p=0.1146*
				Bone Area (cm^2)			
Dairy ≥ 2 servings	49	365.2 ± 4.8	842.4 ± 5.5	1037.7 ± 9.9	501.8 ± 6.6	315.3 ± 3.8	220.4 ± 3.3
Dairy < 2 servings	35	354.9 ± 5.9	836.1 ± 6.9	990.8 ± 12.3	469.2 ± 8.2	304.7 ± 4.7	216.9 ± 4.0
p-value		*p=0.2291*	*p=0.5218*	*p=0.0097*	*p=0.0074*	*p=0.1116*	*p=0.5516*

*All models adjusted for gender, physical activity (Caltrac counts/hour) and **age**, height, BMI, and percent body fat (DXA) at time of bone scan.